

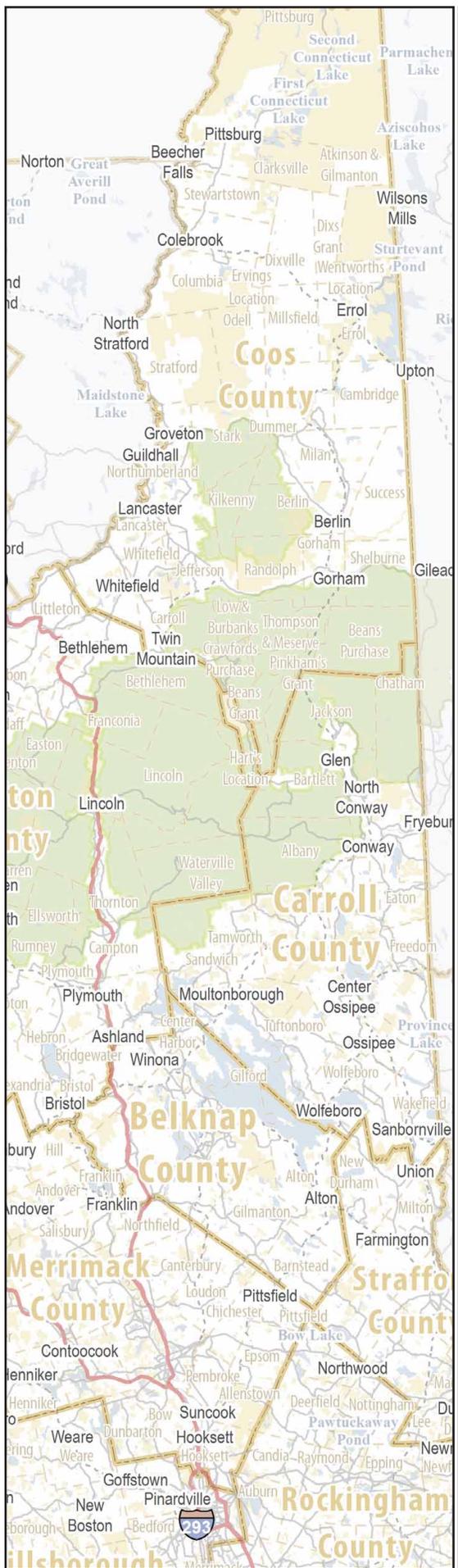


DOE/EIS-0463

**FINAL**  
**NORTHERN PASS**  
**TRANSMISSION LINE PROJECT**  
**ENVIRONMENTAL IMPACT STATEMENT**  
**VOLUME 3: APPENDIX L**

**U.S. DEPARTMENT OF ENERGY**  
**OFFICE OF ELECTRICITY DELIVERY**  
**AND ENERGY RELIABILITY**  
**WASHINGTON, DC**

**AUGUST 2017**





**Department of Energy**  
**Washington, DC 20585**  
August 2017

Dear Sir/Madam:

Enclosed is the final *Northern Pass Transmission Line Project Environmental Impact Statement* (DOE/EIS-0463) prepared by the Department of Energy (DOE) pursuant to the National Environmental Policy Act of 1969 (NEPA) and its implementing regulations.

The United States Forest Service (USFS) – White Mountain National Forest, United States Environmental Protection Agency (EPA) – Region 1, United States Army Corps of Engineers (USACE) – New England District, and the New Hampshire Office of Energy and Planning (NHOEP) are cooperating agencies in the preparation of the EIS.

The proposed DOE action in the final EIS is to issue a Presidential permit to the Applicant, Northern Pass LLC, to construct, operate, maintain, and connect a new electric transmission line across the U.S./Canada border in northern New Hampshire (NH).

DOE has prepared this final EIS to evaluate the potential environmental impacts in the United States of the proposed action and the range of reasonable alternatives, including the No Action alternative. Under the No Action alternative, the Presidential permit would not be granted, and the proposed transmission line would not cross the U.S./Canada border.

In addition to its Presidential permit application to DOE, Northern Pass LLC applied to the USFS for a special use permit that would authorize Northern Pass LCC to construct, own, operate and maintain an electric transmission line to cross portions of the White Mountain National Forest under its jurisdiction. The final EIS will be used by the Forest Supervisor of the White Mountain National Forest to inform the Record of Decision in regard to this requested use.

DOE will use the EIS to ensure that it has the information it needs for informed decision-making.

The final EIS will also be posted on the project EIS website, <http://www.northernpasseis.us/> and DOE's NEPA website at <https://energy.gov/nepa/listings/environmental-impact-statements-eis>.

Sincerely,

A handwritten signature in cursive script, appearing to read "Brian Mills".

Brian Mills  
Transmission Permitting and Technical Assistance,  
Office of Electricity Delivery and Energy Reliability  
U.S. Department of Energy

*FINAL*

**NORTHERN PASS TRANSMISSION LINE PROJECT  
ENVIRONMENTAL IMPACT STATEMENT  
DOE/EIS-0463**

**Volume 3: Appendix L. Comment Response Document**

---

**U.S. DEPARTMENT OF ENERGY  
OFFICE OF ELECTRICITY DELIVERY  
AND ENERGY RELIABILITY**



***COOPERATING AGENCIES***

**United States Forest Service – White Mountain National Forest  
United States Environmental Protection Agency– Region 1  
United States Army Corps of Engineers – New England District  
New Hampshire Office of Energy and Planning**

**August 2017**

## COVER SHEET

**RESPONSIBLE FEDERAL AGENCY:** U.S. Department of Energy (DOE), Office of Electricity Delivery and Energy Reliability

**COOPERATING AGENCIES:** United States Forest Service (USFS) – White Mountain National Forest (WMNF); United States Environmental Protection Agency (EPA) – Region 1; United States Army Corps of Engineers (USACE) – New England District; and New Hampshire Office of Energy and Planning (NHOEP)

**TITLE:** Northern Pass Transmission Line Project Environmental Impact Statement (DOE/EIS-0463)

**LOCATION:** Coös, Grafton, Belknap, Merrimack, and Rockingham counties in New Hampshire

**CONTACTS:** For additional information on this Environmental Impact Statement (EIS) contact:

Mr. Brian Mills, National Environmental Policy Act (NEPA) Document Manager  
Office of Electricity Delivery and Energy Reliability, OE-20  
U.S. Department of Energy  
1000 Independence Ave. SW  
Washington, DC 20585  
Telephone: (202) 586-8267  
[Brian.Mills@hq.doe.gov](mailto:Brian.Mills@hq.doe.gov)

For general information on the DOE NEPA process, please write or call:

Mr. Brian Costner, Acting Director  
Office of NEPA Policy and Compliance, GC-54  
U.S. Department of Energy  
1000 Independence Ave. SW  
Washington, DC 20585  
[askNEPA@hq.doe.gov](mailto:askNEPA@hq.doe.gov)  
Telephone: (202) 586-4600 or leave a message at (800) 472-2756

**ABSTRACT:** Northern Pass Transmission, LLC (Northern Pass) has applied to the DOE for a Presidential permit to construct, operate, maintain, and connect a 192-mile (309-km) electric transmission line across the United States (U.S.)/Canada border in northern New Hampshire (NH). This final EIS addresses the potential environmental impacts of the Project (Proposed Action), the No Action Alternative, and ten additional action alternatives (Alternatives 2 through 6, with variations). The NH portion of the Project would be a single circuit  $\pm$ 320 kilovolt (kV) high voltage direct current (HVDC) transmission line running approximately 158 miles (254 km) from the U.S. border crossing with Canada in Pittsburg, NH, to a new direct current-to-alternating current (DC-to-AC) converter station to be constructed in Franklin, NH. From Franklin, NH, to the Project terminus at the Public Service of New Hampshire's existing Deerfield Substation located in Deerfield, NH, the Project would consist of 34 miles (55 km) of 345 kV AC electric transmission line. The total length of the Project would be approximately 192 miles (309 km).

**PUBLIC COMMENTS:** In preparing this final EIS, DOE considered comments received during the scoping period, which extended from February 11, 2011 to June 14, 2011, and was reopened from June 15, 2011 to November 5, 2013 (DOE accepted and considered all comments during the scoping period from February 11, 2011 to November 5, 2013), and the public comment period on the draft EIS (July 31, 2015 through April 4, 2016). Comments on the draft EIS were accepted during the 45-day period

following publication of EPA's Notice of Availability (NOA) in the *Federal Register* on July 31, 2015; the public comment period was extended until April 4, 2016 following publication of EPA's NOA of the supplement in the *Federal Register* on November 20, 2015. DOE held four public meetings on the draft EIS in Colebrook, NH on March 7, 2016; Waterville Valley, NH on March 9, 2016; Concord, NH on March 10, 2016; and Whitefield, NH on March 11, 2016. All comments were considered during preparation of this final EIS. Appendix L in Volume 3 of this EIS contains the comments received on the draft EIS and DOE's responses to these comments. This final EIS contains revisions and new information based in part on comments received on the draft EIS. Vertical bars in the margins marking changed text indicate the locations of these revisions and new information. Deletions are not indicated. Appendices J and K in Volume 2 and Appendix L in Volume 3 are entirely new parts of this EIS; therefore, they do not contain bars indicating changes from the draft EIS.

The EIS analyzes the potential environmental impacts of DOE issuing a Presidential permit for the proposed Northern Pass Project, which is DOE's proposed federal action. DOE will use the EIS to inform its decision on whether to issue a Presidential permit. Additionally, Northern Pass has applied to the USFS for a special use permit (SUP) authorizing Northern Pass to construct, operate, and maintain an electric power transmission line crossing portions of the WMNF. The WMNF Forest Supervisor will use the EIS to inform its decision regarding: 1) whether to issue a SUP under the Federal Land Policy and Management Act; 2) the selection of an alternative; 3) any need to amend the Forest Plan; and 4) what specific terms and conditions should apply if a SUP is issued.

Copies of the final EIS are available for public review at 30 local libraries and town halls, or a copy can be requested from Mr. Brian Mills. The EIS is also available on the Northern Pass EIS website (<http://www.northernpasseis.us/>). DOE will announce its decision on the Proposed Action in a Record of Decision (ROD) in the *Federal Register* no sooner than 30 days after the EPA publishes the NOA of the final EIS. The USFS will announce its draft decision on the Proposed Action in a draft ROD in the *Federal Register* shortly after the EPA publishes the NOA of the final EIS.

**APPENDIX L**  
**COMMENT RESPONSE DOCUMENT**

---

**Attachment C.**  
**Response to All Comments on the Draft EIS**

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Aug 9, 2015

**ID:** 8247

**Date Entered:** Aug 9, 2015

**Source:** Website

**Topics:** Private Property/Land Use

**Name:** Edward Cenerizio

**Organization:** 41 Dyke Road LLC

**Title:** Manager

**Email:** northpack99@yahoo.com

**Mailing Address:** 1288 Easton Rd

**City:** Sugar Hill

**State:** NH

**Country:** US

**Comment:** ROW transverses 3500' of my property. High towers in this so called low vis impact area will preclude my ability to residentially develop my property (113 acres). Severe negative financial impact will directly result both to me (property sales) and the town in loss of property tax revenue. Who will compensate me and the towns of Easton and Sugar Hill NH for this loss. BURY THE LINE! Additionally, current properties along Easton and Sugar Hill will have to have their property assessments lowered impacting town property taxes with obvious result to services supported by said taxes. Finally, property all along the line suspended by higher towers will lose value. Who will compensate these property owners for the is loss?

1482-1

Thank you for your comment. Section 4.1.2 of the EIS addresses the anticipated impacts of the Project on adjacent properties, property values, and current/future tax assessments/payments. An exhaustive literature evaluation was undertaken to identify peer-reviewed studies which specifically assessed the potential impact of transmissions lines on adjacent real estate values. Due to the spatial extent of the EIS analysis, specific locations and properties were not individually analyzed. This information is presented in the Socioeconomic Technical Resource Report for the final EIS and in the EIS (Section 4.1.2). As a result of comments on the methodology and assumptions provided on the draft EIS, adjustments to the original analysis have now been updated in the final EIS. These updates include changes to the impacts discussed in the Central Section, where Easton and Sugar Hill are located (see Section 4.3.2 of the EIS). As these details are far too complex to be summarized within this response, the commenter is referred to both the Socioeconomic Technical Resource Report for the final EIS, and Section 4.1.2 of the final EIS. Mitigation of lost property value is outside the scope of this EIS.

1482-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Dec 31, 2015

**ID:** 8638

**Date Entered:** Dec 31, 2015

**Source:** Website

**Topics:** Other

**Name:** Theresa Calder

**Organization:**

**Email:** tcalder@metrocast.net

**Mailing Address:** Terry

**City:** Alton Bay

**State:** NH

**Zip:** 03810

**Country:** US

**Comment:** As a realtor, I know full well the impact power lines and visible towers have on property values. In the past I personally handled one property almost did not close because the lender would not lend the full amount due to the proximity of the house to power lines, the seller had to do a private mortgage for 50K to cover what the lender wouldn't, because the property value was diminished in value because of the unsightly and potentially hazardous to live by power lines.

People move to and live in New Hampshire, for rural , country living. They want to see trees, sky , fields and ponds, they will not pay as much for properties if they are encumbered by views of power lines or towers. It impinges on the senses, takes away from the setting. How are you going to compensate the people whose properties will be devalued by these structures??? How many of these home owners even realize this. If the lines are not buried the complete route I am totally against it. It changes the character of the state in a negative way.

Sincerely, Terry Calder

Farms & Barns RE

1483-1

Thank you for your comment. Section 4.1.2 of the EIS addresses the anticipated impacts of the Project on adjacent properties, property values, and current/future tax assessments/payments. An exhaustive literature evaluation was undertaken to identify peer-reviewed studies which specifically assessed the potential impact of transmissions lines on adjacent real estate values. Due to the spatial extent of the EIS analysis, specific locations and properties were not individually analyzed. This information is presented in the Socioeconomic Technical Resource Report for the final EIS and in the EIS (Section 4.1.2). As a result of comments on the methodology and assumptions provided on the draft EIS, adjustments to the original analysis have now been updated in the final EIS. As these details are far too complex to be summarized within this response, the commenter is referred to both the Socioeconomic Technical Resource Report for the final EIS, and Section 4.1.2 of the final EIS. Mitigation for lost property value is outside the scope of this analysis.

1483-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 29, 2016

**ID:** 8989

**Date Entered:** Mar 29, 2016

**Source:** Website

**Topics:** Design Criteria / Mitigation Measures

**Organization:** Resident

**Comment:** I live at the intersection of Hoit and Mountain Rd (RTE132) in Concord NH and feel strongly the line should be buried when passing thru Residential areas...I feel strongly that my property value has dropped in value since the day this project was announced and with economic recovery is being extremely slow for everyone in New Hampshire... this is just another depressing topic to set us back personally...that said I have nothing against providing cost effective power for the general public but for god sakes spend the extra money to help financially affected property owners along its route.

1484-1

Thank you for your comment. Section 4.1.2 of the EIS addresses the anticipated impacts of the Project on adjacent properties, property values, and current/future tax assessments/payments. An exhaustive literature evaluation was undertaken to identify peer-reviewed studies which specifically assessed the potential impact of transmissions lines on adjacent real estate values. Due to the spatial extent of the EIS analysis, specific locations and properties were not individually analyzed. This information is presented in the Socioeconomic Technical Resource Report for the final EIS and in the EIS (Section 4.1.2). As a result of comments on the methodology and assumptions provided on the draft EIS, adjustments to the original analysis have now been updated in the final EIS. As these details are far too complex to be summarized within this response, the commenter is referred to both the Socioeconomic Technical Resource Report for the final EIS, and Section 4.1.2 of the final EIS.

1484-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Aug 30, 2015

**ID:** 8358

**Date Entered:** Aug 30, 2015

**Source:** Website

**Topics:** Purpose and Need, Alternatives, Health and Safety, Vegetation

**Name:** Brad Griswold

**Organization:**

**Email:** bradgriswold@mac.co

**Mailing Address:** 101 Mount Prospect Road

**Mailing Address:** PO Box 110

**City:** Lancaster

**State:** NH

**Zip:** 03584

**Country:** US

**Comment:** The Northern Pass in its various forms to date is not representative of the needs of the community and will cause harm to the local economies and the environment. To consider this green energy when the implementation irreparably harms the National forest and the surrounding views is in short a gross misrepresentation of the facts motivated purely by corporate greed.

As a land owner that would be directly impacted by Northern Pass, I would point out just a few concerns. First, in an area of the country that depends on the tourist trade for a large part of their economic security, permanently damaging the scenic beauty of the area with electrical towers should be enough to give pause to the value of this project. For those who state that the project will create jobs, the sad fact is this project would create a minimal amount of jobs for a short period time while impacting the economic health of the area for years to come.

Secondly, a large portion of the real estate values in this part of the State are based on the properties views. If the towers become part of the view, there should be a reduction of the real estate tax based on the degradation of the view all things being equal. Any tax increase provided by the utility company will be offset by the reduction in property values. Either real estate taxes will increase to offset the decline in property values or services for the community will be eliminated. Either way property

1486-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Section 4.1.2 of the EIS discusses potential impacts on employment.

1486-2

Thank you for your comment. Section 4.1.2 of the EIS addresses the anticipated impacts of the Project on adjacent properties, property values, and current/future tax assessments/payments. An exhaustive literature evaluation was undertaken to identify peer-reviewed studies which specifically assessed the potential impact of transmissions lines on adjacent real estate values. This information is presented in the Socioeconomic Technical Resource Report for the final EIS and in the EIS (Section 4.1.2). As a result of comments on the methodology and assumptions provided on the draft EIS, adjustments to the original analysis have now been updated in the final EIS. As these details are far too complex to be summarized within this response, the commenter is referred to both the Socioeconomic Technical Resource Report for the final EIS, and Section 4.1.2 of the final EIS.

1486-1

1486-2

owners will suffer economically.

Finally, the current proposals are being dictated by the short-term profit motive of the utility company not the long-term benefit of the communities it will impact or the natural environment it will harm. If there proves to be a supportable and documented need for the power generation, then bury it along a highway like Route 95 on Route 91 using existing Right of Ways. Don't scar the land forever.

Sincerely,  
Brad & Valerie Griwold

| 1486-2  
Continued 1486-2 cont'd

1488-1

Thank you for your comment. Section 4.1.2 of the EIS addresses the anticipated impacts of the Project on adjacent properties, property values, and current/future tax assessments/payments. An exhaustive literature evaluation was undertaken to identify peer-reviewed studies which specifically assessed the potential impact of transmissions lines on adjacent real estate values. This information is presented in the Socioeconomic Technical Resource Report for the final EIS and in the EIS (Section 4.1.2). As a result of comments on the methodology and assumptions provided on the draft EIS, adjustments to the original analysis have now been updated in the final EIS. As these details are far too complex to be summarized within this response, the commenter is referred to both the Socioeconomic Technical Resource Report for the final EIS, and Section 4.1.2 of the final EIS.

Hello. Can you hear me all right? I'm Dr. Deborah Warner. I have our own Vanna White here to help us out. Thank you. I'm Dr. Deborah Warner from Littleton, and I have a handout for you. On page 2 I'd like to start there with a study that I did in 2012 as this whole project was developing, and the chart as you see and is being held by Jean shows the results of a study conducted in 2012 that surveys studies more than a 100 attendees at public events in Coos County, New Hampshire, which is where I'm from, right on the border on land right there. The spontaneous answers to the question, what do you like about the North Country. I heard they love the North Country. As you can see in here -- show it to them. The top line there is two thirds of people asked, what do you like about the North Country, spontaneously said, it's the mountains and the forests that they like, and, in fact, as I listened to them, they also said well, I like the people here, I have a family here, I have relations and such. Half of them talked about the people. Two thirds talked about the mountains and forests. They talked about nature activities, about 30 percent. Quiet and daily quality of life and so on. You can see the items on this grid. But as I listened to them I could hear that they weren't just talking about gosh, you know, Exit 43 or Exit 29, it's convenient because there's a store right there. They're talking about the mountains and the forests, and I'm a psychologist so I listen to how people talk, and the way they talked about these things were not talking about inanimate objects. They were talking about the mountains and the forests like they are family members. Their loved ones. So when Northern Pass came on the scene and said we're going to strike these things and we're going to slash the woods, that's what we heard. They're going to scar the landscape. They might as well have said they're going to take our children and do medical experiments on them. It's that profound a feeling inside the people in the North Country who live there. And people live there. There's an economic cost to living in the North Country, and if I might indulge with going to page 1, I will go over here. This is a quick lesson in economics. There's the external market where goods and services are made here, and they're sent away and money comes back. You have a destination market where people come here and they enjoy our beautiful lands which we're happy to share with them and they leave their money here with us. The local market, we buy from each other. And money we have just goes, changes hands among ourselves, and there's the drain market where outside business comes in, uses our resource and the money goes somewhere else. Northern Pass fits into the drain market category of economics. They're coming in from afar, they're not local, they are taking our resources, and in our case, it's the mountains and forests' value that they are taking. If Mr. Clay, I might correct, we actually are taxed on the view. It has economic value. You have a regular property tax based on the market value of your house and then on top of that you have a view tax. Many, many people pay that, and many, many places are going under because the view is in jeopardy with Northern Pass. We have the Owl's Nest Golf Course and huge development in Campton that went under just because of this coming in, and no one would invest anymore and they were thriving before that. There are many, many people as you just heard the gentleman speak from Connecticut who have retirement homes, who come here to live who buy the view and they buy it for the next generation, and that's what they want. And they're not the big spenders necessarily, but they are coming and we do appreciate their business, and we appreciate their love of the area that we're very, very happy to share with them. MR. HONIGBERG: Dr. Warner, how much more do you have? DR. WARNER: I'm probably summing up. Now that you mention it. Thank you very much. I do have one point to make. I do dispute something that Mr. Quinlan has stated supposedly as fact that they have reached out to every municipality along the way. My husband served on the Littleton Selectboard for four out of the past five years, and we never heard anything of it. I haven't seen any Town Hall meetings. The only meetings that we have heard of and been to are the large meetings that are required by this Board that happened

1488-1

at some of the larger places, the venues like Mountain View Grand. I would prevail upon the Board to please ask Mr. Quinlan to provide you with an entire list of the these contacts and the notices given for these meetings, and I certainly would hope it would go onto the notification list because I'd like to see that. I recommend burial. It is done in other states and we should have that as well. Thank you.

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Nov 15, 2015

**ID:** 8508

**Date Entered:** Nov 15, 2015

**Source:** Website

**Topics:**

**Organization:**

**Comment:** Comment period over the holidays in unfair.

1490-1

Thank you for your comment. Following the receipt of the Further Amendment to Presidential Permit Application from Northern Pass on August 31, 2015, DOE prepared a supplement to the draft EIS analyzing the impacts of Alternative 7 - Proposed Action. A Notice of Availability of the supplement to the draft EIS was published by EPA in the Federal Register on November 20, 2015 (80 FR 72719). As a result of the production of the supplement to the draft EIS, the public hearings originally scheduled for October 2015 were rescheduled for December 2015, and were postponed again until March 2016. The comment period was extended until April 4, 2016. See Section 1.5 of the final EIS for a summary of public involvement in the NEPA process.

| 1490-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Nov 16, 2015

**ID:** 8516

**Date Entered:** Nov 16, 2015

**Source:** Website

**Topics:**

**Name:** VICTOR DEMEROTO

**Organization:**

**Mailing Address:** 46 TREMONT ST.

**City:** BOSCAWEN

**State:** NH

**Zip:** 03303

**Country:** US

**Comment:** BURY THE LINE OR STOP THE NORTHERN PASS PROJECT  
DO NOT SHEDULE OUR RESPONSE DEADLINES FO THE WEEK BEFOR CHRISTMAS!!!!  
THAT IS UNFAIR AND UNREASONABLE

1491-1

Thank you for your comment. Following the receipt of the Further Amendment to Presidential Permit Application from Northern Pass on August 31, 2015, DOE prepared a supplement to the draft EIS analyzing the impacts of Alternative 7 - Proposed Action. A Notice of Availability of the supplement to the draft EIS was published by EPA in the Federal Register on November 20, 2015 (80 FR 72719). As a result of the production of the supplement to the draft EIS, the public hearings originally scheduled for October 2015 were rescheduled for December 2015, and were postponed again until March 2016. The comment period was extended until April 4, 2016. See Section 1.5 of the final EIS for a summary of public involvement in the NEPA process.

1491-1

---

**From:** Kris pastoriza <krispastoriza@gmail.com>  
**Sent:** Friday, July 31, 2015 11:15 AM  
**To:** draftEIScomments@northernpasseis.us; jeanie.forrester@leg.state.nh.us  
**Subject:** comments

The 90 day comment period should not start until individuals who requested hard copy of the EIS months ago, actually receive it.

To require access via internet discriminates against those without connections, with slow connections, with data limits, with slow computers, with no computer, with no electricity, no transportation, and those who cannot read and reference such a document in digital form.

Kris Pastoriza  
 Easton, NH

1495-1

1495-1

Thank you for your comment. The public comment period on the draft EIS began on July 31, 2015. On August 31, 2015, the Applicant submitted an amendment to its July 31, 2013, Presidential permit application for the Northern Pass Transmission Line Project, which made changes to the proposed project. To address these changes, DOE prepared a supplement to the draft EIS, which was issued on November 12, 2015 (the notice of availability was published by EPA on November 20, 2015 [80 FR 72719]). At that time, the public comment period on the draft EIS and the supplement was extended to January 4, 2016; this was later extended again to April 4, 2016. A variety of methods were employed to publicize project information and public meetings, including the Federal Register, local newspapers, postal mailing addresses, email addresses, and the project EIS website. Extensive information about the EIS process has been made available through the project EIS website (<http://www.northernpasseis.us/>). Project documents, including the draft EIS and supplement to the draft EIS, were available digitally via the project EIS website and in hard copy by request and at 30 public libraries. As soon as the draft EIS and supplement to the draft EIS were published, DOE mailed printed hard copies and CD copies of the draft EIS and supplement to the draft EIS to those who had previously requested them. If a request was received after publication of the draft EIS or the supplement to the draft EIS, DOE mailed the hard copy to the requestor as soon as the request was received. Because of their voluminous size, the resource technical reports were available only online. DOE received no reports or complaints regarding delays in the receipt of hard copies of the documents or the availability of the technical reports.

*Thank you to Senator Shaker for requesting this hearing  
We should have been the first town set up - rather than in Colebrook  
Thank you for coming - and the time to get real:*

SEC Comments from Julie Moran, Colebrook 3/7/16

Since well before the initial announcement of the Northern Pass transmission project, and throughout its permitting process, the New Hampshire officials, regulators, governors, and legislators have allowed the rape of their citizens and the land. It is time to take the process and the people seriously, and stop the proposed rape of our pristine state and its people by a foreign country and its private business.

There is absolutely enough evidence for the Governor, Legislature, DOE, and SEC to stop this assault that will continue to assault us every second, every minute, every hour and day, of every year, for the rest of our lives.

It is shameful enough that a foreign company has mated with our own energy company to rape us, but for the past 5 years, our own governing bodies have failed us, causing a great exacerbation of our poverty, loss of businesses and property values, and loss of time and energy that you require of us to fight this assault.

Why have we already lost so much? Because of the mere threat of this rape-by-towers along our byways, scenic outlooks, and wooded pathways. And we are still being dragged through the streets, bleeding from the rape of the towers that hasn't even happened yet.

PLEASE! Hear us! Both of the last Governors failed to protect us from this impending assault. Our Federal and State Senators would not stand opposed to this assault. Even our own Coos County Legislators were powerless to be taken seriously by the NH Legislature.

The result is that the people of NH have been served a great injustice because the State has failed to protect us from the rape of our land, livelihood, and our very lives.

I will not apologize for speaking the Truth to you here tonight. We are desperate to be heard and taken seriously in this process. We are begging you at the DOE and SEC to STOP the RAPE of the towers.

Our government has apparently been bought out and we have still not stopped fighting to save ourselves from being raped by towers and strings every second, every minute, every hour of every day for the rest of our lives.

This is complete in justice, and apparently, the SEC and DOE are the only ones left who can save us from this assault.

- The process has included far too many back door sessions;
- Incomplete applications have been allowed;
- The "Site Tour" was hastily scheduled and held on a snowy day where visibility was about a half a mile;

The whole "process" has put our lives on hold, waiting for the rape to occur.  
How can we continue to live like this? How can you continue to put us through this?

The people's complaints have been laughed at and scorned  
Would you laugh at the rape of our daughters and sons?  
Of course NOT!

Then the SEC and DOE must stop this rape of the towers here and now.

Whomever has the power to stop this rape of the towers and does not stop it, will have the blood from it on their hands, every second, every minute, every hour or every day for the rest of their lives.

Therefore, I hope that you will all make the right decision, and deny Northern Pass its plan to dissect New Hampshire with its towers, so that you will have clean hands and a healthy heart for the rest of your lives.

Thank you.

*Tell NPT to Burg this line completely.*

*Added to 3 minutes from*

*SEC  
DOE  
JM*

*SEC  
DOE  
JM*

1497-1

Thank you for your comment. Section 1.5 of the EIS describes public participation in this NEPA process. With respect to an incomplete application, the Further Amendment to Presidential Permit Application was submitted by Northern Pass to DOE on August 31, 2015. DOE reviewed the amended application under 10 CFR 205, found it complete, and determined that it contained adequate information in order for DOE to analyze the impacts of the Project under NEPA. The site visits were organized by the New Hampshire Site Evaluation Committee (SEC). As discussed in Section 1.7.3.1 of the EIS, the SEC "is a non-federal process in which the DOE has no role." Because the SEC process and the SEC are separate and distinct from the NEPA process and the Department of Energy, the actions requested of the SEC are outside the scope of this EIS.

1497-1



## Coös County Commissioners' Office

P.O. Box 10  
 West Stewartstown, N.H. 03597  
 603-246-3321  
 fax: 603-246-8117

State of New Hampshire Site Evaluation Committee

March 7, 2016

Re: Docket No, 2015-06

For the record, my name is Richard J. Samson, Coos County Commissioner, District Three. I represent 11 towns and 8 unincorporated places. Of the 11 towns, 6 will be directly affected by Northern Pass and 4 of the unincorporated places will be affected.

The district I represent begins in Groveton or Northumberland and extends to Pittsburg at the Canadian border. It also extends from Errol, bordering Maine, to the Connecticut River separating New Hampshire and Vermont. It is the largest district in our county and state and the most affected.

The towns of Pittsburg, Clarksville, Stewartstown, Colebrook, Columbia, Stratford and Groveton have all voted at their town meetings in the past several years to oppose the proposed Northern Pass project. It is also in the Stark 2016 town warrant, article 16, to oppose any further overhead development of alternating current or direct current high voltage transmission lines within the borders of the town of Stark.

In Stark, all such future electrical transmission lines must be placed underground within power line rights of ways or within yet to be established power line corridors and installed in a manner approved by the state of New Hampshire's Public Utility Commission and/ or Department of Transportation.

At this time there are no transmission lines in Pittsburg, Clarksville or Stewartstown. There is a transbution line only.

COMMISSIONERS

THOMAS M. BRADY, Jefferson • PAUL R. GRENIER, Berlin • RICK SAMSON, Stewartstown



## Coös County Commissioners' Office

P.O. Box 10  
West Stewartstown, N.H. 03597  
603-246-3321  
fax: 603-246-8117

Has Northern Pass shown disregard and disrespect for upper Coos County by a lack of communication with the local elected officials? No Northern Pass official or representative has contacted the Coos County Commissioners, which serve as the select board for the unincorporated places. RSA 162-H: 16 IV (b) requires the committee to consider the views of municipal governing bodies on the Project's impact on the orderly growth of the region and the economic impact as well.

Would the SEC require Northern Pass to identify who Northern Pass feels are the stakeholders? The residents, landowners and business owners in my district that are negatively affected most by this proposed project have not been given due consideration or input. Northern Pass's refusal to meet with the above mentioned parties and opponents to honestly and openly discuss this proposed project shows a lack of concern for the residents of upper Coos County.

I would respectfully request that the SEC require Northern Pass to have open, honest and sincere discussions with any elected and affected local officials and affected opponents.

If Northern Pass is to be built, let us do what is right and honest for all the residents of our state and benefit our state and not corporate greed. Enough false information has been generated by proponents of this ill-conceived proposed project.

The SEC required that the Coos Wind Park have their financing in place and a decommissioning fund set up before approval. The Coos Wind Park is now 75% owned By Brookfield Power of Toronto Canada. The total decommissioning fund is approximately \$875,000 for 33 high elevation wind turbines. This fund will not begin to decommission the 33 wind turbines.

If permitted will Northern Pass remain owned by Northern Pass or will it eventually be sold to Hydro-Quebec as was the case of the Coos Wind Park?

COMMISSIONERS

THOMAS M. BRADY, Jefferson • PAUL R. GRENIER, Berlin • RICK SAMSON, Stewartstown

1499-1

Thank you for your comment. The state law cited and the comment concern the role of the New Hampshire Site Evaluation Committee (SEC). While the comment is acknowledged, as discussed in Section 1.7.3.1 of the EIS, the SEC "is a non-federal process in which the DOE has no role." Because the SEC process and the SEC are separate and distinct from the NEPA process and the Department of Energy, the actions requested of the SEC are outside the scope of this EIS.

1499-1



## Coös County Commissioners' Office

P.O. Box 10  
West Stewartstown, N.H. 03597  
603-246-3321  
fax: 603-246-8117

Is it the responsibility and obligation of the SEC to protect not only the applicant but also to protect the residents and our state? We the people are the caretakers of New Hampshire and included is the SEC.

“THE SMART WAY TO KEEP PEOPLE PASSIVE AND OBEDIENT IS TO STRICTLY LIMIT THE SPECTRUM OF ACCEPTABLE OPINION, BUT ALLOW VERY LIVELY DEBATE WITHIN THAT SPECTRUM.”

Respectfully Submitted,

Richard (Rick) Samson

County Commissioner District Three

COMMISSIONERS

THOMAS M. BRADY, Jefferson • PAUL R. GRENIER, Berlin • RICK SAMSON, Stewartstown

DOE

Dear Members of the SEC and Council for the Public

~~Dear Members of the SEC and Council for the Public~~ to address you in person. Thank you. *for this opportunity.*

Deerfield is in a unique situation regarding the NP project with the substation at its terminus. Since the projects announcement in 2010 we have been concerned about not only the additional incoming electricity but also the distribution of it.

Residents of Deerfield have wanted details regarding the ROW not just as it pertains to NP but how the configuration of the substation, poles, and lines has been selected with future projects in mind. What is the build out plan for this ROW and for all the many ROW's in town? We cannot ~~and will not~~ consider NPT as an isolated project independent of 10 year, 20 year, or 30 year plan. As a company, Eversource must have such a plan. *We are asking again* This plan must be revealed to our Select Board, ~~and~~ Planning Board, ~~so they~~ can gauge the impacts of NP while *evaluating* keeping in mind Deerfield's impact ~~and~~ capacity for other projects in the future.

Northern Pass has ~~been~~ *not* only answering questions about their proposed route. We have had no information from the applicant regarding any of the alternative routes, several of which site a converter station in Deerfield.

~~As you all well know, this project is entitled Northern Pass Transmission LLC AND Public Service Company of NH DBA Eversource Energy.~~

~~Do you remember the scene in the Wizard of Oz where the Tin Man and friends are told to "pay no attention to the man behind the curtain" I have seen this scene being played behind the curtain refusing to answer some basic questions.~~

~~Would like to give you an example:~~

→ Back in 2013, Eversource bought a 38 acre parcel of land near 35 North Road in Deerfield. Why did they buy it? For the last 3 years, at every opportunity, I have asked for possible ~~uses for this site, no answer.~~ *reasons for this purchase.*

As I already mentioned, several alternatives for the NP project listed in the DOE Draft EIS happen to identify this site for a converter station. The fact that neither

1502-1

Thank you for your comment. A description of Project components in the vicinity of Deerfield are provided in Section 2.3 of the EIS, specifically under Alternatives 2, 3, 4a, 4b, 4c, 6a, and 6b. A description of Alternative 7 - Proposed Action was provided in Section 3 of the supplement to the draft EIS, and has been incorporated into the final EIS (Section 2.3.12). Alternatives 3, 4a, 4b, and 4c include a converter station in Deerfield, NH (North Road Converter Station). In order to analyze a realistic range of fully underground alternatives the identification of a potential converter station site closer to the Deerfield Substation was necessary. This converter station is not included in the current Proposed Action (Alternative 7), as described in Northern Pass' latest Presidential permit application. Line reconductoring projects in the Deerfield area are not related to the Project analyzed in this EIS. AC system upgrades south of the Deerfield Substation are included in the Project (see Section 2.3 of the EIS) and are analyzed in this EIS. Chapter 5 of the EIS discusses cumulative impacts associated with the Project, that is, past, present, and reasonably foreseeable future actions that could, in combination with the Project, have cumulative environmental impacts (see Appendix D of the EIS). The commenter's questions regarding land purchases and sources of funds are beyond the scope of this EIS.

1502-1

1502-1  
Continued

NP nor Eversource will answer this question about this purchase is alarming in itself. The possibility of a converter station within 1/2 mile of the center of our town is also alarming. The last attempt to get an answer to this question was a month ago. I received an email reply saying they were still working on it.

~~Eversource has a business plan in place, what need did this parcel of land fulfill?~~

Will the answer or reason impact the orderly development of Deerfield? Who paid for this parcel? Rate payers? ~~Yes, and how was this purchase justified?~~

There has been line reconductoring ~~under the guise of~~ "upgrades" in Deerfield since this projects announcement. Who is paying for this, NP or NH rate payers? Should these distribution costs be factored into the cost of the project, especially in the cost/benefits analysis? For several years NP has proclaimed the project stops in Deerfield. Why then did Northern Pass do ~~some~~ wetland studies on an outgoing line to Scobie Pond in Londonderry?

Ask any resident within a mile of the existing substation what life in their neighborhood has been like the last few years: Construction noise, lights, steady traffic. The relationship between HQ's "PROJECT" and Eversource's "UPGRADES" is extremely murky. I am asking for SEC oversight and a look back to ensure that the NP project is not being pushed ahead of the approval process.

Since Eversource is a co applicant to this project, it is my hope that the NH SEC process will solicit and require honest answers to questions that reflect our concerns about the long term plans of Eversource for Deerfield and not just the proposed power coming in on the NP line.

Mr. Quinlan has referred to Deerfield as robust. ~~This is not how anyone in Deerfield would characterize our town, excepting maybe during the weekend of the fair.~~ For Southern NH, we are quiet, rural, and extremely community oriented.

The threat of the loss of our landscape weighs very heavy on us and every town along the ROW. I trust you will take our concerns to heart.

Thank you,

Jeanne Menard 36 Mountain Road, Deerfield, NH 03037

*referred to as*

*Eversource*

*I am sure if*

*→ shiley balance between undisturbed soil undisturbed view.*

*undisturbed soil / undisturbed view*

*In Deerfield white?*

*in this way*

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Nov 12, 2015

**ID:** 8477

**Date Entered:** Nov 12, 2015

**Source:** Website

**Topics:** Private Property/Land Use, Design Criteria / Mitigation Measures

**Organization:** They don't own the whole route

**Country:** US

**Comment:** Northern Pass does NOT have 100% legal control of the entire route, no matter which alternative is selected. Therefore, the SEC should deem NPT's application as "incomplete"

1508-1

Thank you for your comment. The Applicant will be responsible for securing all necessary rights and land use approvals to utilize any route permitted by the SEC. Sections 3.1.6.3 and 3.1.6.4 of the EIS discuss rights-of-way and the law, regulation and policy surrounding the use of public rights-of-way for a potential transmission route. Greater detail regarding the pertinent laws, regulations and policies is provided in Section 1.5 of the Land Use Technical Report. Regarding the comment that the SEC should deem the application incomplete, the review process underway by the New Hampshire Site Evaluation committee is separate from and outside the scope of this EIS. As discussed in Section 1.7.3.1 of the EIS, the SEC "is a non-federal process in which the DOE has no role." Because the SEC process and the SEC are separate and distinct from the NEPA process and the Department of Energy, the actions requested of the SEC are outside the scope of this EIS. With respect to DOE's NEPA process, the Further Amendment to Presidential Permit Application was submitted by Northern Pass to DOE on August 31, 2015. DOE reviewed the amended application under 10 CFR 205, found it complete, and determined that it contained adequate information in order for DOE to analyze the impacts of the Project under NEPA.

1508-1

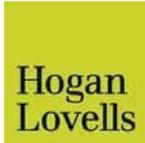
My name is Carol Coulombe, and I'm from Clarksville, New Hampshire, and I'm here tonight to ask the EIS and the DOE to please give towns more time to apply for intermediators for their communities. I realize that the deadline has gone by. But I feel that everybody should have a voice in. They extended more time for other things so I would think that they could do that for the people, and I'm especially concerned about the environment because I see the damage that's being done right on the power lines as we speak. If you've driven through the town of Lancaster recently, just look at the power lines. It's a mess. They have knocked down really a lot of nice trees that were not even near the lines in anticipation of putting this project in, and I think we're jumping the guns because the people don't want it and I don't see how a Canadian government can come over here and say, well, we have a lot of money and we're going to do what we want. They're not really considering how the folks of New Hampshire feel, and I'm very passionate about nature, I'm very passionate about the way we present ourselves as a tourist environment, and the people here have worked very hard on tourism. I feel that the hikers and the skiers and everybody that enjoys the outdoors, even people that like to visit the lodges and like the Balsams, for instance. I hear tell there's a lot of trees that have been cut down over there. I realize that times are hard, but why take it out on the environment. Canada, the government of the Canada is looking out for itself. It doesn't even care about its own people. It has destroyed native lands, to dam up the rivers. It has displaced native peoples and some hard working farmers, and there's still some more that are going to be losing their properties to this project if they already haven't, and my heart goes out to them. The Canadian citizens, the poor people of Canada, are not the ones that have the last say. I think that the government of Canada needs to realize that it can't walk all over the United States. We were friends for many years, Canada and US. We were considered like companion countries on the same side basically, but this is putting a wedge between our countries. They've done a lot of projects in New York, they've put them underground in other states, why can't they bury it here. I mean, is it because they want to give their steelworkers more jobs? It's not really going to help us that much. I don't think that these jobs which are temporary will help the people of this state, and the same thing with the logging. I think the government eventually is going to have to put a moratorium on all logging because the environment's gone. The planet's gone to hell. We're going to have to wake up, and we have to realize that if we don't start taking care of the environment and start looking out for, every tree counts. It puts oxygen on this planet, and the more they destroy, just look at Lancaster. All the old growth trees are gone on the side of the roads. Wherever there's a power line, they've knocked down trees that weren't even touching the power lines. Trees that were not even rotted have been taken down if you look at the stumps and these trees could have probably lived another hundred years. Why are they doing this? Are they trying to really anger us? Because it really angers me. There's no more scenic anything. If they do that in the National Forest and all along Franconia Notch and other places down south, this state is going to look like crap. And it's all for greed. Like everybody said. It's all about greed. Corporate power. I think we need to put our foot down and say enough is enough. Bury it and do as minimal damage to the land as possible. And this is the message for Canadians, especially the government. May God have mercy on you. Because you're bringing a curse upon yourself, and I was enlightened to warn you. Be aware there will be some serious consequences to what you are doing. Do not flood your neighbors below you. Do not destroy the trees that take care of the environment. Please reconsider what you are doing and warn Eversource which is behind all this tree cutting that they're being watched very closely. They're an evil company. They have damaged a lot of people's lives. They try to pretend that they're good and they're doing good. They donate to certain causes but what are they really doing? They're robbing us. They're robbing us for the sake of their own corporate greed. So I

1511-1

1511-1

Thank you for your comment. The meaning of "intermediators" in this comment is unclear. All persons who have requested to intervene to become "parties" in the Northern Pass Presidential permit application proceeding have been permitted to do so. Moreover, DOE currently intends to grant future unopposed petitions to intervene, notwithstanding the deadline to intervene originally set forth in the Notice of Application. On January 27, 2011, DOE sent a letter to all interveners in the proceeding explaining that interveners' "party" status in the Presidential permit application context entitles all interveners to receive notification of all documents submitted in the proceeding. Given the significant public interest and large number of interveners in the Northern Pass proceeding, DOE has established the Northern Pass EIS website (<http://www.northernpasseis.us>) where it makes filed documents available and provides additional resources about the proceeding. In lieu of requiring service on all interveners, DOE intends this website to provide maximum transparency and to ensure that interveners and the public remain apprised of issues and developments for the duration of the proceeding. Any similar status in the New Hampshire Site Evaluation Committee process is outside the scope of this EIS because, as discussed in Section 1.7.3.1 of the EIS, the SEC "is a non-federal process in which the DOE has no role."

don't think that they can be trusted, and I don't think we should trust the Canadian government. I think that we have to get really strict with them. Enough's enough. The people have spoken and nature cries out, and Almighty God has heard your prayers. They will be answered one way or another. Thank you, sirs.



Hogan Lovells US LLP  
Columbia Square  
555 Thirteenth Street, NW  
Washington, DC 20004  
T +1 202 637 5600  
F +1 202 637 5910  
www.hoganlovells.com

**By Electronic Mail**

September 17, 2015

Mr. Brian Mills  
Office of Electricity Delivery and Energy Reliability  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585

**Re: Northern Pass Transmission LLC  
Docket No. PP-371  
Response to Request for Supplemental EIS**

Dear Mr. Mills:

On August 18, in response to concerns raised by certain members of the New Hampshire public, Northern Pass Transmission proposed changes to its Project to bring 1,000 megawatts of low carbon hydropower from Quebec to New England. The changes are designed to dramatically reduce the potential for visual and other impacts of the Project by placing more than 60 miles underground in public roads.

Five organizations that have long urged Northern Pass to take such action now argue that the Department of Energy (DOE) should prepare a supplemental environmental impact statement (EIS) to evaluate the impacts of the redesigned Project. The thorough analysis of 11 different alternatives in the Draft EIS that DOE issued in July makes it clear that no such action is warranted. Indeed, CEQ guidance, DOE's own NEPA guidance and NEPA case law all make clear that this is not a situation where a supplemental EIS is required.

This is a 192-mile long project, and all but three miles of it were fully analyzed in the Draft EIS. Those three miles are underground in public roads where there will be no new environmental impacts because those areas were disturbed by the road construction that occurred long ago. Reflecting that fact, the Draft EIS finds little distinction in its analysis of the impacts of placing the Project underground along the various routes it evaluated in the eight different alternatives it considers that involve placing most or a portion of the Project underground in the roads. The law is clear that "a minor variation" that is qualitatively within the range of alternatives considered requires no further analysis. See Council on Environmental Quality, *Forty Most Asked Questions Concerning*

1517-1

Thank you for your comment. Following the receipt of the Further Amendment to Presidential Permit Application from Northern Pass on August 31, 2015, DOE prepared a supplement to the draft EIS to analyze the impacts of the Applicant's revised proposal. The supplement designated the revised proposal as Alternative 7 - Proposed Action. The proposed changes included modifications to the proposed transmission line route and to the size of the Project from 1,200 MW to 1,000 MW with a potential transfer capability of up to 1,090 MW. The analysis of Alternative 7 presented in the supplement to the draft EIS reflected these modified project design details. Although Alternative 7 was principally evaluated in the draft EIS under a combination of several of the alternatives, DOE determined that providing a supplement would allow the potential environmental impacts of Alternative 7 to be more clearly displayed as an additional singular alternative and facilitate comparison among the other alternatives. A Notice of Availability of the supplement to the draft EIS was published by EPA in the Federal Register on November 20, 2015 (80 FR 72719). The final EIS incorporates the analysis of Alternative 7 - Proposed Action, which had been analyzed originally in the supplement to the draft EIS. Alternative 7 has also been incorporated into the resource technical reports accompanying the final EIS.

1517-1

CEQ's *National Environmental Policy Act Regulations*, 46 Fed.Reg. 18,026, 18,035 (1981). Here, the impacts of the redesigned Project are fully captured in the Draft EIS.

The fact that the redesigned Project partakes of portions of several different alternatives evaluated in the Draft EIS likewise does not warrant a supplemental EIS. To the contrary, it is well established that it is permissible in the NEPA process to adopt a combination of elements of different alternatives evaluated in an EIS. *E.g., Great Old Broads for Wilderness v. Kimbell*, 709 F.3d 836 (9<sup>th</sup> 2013) (no supplemental EIS was required where the Forest Service approved a project that combined aspects of three alternatives analyzed by the FEIS); DOE, *NEPA: Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements* (2d ed. 2004), at 13 ("Sometimes DOE can fulfill its purpose and need by combining elements of two or more alternatives. DOE can choose this approach while the EIS is being prepared or in a record of decision.").

We note that DOE's NEPA regulations provide for the possibility of preparing a "supplement analysis" as a means for evaluating and documenting its decision as to whether a supplemental EIS is required. 10 C.F.R. § 1021.314(c). DOE may wish to issue a supplement analysis here to make clear what Northern Pass believes is obvious, that the Draft EIS more than amply evaluates the impacts of the redesigned Project and that no supplemental EIS is required. Such an analysis need not delay the public hearings on the thorough Draft EIS DOE has prepared, and those hearings are of course just one element of the public's opportunity to comment in the NEPA process.

Respectfully submitted,



Mary Anne Sullivan

Partner  
maryanne.sullivan@hoganlovells.com  
D 202.637.3695

1517-1  
Continued

---

**From:** Robert Tuveson <roberttuveson@hotmail.com>  
**Sent:** Thursday, November 12, 2015 10:40 AM  
**To:** draftEIScomments@northernpasseis.us  
**Cc:** Will Abbott; Susan Schibanoff; Mike Marino  
**Subject:** Supplemental Draft of EIS

Dear Dr. Mills

It is my understanding that the amended application for the Northern Pass Project is proposed to change from 1200 megawatts to 1090 megawatts, not to 1000 megawatts as indicated in your November 12th mailing. Because the number of megawatts is incorrect, does that mean that you are required to make adjustments to the Supplement of the Draft EIS?

Respectfully submitted,  
 Robert Tuveson, Holderness, NH

Robert Tuveson  
 Sent from my iPad

1518-1

Thank you for your comment. Following the receipt of the Further Amendment to Presidential Permit Application from Northern Pass on August 31, 2015, DOE prepared a supplement to the draft EIS to analyze the impacts of the Applicant's revised proposal. The supplement designated the revised proposal as Alternative 7 - Proposed Action. The proposed changes included modifications to the proposed transmission line route and to the size of the Project from 1,200 MW to 1,000 MW with a potential transfer capability of up to 1,090 MW. The analysis of Alternative 7 presented in the supplement to the draft EIS reflected these modified project design details. Although Alternative 7 was principally evaluated within the draft EIS under a combination of several of the alternatives, DOE determined that providing a supplement would allow the potential environmental impacts of Alternative 7 to be more clearly displayed as an additional singular alternative and facilitate comparison among the other alternatives. A Notice of Availability of the supplement to the draft EIS was published by EPA in the Federal Register on November 20, 2015 (80 FR 72719). The final EIS incorporates the analysis of Alternative 7 - Proposed Action, which had been analyzed originally in the supplement to the draft EIS. Alternative 7 has also been incorporated into the resource technical reports accompanying the final EIS.

1518-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Jul 25, 2015

**ID:** 8218

**Date Entered:** Jul 25, 2015

**Source:** Website

**Topics:** Vegetation, Wildlife, Viewshed/Scenery, Water / Wetlands, Recreation, Taxes, Historic/Cultural, Economic, Tourism, Quality of Life, Cumulative Effects, Environmental Justice

**Name:** Kara Maslowski

**Organization:**

**Email:** kdmaslowski@gmail.com

**Mailing Address:** 22 gates lane

**City:** Fremont

**State:** NH

**Zip:** 03044

**Country:** US

**Comment:** I am opposed to the Northern Pass project for many reasons. The natural beauty of NH is unparalleled and it is something we must not barter away. It is the bread & butter of our state's economy because of how our forefathers protected it for our benefit. Let's keep the same thoughtfulness to generations of NH residents to come. The devastating environmental effects of the Northern Pass would cripple our economy. It would impact both the tourism dollars & tax revenue for the state.

1522-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1522-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Jul 25, 2015

**ID:** 8219

**Date Entered:** Jul 25, 2015

**Source:** Website

**Topics:** Purpose and Need, Health and Safety

**Name:** Fred Gunter

**Organization:** PRLAC

**Email:** fgunter@roadrunner.com

**Mailing Address:** POBox 596

**City:** Campton

**State:** NH

**Country:** US

**Comment:** The need of the transmission line for NH is not there. There seems to be a desire on the part of the proponents to disregard the economy of NH for a money grab on their part. NH depends on tourism and beauty of the state for a large part of our economy. If it is deemed necessary for the region, it should be buried in it's entirety. The cost would be recouped in a few years.

1523-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1523-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Jul 26, 2015

**ID:** 8222

**Date Entered:** Jul 26, 2015

**Source:** Website

**Topics:** Cumulative Effects

**Name:** Catherine Bilodeau

**Organization:**

**Title:** Ms.

**Email:** cbb@metrocast.net

**Mailing Address:** 29 Union Road

**City:** Northfield

**State:** NH

**Country:** US

**Comment:** Please do not allow Northern Pass to progress as proposed. This project will have many tragic effects on the state of New Hampshire. New Hampshire is already struggling financially and if Northern Pass is built things will be even worse. Tourism is one of state's biggest industries, and there is no denying that Northern Pass will have an adverse effect on that, leaving our state with less money for schools, infrastructure, and other vital concerns. Property values will drop, leaving our struggling towns with less income too. People will have to give up their homes as property taxes skyrocket to make up for the difference. This is a perfect example of what is wrong with America today, big business trampling over the rest of us with any concern for the consequences, all for financial gain for themselves. Please stand up for the people of New Hampshire, who do not want Northern Pass ruining our beautiful state. Please make a stand against those who are destroying this country in their quest for wealth. Thank you.

1524-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Section 4.1.2 of the EIS additionally includes analysis of the impact on future assessments due to potential adverse impacts on property values.

1524-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Aug 10, 2015

**ID:** 8256

**Date Entered:** Aug 10, 2015

**Source:** Website

### Topics:

**Name:** Mitchell Harrison

**Organization:**

**Email:** mhsierra@yahoo.com

**Mailing Address:** 179 Alstead Center Road

**City:** Alstead

**State:** NH

**Zip:** 03602

**Country:** US

**Comment:** I would like to express my opposition to the Northern Pass project as it is proposed. An above ground power line of this scale is out of character with New Hampshire. If above ground, these obtrusive power lines would run through areas of immense beauty. These areas, such as the white mountains provide renewal to residents not only of New Hampshire but also throughout the northeast and even beyond. This project would change the experience of fly fishing the quality trout waters of northern New Hampshire, of hiking to one of the states high peaks in the the White Mountain National Forest and potentially impact species such as boreal forest nesting birds. All this could affect the tourist economy of our state. Several other similar power lines have been buried along existing transportation corridors and it seems Northern Pass could be as well. The recent cost comparison indicates that although it would cost more to bury the lines, it is no where near where the company estimated. Thank for taking the time to read my comments.

Mitch Harrison  
Alstead, NH

1525-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1525-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Aug 14, 2015

**ID:** 8293

**Date Entered:** Aug 14, 2015

**Source:** Website

**Topics:** Purpose and Need, Alternatives, Health and Safety, Vegetation, Wildlife, Viewshed/Scenery, Water / Wetlands, Soils, Recreation, Private Property/Land Use, Historic/Cultural, Economic, Tourism, Quality of Life, Air Quality, Cumulative Effects, Noise, Forest Service Lands, NEPA Process, Design Criteria / Mitigation Measures, Environmental Justice

**Name:** Joanne Bates

**Organization:** nh resident

**Email:** joannebates143@yahoo.com

**Mailing Address:** 28 stone street

**City:** concord

**State:** NH

**Country:** US

**Comment:** Do not destroy NH. We are known for our Great White Mountains and small scenic towns. This is why folks from all over the world come here- tourism is our lively hood. This is irreversible. There are always better ways and it appears the state is grabbing a quick fix (ironically for another state) rather than looking at long term serious consequences. WE do not need this- so stop it.

1528-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1528-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Aug 14, 2015

**ID:** 8294

**Date Entered:** Aug 14, 2015

**Source:** Website

**Topics:** Viewshed/Scenery, Recreation, Tourism, Cumulative Effects

### Organization:

**Comment:** I understand that it is difficult to quantify the negative financial impact the Northern Pass will have on tourism in New Hampshire. However it's easy to understand that it is not a one time negative effect but it goes on year after year as long as the 2,000 plus steel towers exist. In addition, tourists will tell their friends and neighbors to save their money and avoid New Hampshire. As a result, the negative financial effect will grow in magnitude year after year.

1529-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1529-1

---

**From:** Kurt Flynn <nepa70@ymail.com>  
**Sent:** Thursday, August 06, 2015 9:35 AM  
**To:** draftEIScomments@northernpasseis.us  
**Cc:** nepa70@ymail.com  
**Subject:** NORTHERN PASS TRANSMISSION PROJECT DEIS

August 6, 2015

Dear Mr. Mills,

As described below, I believe the DEIS fails to properly describe the no action alternative and its impacts and, that supplementation of the DEIS with the proper description of no action alternative impacts is required.

The no action alternative, as discussed on page 2-3, is described only as the absence of the proposed action. In accordance with the Council on Environmental Quality, if the agency's lack of action would result in "predictable action by others" then the no action alternative must also describe these actions and their impacts. (See response to question No. 3, CEQ's 40 Questions, dated March 16, 1981.)

The DEIS indicates energy conservation would be such a predictable action. On page 2-37 the DEIS states, "reductions in energy use and demand would offset the need for additional electricity in the New England region, thus rendering the Project unnecessary. Consequently, the Project would not be built". Although elimination of conservation as an action alternative is acceptable, conservation must be considered as part of the no action alternative.

The proper description of the no action alternative is a vital component of DOE and Forest Service's disclosure and consideration of impacts. The lack of a proper no action alternative means the DEIS fails to provide the required disclosure and consideration of impacts. Therefore to ensure NEPA compliance, energy conservation actions and their impacts need to be analyzed and described as part of the no action alternative in a supplemental DEIS.

Sincerely,

Kurt Flynn  
 190 Sandpiper Rd.  
 Midway, GA 31320  
 NEPA70@ymail.com

1530-1

Thank you for your comment. The No Action Alternative is analyzed throughout the EIS. The No Action Alternative represents a continuation of the existing condition which is described in Chapter 3 of the EIS. Chapter 3 describes in detail the existing condition for all resources throughout the study area. In particular, existing electricity system infrastructure is described in Section 3.1.2.5 of the EIS; this information has been updated for the final EIS. Section 1.4 of the EIS has also been updated to reflect current trends and conditions in the regional energy market. Additionally, the Socioeconomics Technical Report includes a discussion of modeling completed for this EIS, including a projection of future base case conditions in New Hampshire and the ISO-NE region through 2030. The modeling was updated for the final EIS to incorporate current market conditions and trends. The future base case condition was modeled based on the best available information from ISO-NE; this modeling represents the potential condition under the No Action Alternative and serves as a baseline against which to analyze the potential impacts of the Project. Under the No Action Alternative, it is assumed that existing energy sources, including alternative energy generation would continue to supply the ISO-NE region and that energy efficiency measures would continue. Existing issues with the electricity supply, including diversity, would persist. Finally, NEPA's purpose is to analyze and consider the potential environmental impacts of a federal action. While the EIS analyzes possible impacts to the electricity system in the socioeconomics analysis, a detailed analysis of these impacts is performed through DOE's reliability study completed in cooperation with ISO-NE via a separate process. An energy conservation alternative was considered but was eliminated from detailed analysis in the EIS because DOE determined it is not a reasonable alternative, in part because energy efficiency and conservation cannot alone meet the growing demand for electricity in ISO-NE. Section 2.4.9 of the final EIS has been updated with additional information about this alternative.

1530-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Aug 13, 2015

**ID:** 8291

**Date Entered:** Aug 13, 2015

**Source:** Website

**Topics:** Alternatives, Wildlife, Viewshed/Scenery

### Organization:

**Comment:** I am opposed to the Northern Pass project as planned because it will Destroy the Natural Beauty of New Hampshire especially the Northern most part which relies on it for the economic prosperity of this region for the purpose to supply other states with electricity. These other states are not willing to conserve or offer alternative forms of power for their own regions that will affect their areas economy. We here in New Hampshire value the Beauty and Wildlife and Do Not Need or abuse our energy at the cost of these states that will Benefit from Northern Pass. If this project goes forward as proposed it will have a Negative Impact on Tourism which is now the Main resource for our economy, I would recommend that if the project is to be accepted byus it would and should be buried the entire length through our state. Even if it is buried it will still scar our landscape but if it in the right of way that is now established it will not be a long path of ugly towers that are throughout the Southern States the residents of that region accept and have lived with and they don't rely on for their economy. The cost of burial is miniscule to the cost the residents of New Hampshire will live with everyday when the Towers scar our landscape for the benefit of the wasteful residents that will ultimately receive the electricity created from this project. Please look at alternative energy that is created here in the United States before any permits are granted. Thank you.

1532-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1532-1

---

**From:** Sean Brungot <brungy1971@gmail.com>  
**Sent:** Tuesday, August 11, 2015 6:30 AM  
**To:** draftEIScomments@northernpasseis.us  
**Subject:** Northern Pass

To Whom It May Concern,

I'm writing as a concerned citizen of Northern NH. Northern NH is a place of unprecedented scenic natural beauty. That beauty attracts tourism but it is also a source of pride to the people of Northern, NH who call this place home. In fact, this scenic natural beauty is one of the main reasons that many people decide to live here permanently. Northern Pass with its steel lattice transmission towers and overhead transmission lines is a major threat to this natural beauty. It is also a threat to tourism and property values.

Northern Pass is an affront to people of this State, but particularly to the people of Coos County. I, along with many other citizens, are deeply disturbed by the fact that Northern Pass is not going to bury all of its proposed transmission lines related to this project. With today's technology there is no reason that the lines cannot be buried for the entire route. In fact, burying the lines would create more construction jobs and would have little to no impact on tourism and property values. These facts are actually confirmed in the DRAFT EIS. A final permit to construct this project should REQUIRE burial of all of the lines running through our great State.

It is sad that Eversource and Hydro Quebec would threaten our quality of life for a project that is designed solely for their corporate profit. If the Federal Government allows this project to be built as proposed then "we the people" is a phrase that no longer exists. "We the people" of NH have spoken in overwhelming numbers against this project as proposed. "We the people" want Eversource and Hydro Quebec to bury the lines. If not, then "we the people" do not want this project to move forward and ruin our State.

I sincerely hope that the Federal Government hears the people of NH. This project should NOT be approved unless ALL of the lines are buried below ground.

Thank you for taking my comment,  
 Sean Brungot  
 Berlin, NH

1533-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1533-1

# Northern Pass EIS Website Comment Receipt

1537-1

Thank you for your comment.

## Refers to Comment placed on Mar 30, 2016

**ID:** 8992

**Date Entered:** Mar 30, 2016

**Source:** Website

**Topics:** Alternatives, Vegetation

**Organization:** Appalachian Mountain Club

**Comment:** I am in favor of complete burial of the transmission lines because the extreme height of the towers would have a negative impact on the view of landscapes along the transmission route. As well as aesthetics there would be a corresponding impact on property values as well. I think the burial of the transmission lines is economically feasible despite the objections of Eversource, since other states such as Vermont and New York have chosen that option.

1537-1

---

**From:** Fred W. Martin <extra@nbeam.com>  
**Sent:** Sunday, August 30, 2015 11:01 AM  
**To:** draftEIScomments@northernpasseis.us  
**Cc:** lmrapp@lmrapp.com  
**Subject:** tourism questionnaire?

50 Village Ave  
Dedham MA 02026

2369 US rte 3  
North Stratford NH 03590

Mr. Brian Mills  
Office of Electricity Delivery and Energy Reliability  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585

Dear Mr. Mills:

This is a comment on the draft EIS for the Northern Pass project, favoring alternative 3 for socioeconomic reasons.

Sections 3.3.2.4 (central region tourism), 3.2.2.4 (northern region tourism), 3.1.2.4 (tourism in general), and 2.5.2 (socioeconomics) are inadequate. The section on tourism in general recites past statistics, but makes no attempt to estimate the effect of the powerline on tourism. Section 2.5.2 says impacts are "not quantifiable".

Before the final EIS, why not send out a questionnaire to affected parties such as chambers of commerce and town governments along the route of the powerline, asking their estimates of the loss of tourist business? The effect on a \$4.4 billion business (pg 3-7) deserves a better characterization than "not quantifiable."

The proposed alternative 2 will involve towers nearly twice the height of trees visible to the side of the main highway I-93 travelled by most tourists to access vacation homes in NH. There are multiple crossings of this highway by the powerline. The tall towers will also cause a change in the economics of Coos County and the White Mountains region as destinations, because fewer vacation tourists and summer residents will be attracted by the rural scenery. Tourism is critical to Coos County, where the departure of the paper mills resulting from international competition and the loss of dairy farms to southwestern US agribusiness has left the hospitality industry as the only major source of revenue.

In its sections on Environmental Justice the report compares locations near the powerline to locations in the same county, ignoring the difference among counties. The EIS lists 10% of directly affected families below the poverty level in the northern region (page 4-136) and 4% in the general southern region (page 4-333), and nearly a doubling of the median household income, ignoring the difference among regions.

Additionally, the recent modified proposal to bury the line only in the White Mountains does not consider the effects along I-93 or within Coos County..

Alternative 1 (no-build) or alternative 3 (full burial along the proponent's proposed route) are preferable to alternative 2 as proposed.

Sincerely yours,

1538-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1538-1

Frederick W. Martin

12/14/2015

Mr. Brian Mills

Senior Planning Advisor

Office of Electricity Delivery & Energy

Reliability (OE-20)

US Dept of Energy

1000 Independence Ave SW

Washington DC 20585

Dear Mr. Mills:

Northern Pass is not what the people of the United States want or need. It is time for us to develop Solar & Wind Power to produce clean natural energy. I live in northern New Hampshire and often travel to Northern New York where my son is attending Clarkson University in Potsdam, NY. I am always anxious to see the wind turbines that dot the landscape on my way there. They are not ugly, dirty or noisy.

I also use solar power on a small scale on my family land in Northumberland, NH. It is clean, not noisy and very efficient.

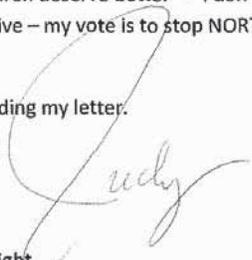
I do not want to see the towers from my home in Littleton, NH or on the family farm in Northumberland, NH.

I believe our children deserve better - I don't believe burying it or have it hundreds of feet in the air is healthy or attractive - my vote is to stop NORTHERN PASS and develop solar & wind power on a greater scale.

Thank you for reading my letter.

Sincerely,

Judith K Barnes-Hight



1542-1

Thank you for your comment.

1542-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 9, 2016

**ID:** 8730

**Date Entered:** Mar 9, 2016

**Source:** Website

**Topics:** Purpose and Need, Wildlife, Viewshed/Scenery

### Organization:

**Comment:** While burying the lines will result in more expense, not burying the lines WILL damage the property values and economic interests of NH residents. NH has very little industry and relies on tourism. NH will only minimally and temporarily benefit from this project. Yet NH WILL suffer economically from this project unless the lines are buried. Bury the lines, and I'm all for it!

1543-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1543-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 28, 2016

**ID:** 8877

**Date Entered:** Mar 28, 2016

**Source:** Website

**Topics:** Alternatives, Viewshed/Scenery, Recreation, Economic, Design Criteria / Mitigation Measures

**Name:** Charles Raeburn

**Organization:** Retired

**Title:** Retired

**Email:** cgraeburn@gmail.com

**Mailing Address:** 41 Norton Rd

**City:** Hampton

**State:** NH

**Zip:** 03842

**Country:** US

**Comment:** As someone who grew up in Gorham, New Hampshire and who spends a lot of time hiking in New Hampshire's North Country, I feel the Northern Pass project is greatly flawed.

The proposal to have large towers to carry the electrical lines through New Hampshire will become a huge deterrent for those who want to come to our state as tourists to enjoy the pristine views, wildlife, and recreation. This will impact the North Country's fragile economy in an unfavorable manner for many years (as opposed to the one time bump that may be received from the construction effort).

There are a couple of options that seem quite feasible yet have been rejected by the project sponsors. The most obvious option is to bury the lines, but that might cost a few dollars more. Another option might be to use existing corridors through the State of Vermont or bury the lines under I 91 which Vermont has proposed, but that would take the US sponsor (Eversource) out of the picture.

Its time to put more weight on the environmental impact and to downplay the one sided economic interests of the US project sponsor.

1545-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1545-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 28, 2016

**ID:** 8894

**Date Entered:** Mar 28, 2016

**Source:** Website

### Topics:

**Name:** Anita Craven

**Organization:**

**Email:** acraven@togther.net

**Mailing Address:** 777 Paine Road

**City:** Easton

**State:** NH

**Country:** US

**Comment:** Here is proof of the astounding number of “just plain people” who don’t want towers – people from in- and out-of-state in equal numbers. I was curious to see if the numbers were really as big as we claimed, so I posted a sign-in sheet on a less-heavily used hiking trail, and in 4 weeks there were over 300 names, all saying “No Towers.”

The trail goes to North Kinsman from Route 116. Along the way is Bald Nob with a beloved view overlooking 6-plus miles of Northern Pass right-of-way where it cuts through National Forest and undeveloped hills. The posted sheets explained that wooden towers were there, barely discernible, in a lovely peaceful outlook. I asked people to write their names if metal towers, twice as tall and visible the entire length would bother them. The answer was a resounding “NO TOWERS”!

I collected 300+ names from one off-the-beaten-path trail. It rained a lot and was hard to write, but people took the time – adding extra paper and writing on the backs. Multiply these numbers by other trails on other days. Then add the non-hikers who see towers on their drive north, or south. They shouldn’t have these ugly towers thrust on them in the super-beautiful landscape so touted by New Hampshire Tourist Bureaus!

It is time to take New Hampshire into the 21st century. Bury the lines. Show that regulators listen. The numbers shout that “we the people” don’t want to be wrapped in overhead wires of the past. Make New Hampshire a leader in 21st century technology. Make New Hampshire a forward-looking bell-

1547-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that “while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable.” Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1547-1

weather state. The technology is here. Use it. Bury all the lines all the way! LISTEN TO THE PEOPLE.

1547-1  
Continued

1547-1 cont'd

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Apr 1, 2016

**ID:** 9153

**Date Entered:** Apr 1, 2016

**Source:** Website

**Topics:** Purpose and Need, Alternatives, Viewshed/Scenery, Historic/Cultural, Economic, Tourism, Quality of Life, Design Criteria / Mitigation Measures

**Name:** Andrew Brana

**Organization:**

**Email:** aadbrana@yahoo.com

**Mailing Address:** POB 76

**City:** Jefferson Valley

**State:** NY

**Zip:** 10535

**Country:** US

**Comment:** The Northern Pass electricity transmission project should be required to bury all the transmission lines and ideally use existing transportation corridors as much as possible. Line burial is an existing technology that is already used in many projects. The damage to our cultural and natural resources and landscape should not be allowed. There is quality of life and a huge tourism industry that many people benefit greatly from and this project should not compromise there.

1551-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1551-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Apr 3, 2016

**ID:** 9177

**Date Entered:** Apr 3, 2016

**Source:** Website

**Topics:** Viewshed/Scenery, Recreation, Private Property/Land Use, Historic/Cultural, Economic, Tourism, Quality of Life

### Organization:

**Comment:** I am against the Northern Pass as proposed. It should be done in a way that respects NH communities, scenic landscapes, conserved land and the interest of landowners. As recommended by opposition groups, full burial along appropriate transportation corridors makes much more sense.

The beauty of our state, it's conservation lands and national forest should not be used for commercial development.

I'm an avid outdoor enthusiast who enjoys what our state has to offer. This will scare our states landscape and effect the tourism economy we greatly depend on.

Please reconsider giving our state away to commercial development.

Barry Greenhalgh

1552-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1552-1

March 21, 2016

Mr. Brian Mills  
Office of Electricity Delivery and Energy Reliability (OE-20)  
U.S. Department of Energy  
1000 Independence Avenue, S. W.  
Washington, D. C. 20585

Re: The Northern Pass Transmission Line Project  
Draft Environmental Impact Statement  
Docket No. 2015-06

Mr. Mills,

**I do not want this Northern Pass Project to go forward. If it is to be built, it must be completely buried for the entire route.** The project would have a negative impact on the view shed which is the basis of the state's tourist industry and recreational activities, and adversely effect real estate values.

**4A** is the **fully underground** Alternate Route option analyzed by the Department of Energy in the Draft Environmental Impact Statement(DEIS) for Northern Pass. It uses state roads from Pittsburg to Franconia, I-93 from Franconia to Concord, and federal and state roads from Concord to Deerfield. In the Draft EIS, the DOE confirms this: "DOE has determined that extended burial of a transmission line with the capacity of 1,000MW would be practically and technically feasible."

**4A clearly demonstrates that burial is the preferred way.**

It has come to my attention through the Site Evaluation Committee(SEC) hearings that I attended in both Grafton and Coos Counties this past March, 2016, that, per the New Hampshire Department of Transportation(DOT), to bury the proposed Northern Pass/Hydro-Quebec powerline within the right of way(ROW) of New Hampshire Interstate 93 (I-93), would be impossible.

It was stated that safety concerns of cars traveling at highway speeds of seventy(70) miles per hour would preclude construction of this line. Also stated was that the line could not be buried along the median strip or breakdown lane of I-93, but would have to be constructed at the fence line.

It is my understanding that the average width of the I-93 corridor is approximately two hundred and twenty(220) feet. At the time of the two hearings I attended, an Eversource representative stated that the burial of the powerline would require a trench four(4) feet wide and four(4) feet deep. This would leave more than adequate room beyond the paved travel ways of the I-93 to construct and bury the powerline without severely disrupting traffic.

1553-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1553-1

1553-2

Thank you for your comment. Because an EIS is intended to inform decisionmakers and the public about potential impacts of a major federal action, DOE analyzes in detail several alternatives that involve underground cable in the I-93 corridor, including Alternatives 4a, 4b, 4c, 5a, 6a, and 6b. The regulatory framework governing utilities in roadway corridors is discussed in the Land Use Technical Report and the EIS, see Section 3.1.6.4. DOE has considered this comment and no change to the EIS was made.

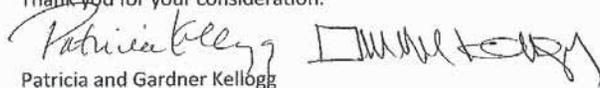
1553-2

Throughout this summer 2015, NH I-93 had construction projects which included one-lane closures. This work did not dramatically interfere with the safety and convenience of the traveling public.

The State of New Hampshire is constantly struggling with the funding of DOT, and many projects are delayed or postponed due to no money. Northern Pass/ Hydro-Quebec would pay for this 4A burial project, and future funds would come to the State of New Hampshire from them paying to put the powerline along these roads.

**This project should not go forward. The only way for it to take place is for the entire route to be buried, that is, 4A of the Draft Environmental Impact Statement.**

Thank you for your consideration.



Patricia and Gardner Kellogg  
320 Manns Hill Road  
Littleton, N.H. 03561

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Jul 22, 2015

**ID:** 8204

**Date Entered:** Jul 22, 2015

**Source:** Website

**Topics:**

**Name:** Peter Bosco

**Organization:** Self

**Email:** pboscoprivate@yahoo.com

**Mailing Address:** 1465 East Putnam Ave., 203

**City:** Old Greenwich

**State:** CT

**Zip:** 06870

**Country:** US

**Comment:** I live in southwestern Connecticut - hundreds of miles away, unaffected, by the Northern Pass. In the last 35 years, I have spent tens of thousands of dollars recreating in New Hampshire. I ski, hike, bike and travel the North Country. I visit 3 - 4 times a year. I have rented cabins and cottages. I have backpacked, camped and stayed at remote back country leantos. I have been to places few New Hampshire residents have seen. I love New Hampshire.

Simply stated, if the Northern Pass project goes through as proposed, with high-tension towers, I will, sadly, stop recreating in New Hampshire. I will visit Vermont (where a similar line will be buried), or Maine. I am not the only tourist who will stop being a customer of New Hampshire. It will have a cascading economic hardship on the people and businesses of New Hampshire. I cannot implore you enough to mandate these power lines be buried. EverSource stands to make 50+ billion dollars over the life of these towers. The can amortize some of the cost of burial over 40 years to their customer and make a billion dollars less. It is the right and only thing to do. Please do the right things and stop this project as proposed. Sincerely, Peter Bosco, Old Greenwich, CT

1554-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1554-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Sep 23, 2015

**ID:** 8394

**Date Entered:** Sep 23, 2015

**Source:** Website

**Topics:** Health and Safety, Viewshed/Scenery, Recreation, Private Property/Land Use, Tourism

### Organization:

**Comment:** The benefits of Northern Pass are likely needed in Mass. Conn. and perhaps New York. Sooner or later, NH may be needing those same benefits, but NOT at the expense of the state of our great state of NH. What could be health issues caused by living to a 1000 Megawatt power line? Scarring the state of NH from the far north all the way down our state would be devastating to tourism to say the least.

Northern Pass should be built, but only if it is totally buried, all 192 miles of it! Eversource claims that if it is forced to completely bury the power lines that it would make it cost prohibitive, well, I don't believe that!

It would be cost prohibitive for the state of NH with the loss of revenue if tourism is destroyed by these above ground ugly power transmission lines right through our beautiful state. I implore the DOE to not allow this project to move forward as proposed. Thank you for your time and please keep in mind that from everything I see and read about Northern Pass that an overwhelming majority of the people of this state are against the project as proposed. It may take longer for Eversource to realize a profit, but I can assure you that they still would. Similar projects were undertaken in other states (completely underground) and they realized a profit, so why wouldn't Eversource? Again, thanks for your time.

1562-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1562-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Sep 24, 2015

**ID:** 8395

**Date Entered:** Sep 24, 2015

**Source:** Website

**Topics:** Purpose and Need, Viewshed/Scenery, Private Property/Land Use, Taxes, Tourism, Quality of Life, Other

**Name:** Christina Weissbrod

**Organization:**

**Email:** cweissbrod@gmail.com

**Mailing Address:** 57 Smith Hill Road

**City:** Ashland

**State:** NH

**Zip:** 03217

**Country:** US

**Comment:** Towers carrying the line for Northern Pass will dramatically impact the land values of properties on which it runs through, as well as those adjacent, affecting the tax base of the town afflicted with them. It will affect tourism and the scenic beauty that tourists come to experience, it will not provide electricity to NH, the tax benefits proposed are too low to be of real value, and I know that every time I see them on our beautiful and inspirational mountains, I will feel betrayed by the NH DOE.

I see NO reason that the NH DOE should allow this gross visual pollution to be permanently in place so that the stock holders of the Northern Pass company will reap bigger benefits!

NH DOE should not sell NH so cheaply. Maine and Vermont value their natural resources and have successfully negotiated for complete burial. NH must do the same. Burial of the entire line is mandatory.

1563-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result. The Visual Resources section specifically evaluates the scenic landscape of New Hampshire and the potential for impacts to the viewshed from several viewing distances.

1563-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Oct 14, 2015

**ID:** 8436

**Date Entered:** Oct 14, 2015

**Source:** Website

**Topics:** Viewshed/Scenery, Historic/Cultural, Tourism

**Name:** Gail Lauermann

**Organization:**

**Email:** g.lauermann@aol.com

**Mailing Address:** 21 Sherman Avenue

**City:** Brentwood

**State:** NH

**Zip:** 03833-6225

**Country:** US

**Comment:** Tourism, dependent in NH on unspoiled vistas, cultural centers and historic locations, is the primary industry of this state. To allow a private company to compromise to any extent the above elements is in blatant disregard to the general welfare of the population. Northern Pass is a money scheme cooked up by Hydro Electric of Quebec and Eversource of New England cloaked in a promise of more jobs and cheaper electricity for the residents of NH. Seabrook Station back in the 1980s has convinced everyone that it just isn't so. There are better ways for NH to generate electricity without being used as a conduit for the southern tier of New England. That is the area that will reap the benefit of any additional power. Say NO to this project! Thank you.

1564-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result. The Visual Resources section specifically evaluates the scenic landscape of New Hampshire and the potential for impacts to the viewshed from several viewing distances.

1564-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Oct 15, 2015

**ID:** 8438

**Date Entered:** Oct 15, 2015

**Source:** Website

**Topics:** Environmental Justice

### **Organization:**

**Comment:** I cannot understand why people don't realize that buried lines will only mean removal of the trees to lay the lines in the first place, then continued clearance of trees and vegetation to service/repair the lines. Buried or above-ground, Northern Pass can lead only to destruction of scenery and less tourism. No one is going to want to see a scarred state, and tourism will no longer be a valued source of revenue.

1565-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1565-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Oct 20, 2015

**ID:** 8443

**Date Entered:** Oct 20, 2015

**Source:** Website

**Topics:** Purpose and Need, Wildlife, Viewshed/Scenery, Historic/Cultural, Tourism, Quality of Life

**Name:** Searle Redfield

**Organization:**

**Email:** mountainbound17@comcast.net

**Mailing Address:** Sugar Hill Rd. Rt.117

**City:** Sugar Hill

**State:** NH

**Zip:** 03586

**Country:** US

**Comment:** Please do not allow Eversource to desecrate the landscape of the uplands of New Hampshire forever. The visual impact that would result from 125' high tension towers would be so detrimental to the beauty and serenity of the Granite State, we could never recover either in terms of our "sense of place" or the lost tourism (which is the last real industry we have here). Using our state as an extension cord to power the grid for southern New England at our expense is an unfathomable injustice.

One only needs to spend some time in the region that would be impacted to gain an appreciation for what we have here and why it is so dear to our hearts and worth fighting for. Generations of families have called this place home for decades and to stomp on their heritage and beloved landscape would be a travesty.

Please, please if this transmission line must be built, bury it for it's entire length or don't build it at all. Plans developed for Vermont and Maine call for complete burial. Why should New Hampshire accept anything less? Are all these lines really necessary? Can the capacity of the lines in the current ROW suffice?

Going forward, please consider the above issues as if you, and your family lived here all your lives and what this would all mean to you. The compassion we feel for our state is warranted and justifiable.

This is New Hampshire, not just anyplace.

Thank You.

1566-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result. The Visual Resources section specifically evaluates the scenic landscape of New Hampshire and the potential for impacts to the viewshed from several viewing distances.

1566-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Oct 20, 2015

**ID:** 8445

**Date Entered:** Oct 20, 2015

**Source:** Website

**Topics:** Viewshed/Scenery

### Organization:

**Comment:** Ms. Monroe, I'm a resident of NH, and I'm writing to voice my opinion on the Northern Pass issue. I think that any small benefit the state may gain from this project is not even close to what it will lose in tourism by erecting gigantic towers all along our state's real money-maker: our naturally beautiful landscape. People come up en masse from MA not just for our liquor and tattoo shop but to hike, camp, swim and fish as well as many other things. No one, especially those of us who live here, do not want a huge, ugly electric corridor savagely cut through our forests and towns. And burying it is only marginally better, because, like "The Sunshine State," or "Vacationland," we're The Granite State. Granite: very hard rock. How long and destructive will it be to bury the lines compared to just saying NO? Too long and too destructive for any small financial gain the state may make by offering its throat to the wolf with the red roses.

I don't support the Northern Pass, and I never will. If Massachusetts and other southern NE states can't make enough power for themselves, let them look into alternative energy. They look at Canada's power with slaving mouths, and they view our whole state as merely an obstacle to be crushed in their pursuit of that energy. Tell them NO! We're much more than just an inconvenience, and we're not stupid enough to go for their ideas! Tell them NO, we aren't fools!

1568-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result. The Visual Resources section specifically evaluates the scenic landscape of New Hampshire and the potential for impacts to the viewshed from several viewing distances.

1568-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Oct 28, 2015

**ID:** 8457

**Date Entered:** Oct 28, 2015

**Source:** Website

**Topics:** Purpose and Need, Vegetation, Wildlife, Viewshed/Scenery, Recreation, Tourism, Quality of Life, Environmental Justice

**Name:** SUSAN CLARK

**Organization:**

**Email:** sukieclark@hotmail.com

**Mailing Address:** 55 CALEF HILL RD

**City:** TILTON

**State:** NH

**Zip:** 03276

**Country:** US

**Comment:** I've lived in Tilton, NH for 40 years, and have owned a camp in Stewartstown, NH for the last 4 years. In addition, I have hiked, skied, or biked over thousands of miles of trail during that time. I love the opportunities for recreation, viewing the scenery, and the wildlife. Needless to say, I am vehemently opposed to the Northern Pass! To begin with, it appears that none of this power will benefit the residents of NH, so why should we suffer the indignation of these atrocious towers? When I drive to the north country, I marvel at the wonderful scenery and natural beauty that surrounds me, but if this plan is approved, most of these views would be ruined, and millions of trees would be decimated. Tourists come from long distances to enjoy the natural resources and beauty that we hold so dear - I doubt they would continue to come and enjoy (and spend money!) our state if this project goes forth as proposed. I have come to know and love the quality of life that New Hampshire offers, but if this project is approved, I will look into moving to another state, such as Vermont or Maine, that has it's priorities straight : they have new and projected power lines that will be buried or immersed under water. It's possible that I would support this power line if it is ONE HUNDRED PERCENT BURIED. That, to me, is the only possible solution, and it would be fair to those to the south who need this power, and those, here in New Hampshire, who will allow that to happen. Please insist on total burial.

I have attempted to attach a photo which I took in Canada, about 20 miles east of Montreal. I estimated that these towers are about the same height as those proposed for NH. Do we really want

1570-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result. The Visual Resources section specifically evaluates the scenic landscape of New Hampshire and the potential for impacts to the viewshed from several viewing distances.

1570-1

these in our state??!

1572-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result. The Visual Resources section specifically evaluates the scenic landscape of New Hampshire and the potential for impacts to the viewshed from several viewing distances.

TO: Members of the SEC Commission

From: Merrill and Judy Dalton, 2787 North Main St, Pittsburg,NH 03592

Date: Nov 1, 2015

RE: Northern Pass

My husband and I are writing to express our opposition to the Northern Pass project as currently proposed and to declare our support for the stand taken by our courageous neighbors and fellow North Country citizens who have refused to be influenced by the extravagant offers of monetary rewards as a payoff (one might say "bribe") for acquiescing to the corporate pursuit of profits. It is our belief that the limited benefit of an above ground power line is absolutely contrary to the needs and wants of the great majority of Northern NH citizens. If there is to be a Northern Pass, it must be an underground line. It can be done. It is proposed in Maine: Vermont has already indicated its support for a totally underground line in that state. A buried gas pipeline in this same area makes it clear that it is doable and economically realistic.

Arguments that the North Country will benefit from this power line are short sighted and self-serving. Few if any permanent jobs will be generated at a forever cost to our pristine landscape. People from the world over travel to northern New Hampshire to enjoy the uniqueness of a world devoid of the hard, harsh structures found in the modern industrialized world. Thousands of visitors travel here each of the four seasons to enjoy and be rejuvenated by the pristine beauty and majesty of nature in our Great North Woods. The base of our regional economy is tourism based on the natural beauty of our underdeveloped valleys and mountains. Towering steel giants will destroy our "last frontier".

Pittsburg and the North Country are among the few remaining areas in New Hampshire largely untouched by the ravages of mankind. This region should not be destroyed for the sake of corporate desire for maximum profits when other reasonable alternatives exist. We will continue to champion the rich heritage so important to so many.

We trust you can understand our belief in the supreme value of this rich heritage and you will join us in saying no to Northern Pass. It is unconscionable to destroy the beauty of our region when there are other reasonable options.

Underground or No to Northern Pass

1572-1

Pittsburg, NH 03592

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Nov 14, 2015

**ID:** 8504

**Date Entered:** Nov 14, 2015

**Source:** Website

**Topics:**

**Name:** Dennis Moloney

**Organization:**

**Email:** moloney.dennis@gmail.com

**Mailing Address:** 5 Waters Edge Lane

**City:** New Hampton

**State:** NH

**Zip:** 03256

**Country:** US

**Comment:** This project has the potential to decimate the tourism economy in northern Nh. The proposed route through New Hampton, along the 193 corridor between exit 23 and 24 will,be a well ominous eyesore to anyone headed north on I 93

1573-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result. The Visual Resources section specifically evaluates the scenic landscape of New Hampshire and the potential for impacts to the viewshed from several viewing distances.

1573-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Nov 15, 2015

**ID:** 8512

**Date Entered:** Nov 15, 2015

**Source:** Website

**Topics:** Viewshed/Scenery, Economic, Tourism, Quality of Life

**Name:** Diana Curington

**Organization:**

**Email:** c.curington@comcast.net

**Mailing Address:** 540 Greenside Ave

**City:** Portsmouth

**State:** NH

**Country:** US

**Comment:** Northern Pass is a poor choice for our energy source. It despoils New Hampshire's greatest asset, our world-class scenic beauty. Our mountains, trees and vistas bring in millions of tourists every year, with millions of dollars fattening our \$ bottom line. We can't afford to trash our treasury by gashing our landscape with "War of the Worlds" structures looming over our splendid fall foliage season! That makes no sense! Our quality of life is worth fighting for-- That's the New Hampshire Way!

Diana Curington

1574-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result. The Visual Resources section specifically evaluates the scenic landscape of New Hampshire and the potential for impacts to the viewshed from several viewing distances.

1574-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Dec 16, 2015

**ID:** 8610

**Date Entered:** Dec 16, 2015

**Source:** Website

**Topics:** Soils

**Name:** Frederick W Martin

**Organization:**

**Email:** extra@nbeam.com

**Mailing Address:** 50 Village Ave

**City:** Dedham

**State:** MA

**Zip:** 02026

**Country:** US

**Comment:** This is a comment on the draft EIS Supplement of November 2015, by a landowner and seasonal resident in Coos County NH. . Alternative 7 as proposed in the supplement is inadequate, and therefore the DOE should choose the "No Build" option.

The tall towers of the above-ground portion of alternative 7 are a visual and scenic detriment to the tourist industry, which is the main economic support of northern New Hampshire. As mentioned in my comment #8367 or #150830, this is a \$4 billion business and the DOE should at least poll the inhabitants and businesses with a questionnaire, rather than saying the impact is "not quantifiable".

The no-build alternative may also force Northern Pass to consider a different entry point into the US, as advocated by the Society for Protection of NH Forests, whereby the entry point would be along the I-91 corridor into Vermont, and the Interstate highway corridor would be used all the way to Concord NH. Such a route avoids unwanted crossing of private lands, and probably adds a rental fee for use of the right-of-way of benefit to NH taxpayers.

1575-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1575-1

---

**From:** Brad Griswold <bradgriswold@mac.com>  
**Sent:** Thursday, November 12, 2015 11:55 AM  
**To:** draftEIScomments@northernpasseis.us  
**Subject:** Amended Northern Pass Permit Application

The proposal to bury a portion of the transmission lines and reduce the project size from 1200 megawatts to 1,000 megawatts for the Northern Pass Proposal is a first step, but falls far short of what should be required which is a complete burial of the lines over the entire length of the project. As it stands, the lines would be visible over long stretches that would have a negative impact on the scenic beauty of the White Mountains and therefore by extension the tourist industry not to mention our environment for years to come.

The argument that the project would be too costly to pursue if completely buried is erroneous and does not stand up to independent analysis. It would be more accurate to state that if the entire line was buried, the higher construction cost would impact the initial profitability of the project, but still allow the Canadian holding company to generate a competitive profit for many years in the future. The debate comes down to protecting the interests of the U.S. citizens and the economy of northern New Hampshire or generating profits for the shareholders of a foreign company.

I hope that the Department of Energy will decline the permit being sought for Northern Pass and by doing so side with the citizens of New Hampshire and the many individuals and families who come to enjoy the natural beauty of the White Mountains.

Sincerely,

Brad Griswold

PO Box 110  
 Lancaster, New Hampshire 03584  
[bradgriswold@mac.com](mailto:bradgriswold@mac.com)  
 610-216-8131

1577-1

1577-2

1577-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1577-2

Thank you for your comment. The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c). The potential environmental impacts of all twelve alternatives, as well as technical constraints and costs, are discussed throughout the EIS.

24 DECEMBER 2015

Dear Brian Mills,

I am writing to express my concern about the proposed Northern Pass project through the state of New Hampshire.

I oppose the current plan because it will do irreparable damage to the tourist industry - a strength of our state. The huge towers will forever ruin the scenic beauty along the route.

If the Northern Pass must go through - the entire route should be underground. Hydro-Quebec and Eversource should be willing to compromise and absorb the additional cost for complete burial.

I appreciate your attention to my concerns.

Sincerely,  
 Vincent J. Buscemi  
 VINCENT J. BUSCEMI  
 PO BOX 7021  
 GILFORD NH 03247-7021

1578-1

1578-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 7, 2016

**ID:** 8724

**Date Entered:** Mar 7, 2016

**Source:** Website

**Topics:** Tourism

**Name:** david lynde

**Organization:**

**Email:** dwlynde@comcast.net

**Mailing Address:** 38 timberline drive

**City:** concord

**State:** NH

**Zip:** 03301

**Country:** US

**Comment:** I am a native NH resident who grew up in Northern NH. I now live in Concord, NH. I am completely opposed to the idea of a northern pass electrical transmission line that runs through the most important resource of NH, which is our land. We need energy efficiency not energy supply lines that will scar our land. We have hiked in France where such transmission lines "co-exist" with hiking trails. It is not a pretty or welcome sight. Our state relies on tourism for our main source of income, this will damage that source of income while also damaging the beauty of our wonderful land. Please stop northern pass and start working on true non-environmentally damaging energy solutions!

Sincerely,

David Lynde  
38 Timberline Drive  
Concord NH 03301

1579-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1579-1

COMMENT CARD

NH Site Evaluation Committee, Docket No. 2015-06  
Public Hearing, RSA 162-H:10, I-c

RE: Joint Application of Northern Pass Transmission LLC  
& Public Service Company of New Hampshire d/b/a Eversource Energy  
for a Certificate of Site and Facility

LOCATION (circle one): Meredith (March 1), Colebrook (March 7); Concord (March 10);  
Holderness (March 14); Deerfield (March 16)

FIRST NAME: Tom LAST NAME: CARON

STREET ADDRESS: 545 KEMP HILL RD.

TOWN: CAJAN STATE VT ZIP 05903

EMAIL ADDRESS: tom@talltimber.com

If you wish to provide written comments for the record, please provide your comments below:

While there may be short term economic gains for lodging  
and restaurant establishments when the line is under construction,  
we are concerned that the loss of regional natural beauty will have  
lasting economic consequences. Tourism, like most industries in today's  
economy, is fiercely competitive from region to region. If northern  
pass truly respects the wishes of the inhabitants of the area, they  
will bury the line through the entirety of northern New Hampshire.  
They will accomplish their mission and make the project more  
palatable for residents and tourists alike.

1581-1

1581-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

March 9, 2016

To Whom It May Concern,

My husband and I bought our house in Whitefield in 1997 and planned to raise our kids here and to live here after our kids have moved on with their own lives. If Northern Pass (NP) comes through our town, this will change things for us drastically. We live next to the substation and powerline, which we are OK with. However, if those towers are going to be built, NP will force us to give up our dreams and sell our home because we do not want to live next to those monstrous towers. And at that, our house/property value will greatly diminish. We wouldn't be able to sell our house for what it's really worth because it won't be worth much if NP is to go through or let alone even sell it.

How dare they think about putting those towers up right through our town or any town. If NP does go through, the lines should be buried if it is to go through a town, out of respect of the town, no questions asked. Do they have any sense of value or morals? They don't care about anything like that, all they care about is the almighty dollar and what they stand to gain from this (BILLIONS OF DOLLARS!!!) This will affect thousands of people, towns and land. We strive on our land for tourism, we depend on it. Thousands of people come up to northern NH for tourism, sightseeing and hiking. When they do this in places where the towers are proposed to be built, they don't want to see towers, they want to see the mountains, the scenic views. This will affect our state immensely. How can you give them permission to build, there is so much at stake. They stand to gain billions (\$\$\$\$\$) while we stand to lose our properties, land and state (our way of life).

Tell me this, if you lived by the powerline and NP was to be coming through, would YOU want to live there and see those towers day in and day out? I have enclosed some pictures that I took from our home toward the substation and powerline. That's what our view is, now picture the towers. Did they honestly think that they could bulldoze their way right through our state and not have any problems, that no one would complain, that we would say "go right ahead".

NP is just a selfish thing and if they had proposed to bury it entirely from the beginning, things may have been a different. They may not have gotten so much resentment from it. But they don't care. With all the money they have spent on newsletters, mailings, meetings, research etc, they could have buried that line by now. But at this point, don't even bother building it, we don't want it!!

Tim and Brigitte White

Whitefield

1582-1

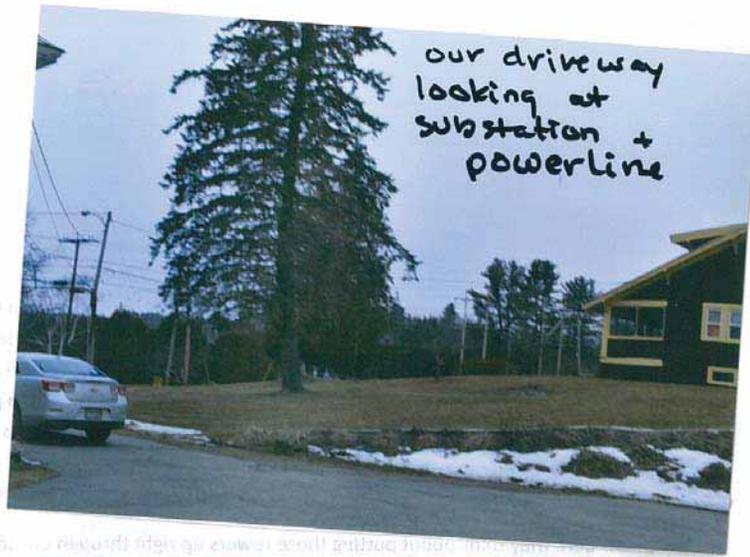
Thank you for your comment. Section 4.1.2 of the EIS addresses the potential for impact to property values as a function of proximity of the Project to private property. Adjustments to the original analysis presented in the draft EIS have been updated in the final EIS to reflect comments on the methodology and assumptions.

1582-2

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1582-1

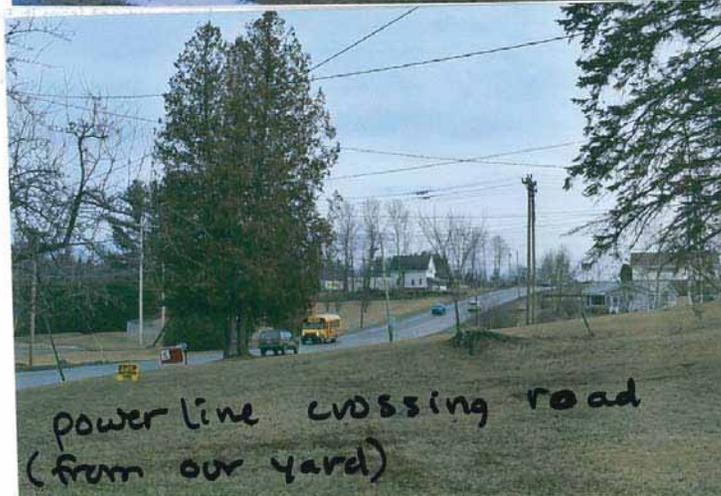
1582-2



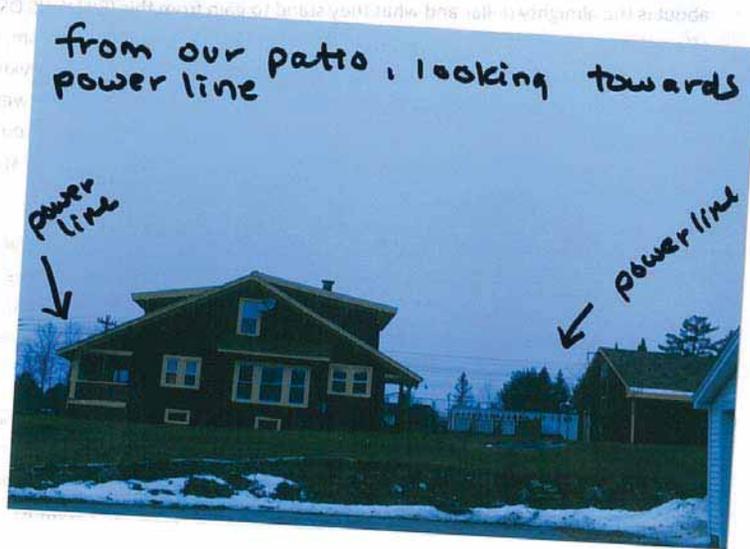
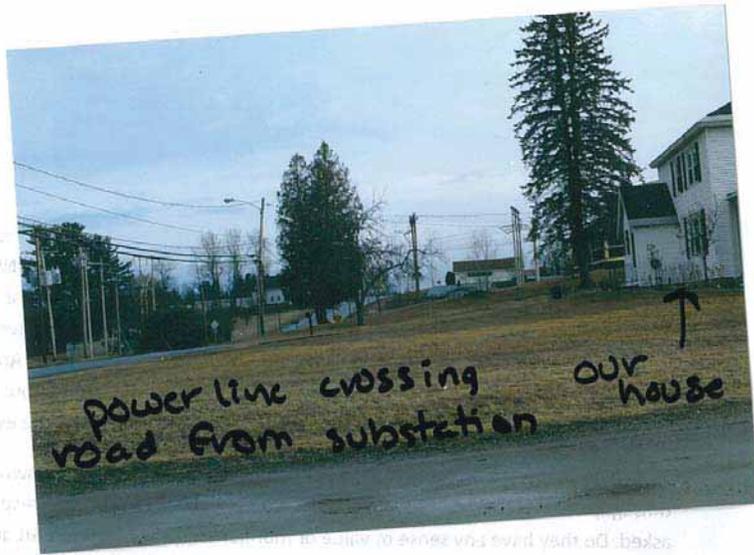
our driveway  
looking at  
substation +  
powerline



from our kitchen door  
toward substation +  
power line



power line crossing road  
(from our yard)



# Northern Pass EIS Website Comment Receipt

**Refers to Comment placed on Mar 28, 2016**

**ID:** 8887

**Date Entered:** Mar 28, 2016

**Source:** Website

**Topics:** Viewshed/Scenery, Economic, Tourism

**Organization:**

**Comment:** I am in favor of having the Quebec electrical lines that travel through the state of New Hampshire buried, starting where they enter the state in the north and remaining underground completely until they exit the state. A significant part of our state economy is based on tourism and the proposed power lines (if above ground) reduces the natural beauty that exists in this state. This in itself has the potential to affect tourism negatively. Additionally I as a resident of the state do not want to deal with the negative visual pollution resulting from construction of an above ground set of power lines. This is a quality of life issue as well as an economic issue.

1584-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1584-1

That is correct. It's Hunnewell. My name is Anne Hunnewell, and I want to thank you for the opportunity to speak tonight. There's several points I want to make. I'm not a scientific person, but I do have certain emotional feelings about this project. I am most upset about the psychological impact that Northern Pass has had on the New Hampshire citizens for the last five years. Everyone looks at the economic impact of this project, but there has been terrible stress caused by the actions of Hydro-Quebec. This project has been hanging over our heads like an ax waiting to fall. Was there a chance that I would get some work in this state, some people thought. Other people thought, am I going to lose the value of my house because it sits next to this gigantic electric tower. Thirdly, the economy of the state is largely supported by tourism. Indeed, this winter is an excellent example of how important it is. Lack of snow has greatly impacted on the revenue for our businesses and our state. Well, lack of beautiful vistas will do the same thing. Eversource has said that Northern Pass is supposedly going to lower our electric bills. However, what good will that do when our businesses do not have tourist dollars to pay the bills. Finally, Northern Pass has pitted one group of citizens against another. As it has been said many times, there should be no winners or losers in this project. This electric line needs to be buried completely because if it is not, New Hampshire will be the loser. Thank you very much.

1585-1

Thank you for your comment. Section 4.1.2 of the EIS addresses the potential for impact to property values as a function of proximity of the Project to private property. Adjustments to the original analysis presented in the draft EIS have been updated in the final EIS to reflect comments on the methodology and assumptions.

| 1585-1

1585-2

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

| 1585-2

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 28, 2016

**ID:** 8935

**Date Entered:** Mar 28, 2016

**Source:** Website

**Topics:** Purpose and Need, Alternatives, Health and Safety, Vegetation, Wildlife, Viewshed/Scenery, Water / Wetlands, Soils, Recreation, Historic/Cultural, Economic, Tourism, Quality of Life, Forest Service Lands

### Organization:

**Comment:** I oppose the Northern Pass Project for several reasons, including the horrible visual impact to not only residents, but also visitors to all the affected regions of the state. One of NH's best selling points for attracting business to the state, in the form of both tourism and new businesses locating in the state, is the character of the region, specifically it's beautiful landscapes, and outdoor recreation opportunities.

The landscapes as they exist with intricate balance of soil structures, watersheds, wildlife corridors, historically, recreationally and culturally valuable trails, and sites (parks, historical sites and buildings, etc) is a treasure unique to this region. As a resident of this state, one of the primary reasons I choose to live here is the character of the landscape and the recreational opportunities in our state. And clearly these are the reasons that people come here to vacation as well.

The building of a antiquated tower structure and adding additional dependence on Canadian hydro-power is shortsighted and narrow minded when one considers the more diversified and smarter options of improving the existing power grid, improving storage capacities, and investing in more environmentally sound options such as solar (which also creates more local benefit in the form of jobs for NH residents). Of note, there really is no benefit of Northern Pass to the residents of NH.

If the Northern Pass project is ever allowed, the lines should be fully buried along existing transportation corridors.

1586-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1586-1

1586-2

Thank you for your comment. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. Additionally, seventeen alternatives were considered but eliminated from detailed analysis. Section 2.4 of the final EIS has been updated with additional information on alternatives considered but eliminated from detailed analysis. A power generation alternative was considered but was eliminated from detailed analysis in the EIS because it is not a reasonable alternative. Section 2.4.8 of the final EIS has been updated with additional information about this alternative. Section 1.4 of the final EIS has been updated to include new information on market trends and energy use, including demand-side management and energy efficiency, since the draft EIS was published in 2015.

1586-2

Hello. I'm Luke Wotton, I'm from Whitefield, New Hampshire, and I came here thinking this was like a, not a hydro thing but an Eversource thing. That's what I'm really going to. So I came with a whole big speech declaring war on them and stuff, but I don't see any people from there here so thanks for that. And just to touch bases on the job creation that the guy was just talking about, it's like when they put the underground, I forget what type of oil or pipeline they put down through Colebrook and everyone was against that, and it finally did get passed and approved, and the jobs that it did come, it did stimulate the economy for like four months, and then they're done and then it all went back to normal. So it's something you really have to consider when you look at this. They're going to bring all these jobs for a short-term goal, and then they're going to hurt the tourist industry and then the short-term people jobs are going to leave and then the tourism industry is still killing and that was very touching what the girl mentioning the mountains and everything and how like we love those mountains and it brought me to tears and I don't know. Like I'm ready to fight this until the end, whether that's fighting it in a jail cell or not, but I really am so against this project. I'm against Hydro-Quebec. Believe it or not, Hydro-Quebec actually already started building a dam in 2009 thinking that they would already have this line in place. So they're already building this dam and they're already flooding all the frozen terps and everything like that and it just really, it's a horrible situation. And I don't know if you guys can look into it, but I wrote a paper back in the day about Hydro-Quebec, and it was very easy to find information about it, and when I go back today and I try to look for it, they have censored the information that is available to the public. So much that you really can't find any, anything too much negative about Hydro-Quebec. But it's out there. I sent my paper to the SEC so they have it, and they have all the links because it was like a real college paper and everything. It has everything on there, but that's it. Thanks.

1587-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1587-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 29, 2016

ID: 8971

Date Entered: Mar 29, 2016

Source: Website

Topics: Purpose and Need, Alternatives, Viewshed/Scenery, Recreation, Historic/Cultural, Economic, Tourism, Quality of Life, Forest Service Lands

### Organization:

**Comment:** To the Department of Energy (DOE) - Thank you for the opportunity to comment on the Northern Pass project under consideration in New Hampshire. As you are already aware, this project has generated a lot of opposition from residents in NH; I am one of those opposed. There are several reasons. First, New Hampshire does not need this energy; it will pass through our state to other users. Second, we should be promoting conservation of energy rather than building unnecessary capacity. Third, the economic impact on the tourist economy, which is largely driven by outdoor enthusiasts, of the proposed towers - up to 160 feet in height - will be very negative. The towers will pass through iconic mountain areas, including White Mountain National Forest. This final point suggests that if the DOE believes that energy is necessary, the lines should be buried from beginning to end.

Thank you for considering my input.

Sincerely,  
Laurie Gabriel

1588-1

Thank you for your comment. DOE determined that energy conservation does not meet the purpose and need for DOE's action. Under the No Action Alternative, it is assumed that existing energy sources, including alternative energy generation, would continue to supply the ISO-NE region and that energy efficiency measures would continue. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c).

1588-1

Good evening. For the record, my name is John Amey. I'm from Pittsburg, and before I start my written comments which will only take two minutes, we haven't heard anything from Brian Mills since I got here. I'm so happy to see Brian Mills back. I suspect we might see you back next spring the way things are going. It's so nice to see you. I would like to welcome the representatives of the Site Evaluation Committee to the North Country. Thank you for coming all the way to Pittsburg today to better understand our concerns with this application of Northern Pass, and I hope that you will return so you can see the rest of what you missed today. You did see the signs down near the ground, but you didn't see the viewshed. I'm a direct descendant of the Indian Stream Republic when Pittsburg was its own country from 1832 to 1840. I have friends and relatives here tonight that share this honor. All of Pittsburg is a historical town, the largest in our country, and much of which was part of Canada before it declared its independence from Canada and New Hampshire. The epicenter of the former Republic is where I live and where my family has lived since that time. For those that may be unaware of the geography of our town, there are two primary routes as well as two secondary roads entering our town. All four of these roads are directly affected by this proposal from Northern Pass. In fact, three routes will have transition towers besides roadways as the project moves from above to underground. It is important to note that I and the people I represent believe that the residents of our town as well as the thousands of people who vacation here deserve no less than the residents nearby and vacationers that travel each year to the White Mountain National Forest. Our economy in Pittsburg is very dependent on the millions of dollars that our visitors bring here. While we are promised significant tax revenues, those will be a mere pittance when compared to our history and our recreation industry. It is for these reasons and others that we, the residents of Pittsburg, and the descendants of the Indian Stream Republic respectfully ask you, the Site Evaluation Committee, to deny approval of this application as presented until such time that we are granted the same concern that has been granted to the White Mountain National Forest. Furthermore, we request that the complete analysis be made public regarding burial of the entire project in the State of New Hampshire transportation corridors. In closing, thank you in advance for addressing our concerns.

1589-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result. Finally, the EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c) and two additional alternatives in which the line would be buried everywhere north of Franklin, NH (Alternatives 6a and 6b).

1589-1

1591-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Section 4.1.2 of the EIS additionally includes analysis of the impact on future assessments due to potential adverse impacts on property values.

Thank you, Mr. Chairman, and Members of the Committee. My name is Walter Palmer. I'm from Franconia, New Hampshire. I wasn't planning on getting up and making a comment here tonight, but I feel like somebody has to get up and say this. I'm reacting to a statement made by Mr. Quinlan earlier this evening. Mr. Quinlan stated several times that, quote, New Hampshire residents are not being asked to bear any of the costs of this project. This is one of the most outrageous and incredibly insensitive statements I've heard so far in this proceeding. New Hampshire residents are asking to bear the brunt of the cost of this project in terms of major visual impacts, loss of property values, damage to the tourism economy, crushed dreams and ruined lifestyles. That's why we're all here protesting this project and have been doing so for the last five years. Northern Pass brings out so-called experts who assert that the visual impacts, property value impacts, tourism impacts somehow all will be negligible with this project. But New Hampshire residents know that this is ridiculous. We've already heard many testimonies here tonight of people here in New Hampshire who are already experiencing negative economic and other impacts just from the threat of Northern Pass. How much more so once Northern Pass, if Northern Pass were to be built. Your experts are like performing magicians. They pull a little bit of misdirection based on dubious studies, and, presto, somehow serious impacts of the project seem to magically disappear, but we all know it's just a trick. You can't make the very real and serious negative impacts of this project just disappear by waving your hands at them. If you really are so eager to make the impacts disappear, why not try listening to the will of the residents of New Hampshire and propose to bury the transmission line along interstate corridors or not build it at all. Mr. Quinlan, I'm afraid your statement that New Hampshire residents are not being asked to bear any cost of the project reveals how little you think of New Hampshire residents and the real cost of this project. Northern Pass would externalize all of the serious visual property values and economic costs so you don't even recognize these costs exist. To us, these costs mean everything. To our way of life, quality of life, to our lifestyle. So please, Mr. Quinlan, I ask you that you be good enough not to make that statement at future meetings like this. You are asking us to bear onerous and massive costs, and you would do well to acknowledge that. The only way New Hampshire residents will not bear any cost to this project is if the project is not permitted and not built as proposed. Thank you.

1591-1

Hi. My name is Craig Pullen. My wife and I own a 140-acre farm, equestrian facility, bed and breakfast in Canterbury, New Hampshire. It's a historic farm. We rely on tourism. We have allowed trees to grow on our property to hide the existing 40-60 foot towers that are on our property right now, less than a quarter mile from our buildings. Eversource's proposing up to 130-foot towers on our property. There's no hiding these. They're towers. We've allowed these trees to grow at the expense of our hay fields. They're shading them out. We also have a snowmobile corridor that goes through our property, a major corridor. We've diverted that corridor off the right-of-way. That's the last thing people want to see on a snowmobile ride is transmission lines. Just recently we traveled south, my wife and I, on the eastern seaboard, and we got an eyeful of transmission lines. Coming home back to New Hampshire I was wowed by the beauty of New Hampshire. We have a gem of a state here. We need to protect New Hampshire, protect small business, protect tourism, protect people's life investments here. I had a hard time swallowing some of the answers tonight. I wish you would consider please say no to this project. Protect New Hampshire. Thank you.

1592-1

1592-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Section 4.1.2 of the EIS additionally includes analysis of the impact on future assessments due to potential adverse impacts on property values.

1593-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

My name is Peter Powell, and I'm from Lancaster, and I'm in my 42nd year of service to the region as a realtor. I'm going to read fast to avoid talking longer. Like politics, all real estate is local. Studies not performed here are irrelevant. None has been performed here because the lines do not exist here, and no other study can adequately apply. My experience cannot be used to determine outcomes in other regions and outcomes and experiences in other regions cannot determine outcomes here. Nor are the influences on value the same from one location to another. It is said that experience is something you get just after you needed it. The same might be said of wisdom and perhaps of evidence. It is my fervent hope that no one will be coming here in the future to measure how great the loss has been as a result of this project in order to determine what could also happen some place else. The flaw in any study from another place is that unlike urban and suburban areas near high employment where degradation already exists and tradeoffs have been made for the convenience of location. We begin here without degradation from a beginning of relative period. Money is spent for beauty, often at the sacrifice of convenience, and the degree of change to the landscape would be far greater and more severe. How the market responds is evidenced by quality subdivisions everywhere, where one of the first things a developer does is bury the lines, and if they are not buried along the streets, then individual homeowners bury them when they build their homes. They do this because even when small, lines are ugly, and owners will realize greater value and greater satisfaction if lines are not seen but put underground. You cannot put ugly objects on a beautiful landscape without reducing the value of all those properties which gaze upon them, and in mountains and valleys more than on level landscapes. It is absurd to think that it will not impact tourism. Think of placing them in front of this hotel. For that is the relationship it will have with Rogers Campground in Lancaster, the land across Route 2 and countless locations throughout the North Country. Reduce tourism and we further reduce the flow of capital into the region, and if one business is hurt we are all hurt. I don't like this project for many reasons. When plants closed and jobs were lost, many of us gathered and pondered the hope that an economic transition could include a future in the production of energy from alternative means, encouraged by constantly changing technology which offers more and more options to produce and store energy. There are countless industries growing around those opportunities. Allowing this project will further diminish the demand, the southern demand for energy we may be able to produce here in New Hampshire. A demand we may profit from by satisfying. We should heed the statement included in the recent State of the Union address when the President said why should we want to pass up the chance for American business to produce and sell the energy of the future. Why indeed. A question for any president who may approve or deny this permit. Why do we want to create a greater dependence on a foreign source of energy with benefits accruing to that company and that nation instead of our own. Why do we want to again consider exporting precious capital from a region already threatened by a weakened tradable sector, one where the industry exports products and imports capital as our jobs here used to do. Northern Pass would import product and export capital which is counterintuitive to building a stronger economy. I remember the lure of cheap foreign oil and candidates who run for office on the basis of attracting it. Onassis wanted a refinery. A developer wanted a refinery at the bottom of the hill leading into Lancaster, getting crude from the Portland pipeline. It only didn't happen because Carter terminated the subsidy that would have supported it or we'd be looking at a rusty hulk today. After an embargo and the experience of greater, not lesser, expense, we gained greater wisdom and sought energy independence instead of energy dependence. The project only promises more of the same regret, and it will cost us in lost opportunity now and great advantage in the end. We should learn from history and not repeat it. We are struggling here to rebuild and restore and reinvent and repurpose

1593-1

assets weakened by loss. As communities, we have to make decisions every day about where to do things, how to have zoning protect our communities and our Natural Resources. There is a place for industry and commerce, a place for intense residential development and a place where things should not happen. If this project has to happen, it, too, has a place and it's underground, and if it's any other way, then it's too great a sacrifice for us to endure, and if a permit cannot be granted with a condition to put it underground, then a permit should not be granted, and if the measure of that outcome is the loss to an industry such as Eversource or a company in another nation, then they need to either lower their rate of return which is excessive or simply go away and perhaps work with us to find a way to make energy production work for us all and not against any of us. Thank you.

My name is Frank Lombardi, a resident of Whitefield, New Hampshire. In September 2015 the following Petition was presented to the New Hampshire Site Evaluation Committee and the Public Utilities Commission in response to the amended route of Northern Pass's proposed transmission line. Now more than 6 months later, the people of the Whitefield community are still outraged that the Northern Pass continues to propose above-ground lines through our town and community while proposing burial in other locations. 535 registered voters and concerned residents of the Whitefield community signed the following Petition requesting full burial of the Northern Pass Transmission lines through Whitefield should the project be approved. We now present a copy of this Petition to the US Department of Energy in a show of opposition. This Petition speaks to all those who stand against the proposed Northern Pass Transmission project and the many harmful effects it would have on our community. The Petition reads: As residents of Whitefield, we are very upset the Northern Pass now proposes to bury the lines for 52 miles starting just south of our town but isn't willing to do the same here. With 10.4 miles of proposed lines, Whitefield has the second most total mileage of any town and the most overhead mileage on the route. Whitefield is a destination for tourists and the gateway to the Great North Woods, the engine of Coos County's tourism economy. The proposed overhead lines would be visible from all points of access to or through our village and would damage our town's beauty and appeal. These above-ground lines do not respect Whitefield citizens, our community and businesses, our historic village and heritage, our landscapes and vistas, our conservation land or our sense of place. This is our town and our future. We will not stand by and watch as Whitefield is destroyed by monstrous above-ground lines. Whitefield's historic town slogan identifies us as a friendly town with a beautiful point of view, and we intend to keep it that way. If Northern Pass is to go forward, we insist that the lines be buried. Thanks.

1594-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1594-1

**From:** [Mills, Brian](#)  
**To:** [Travis Beck](#)  
**Subject:** FW: Northern Pass  
**Date:** Tuesday, April 5, 2016 6:54:03 AM

---

-----Original Message-----

From: Arlene Stoppe [<mailto:arlene@stoppemanagement.com>]  
Sent: Monday, April 04, 2016 7:28 PM  
To: pamelamonroe@nh.gov; Mills, Brian <[Brian.Mills@hq.doe.gov](mailto:Brian.Mills@hq.doe.gov)>  
Subject: Northern Pass

Hi Pamela and Brian,

I am very concerned about the negative impact that Northern Pass will have on the tourist industry in our state. Along with the unsightly construction over a long period of time, any above ground utility poles in the tourist regions, including Laconia and all points north, the Lakes Region, White Mountains Region will be unsightly and deter vacationers on which many businesses in NH rely. The tourist industry is one of NH's primary industries and needs to be protected.

Thank you,  
Arlene Stoppe  
85 Leavitt Hill Road  
Ashland, NH 03217  
[arlene@stoppemanagement.com](mailto:arlene@stoppemanagement.com) <<mailto:arlene@stoppemanagement.com>>

Cell: 603-481-0374 <<tel:603-481-0374>>

1599-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1599-1

Anne W. Hunnewell from Holderness, NH

March 9, 2016 Northern Pass and DOE

*Thank you for the opportunity to speak.*

There are several points I want to make. First, I am extremely angry that this meeting as well as other NP meetings has been scheduled for March. March is the month of town meetings when true democracy takes place. I am missing my town meeting because I feel so strongly about the impact of this project .

Secondly, I am most upset about the psychological impact that NP has had on NH citizens for the last 5 years. Everyone looks at the economical impact of this project. But there has been terrible stress caused by the actions of Hydro-Quebec. This project has been hanging over our heads like an axe waiting to fall. Was there the chance I would get work here in my state? Was I going to lose the value of my home because it sits next to gigantic electrical tower?

Thirdly, the economy of our state is largely supported by tourism. Indeed this winter is an excellent example of how important it is. Lack of snow has impacted greatly on revue for our businesses and our state. Well, lack of beautiful vistas will do the same. Eversource has said that NP is supposedly going to lower our electric bills. However, what good will that do when our businesses do not have tourist dollars to pay their bills.

Finally, NP has pitted one group of citizens against another. As it has been said many times ... there should be no winners or losers in this project. This electrical line needs to be buried <sup>completely</sup> because if it is not NH will be the loser ~~and~~ ~~Hydro-Quebec will be laughing all the way to the bank!~~

1600-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1600-1

Mr. Mills:

In September 2015 the following petition was presented to the New Hampshire Site Evaluation Committee and the Public Utilities Commission in response to the amended route of Northern Pass' proposed transmission line. Now, more than six months later, the people of the Whitefield Community are still outraged that Northern Pass continues to propose above-ground lines through our town and community while proposing burial in other locations. 535 registered voters and concerned residents of the Whitefield community signed the following petition requesting full burial of the Northern Pass transmission lines through Whitefield, should the project be approved. We now present a copy of this petition to the U.S. Department of Energy, in a show of opposition. This petition speaks for all those who stand against the proposed Northern Pass Transmission Project and the many harmful effects it would have on our community.

The Petition Reads:

As residents of Whitefield, we are very upset that Northern Pass now proposes to bury the transmission lines for 52 miles starting just south of our town, but isn't willing to do the same here. With 10.4 miles of proposed lines, Whitefield has the second most total mileage of any town, and the most overhead mileage on the route. Whitefield is a destination for tourists, and the gateway to the Great North Woods, the engine of Coos County's tourism economy. The proposed overhead lines would be visible from all points of access to or through our village and would damage our town's beauty and appeal. These above-ground lines do not respect Whitefield's citizens, our community and businesses, our historic village and heritage, our landscapes and vistas, our conservation land, or our sense of place.

This is our town and our future. We will not stand by and watch as Whitefield is destroyed by monstrous above-ground lines.

Whitefield's historic town slogan identifies us as "A friendly town with a beautiful point of view", and we intend to keep it that way. If Northern Pass is to go forward, we insist that the lines be buried.

1603-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1603-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Nov 20, 2015

**ID:** 8532

**Date Entered:** Nov 20, 2015

**Source:** Website

**Topics:** Purpose and Need

**Name:** Samuel Aubin

**Organization:**

**Email:** samwiseaubin@gmail.com

**Mailing Address:** 360 Circle Road

**City:** Manchester

**State:** NH

**Zip:** 03103

**Country:** US

**Comment:** I support the Northern Pass. Anti-Northern Pass groups continue to block their ears and stomp their feet loudly about issues that have already been addressed in the new Forward NH plan. One claim they're stuck on is that tourism is going to be negatively impacted significantly. New Hampshire precedent proves otherwise, as there are already hundreds of miles of transmission lines though New Hampshire's North Country and scenic areas like Tenney Mountain and Newfound Lake, and tourism is alive and well in these areas.

Yes, there are people who come to NH specifically for the views of Franconia Notch and the White Mountain National Forest. However, that area will now have 52 miles of the line buried, making 80% of the line underground or along existing transmission lines. Have you seen the photo simulations? The views are still worth the drive for our visitors. Also, our state has more to offer than just mountainous views. We have the Verizon center, ski resorts, lakeside hotels, restaurants, etc. Let's ensure those businesses stay open by lowering energy costs by \$80 million annually. Not to mention the project is allocating \$200 million for tourism, economic development, and community betterment.

With that and all the other benefits added to the plan, Northern Pass offers far more positives than negatives for New Hampshire.

1605-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1605-1

**Harry C. and Susan O. Brown**  
**19 Backiel Drive**  
**Stewartstown, NH**  
**03576**  
**603-237-5716**

SEC Hearing – Colebrook - March 7, 2016

My name is Harry Brown and I am currently the President of the New Hampshire Off Highway Vehicle Association but I am not representing them tonight. I am speaking for my wife and myself. We live in Stewartstown and have not taken a position pro or con on the project, but we feel the majority of testimony given thus far has seemed unbalanced. We want to take this opportunity to express our concern over the behavior of some of our North Country neighbors that has been exhibited at previous hearings. They have hissed, booed, and shouted out derogatory remarks to individuals that have expressed neutral or supporting views of the project. This behavior is and will remain unacceptable to us and is just another form of bullying. Respecting the process is as important as having supporting, opposing or neutral views.

The Society for the Protection of New Hampshire Forests campaign has stated that the above ground transmission lines will have a negative impact on tourism and recreation. In our opinion this has no factual basis from any studies and is pure hype, a scare tactic. Coos County's economy relies heavily on OHRVing and snowmobiling and it **will not be** affected by the Northern Pass transmission lines. Where presently allowed, they utilize many miles of trail under power lines throughout New Hampshire, the rest of the United States, and the Canadian Provinces. This is **without** any negative effects to the participants concerning these types of recreational pursuits, quite the opposite, it allows them access to trails that would not otherwise be available. The State of New Hampshire, clearly recognizes that the sport is greater than a half billion dollar a year industry especially in Coos County as it has lit new life for many current and new business owners – an economic stimulus when many could not see any light through the tunnel previously.

We want to recognize that without landowners giving us permission to utilize their properties for our trails, there would be no Ride the Wilds nor snowmobiling in Coos County or throughout the state. Northern Pass is one of those landowner, allowing the sports on their land that affects ten major trails – without them being a good neighbor, this would virtually shut down Northern Coos County for the sports.

Yes, we voted at the Stewartstown Town Meeting on March 3, 2011 to oppose the 1200 Megawatt High Voltage Direct Current Transmission Line as PRESENTLY PROPOSED. This was almost five years ago. Since then the project has been down sized to 1090 megawatts and all the line is being buried in Stewartstown except for on land that Northern Pass owns. Susan and I are retired and living on entitlements such as Social Security – if the latest route is accepted this will afford us nearly 50% in property tax relief. Many of my fellow citizens in Stewartstown are economically challenged – this would provide significant relief for taxpayers. Just think – Northern Pass would pay huge property taxes annually without any buildings so that we will **not** have to provide fire, EMS and police and no KIDS – no BIGGER SCHOOLS. These are examples of the positive side of the project.

Finally, neither Susan nor I are OHRV enthusiasts. Through the OHRV initiative, we just wanted to help our neighbors be able to raise their standards of living. We are also concerned that in the end result, all the conservation groups that oppose Northern Pass will cash in like they always do in projects like this and that will not help our economic initiative at all – quite the contrary they will do whatever they can to curtail OHRVing and Snowmobiling in Coos County. We hope that SEC can deliberate wholly on the facts. Thank you.

1607-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1607-1

1608-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1608-1

My name is Harry Brown, and I'm currently the President of New Hampshire Off Highway Vehicle Association, but I'm not representing them tonight. I'm speaking on behalf of my wife and myself. We live in Stewartstown and have not taken a position pro or con on the project, but we feel the majority of the testimony given thus far seems to be on balance. We want to also take this opportunity to express our concern over the behavior of some of our North Country neighbors that have exhibited at previous hearings. They have hissed, they booed and they shouted out derogatory remarks to individuals that expressed neutral or supporting views of this project. This behavior is and will remain unacceptable to us and is just another form of bullying. Respecting the process is as important as having the supporting, opposing or neutral views. The Society for the Protection of New Hampshire Forests campaign has stated that the above ground transmission lines will have a negative impact on tourism and recreation. In our opinion, this has no factual base from any studies, and it's pure hype. A scare tactic. Coos County economy relies heavily on OHRV and snowmobiling and will not be affected by the Northern Pass Transmission lines. We're presently allowed many miles of trails under power lines throughout New Hampshire, the rest of the United States and throughout Canada. This is without any negative effects to the participants concerning these types of recreational pursuits. Quite the opposite. It allows them access to trails that would not otherwise be available. The State of New Hampshire clearly recognizes that the sport is greater than a half million dollar a year industry, especially in Coos County, and it has lived a new life for many current and new business owners and economic stimulus when many could not see any light through the tunnel previously. We want to recognize without land owners giving us permissions to utilize their problems for our trails there would be no Ride the Wilds or snowmobiling in Coos County or throughout the state. Northern Pass is one of those landowners allowing the sports on the land that affects ten measured trails. Without them being good neighbors, this would virtually shut down the entire northern Coos County. Yes, we voted at the Stewartstown meeting on March 3rd, 2011, to oppose the 1200 megawatt high voltage direct current transmission line as presently proposed. This was almost five years ago. Since the project has been downsized to the 1090 megawatts and is being buried in Stewartstown except for on the land that Northern Pass owns. Susan and I are retirees and are living on entitlements such as Social Security. If the latest route is accepted, this will afford us nearly 50 percent in tax relief. Many of my fellow citizens in Stewartstown are economically challenged. This will provide significant relief for taxpayers. Just think. Northern Pass will pay huge property taxes and annuities without any buildings so we don't have to provide fire, EMS or police, and oh, by the way, no kids. No bigger schools. These are examples of the positive side of project. Finally, neither Susan nor I are OHRV enthusiasts. Actually, through the OHRV initiative, we just wanted to help our neighbors to be able to raise their standard of living. We're also concerned that in the end result, all the conservation groups that oppose Northern Pass will cash in like they always do in projects like this and that will not help our economic initiative in Coos County. Quite the contrary. They will do whatever they can to curtail OHRVing and snowmobiling. We hope that the SEC will deliberate fully on all the facts. Thank you.

**Testimony of Leslie B. Otten to the NH Site Evaluation Committee**  
**March 7, 2016**

Good evening and thank you for the opportunity to speak. I am Les Otten, owner of Maine Energy Systems – a renewable energy company founded in 2008 - and developer of the Balsams Resort in Dixville.

I'm for clean energy, and renewable resources. I have long supported replacing fossil fuels with renewable energy. In fact – that's what Maine Energy Systems does – deliver efficient wood pellet boilers and heating systems so residents and businesses can stop burning oil and propane.

I am also for jobs, and growing our North Country economy. I've spent the last 2-and-a-half years creating a plan for the Balsams that could lift the entire region. The fulfillment of that plan is my first responsibility.

Personally, I believe that climate change is real. It's our responsibility to mitigate the most potentially damaging activity man has inflicted on our planet. But this is about jobs and the economy - and Dixville in particular was where manufacturing, power and tourism thrived together for decades. Power has been a central component in the North Country's history.

People resist change – and they fear the unknown. I completely understand. We have a Hydro Quebec line that is taller than the proposed Northern Pass line, built in 1986. That line runs directly through major tourism areas – without negative impacts.

And 33 wind turbines were built on mountain ridges above Dixville and depending on perspective – they dominate the viewscape. For me, it's not credible to say a power line along the valley floor would hurt the viewscape.

If I thought for a minute that wind towers and Northern Pass would keep people away from the Balsams – I certainly would not be spearheading a \$143 million investment into restoring it.

From a life-time developing resorts in NH and across the country - I know that tourism will be not be negatively impacted by the line.

Views are important. I should know. But the North Country is also facing serious social and economic issues. The highest unemployment in NH –

1609-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable."

1609-1

which has caused our young workers to leave. A drug addiction epidemic. Schools, roads and other infrastructure that all need more funds to fix.

The socioeconomic situation of Coos County has been declining for years. It is *only* going to deteriorate further if we continue to rely *only* on what we have now.

Northern Pass, through the Forward New Hampshire Fund, has invested \$2 million in our project without strings. And we are discussing the potential for a more substantial investment by the Fund as Northern Pass progresses. This will help us fulfill our goal of restoring the Balsams resort and revitalizing the North Country economy.

When we re-open with Phase 1 – Northern Pass will also save the Balsams significant annual energy costs. That's welcome news – since we know NH pays among the highest rates for electricity in the Continental U.S. – and we'll use a lot of energy.

As I talk to people about Northern Pass, they're all looking for proof that it will benefit the North Country. The Balsams is proof. Northern Pass didn't have to step up early and invest in our project. This is a risk for them – but it's important to Northern Pass that the Balsams succeeds – and that the entire North Country prospers.

Already – Northern Pass is helping the North Country in a very significant way. Approving the project will bring much more investment into our region.

Let there be no doubt I favor the rebirth of the North Country - and I favor Northern Pass and the opportunities it will create - which may well endure for the next century.



# The Northern Pass EIS

## PUBLIC COMMENT SHEET

If you would like to provide Comment on the Northern Pass Project to the Department of Energy (DOE), you can write your comment in the space below and return the sheet to a DOE representative at one of the sign-in tables at this meeting. You can also fill this Comment Sheet out at home and return it to Brian Mills, DOE, via mail or fax to the address posted below. Comments must be received before April 4, 2016 to be considered in the scoping process; comments received after this date will be considered to the extent practicable. Please print legibly.

Name: Kathleen Jablonski  
 Address: PO Box 875 (Physical: 5 Rt 18, Sugar Hill)  
 City: Francenia State: NH Zip: 03580  
 Email: mainehill42@yahoo.com  
 Comment: \_\_\_\_\_

Northern N.H. is one of the few undeveloped natural settings remaining in the Northeast United States; accessible to major urban areas w/in hours

The cultural heritage of the region depends & relies on the (franklin, undisturbed natural settings) and one thing that draws tourists

It is known there are other routes that can be followed. It is my understanding there are alternatives to overhead lines that would eliminate the high towers that would preserve the visual & artistic culture of this region. Our scenic views are our heritage, our attraction for tourists and our native's return to nature in this high tech world we live within.

Please eliminate the tall towers & bury the line <sup>along</sup> if it, indeed, needs to pass through N. Hampshire.

Note: By Providing your name and address, it becomes public information and may be provided to individuals and organizations upon request under provisions of the Freedom of Information Act of 1974. Except for proprietary information, DOE will make all submissions from organizations or individuals available to the public in their entirety.

[www.northernpasseis.us](http://www.northernpasseis.us)

Brian Mills, Senior Planning Advisor  
 Office of Electricity Delivery and Energy Reliability (OE-20)  
 U.S. Department of Energy  
 1000 Independence Ave. SW  
 Washington, DC 20585  
 FAX: 202-586-8008

1613-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1613-1

Neil Irvine. Good evening. Brian, welcome back to New Hampshire. Tom, thank you for everything you do for the White Mountain National Forest. I appreciate the opportunity to address you this evening. As Chairman of the Board of Selectmen, it is my honor to speak on behalf of the residents of New Hampton and to continue to give voice to their opposition to the Northern Pass project as currently proposed. Our observations, comments and objections submitted in writing September the 10th, 2015, remain unchanged. Our position that as a participant funding merchant project, any disruption, inconvenience or financial impact be borne in its entirety by the Applicant stands. Tonight I have been asked by the residents of New Hampton to present you with copies of a petition carrying 708 signatures which reads, New Hampton is the gateway to the White Mountains and the Lakes Region. Our viewscapes are directly related to the values of our properties, and the tourist-driven economy of our community will undoubtedly be negatively impacted if the transmission line is constructed above ground. It is the intent of the New Hampton townspeople to protect the rural character of the community, protect property values and the national beauty and resources that surround us such as the Pemigewasset River Valley. We, the residents, business and property owners of New Hampton can only support this project moving forward with the lines are buried along the entire route. I'm going to go off script here, Cindy. Over the last few months, we've seen many states bought in the primary election, and we've struggled with the results that we're seeing. We're trying to make sense of it all. And one of the common phrases we're hearing across the nation is our distrust and our disgust with Washington. You have been afforded an opportunity with the Presidential permit application to show that you are truly a government of, by and for the people. Hear the people of New Hampshire. For five and a half years we have said the same thing. So we respectfully request that the Department of Energy deny the Northern Pass Presidential permit application as currently submitted. Thank you.

1614-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1614-1

# Northern Pass EIS Website Comment Receipt

1619-1

Thank you for your comment.

## Refers to Comment placed on Mar 22, 2016

**ID:** 8771**Date Entered:** Mar 22, 2016**Source:** Website**Topics:** Alternatives**Name:** Peter Bergh**Organization:****Email:** pb@princecom.com**Mailing Address:** 54 Lincoln Ave**City:** Portsmouth**State:** NH**Zip:** 03801**Country:** US

**Comment:** While I question the need for this project overall, I am largely writing to implore the DOE to ONLY consider options that would require the ENTIRE line be placed underground. The technology exists to readily do this and the visual impact costs--and related negative impact to views, adjoining property values, and tourism--have not been properly factored into to any above ground options.

1619-1

# Northern Pass EIS Website Comment Receipt

1620-1  
Thank you for your comment.

## Refers to Comment placed on Mar 28, 2016

**ID:** 8866

**Date Entered:** Mar 28, 2016

**Source:** Website

**Topics:** Environmental Justice

**Name:** Michael Speltz

**Organization:**

**Email:** mikespeltz@me.com

**Mailing Address:** 18 Sugar Plum Lane

**City:** Londonderry

**State:** NH

**Zip:** 03053

**Country:** US

**Comment:** The DEIS does not account for the egregious imbalance between environmental costs to New Hampshire and the claimed economic benefits to the rest of New England. New Hampshire will absorb 100% of the environmental costs of this project, but will keep around 10% of the electricity carried. Since the hydropower lies to the north and the consumers of the power to the south of New Hampshire, the only way to correct the imbalance between impacts and claimed benefits is to reduce the impacts. This can be done by burying the line for its entire length, including in my home town of Londonderry. Such an approach may even create the opportunity to bury parallel lines that now crisscross our town and mar its landscape.

1620-1

1623-1

Thank you for your comment.

---

**From:** Lynn Litow Flayhart <llitow@litowconsulting.com>  
**Sent:** Monday, August 03, 2015 9:59 AM  
**To:** Bob Ziegel  
**Cc:** draftEIScomments@northernpasseis.us; rflay5962@comcast.net; gillevine@gmail.com; casworthen@yahoo.com; rlougee@mcsbnh.com  
**Subject:** Re: Northern Pass Draft EIS Comments

Bob,

I like this. Do we send our version to that email address? [draftEIScomments@northernpasseis.us](mailto:draftEIScomments@northernpasseis.us)

Thanks.

XxL

On Aug 3, 2015, at 11:35 AM, Bob Ziegel wrote:

Brian Mills  
 Office of Electricity Delivery and Energy Reliability  
 U.S. Department of Energy  
 1000 Independence Ave.  
 SW, Washington, DC 20585.

Dear Mr Mills:

I have reviewed the proposed new route for Northern Pass and find it just as lacking and disfiguring of the landscape as the earlier proposal.

A combination of burying the line and placing it next to superhighways (like I93, I91 and I89) where the landscape is already compromised seems the only practical compromise that works for both route residents and the power companies/power users to the South.

Many people along the new proposed route have already suffered and protested the environmental/visual insult of under utilized wind generators that have scarred the land and damaged the natural views that are part of their lives and life choices.

If we wanted to live in an area where the quality of our lives was changed by living under or near the facilities that provide power to city dwellers to the South, we would move to New Jersey.

Obviously, I'm being facetious, but I hope you get the point. Our quality of life is a core value that is important to us. The new proposed northern pass route would damage irrevocably the quality of life for thousands of New Hampshire citizens who will receive no benefit from it.

Please tell the applicants that a route that minimizes environmental and aesthetic damage is the only acceptable solution to northern pass.

1623-1

Thank you for considering my comments. I care very much about this issue.

Robert L Ziegel  
66A Windridge Road  
Bristol, NH 03222

1623-1  
Continued

1623-1 cont'd

**1623**

1624-1

Thank you for your comment. Because an EIS is intended to inform decisionmakers and the public about potential impacts of a major federal action, DOE analyzes in detail several alternatives that involve underground cable in the I-93 corridor, including Alternatives 4a, 4b, 4c, 5a, 6a, and 6b. The regulatory framework governing utilities in roadway corridors, including through Franconia Notch (Section 4.3.6.4 of the EIS), is discussed in the Land Use Technical Report and the EIS, see Section 3.1.6.4. DOE has considered this comment and no change to the EIS was made.

Thank you, Panel. My name is Walter Palmer. I'm from Franconia, New Hampshire, and my comments tonight are regarding the project alternative 4 A as identified in the Draft Environmental Impact Assessment and also the EIS supplement. Under alternative 4 A, the project will be constructed as an underground transmission cable for its entire length. It would be buried under or adjacent to existing roadways for its entire length and within the White Mountain National Forest including in Franconia Notch. Alternative 4 A would be buried in the I-93 roadway corridor. Alternative 4 A is a simple and streamlined proposal, has no visual impacts. And to the extent that it utilizes interstate corridors, it has practically no abutters. It gets the job done with minimal impact. The DEIS concludes that alternative 4 A although possibly more expensive would impose the fewest environmental impacts due to the lack of visual impacts and the use of already disturbed roadways. Alternative 4 A is, quite frankly, the optimal alternative in terms of benefits to the people of New Hampshire. It will still provide all of the benefits claimed by Northern Pass for its project. Including transmitting power from Quebec to the southern New England, boosting jobs and boosting the economy, but it would do so without posing all of the major environmental impacts that are being posed by the proposal that Northern Pass is advancing right now. Northern Pass really, really doesn't want to implement alternative 4 A. It's Northern Pass's worst nightmare that the SEC siting process might latch on to the fact that Alternative 4 A is the best alternative for the people of New Hampshire and might actually require Northern Pass to implement Alternative 4 A. Why does Northern Pass not want to build alternative 4 A? Why, instead, is Northern Pass proposing its incredibly ill-conceived hodgepodge turkey of a proposal, now known as Alternative 7, meandering here and there throughout the state overhead, underground, overhead, underground with a thicket of over 1,000 massive ugly towers and burial of high voltage transmission cables right down the main streets of New Hampshire towns. Why? Why are they proposing this? It's simple. Eversource stands to make the most money by force-fitting this transmission project into Eversource's existing rights-of-way. As Northern Pass's own representative, Mark Hodgdon openly stated at the Colebrook meeting on March 7, it really just comes down to a question of money. Its profit. Eversource doesn't want to implement Alternative 4 A purely due to corporate greed and profit. How badly does Northern Pass not want to implement alternative 4 A? They've hired Mark Hodgdon, a so-called DOT expert, and his team apparently for the sole purpose of getting to the no answer on Alternative 4 A. This team's sole function seems to be to develop an argument against Alternative 4 A. Northern Pass has submitted a comment to the Department of Energy on the DEIS on January 1st, 2016, asserting that alternative 4 A should be dropped as a reasonable alternative from the EIS. Mr. Hodgdon is trotted out at every one of the SEC meetings to explain to us why New Hampshire's interstate corridors are off limit to Northern Pass. So Northern Pass has developed an entire argument as to why Alternative 4 A is not liable. The only problem is that this, every point in their argument is either unsupported or demonstrably false. I'll submit a written comment to DOT refuting each of the points in Northern Pass's assertion that Alternative 4 A is not viable. However, I'd like to just give one example here today. Northern Pass asserts that DOT would never allow Northern Pass to bury their transmission line along I-93. This is patently untrue and refuted by historical fact. In 2011 New Hampshire's legislature enacted Senate Bill 361, a bill creating a Commission to study the feasibility of establishing energy infrastructure corridors within existing transportation rights-of-way in New Hampshire. These corridors will be for the express purpose of siting projects like Northern Pass. SB 361 Commission included DOT staff and worked very closely with DOT. Final SB 361 Commission report published on November 30th, 2012, stated that DOT, DOT now, had identified four highway corridors as preferred energy infrastructure corridors. These four identified corridors included I-93 and I quote, I-93 from the Massachusetts border to the Vermont

1624-1

1624-1 cont'd

1624-1  
Continued

border. So DOT themselves in 2012 identified I-93 including the portion through Franconia Notch as a preferred corridor for the site of the energy projects such as Northern Pass. I-93 and Franconia Notch are not off limits to New Hampshire. In fact, the opposite is true. I-93 has been identified through a coordinated statewide study to be the preferred energy infrastructure corridor for projects such as Northern Pass. This is just one example of how Northern Pass's arguments against Alternative 4 A are factually incorrect. In conclusion, alternative 4 A is in fact a perfectly reasonable and viable alternative. Just because Northern Pass doesn't want to implement it, that doesn't make the alternative unreasonable or unviable. I urge DOE to deny Northern Pass's request to drop Alternative 4 A from the final EIS. Instead, I urge DOE to concentrate greater effort on analyzing Alternative 4 A's and refining it so it brings Northern Pass down interstate corridors throughout the state because this is the alternative that clearly provides the greater benefits to the people of New Hampshire, and by rights, it is the alternative that should ultimately be selected through the SEC siting process. Thank you.

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Jul 27, 2015

**ID:** 8231

**Date Entered:** Jul 27, 2015

**Source:** Website

**Topics:** Alternatives

### Organization:

**Comment:** Eversource refuses to consider burying the high voltage line they wish to run through New Hampshire to markets in southern New England. They claim doing so would be prohibitively expensive, but Hydro Quebec's own construction subsidiary, Trans Energie has testified before FERC that burial along prepared surfaces, such as highway verges, retired rail beds and even underwater is cost competitive with overhead installation. Further, long term, burial is cheaper because buried lines don't suffer storm damage and there is less line maintenance. The reason Eversource would prefer to damage New Hampshire rather than bury their lines is that they wish to extract rent from Hydro Quebec for the use of the lines. If the line were buried the state would receive royalties for the use of the right of way. It seems fair that if they wish to use our landscape as a power through-way they should be made to pay for the privilege and not be allowed to damage our land.

1628-1

Thank you for your comment. The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c). The potential environmental impacts of all twelve alternatives, as well as technical constraints and costs, are discussed throughout the EIS.

1628-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Aug 16, 2015

**ID:** 8317

**Date Entered:** Aug 16, 2015

**Source:** Website

**Topics:** Other

### Organization:

**Comment:** Regardless of what cost estimate you chose for burying the NPT line, the claim by the private company promoting the NPT, LLC, of it being 'too expensive' to entirely underground, is a false one. Please consider the Eversource profits in just one quarter:  
<http://www.hartfordbusiness.com/article/20150731/NEWS01/150739990> . The salary of company executives is 'Ever(source)' increasing, as shown in the following link:  
<http://www.courant.com/business/hc-eversource-energy-tom-may-executive-compensation-2014-20150305-story.html> . If the private entity that stands to gain gargantuan profits is citing it's 'too expensive' for them to responsibly bury the NPT, then we should take them at their word and immediately shut down any further consideration of this project! If they can't afford to construct with industry standard technologies, then they can't afford it period.

1629-1

Thank you for your comment. The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c). The potential environmental impacts of all twelve alternatives, as well as technical constraints and costs, are discussed throughout the EIS. Consideration of Eversource's profits is outside the scope of this EIS.

1629-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 14, 2016

**ID:** 8738

**Date Entered:** Mar 14, 2016

**Source:** Website

**Topics:** Alternatives

**Name:** Michael Capone

**Organization:** Town of Holderness

**Title:** Town Administrator

**Email:** administrator@holderness-nh.gov

**Mailing Address:** PO Box 203

**Mailing Address:** 1089 US Route 3

**City:** Holderness

**State:** NH

**Country:** US

**Comment:** On behalf of the Select Board and the residents of the Town of Holderness, NH I wish to submit the following comment with regard to the proposed route of the Northern Pass project.

The residents have voted unanimously at two Town Meetings to support the "full burial" alternative. We feel that this will meet Eversource's energy supply goals while still providing jobs for New Hampshire as well as increased tax revenues for New Hampshire communities while protecting the scenic beauty of our State.

We would appreciate your consideration of our position.

Sincerely,

Michael R. Capone  
Holderness Town Administrator

1632-1

Thank you for your comment. Northern Pass has applied to the Department of Energy for a Presidential permit for an HVDC transmission line that would run from Quebec, Canada to Deerfield, NH. Executive Order (EO) 10485, as amended by EO 12038, "requires that executive permission be obtained for the construction and maintenance at the borders of the United States of facilities for the exportation or importation of electric energy." DOE is authorized to "receive applications for the construction, operation, maintenance, or connection, at the borders of the United States, of facilities for the transmission of electric energy between the United States and a foreign country[,]" and "[u]pon finding the issuance of the permit to be consistent with the public interest, and, after obtaining the favorable recommendations of the Secretary of State and the Secretary of Defense thereon, to issue to the applicant, as appropriate, a permit for [the] construction, operation, maintenance, or connection." (EO 10485). DOE, however, does not have siting authority for the Project. In this case, the New Hampshire Site Evaluation Committee has siting authority for the Project in the state of New Hampshire. Additionally, the USFS has siting authority for portions of the Project located in the White Mountain National Forest. (For further discussion, see Sections 1.1-1.3 of the final EIS.) While DOE's authority is limited to the approval or denial of the amended Presidential permit application (August 2015) as requested by the Applicant, DOE's policy is to analyze not only the proposed border crossing, but also the alignment of new infrastructure required between the proposed border crossing and connection to the existing U.S. electricity system as a connected action. In keeping with this policy, DOE analyzed the potential environmental impacts of the alignment proposed by the Applicant. In addition, in response to input from Cooperating Agencies, other agencies, and extensive public comment, DOE analyzed a range of other alignments and underground and overhead configurations between the proposed border crossing and connection with the existing U.S. electricity system. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c). The potential environmental impacts of all twelve alternatives, as well as technical constraints and costs, are discussed throughout the EIS. Additionally, seventeen alternatives were considered but eliminated from detailed analysis. Section 2.4 of the final EIS has been updated with additional information on alternatives considered but eliminated from detailed analysis.

1632-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 28, 2016

**ID:** 8906

**Date Entered:** Mar 28, 2016

**Source:** Website

**Topics:** Alternatives, Viewshed/Scenery

**Organization:** AMC

**Comment:** I am writing to urge the DOE to consider having the energy transmission lines buried along their entire length. I understand that this is initially more costly to the power company. That said, it will pay them dividends over time with lower (or near zero) maintenance costs.

Additionally, burying the lines will pay visual "dividends" for decades to the millions of people who frequent the north country. Recall that on a clear day in New Hampshire you can see 100 miles from the mountaintops - all the way east to the Atlantic and all the way north into Canada. It would certainly be nice not to overlay those vistas with something that will likely be visible from outer space.

1633-1

Thank you for your comment. Northern Pass has applied to the Department of Energy for a Presidential permit for an HVDC transmission line that would run from Quebec, Canada to Deerfield, NH. Executive Order (EO) 10485, as amended by EO 12038, "requires that executive permission be obtained for the construction and maintenance at the borders of the United States of facilities for the exportation or importation of electric energy." DOE is authorized to "receive applications for the construction, operation, maintenance, or connection, at the borders of the United States, of facilities for the transmission of electric energy between the United States and a foreign country[,]" and "[u]pon finding the issuance of the permit to be consistent with the public interest, and, after obtaining the favorable recommendations of the Secretary of State and the Secretary of Defense thereon, to issue to the applicant, as appropriate, a permit for [the] construction, operation, maintenance, or connection." (EO 10485). DOE, however, does not have siting authority for the Project. In this case, the New Hampshire Site Evaluation Committee has siting authority for the Project in the state of New Hampshire. Additionally, the USFS has siting authority for portions of the Project located in the White Mountain National Forest. (For further discussion, see Sections 1.1-1.3 of the final EIS.) While DOE's authority is limited to the approval or denial of the amended Presidential permit application (August 2015) as requested by the Applicant, DOE's policy is to analyze not only the proposed border crossing, but also the alignment of new infrastructure required between the proposed border crossing and connection to the existing U.S. electricity system as a connected action. In keeping with this policy, DOE analyzed the potential environmental impacts of the alignment proposed by the Applicant. In addition, in response to input from Cooperating Agencies, other agencies, and extensive public comment, DOE analyzed a range of other alignments and underground and overhead configurations between the proposed border crossing and connection with the existing U.S. electricity system. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c). The potential environmental impacts of all twelve alternatives, as well as technical constraints and costs, are discussed throughout the EIS. Additionally, seventeen alternatives were considered but eliminated from detailed analysis. Section 2.4 of the final EIS has been updated with additional information on alternatives considered but eliminated from detailed analysis.

1633-1

1634-1

Thank you for your comment. Northern Pass has applied to the Department of Energy for a Presidential permit for an HVDC transmission line that would run from Quebec, Canada to Deerfield, NH. Executive Order (EO) 10485, as amended by EO 12038, "requires that executive permission be obtained for the construction and maintenance at the borders of the United States of facilities for the exportation or importation of electric energy." DOE is authorized to "receive applications for the construction, operation, maintenance, or connection, at the borders of the United States, of facilities for the transmission of electric energy between the United States and a foreign country[,]" and "[u]pon finding the issuance of the permit to be consistent with the public interest, and, after obtaining the favorable recommendations of the Secretary of State and the Secretary of Defense thereon, to issue to the applicant, as appropriate, a permit for [the] construction, operation, maintenance, or connection." (EO 10485). DOE, however, does not have siting authority for the Project. In this case, the New Hampshire Site Evaluation Committee has siting authority for the Project in the state of New Hampshire. Additionally, the USFS has siting authority for portions of the Project located in the White Mountain National Forest. (For further discussion, see Sections 1.1-1.3 of the final EIS.) While DOE's authority is limited to the approval or denial of the amended Presidential permit application (August 2015) as requested by the Applicant, DOE's policy is to analyze not only the proposed border crossing, but also the alignment of new infrastructure required between the proposed border crossing and connection to the existing U.S. electricity system as a connected action. In keeping with this policy, DOE analyzed the potential environmental impacts of the alignment proposed by the Applicant. In addition, in response to input from Cooperating Agencies, other agencies, and extensive public comment, DOE analyzed a range of other alignments and underground and overhead configurations between the proposed border crossing and connection with the existing U.S. electricity system. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c). The potential environmental impacts of all twelve alternatives, as well as technical constraints and costs, are discussed throughout the EIS. Additionally, seventeen alternatives were considered but eliminated from detailed analysis. Section 2.4 of the final EIS has been updated with additional information on alternatives considered but eliminated from detailed analysis.

Tara Bamford. The Planning Director at North Country Council. North Country Council is the state designated regional planning commission for the Northern Pass corridor from the Canadian border all the way to the Plymouth/Bridgewater line. In the interest of time, I'm just going to focus on one point. My role of planner is to look for the solution that pleases the highest number of residents of our region. Just a kick look at the summary of the November supplement, if you take another look at alternatives 4 and 6, you'll see that burial of the line increases all of the benefits that the Applicant has listed for the project. You'll see that burial reduces all of the negative impacts, not just the scenic impacts, but loss of property values, loss of property tax income for towns, archeological impacts, wetland impacts, CO2 uptake that's lost. Prime farmland that's lost. They're all lessened by burial. All of the benefits, again, that the Applicant missed are increased with burials. Both the short-term and long-term economic benefits are higher than alternatives four and six where it's buried throughout our region. The number of jobs, which we're hearing on both sides of the conversation, the number of jobs in both the short-term of construction and long-term with maintenance are higher with burial. Energy costs would be reduced by the same amount so that benefit doesn't change. Only the cost of construction to the Applicant is higher with burial. Not by orders of magnitude, not by an unreasonable amount. By 33 percent in the case of alternative 6 A. Thank you for listening. I know it's a long hearing.

1634-1

**Hello my name is Randy Perkins**

**I have worked for Eversource Energy for the past 30 years and my current job is a Strategic Account Executive in which I provide services to the largest companies with my service territory covering all of Northern New Hampshire.**

**Serving these large companies, I consult on Energy Efficiency projects to cost-effectively lower their electric bill; respond to power quality issues, assist in construction, and offer advice on energy and many other topics.**

**The number 1 concerns from my customers are the high energy costs and the need for stable energy prices—and avoiding the volatile energy prices we've seen in recent years.**

**In New Hampshire, electric rates for the industrial sector are nearly double the national average. Commercial business electric rates in NH are 40% higher than the national average. These are critical issues for the future well-being of our state's businesses and industry.**

**Electricity is a large part of the budget for business and industry—including those in our NH tourist industry. For instance, ski areas use the bulk of their energy in the winter months making snow.**

**Most of my ski areas see their electric bills soar between \$100,000 and \$250,000 a month! It is important to remember that Northern Pass would reduce yearly energy cost by \$80 million which is roughly 5% off their electric bills.**

**That may not seem like much to some, but keep in mind that 5% would represent between \$5000. and \$12,500. each month for the ski industry which is very important to the New Hampshire economy.**

**It's for these reasons that I support the Northern Pass Project - I believe it can help reduce energy prices for the state's businesses and industry I serve every day - keeping New Hampshire businesses in New Hampshire so they don't relocate elsewhere, and at the same time introducing more green power into our state and region!**

1637-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

1637-1

COMMENT

1639-1  
Thank you for your comment.

## U S DEPARTMENT OF ENERGY

RE DEIS for Northern Pass -

Whitefield, NH

Peter Grote  
1437 Easton Road  
Franconia, NH 03580

March 11, 2016

I appreciate that the US DOE is hosting this public meeting in Whitefield today.

For over one million years, the Appalachian Mountain System, which includes Franconia Notch, has survived ice sheets, glaciers, earthquakes, fires, floods, landslides and in recent times, the construction of Interstate Highway Systems, including Interstate I-93, a designated energy corridor.

Why does the management of Northern Pass insist that this durable, geologic structure, in any way, could be damaged or harmed by the underground installation of a set of copper cables?

The proposed route, consisting of towers and buried lines under NH State Route 18, Route 116, Route 112 and Route 3 would impose far greater long-term, economic, environmental and aesthetic impacts than an alternative route through the Interstate Highway System.

The Utility's management has made many claims that using Interstate I-93 would be "uneconomic" without offering the public a detailed analysis or justification for its claims.

1639-1

The economic and qualitative impact of

- some 1,200 new towers
- 600 relocated towers, spanning over 130 miles &
- 90 miles of cables buried under state highways

**Will all be affecting over 90,000 NH residents and voters.**

**An underground route through the Interstate Highway System will be orders of magnitude less disruptive.**

During recent public meetings in Lincoln, Colebrook and again in Whitefield today, Northern Pass representatives stated that:

- It would be **TECHNICALLY** possible to bury the entire proposed Line.
- The **LIFE SPAN** of the towers was sixty or seventy years.
- This presumes that the **entire Line** would have a sixty or seventy year life.
- **HYDRO-QUEBEC**, not NH ratepayers, will pay for the construction of the Line.

While the NPT is still withholding from the public an important report titled "**Cost/Benefit and Local Economic Impact Analysis**", Hydro-Quebec continues to disclose detailed financial results and projections about its operations.

1639-1  
Continued

- For the six months ending September, 2015, Hydro-Quebec reported net result of over C\$ 2 billion.
- Adding NPT anticipated profits, Hydro-Quebec would have the **capacity** to earn some US \$ 200 billion over a projected life span of 60 to 70 years at current exchange rates.
- This model of future cash flows suggests the extra cost of burying the entire Line, including using the **Interstate I-93** corridor, could be less than 1% of Hydro-Quebec's potential, **cumulative net profit** from the project.

To conclude: NPT representatives have told members of the NH SEC Committee and public at its hearings that:

“It's not economically viable to bury the entire line”

When will Northern Pass Management support this “**Hypothesis**” with a written analysis of hard facts in public?

Thank you

1639-1  
Continued

## SEC Testimony on Northern Pass

*Representative Katherine Rogers – Concord, Merrimack County  
District 28*

Good evening, my name is Katherine Rogers, I am a New Hampshire Representative who lives here in Concord. I am speaking out in favor of this project because of my constituents.

As a state legislator, I work to balance the sometimes competing interests of issues like this. Two areas in which we all agree is that number of older power plants retiring and going off-line requires this conversation. And if we don't embrace projects like this, we will not make any progress in lowering electric rates, which remain among the highest in the country.

My constituents tell me their electric bills are way too high. Many of the people I represent are low income families who struggle with their monthly payments. They need help. I also have heard from businesses who tell me their utility costs are too expensive. They need relief, too. We can't forget about these folks.

Eversource has repeatedly explained this project is estimated to lower residential electric rates by 5%. Businesses are in line to save substantially more. That is on top of the \$80 million dollars in property tax revenue to the communities along the route you cited. Those are real savings for people who live in our community and I cannot ignore that type of savings.

In addition, as a representative of a working class neighborhood, I have heard from many people who celebrate the fact that this proposal means well over a thousand jobs, with training opportunities available to actually participate in the economic benefits of Northern Pass in direct ways. Some of my constituents are members of the International Brotherhood of Electrical Workers, and they are clear and unanimous in their unwavering support for this project and the jobs that would be created by allowing it to proceed.

1643-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

1643-1

This project has become demonized by many in this debate and I feel like we have lost sight of why we are talking about Northern Pass. Are there 77 new towers going up to sustain the line? Yes. There are also 122 poles that are being relocated to lessen impact and visibility, so there is positive response based on resident feedback.

And I keep coming back to this reality: every inch of this line through this area is in a utility right of way, which was designed many decades ago to be the acceptable pathway for power lines. Perhaps there are ways to keep lowering the heights, but if we want new energy resources, we have to be willing to connect to them.

I'm not saying I whole-heartedly and enthusiastically endorse every detail of this project, but I know major progress when I see it, and I know a proposal that resolves constituent concerns when I see it... and this does both.

What I see is a plan that will lower electric rates, provide new jobs and it will produce clean energy that can actually take a bite out of our carbon footprint. These are good things. I fear that absolutes in this debate – that an all or nothing sentiment – jeopardizes the many benefits a project like this can bring to New Hampshire. I urge the members of the Site Evaluation Committee to find the common ground to move this project forward so our state can enjoy the benefits it would bring.

Thank you.

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Nov 19, 2015

**ID:** 8529

**Date Entered:** Nov 19, 2015

**Source:** Website

**Topics:** Purpose and Need

**Name:** Zachary Wielgoszinski

**Organization:**

**Email:** wielgoszinskiz@gmail.com

**Mailing Address:** 70 Foundry St.

**City:** Manchester

**State:** NH

**Zip:** 03102

**Country:** US

**Comment:** I'm fortunate to work for one of the world's largest financial companies, so it is unlikely I'd be out of a job due to my company's inability to pay high electric bills. However, that's not the case for everyone and as someone who has lived here my whole life, I've seen countless businesses come and go - in part because of the extremely high cost for power. How is NH supposed to prove itself to business owners as a desirable destination if what they see is a list of past businesses forced to shut down or move out of state? Plus, the problem is only getting worse as more power plants are closing and there's no solution to replace the energy source.

The thing is, we DO have a solution and it's to bring clean power from Hydro-Quebec through the Northern Pass. It's unrealistic for our infrastructure to rely exclusively on renewable power such as wind and solar at this point. So while we have the opportunity to get on board with this solution, which brings the promise of 2,600 new jobs, tax benefits and lower energy costs, we should take advantage. If not, we risk the project moving to a different state and therefore losing out on all the benefits it provides. Or worse, more reliance on burning fossil fuels to make electricity. I hope young professionals like myself, the future home and business leaders of NH, join me in supporting the Northern Pass.

Zachary Wielgoszinski

1644-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

1644-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Nov 19, 2015

**ID:** 8531

**Date Entered:** Nov 19, 2015

**Source:** Website

**Topics:** Purpose and Need, Alternatives, Health and Safety, Taxes, Historic/Cultural, Economic

**Name:** Thomas Brisendine

**Organization:**

**Email:** thomasbrisendine@hotmail.com

**Mailing Address:** 205 Main Street

**Mailing Address:** Apt 130

**City:** Salem

**State:** NH

**Zip:** 03079

**Country:** US

**Comment:** It's no surprise that New Hampshire has one of the highest energy rates, and now that we're seeing the closure of other plants around new England, we need to move quickly to bring more clean energy to the regional grid from which we get New Hampshire's power. The average retail price per kilowatt-hour is 10.41 cents across the United States, whereas the average price per kilowatt-hour in New England is nearly 17 cents. New England is close to double the national average! We cannot continue to brush off the need for reducing our electricity costs anymore.

As a supporter of the Northern Pass' Forward NH Plan, I'm very happy to hear and appreciate the efforts that have been made to guarantee that there will be no view obstructions in the White Mountain National Forest, a place I frequently visit in the winter months, and that there would be approximately \$3.8 Billion dollars of economic and community benefits for the state of New Hampshire. Let's also not forget that the Forward NH plan would bring 2,600 jobs to our state along with \$30 million dollars annually in new property taxes. The Forward NH Plan brings opportunity to New Hampshire, a state which continues to be challenged with keeping businesses here. It also gives me reassurance for years to come that when I become a homeowner, I won't have to worry about sky-

1645-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

1645-1

rocketing electricity rates.

Thomas Brisendine  
205 Main Street  
Salem, NH

| 1645-1  
Continued 1645-1 cont'd

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Dec 4, 2015

**ID:** 8570

**Date Entered:** Dec 4, 2015

**Source:** Website

**Topics:** Other

**Name:** Mark Leach

**Organization:**

**Email:** racewayelectrical@yahoo.com

**Mailing Address:** 20 Maple Avenue

**City:** Hudson

**State:** NH

**Zip:** 03051

**Country:** US

**Comment:** I am in favor of the Northern Pass electricity project and here is why: This project will create 2,600 new jobs for our state. This is especially important for the North Country where new jobs are needed for that region.

And according to the revised proposal from Northern Pass, when the project is complete, citizens of NH will save 80 million dollars in annual energy costs. This is great news considering we are one of the highest paying states for energy costs in the nation today. Additionally, an extra 30 million dollars of annual state and local tax revenue will be generated by this project. NH is a frugal state and any additional revenue we can receive is a tremendous help to taxpayers.

We need to move forward with this project in order to create jobs, lower our electricity rates, and increase tax revenue for the betterment of citizens of New Hampshire.

1646-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

1646-1

## COMMENT CARD

NH Site Evaluation Committee, Docket No. 2015-06  
Public Hearing, RSA 162-H:10, I-c

RE: Joint Application of Northern Pass Transmission LLC  
& Public Service Company of New Hampshire d/b/a Eversource Energy  
for a Certificate of Site and Facility

LOCATION (circle one): Meredith (March 1); Colebrook (March 7); Concord (March 10);  
Holderness (March 14); Deerfield (March 16)

FIRST NAME: Brian LAST NAME: Emetson

STREET ADDRESS: 3 West St

TOWN: Groveton STATE: NH ZIP: 03582

EMAIL ADDRESS: moosecountryguide@hotmail.com

If you wish to provide written comments for the record, please provide your comments below:

As a former business owner in Coos County, I  
urge the SEC to approve the Northern Pass  
project, as proposed. A number of years ago,  
a pipeline was constructed through our region.  
We saw our business traffic + sales spike  
measurably as a result of the additional  
workers that were employed by that project.  
Other businesses in our town also saw noted  
increases in sales + services, boosting the  
local economy by a large degree. That project  
was relatively small-scale as compared to the  
scope of the Northern Pass. Please help the  
residents + businesses in Coos County enjoy

NH Site Evaluation Committee, 21 South Fruit Street, Suite 10, Concord, NH 03301 (603) 271-2435  
Martin P. Honigberg, Chair • Thomas S. Burack, Vice-Chair • Pamela G. Monroe, Administrator

[www.nhsec.nh.gov](http://www.nhsec.nh.gov)

the benefits of such a large-scale project.  
Our economy depends on things like this. *Thank you.*

1647-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

1647-1

**SEC Docket No. 2015-06, Northern Pass  
Public Hearing – March 10, 2016  
Concord, N.H.**

**Comments from Don Welch**

Dear SEC, DOE and Other Officials:

Thank you for the opportunity to speak this evening. Out of respect for the many folks here who are also waiting to speak, I will keep my comments brief.

My name is Don Welch. I am a N.H. native, currently live in Bow, and am the President of Globe Manufacturing Company in Pittsfield, N.H. At Globe we build protective clothing for firefighters all across the United States – from small local volunteer departments to large city departments like Boston, Atlanta, Indianapolis, and Dallas. We employ approximately 300 terrific employees in Pittsfield and also have smaller plants in Maine and Oklahoma.

We are fortunate to have a great workforce and are able to provide good paying jobs with excellent benefits to our employees. We are by far the largest employer in the Pittsfield area – a region with a long and proud manufacturing heritage that has seen its manufacturing base crumble over the past few decades.

As a manufacturer that relies on electricity to power our equipment, one of my essential and most basic needs is for reliable, low cost power. Every single employee in our operation is connected in some way to the electric grid whether it be for the machines that cut the high tech fabrics we use, the specialized sewing machines to stitch the panels together, or the computer terminals that our customer service folks need to communicate with customers efficiently and quickly.

As we all know, our electric rates in New Hampshire are among the highest in the country. I could save nearly 50% on my electric bill if we relocated our Pittsfield operation to Oklahoma, where we already have a plant. Labor

1648-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

rates, housing costs and medical insurance rates are also less in Oklahoma and neighboring states. As I talk with other manufacturers in the state, I hear many struggling with the same issues.

The bottom line is that we must find ways to lower electricity costs in order to keep and create manufacturing jobs here in New Hampshire. The Northern Pass project will bring reliable lower-cost energy to New Hampshire which will begin to address our region's economic competitiveness.

Now I don't believe that Northern Pass alone is going to solve all of the region's needs. I support other energy development projects as well including wind, solar and more natural gas pipeline capacity, and I believe we must continue our energy conservation work. But, the Northern Pass project is a great opportunity that will provide reliable, inexpensive and clean electricity we must not let slip away.

As a New Hampshire native, I have always enjoyed outdoor activities in the White Mountains and North Country including hiking, skiing and snowmobiling. So I appreciate the concerns that some have about the visual aspects along the route. However, I think Eversource has been responsive in modifying the route and offering to bury 60 miles in the White Mountains. The proposed route is primarily along existing transmission corridors or underground in public roadways. Calls to bury more of the cable will drive up costs and the rates we all pay.

In closing, as a long term and relatively large employer in the state I want to voice my support for the project. Manufacturing companies in the region need lower-cost, reliable power. Approval of the Northern Pass project is an important step to help us achieve that goal.

Thank you.

1648-1

1650-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

1650-1

Good evening. Speaking for Katherine Rogers: Good evening. My name is Katherine Rogers. I am a New Hampshire representative who lives here in Concord. I am speaking out in favor of this project because of my constituents. As a state legislator, I work to balance sometimes competing interests of issues like this. Two areas in which we all agree is that a number of older power plants retiring and going off line requires this conversation, and if we don't embrace projects like this, we will not make any progress in lowering electric rates which remain among the highest in the country. My constituents tell me their electric bills are way too high. Many of the people I represent are low income families who struggle with their monthly payments. They need help. I also have heard from businesses who tell me their utility costs are too expensive. They need relief, too. We can't forget about these folks. Eversource has repeatedly explained this project is estimated to lower residential electric rates by 5 percent. Businesses are in line to save substantially more. That is on top of the \$80 million in property tax revenue for the communities along the route. Those are real savings for the people who live in our communities, and I can't ignore that type of savings. In addition, as a representative of a working class neighborhood, I have heard from many people who celebrate the fact that this proposal means well over 1,000 jobs with training opportunities available to actually participate in the economic benefits of Northern Pass in direct ways. Some of my constituents are members of the International Brotherhood of Electrical Workers, and they are clear and unanimous in their unwavering support for this project and the jobs that will be created by allowing it to proceed. This project has become demonized by many in this debate, and I feel like we have lost sight of why we are talking about Northern Pass. Are there 77 new towers going up to sustain the line? Yes. There are also 122 poles that are being relocated to lessen the impact on visibility so there is positive response based on resident feedback, and I keep coming back to this reality. Every inch of this line through this area is in a utility right-of-way which was designed many decades ago to be the acceptable pathway for power lines. Perhaps there are ways to keep lowering the heights, but if we want new energy resources, we have to be willing to connect them. I'm not saying I wholeheartedly and enthusiastically endorse every detail of this project, but I know major progress when I see it and I know a proposal that resolves constituent concerns when I see it and this does both. What I see is a plan that will lower electric rates, provide new jobs and it will produce clean energy that can actually take a bite out of our carbon footprint. These are good things. I fear that absolutes in this debate, that all in or nothing sentiment, jeopardizes the many benefits a project like this can bring to New Hampshire. I urge the members of the Site Evaluation Committee to find the common ground to move this project forward so our state can enjoy the benefits it would bring. Thank you.

1660-1

Thank you for your comment. Potential socioeconomic impacts of the Project, including potential changes to wholesale electricity costs, are analyzed in detail in Section 4.1.2 of the EIS. The analysis presented in the final EIS was updated to reflect current market conditions and inputs. The analysis does not attempt to determine impacts to individual rate payers or energy prices at the rate payer level. Rather, data is provided for the anticipated changes in wholesale electricity expenditures across both New Hampshire and the ISO-NE region. The changes in wholesale electricity expenditures aggregate individual residential and commercial consumers of electricity. The potential impacts to individual rate payers or energy prices at the rate payer level by distribution utilities are decided by the New Hampshire PUC and are beyond DOE's scope of analysis.

1660-1

Howard Moffett. Thank you, Mr. Chairman. I'd just like to take another couple of minutes to talk about one issue that I didn't get chance to talk about, and it's one that seems to have been relevant to a number of people who have spoken tonight. It's the question of whether and to what extent Northern Pass is actually going to reduce electric rates in New Hampshire and New England. I think there's a case to be made that it will have or could have a modest effect in terms of reducing electric rates, but I think it's going to be very important for the committee if they want to get a handle on this to really look carefully at these claims. Mr. Quinlan has told you that Northern Pass hydropower would displace higher cost generation in the ISO New England bid stack resulting in \$800 million in annual savings for New England, and that New Hampshire's share of those savings would be ten percent or \$80 million based on our 9 percent share of New England's electric load. He calls this the market suppression effect. What he didn't tell you or at least he hasn't emphasized is that Hydro-Quebec plans to sell Northern Pass power at prevailing market rates, meaning it will charge as much as the market will bear. So yes, Northern Pass could in theory displace the most expensive thousand megawatts of the 16 to 20,000 megawatts that New England uses in an average winter day, but that doesn't mean that electric rates paid by New Hampshire ratepayers would be cut by five percent. Not even close. The effect of Northern Pass on the average ratepayer's monthly electric bill will be much, much smaller than some of the figures you've heard tonight. I heard a figure of five percent, and, frankly, I don't know where that could come from if Hydro-Quebec is going to be charging prevailing market rates. Mr. Quinlan also mentioned a beneficially priced Power Purchase Agreement, Mr. Tilton referred to it earlier, for ten percent of Northern Pass's power, but as you've heard before, Eversource has been talking about that for several years, but we have yet to see the contract. You don't have to take my word for this. Okay? I'm not an expert on electric rates, but you have available to you some people that are experts on electric rates, and I would suggest that if you want to get a sense of how to weigh the potential effects of the Northern Pass project would have on reducing electric rates, you might want to look carefully at another project that is coming before your committee, that's the Tennessee Gas Pipeline Project, the Northeast Energy Direct Project. Because members of the PUC staff in an investigative study that they did last year in IR 15124, coming out of that study they have, they've concluded that the Northeast Energy Direct Project would actually reduce electric rates in New England by somewhere between 7 and 11 percent. That's not 7 to 11 cents. It's 7 to 11 percent. And I don't think there's any other project on the drawing boards anywhere that comes close to that. Certainly not the Spectra AIM project, and I don't think Northern Pass is going to come close to it either. My point is, if you really care, if you really think that this project is going to benefit New Hampshire ratepayers by significantly reducing electric rates, I would ask you, I would urge you do your homework. Take advantage of the expertise you have in the PUC and find out because I don't think it makes sense. That's all I'll say. No, it's not all I'll say. I'm going to say a couple more things. It's the cost to the public that really make this project unacceptable unless it's buried. You can't quantify those costs. Because if Northern Pass is hung from hundred-foot towers, the damage to the state's most treasured natural landscapes would be incalculable. You've heard countless people testify about that tonight. New Hampshire's sense of itself would be irretrievably compromised, and as for the state's symbol and welcome sign, you would be asking us to trade the Old Man for 130 miles of overhead transmission lines. Thank you.

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 28, 2016

**ID:** 8881

**Date Entered:** Mar 28, 2016

**Source:** Website

**Topics:** Alternatives, Viewshed/Scenery

**Name:** Malcolm Smith

**Organization:**

**Email:** mms7r@virginia.edu

**Mailing Address:** 2951 Mt Aire Rock Lane

**City:** Charlottesville

**State:** VA

**Zip:** 22901

**Country:** US

**Comment:** Visual impact: I am a resident of the Commonwealth of Virginia. However, for the past 20 years or more, my family and I have spent anywhere between 2 weeks to a month in the White Mountains and regions to be impacted by the Northern Pass project. We are not alone. In our visits we routinely encounter many people from the US and Canada that are not residents but who nevertheless spend considerable time in the region hiking, skiing, tenting, cycling, and climbing. In this context, the visual impact analysis done for the DEIS is grossly inappropriate, being based on US Census data for local residents rather than the real total population that will suffer the impact. This defective analysis must be corrected.

Alternatives. There is no excuse not to fully bury the Northern Pass line. The argument from Northern Pass that full burial along the I-93 corridor is not possible is merely their assertion and is unsubstantiated. Secondly, even if that were true, alternative international border crossings, such as I-91, should be considered in the DEIS. In fact, DOE has issued Presidential Permits for full burial of other projects crossing from Canada into Vermont and New York. All burial alternatives should be considered by the DEIS.

1681-1

Thank you for your comment. The value of scenic sensitivity used in the analysis is the greater of scenic concern or viewer exposure, not the average. Therefore, low viewer exposure in the Northern Section and the WMNF, for example, does not lower the scenic sensitivity of these areas. The rationale for the viewer exposure ratings is explained in Section 2.4.2.5 of the Visual Impact Assessment Technical Report. As discussed, use data are generally not available for scenic or recreation resources in New Hampshire and estimates of transient and tourist populations would be excessively speculative. Therefore, census data were used as an indicator of how many potential viewers exist in an area. The scenic value of the undeveloped nature of the area is captured through the other elements of the landscape assessment, including intrinsic visual quality. The viewer exposure metric was included in this analysis to represent the sensitivity of areas with many viewers but less intrinsic scenic quality.

1681-2

Thank you for your comment. Because an EIS is intended to inform decisionmakers and the public about potential impacts of a major federal action, DOE analyzes in detail several alternatives that involve underground cable in the I-93 corridor, including Alternatives 4a, 4b, 4c, 5a, 6a, and 6b. The regulatory framework governing utilities in roadway corridors, including through Franconia Notch (Section 4.3.6.4 of the EIS), is discussed in the Land Use Technical Report and the EIS, see Section 3.1.6.4. DOE has considered this comment and no change to the EIS was made.

1681-1

1681-3

Thank you for your comment. Northern Pass has applied to the Department of Energy for a Presidential permit for an international border crossing associated with an HVDC transmission line that would run from Quebec, Canada to Deerfield, NH. Executive Order (EO) 10485, as amended by EO 12038, "requires that executive permission be obtained for the construction and maintenance at the borders of the United States of facilities for the exportation or importation of electric energy." DOE is authorized to "receive applications for the construction, operation, maintenance, or connection, at the borders of the United States, of facilities for the transmission of electric energy between the United States and a foreign country[.]" and "[u]pon finding the issuance of the permit to be consistent with the public interest, and, after obtaining the favorable recommendations of the Secretary of State and the Secretary of Defense thereon, to

1681-2

1681-3

issue to the applicant, as appropriate, a permit for [the] construction, operation, maintenance, or connection." (EO 10485). DOE, however, does not have siting authority for the Project. In this case, the New Hampshire Site Evaluation Committee has siting authority for the Project in the state of New Hampshire. Additionally, the USFS has siting authority for portions of the Project located in the White Mountain National Forest. (For further discussion, see Sections 1.1-1.3 of the final EIS.) While DOE's authority is limited to the approval or denial of the amended Presidential permit application (August 2015) as requested by the Applicant, DOE's policy is to analyze not only the proposed border crossing, but also the alignment of new infrastructure required between the proposed border crossing and connection to the existing U.S. electricity system as a "connected action" under NEPA. In keeping with this policy, DOE analyzed the potential environmental impacts of the alignment proposed by the Applicant. In addition, in response to input from Cooperating Agencies, other agencies, and extensive public comment, DOE analyzed a range of other alignments and underground and overhead configurations between the proposed border crossing and connection with the existing U.S. electricity system. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. Additionally, seventeen alternatives were considered but eliminated from detailed analysis. Section 2.4 of the final EIS has been updated with additional information on alternatives considered but eliminated from detailed analysis. Among these alternatives, DOE considered two alternate border crossings. One was an alternative that would utilize the existing National Grid Phase I/II route, including its border crossing in Vermont. Based on its review of the National Grid alternative DOE determined that this alternative is not reasonable. Section 2.4.3 of the final EIS has been updated with additional information related to the National Grid alternative. Separately, in response to comments received on the draft EIS, DOE considered a second alternative border crossing in Vermont, specifically identified as a border crossing at Derby Line, VT that would utilize I-91. DOE determined that this alternative is not reasonable. Section 2.4.17 of the final EIS has been added to reflect consideration of this alternative and DOE's determination.

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 28, 2016

**ID:** 8922

**Date Entered:** Mar 28, 2016

**Source:** Website

**Topics:** Viewshed/Scenery

**Organization:** Retired

**Comment:** I am an avid hiker in the White Mountains and the NH north country. I do not live in the area but I do have a three season home in Meredith, NH. We often hike in the White Mountains and north. My wife and I view the addition of a long above ground power line access to causes a severe visual impact. I have come to find out that DEIS uses an approach based on the US Census data for the North Country. Using US Census data as a surrogate for real viewer experiences grossly underestimates the visual impacts of a project like Northern Pass on viewers and viewer expectations of this landscape. Regions such as New Hampshire's North Country, with more natural and undeveloped landscapes, typically have low resident population densities. Rather than US Census data, the FEIS should assess the visual expectations for the undeveloped landscape qualities of the North Country held by residents, second home owners, and visitors to the region. The alternative of fully burying the power lines would be my preference. The increased costs of burying can be overcome but the visual impact on this wonderful landscape can never be recovered if the right of way includes the above ground towers.

1687-1

Thank you for your comment. The value of scenic sensitivity used in the analysis is the greater of scenic concern or viewer exposure, not the average. Therefore, low viewer exposure in the Northern Section and the WMNF, for example, does not lower the scenic sensitivity of these areas. The rationale for the viewer exposure ratings is explained in Section 2.4.2.5 of the Visual Impact Assessment Technical Report. As discussed, use data are generally not available for scenic or recreation resources in New Hampshire and estimates of transient and tourist populations would be excessively speculative. Therefore, census data were used as an indicator of how many potential viewers exist in an area. The scenic value of the undeveloped nature of the area is captured through the other elements of the landscape assessment, including intrinsic visual quality. The viewer exposure metric was included in this analysis to represent the sensitivity of areas with many viewers but less intrinsic scenic quality.

1687-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Mar 28, 2016

**ID:** 8945

**Date Entered:** Mar 28, 2016

**Source:** Website

**Topics:** Alternatives, Viewshed/Scenery, Historic/Cultural, Tourism, Quality of Life, Cumulative Effects

### Organization:

**Comment:** The transmission lines for the Northern Pass project... should it even be approved, given that the need for the project is not demonstrated... these lines should be buried, from beginning to end. It is feasible, as demonstrated by plans for a similar project in Vermont.

The burial of the lines will create plenty of jobs, and will be more secure, with less vulnerability to storms and sabotage.

The value of the scenery is hard if not impossible to quantify. It is clearly inappropriate to use population levels to assess value... for example, there are very few people in Wyoming, but that didn't make Yellowstone and the Grand Tetons less valuable...

We have only this one opportunity to do this right; once the landscape is marred, there will be no correcting the damage. Northern New England's identity and marketing image depends upon its natural beauty... everything from recreation to leaf peeping... and that identity does not stop at the borders of the White Mountains.

In fact, these towers would be visible from the White Mountains... doing indirect damage to the area that EverSource has already conceded needs protection. Now let's protect the rest of that resource, with all its natural, human, and economic value.

Bury The Northern Pass, entirely, no matter which route it takes.

1688-1

Thank you for your comment. The value of scenic sensitivity used in the analysis is the greater of scenic concern or viewer exposure, not the average. Therefore, low viewer exposure in the Northern Section and the WMNF, for example, does not lower the scenic sensitivity of these areas. The rationale for the viewer exposure ratings is explained in Section 2.4.2.5 of the Visual Impact Assessment Technical Report. As discussed, use data are generally not available for scenic or recreation resources in New Hampshire and estimates of transient and tourist populations would be excessively speculative. Therefore, census data were used as an indicator of how many potential viewers exist in an area. The scenic value of the undeveloped nature of the area is captured through the other elements of the landscape assessment, including intrinsic visual quality. The viewer exposure metric was included in this analysis to represent the sensitivity of areas with many viewers but less intrinsic scenic quality.

1688-1

- Subcommittee gathered information from Eversource and other stakeholders to determine the impact of the proposed project in Concord

171  
Council  
Matsom

- Report submitted to Council who voted unanimously to file a petition to intervene and recommend burial of lines.

- Request for burial of the lines based on the project's current proposed aerial path and subsequent impacts to character, property values as well as visual and audio impacts due to close proximity of residences

1703-1

- Concord spent nearly 2 mill to bury utility lines in downtown Penacook, and is considering burial of lines on S. Main St. Current subdivision regulations require new subdivisions to bury utility lines.

E - proposed route of NP passes through 31 communities. Using 2010 census slightly more than 177k people live in those communities

- Concord's population is 42,695 which is slightly more than 36% of the affected population.

1703-1

Thank you for your comment. Visual impacts in Concord are discussed in the EIS (Section 4.4.1). Potential visual impacts in urban areas were overstated in the draft EIS. Because the Concord area is urban, there was no estimation of screening from land cover which leads to an overstatement of visibility in the developed areas of Concord. The analysis has been updated for the final EIS to include additional data reflecting the height of land cover in Concord which better represents the visibility of the Project.

I - There are 8.1 miles of overhead lines proposed for Concord, approx. 6% of the total overhead route <sup>12</sup>

II - Per NP the most common height of existing structures in ROW in Concord is 43 ft. The height of structures <sup>being</sup> relocated for the project will increase from 43 to an average height of 88 ft.

- Oct 2014 NP project map indicates 120 structures over 90 feet in Concord  
60 of the 120 will be between 100-125 ft. Capital Dome is 150 feet.

III - NP claims avg. scenic impact is 1.79 on a scale of 0-5. low to very low. However for the Southern Section which includes Concord the impact rises to 1.92 to 2.29 with additional 6 sq miles of the viewshed rating high or very high. The view from roads will increase from low to moderate to moderate to high.

IV DOE Draft Environmental Impact Statement July 2015 p 4-286 cites 2 areas in Concord with strong aesthetics/visual impact. 1703-2

- 1 Lorton Road increases from moderate to Severe
- 2 Turtle town pond increases from moderate to strong.

Clearly the visual impact to Concord will be significant.

V Brian Basse of Eversource told the subcommittee cost of aerial installation is 3 mill/ft. cost of underground is between 8-13 mill/mile. Subcommittee conciders asked on varying occasions for cost estimate breakdown due to variety of soil cond in Concord. The information was never provided. 1703-3

VI citizens of Concord have been clear and consistent in their position on the Northern Pass. Aerial installation will have lasting negative effects on individuals and the city as a whole with respect to quality of life and economic development. Therefore we request burial of the lines through the city of Concord.

1703-2

Thank you for your comment. Potential visual impacts in Concord, NH are discussed in Section 4.4.2 of the EIS. The Key Observation Point (KOP) CO-1 visual simulation in the draft EIS depicts a viewpoint in Concord, NH.

1703-3

Thank you for your comment. The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c) which include burial through Concord. The potential environmental impacts of all twelve alternatives, as well as technical constraints and costs, are discussed throughout the EIS.

1704-1  
Thank you for your comment.

December 15, 2015

Mr. Brian Mills

Sr Planning Advisor

Office of Electricity and Energy Reliability (OE-20)

US Department of Energy

3000 Independence Ave SW

Washington, DC 20585

Dear Mr. Mills,

Below is the email I just sent re the Northern Pass and New Hampshire.

This Northern Pass plan to route its transmission lines for 132 miles through the most pristine, beautiful, and near sacred land is outrageous. If you want to go through our lands, you may not use eyesores such as aerial towers no matter how high!! Try going off shore with the Wind Mills! But, not in New Hampshire!!

Very truly yours,

Philip W Terrell

Rte. 3

Franklin, NH

I want you to consider this correspondence as a formal objection to the Northern Pass plan to deface our great state of New Hampshire.

Very truly yours,



Philip W Terrell

7205 Manor Oaks DR

Raleigh NC 27615

1704-1

Re: Northern Pass  
PROJECT

Brian Mills  
OFFICE OF ELECTRICITY  
DELIVERY & EFFICIENCY  
US. DEPT OF ENERGY  
1000 INDEPENDENCE AVE  
WASHINGTON, DC 20585

1705

Dear Mr. Mills

First, my apologies for my handwriting resulting from my computer's refusal to communicate with my printer. I am writing to express my opposition and dismay at the proposed Northern Pass project in New Hampshire. I am a retired Marine Biologist having recently retired from the Army Corps of Engineers, who has spent a great deal of time protecting the Lake Region of New Hampshire through conservation easements and watershed management plans. I have lived in many parts of the U.S. but have none that rival the beauty of my adopted home of Meredith, New Hampshire, and of the rest of the state. The idea of constructing massive, ugly monoliths across our state is appalling, particularly when its major goals include the increased enrichment of a selected few, at the expense of my fellow residents.

It took millions of years to create a state that I and millions of residents & tourists who visit each year find incredibly beautiful. This is particularly true when the threat to that beauty is unnecessary as there <sup>are</sup> clear alternatives to the construction as proposed. The Northern Pass officials have admitted that they have the capability, with new cable technology, to bury their proposed transmission line.

They are in fact saying that by not burying their lines they will maximize their profits at the expense of New Hampshire residents who have much to lose aesthetically, but also financially through the loss of tourist income. Millions of tourists visit our state each year, expecting to see the natural beauty of our mountains & lakes. To dot our hillsides, mountains and lake views ~~with~~ with the proposed monoliths would be the ultimate desecration of the state we love.

It is hard to accept that a huge organization will be allowed to effect this desecration in spite of the massive opposition to this project by the residents of New Hampshire.

It is up to you and other government officials to show the public that you still have the ability to empathize, and to do the right thing by stopping this project.

Respectfully Submitted  
 Roger Hogan  
 PO Box 1312  
 Meredith, NH  
 03253

1705-1

1705-1

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Jan 2, 2016

**ID:** 8644

**Date Entered:** Jan 2, 2016

**Source:** Website

**Topics:** Economic, National Security

### Organization:

**Comment:** 1/02/16

Policymakers,

I am writing to comment on the Northern Pass Transmission, LLC's application for an electric transmission line through the state of New Hampshire. I strongly believe that this new line should be placed underground along existing highway corridors. The nature of my concern for this project is two fold. The first falls under the area of national security and the second is an economic concern.

Recently, it has been highlighted how exposed and unprotected America's electrical infrastructure is. Ted Koppel's new book, Lights Out (2015), gives a chilling expose on how vulnerable the US electrical grid is to attack by both physical and cyber forces. My feeling is that any major new electrical infrastructure project should be build in a way that is sheltered and protected such as being placed underground rather than on high towers that can easily be targeted. While I realize that this is a new area of concern, it seems that if millions of dollars are to be spent on this project than it should be done in a way that makes it as secure and protected as possible.

In addition to being a national security issue, I believe erecting 132 miles of overhead transmission line through the state of New Hampshire is an unfair economic burden. While other states have multiple industries and resources, New Hampshire is very heavily reliant on the tourism and recreation industry. This includes fishing, downhill skiing, boating, snowboarding, hunting, snowmobiling, swimming, hiking, cross country skiing and snowshoeing. To intentionally build a series of structures that blight New Hampshire's landscape when there is an underground alternative, is unacceptable. New Hampshire does not need another economic challenge.

As a summer resident in Belnap County for 35 years, I strongly encourage the DOE to permit this project only if it is placed underground along highway corridors for reasons of both national security and economic viability.

Respectfully,  
Susan Purser  
Alton, NH

1706-1

Thank you for your comment. Section 4.1.4.2 in the EIS and Section 3.1.9 of the Public Health and Safety Technical Report discuss impacts related to intentional destructive acts. Impacts to health and safety from intentional destructive acts would be unlikely to be greater than the potential impacts from events involving extreme weather. If such an act were to occur and to succeed in destroying aboveground infrastructure or other components of the project, the main consequence for the public would be the temporary loss of electrical service from the Project (i.e., the loss of the 1,090 or 1,200 MW supplied by the Project) in the ISO-NE region.

1706-2

Thank you for your comment. The EIS evaluates several alternatives that include burial of the Project and/or specific segments of the Project. Each of these alternatives is evaluated and compared within the Socioeconomic section of the EIS (see Section 4.1.2). The EIS additionally analyzes the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 addressed potential impacts to Visual Resources which may result.

1706-1

1706-2

# Northern Pass EIS Website Comment Receipt

1707-1

Thank you for your comment.

## Refers to Comment placed on Jan 3, 2016

**ID:** 8645**Date Entered:** Jan 3, 2016**Source:** Website**Topics:** Health and Safety**Name:** david nadolski**Organization:****Title:** DR.**Mailing Address:** 515 northwest rd**City:** canterbury**State:** NH**Zip:** 03224**Country:** US

**Comment:** My concern is in regard to the Northern Pass project in New Hampshire. As a resident of Canterbury New Hampshire I am opposed to the over head transmission line from Eversource Energy. The effects on the environment because of electromagnetic fields and the destruction of scenic views is non debatable. I am in favor of BURYING the power lines to eliminate the eye sore of electrical towers. If this country is all about preserving nature and going green, please stop the destruction of natural beauty in New Hampshire by forcing Eversource to bury their proposed electrical lines along the full route of the Northern Pass.

1707-1

# Northern Pass EIS Website Comment Receipt

1708-1

Thank you for your comment.

**Refers to Comment placed on Jan 3, 2016**

**ID:** 8646

**Date Entered:** Jan 3, 2016

**Source:** Website

**Topics:**

**Organization:**

**Comment:** NO!

| 1708-1

# Northern Pass EIS Website Comment Receipt

1709-1

Thank you for your comment.

## Refers to Comment placed on Jan 4, 2016

**ID:** 8647**Date Entered:** Jan 4, 2016**Source:** Website**Topics:** Alternatives, Wildlife, Viewshed/Scenery, Historic/Cultural, Quality of Life, Forest Service Lands, Design Criteria / Mitigation Measures**Name:** Timothy Proulx**Organization:****Email:** tim.proulx1@gmail.com**Mailing Address:** 317 Effey St**City:** Santa Cruz**State:** CA**Zip:** 95062**Country:** US**Comment:** Brian Mills  
Senior Planning Advisor, OE-20  
US Department of Energy  
1000 Independence Ave SW  
Washington, DC 20585

Dear Mr. Mills,

We are writing to provide input to the proposed Northern Pass transmission line routing. We understand that the EIS is soon to be under review by your agency. This project has caused significant concern in NH over the last 5 years due to the potential long term negative impact on the environment, and the natural beauty and wildness of our state. While transmission lines are admittedly common and the people of NH will benefit from the clean hydropower delivered by Northern Pass, it is hard to overstate the size of the project and the visual (and emotional) impact the great swathes of forest that will be removed to transport this power. We urge you to consider that options exist for limiting the above-ground portion or rerouting it along existing corridors for the HVDC lines.

1709-1

We hope that we can add our voice to the opposition to the currently proposed project. We do not profess to be experts on this subject, but want to stress our belief that the project will affect this and future generations who will have to live with the huge scar on the countryside and the constant reminder that wilderness is a thing of the past – there is no going back once the above-ground project has started. It is within the power of the current generation to promote an alternative and rational approach that limits the public impact, especially when a private company is due to benefit. We hope that you will consider this.

Sincerely,

Timothy Proulx  
Deborah Tracy-Proulx

1709-1  
Continued 1709-1 cont'd

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Jan 4, 2016

**ID:** 8648

**Date Entered:** Jan 4, 2016

**Source:** Website

**Topics:** Purpose and Need, Alternatives, Vegetation, Wildlife, Viewshed/Scenery, Recreation, Private Property/Land Use, Historic/Cultural, Economic, Tourism, Quality of Life, Air Quality, Forest Service Lands, Design Criteria / Mitigation Measures, Environmental Justice

**Name:** Ronald Fitz

**Organization:**

**Email:** cforon@gmail.com

**Mailing Address:** 6 Pheasant Lane

**City:** Portsmouth

**State:** NH

**Zip:** 03801

**Country:** US

**Comment:** Since the SEC is in the review stage of the application made by Hydro Quebec, it is our opinion, that without due process (specifically invoking eminent domain) it is inappropriate for Hydro Quebec to utilize property belonging to the Forest Society or anyone else for its private use, regardless of whether it is for the benefit of the citizens of New Hampshire. The "taking" of private property is not justified.

We are in favor of the generation of electricity by clean sources such as proposed by Hydro Quebec. The generation of this power in place of fossil fuels will go a long way toward reducing global warming and other pollution of our environment. However, the scaring of the scenic beauty of the New Hampshire landscape is not an acceptable or necessary trade-off for clean energy.

We believe that the generation of power by Hydro Quebec should be transmitted its entire length by buried utility lines. If in the short term this costs consumers a little more, that is a small price to pay.

We encourage Hydro Quebec to continue to pursue the Northern Pass project in a totally environmentally sensitive and responsible manner.

1710-1

Thank you for your comment. This EIS presents the potential environmental impacts resulting from the issuance of a Presidential permit authorizing Northern Pass to build an electric transmission line crossing the international border between the U.S. and Canada. The application for a Presidential permit under review by DOE was submitted by Northern Pass, not Hydro Quebec. The review by the State of New Hampshire Site Evaluation Committee is separate from the DOE's review under NEPA. The Applicant is responsible for securing all necessary rights and land use approvals to utilize any route permitted by the SEC. For the purposes of eminent domain, the New Hampshire Public Utilities Commission has authority to rule on matters of eminent domain for electric transmission lines pursuant to Chapter 498-A of the Eminent Domain Procedures Act. Land use impacts of the Project, including the need for new agreements with private landowners, are analyzed in the EIS (Section 4.1.6.1).

1710-1

1711-1

Thank you for your comment.

---

**From:** Joanna Brown <jwb1989@gmail.com>  
**Sent:** Saturday, January 02, 2016 7:39 PM  
**To:** draftEIScomments@northernpasseis.us  
**Subject:** Full Burial or No Northern Pass!

I am a resident of MA; however, I spend weekends in the beautiful mountains of NH. In order to protect NH's incredible landscape and views, I vote for the viable option of burying the line all the way to Deerfield, or simply saying NO to Northern Pass. Other transmission projects have done it, why can't NP?

| 1711-1

Joanna Brown

1712-1  
Thank you for your comment.

---

**From:** Lisette Placey <lplacey@gmail.com>  
**Sent:** Monday, December 28, 2015 4:53 PM  
**To:** draftEIScomments@northernpasseis.us  
**Subject:** We are pleased to hear from northern pass and that are going forward this is a very good news we need the energy and been affordable is good news also hope the rest of the permit goes good congratulations from Landon and Lisette Place

1712-1

---

**From:** Linda Upham-Bornstein <lubornstein@gmail.com>  
**Sent:** Sunday, January 03, 2016 6:50 PM  
**To:** draftEIScomments@northernpasseis.us  
**Subject:** NP Draft EIS Comments  
**Attachments:** UphamBornstein NP Draft EIS Comments.pdf

Mr. Mills,

Attached is a **corrected** pdf scan of my comments on the Supplement to the *Draft Northern Pass Transmission Line Project*. As stated, I remain strongly opposed to the project as proposed.

Best,  
Linda

Linda Upham-Bornstein, Ph.D

Cell: 603-381-6552

Email: [lubornstein@gmail.com](mailto:lubornstein@gmail.com)

**Linda Upham-Bornstein, Ph.D.**

185 Mount Prospect Road  
Lancaster, New Hampshire 03584  
Email: lubornstein@gmail.com

January 3, 2016

Mr. Brian Mills  
National Electricity Delivery Division  
Office of Electricity Delivery  
and Energy Reliability  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, D.C. 20585

Dear Mr. Mills:

Re: Proposed Northern Pass Transmission Line

Having reviewed the *Supplement to the Draft Northern Pass Transmission Line Project Environmental Impact Statement* (Supplemental EIS), I am writing to advise you of my continued strenuous opposition to the proposed Northern Pass Transmission Project, which the Supplemental EIS refers to as Alternative 7. I object to the construction of an above-ground transmission line across nearly 130 miles of New Hampshire for the personal and public policy reasons that I articulated in my September 6, 2015 letter to the New Hampshire Site Evaluation Committee, a copy of which I attach hereto and incorporate by reference herein. I urge the Department of Energy to deny a Presidential Permit for the Northern Pass Project as proposed.

The Supplemental EIS confirms that Alternative 7 is not in the public interest and that full burial of any transmission line pursuant to Alternative 4a will create many more public benefits and cause much less harm to the public than Alternative 7. For example, Alternative 4a will generate far greater economic benefits than Alternative 7 in that full burial of the entire transmission line under Alternative 4a will create 46% more annual construction jobs over three years and 50% more permanent FTE jobs, will have 50% more annual economic impacts and nearly 50% more economic impacts from construction, and will generate 54% more statewide annual property tax revenues than the proposed transmission project under Alternative 7. (Supplemental EIS, 6 – 7) In contrast, Alternative 7 will cause considerably greater environmental damage than Alternative 4a in that (1) the loss of carbon dioxide uptake from vegetation removal and the resulting adverse impacts on air quality will be six times greater, (2) the adverse impacts to wildlife and vegetated habitats will be four times greater, (3) the negative impacts to forest lands will be almost seven times greater, and (4) the disturbance to prime and important farmland will be twice as much. (Supplemental EIS, 15 – 17, 22)

I request that the Department of Energy deny a Presidential Permit for the Northern Pass Project as proposed in Alternative 7 and that it consider granting a permit only if the entire transmission line is buried in accordance with Alternative 4a.

Sincerely,



Linda Upham-Bornstein, Ph.D.

1713-1

Thank you for your comment. The EIS analyzes the potential environmental impacts of Alternative 7 - Proposed Action, as well as Alternative 4a and nine other action alternatives. A summary comparison of impacts is presented in Sections S.9 and 2.5 of the EIS. Northern Pass has applied to the Department of Energy for a Presidential permit for an HVDC transmission line that would run from Quebec, Canada to Deerfield, NH. Executive Order (EO) 10485, as amended by EO 12038, "requires that executive permission be obtained for the construction and maintenance at the borders of the United States of facilities for the exportation or importation of electric energy." DOE is authorized to "receive applications for the construction, operation, maintenance, or connection, at the borders of the United States, of facilities for the transmission of electric energy between the United States and a foreign country[.]" and "[u]pon finding the issuance of the permit to be consistent with the public interest, and, after obtaining the favorable recommendations of the Secretary of State and the Secretary of Defense thereon, to issue to the applicant, as appropriate, a permit for [the] construction, operation, maintenance, or connection." (EO 10485). DOE, however, does not have siting authority for the Project. In this case, the New Hampshire Site Evaluation Committee has siting authority for the Project in the state of New Hampshire. Additionally, the USFS has siting authority for portions of the Project located in the White Mountain National Forest. (For further discussion, see Sections 1.1-1.3 of the final EIS.) While DOE's authority is limited to the approval or denial of the amended Presidential permit application (August 2015) as requested by the Applicant, DOE's policy is to analyze not only the proposed border crossing, but also the alignment of new infrastructure required between the proposed border crossing and connection to the existing U.S. electricity system as a connected action. In keeping with this policy, DOE analyzed the potential environmental impacts of the alignment proposed by the Applicant. In addition, in response to input from Cooperating Agencies, other agencies, and extensive public comment, DOE analyzed a range of other alignments and underground and overhead configurations between the proposed border crossing and connection with the existing U.S. electricity system. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. Additionally, seventeen alternatives were considered but eliminated from detailed analysis. Section 2.4 of the final EIS has been updated with additional information on alternatives considered but eliminated from detailed analysis.

1713-1

**LINDA UPHAM-BORNSTEIN**

185 Mount Prospect Road  
 Lancaster, New Hampshire 03584  
 Email: lubornstein@gmail.com

1713-2

Thank you for your comment. The EIS and Visual Impact Assessment Technical Report analyze potential impacts to visual resources resulting from the Project. Visual impacts in the Northern Section are analyzed in Section 4.2.1 of the EIS. Potential impacts to property values are analyzed in Section 4.1.2 of the EIS.

September 6, 2015

Martin Honigberg, Chairman  
 New Hampshire Site Evaluation Committee  
 New Hampshire Department of Environmental Services  
 29 Hazen Drive  
 P.O. Box 95  
 Concord, NH 03302-0095

Dear Chairman Honigberg: Re: Proposed Northern Pass Transmission Line

I am writing to advise you of my strenuous opposition to the proposed Northern Pass Transmission Project. I object to the construction of an above-ground transmission line across nearly 130 miles of New Hampshire for both personal and public policy reasons. I respectfully submit that the proposed above-ground transmission line will have significant and unreasonable adverse impacts on the people's welfare, the private properties within the Northern Pass view shed, the overall economic growth of the state, the state's environment, historic sites within the view shed, and aesthetics. See RSA 162-H:1; RSA 162-H:16, IV (c)

On a personal level, my husband and I own a home on twenty acres of land on Mount Prospect Road in Lancaster. Mount Prospect Road is a designated scenic road under New Hampshire's scenic road statute, RSA 231:157-158. The proposed transmission line in this area will not be buried but will be placed on large metal transmission towers running roughly parallel to and approximately two-tenths of a mile from the eastern border of our property. The portion of the proposed transmission line that will be plainly visible from, and adversely impact, our property begins at Wesson Road and extends approximately two miles south. The proposed transmission towers in this segment will be 85 to 95 feet tall, or more than twice the height of and substantially wider than the existing wood utility poles, which are not visible from our property.

If these very large metal transmission towers are installed in this two-mile section, they will deface the landscape and ruin the many beautiful views that we presently have of the White Mountains (specifically, the Pliny Range and the Presidential Range). I enclose several photographs depicting some of those views. In her 1887 *Lancaster Sketch Book*, Persis F. Chase remarked that "of all short drives in this vicinity, the one around Mt. Prospect affords the grandest mountain views." Chase further notes that from the "farm owned by Mr. Johnson [our property] one can see the village of Jefferson, with Mt. Starr King, rising above" and that "towering grandly over all, [is] the "White ... mountain range." The view shed of Weeks State Park on Mount Prospect includes our view shed. The United States Department of Energy's *Northern Pass Transmission Project Environmental Impact Statement* (EIS) has determined that the existing contrast-dominance rating for the Weeks State Park view shed is "weak" but that its contrast – dominance rating if the proposed above-ground transmission line is constructed would be on the high end of 'moderate,' which "indicates that the visual change would be clearly noticeable to a casual observer, and is likely to be considered adverse." (EIS, 4 – 95.) Moreover, the significant and adverse impact on our view shed will substantially reduce the market value of our property.

1713-2

1713-3

Thank you for your comment. Commentor's concerns about the J.A. Johnson property are noted. DOE is addressing potential adverse effects on architectural resources in accordance with Section 106 of the National Historic Preservation Act and its implementing regulations. This includes architectural resources such as the J.A. Johnson property if they were identified within the area of potential effects ("APE") [36 C.F.R. Section 800.16(d)]. For more information on how DOE is addressing potential adverse effects on architectural resources, see Sections 1.6, 2.5.8, and 3.1.8 of the FEIS. Additionally, if architectural resources such as J.A. Johnson property were identified within the APE: Sections 1.4.1, 1.4.3, 1.4.4, and 1.4.6 of the Cultural Resources Technical Report contain information on the methodologies that have been, or will be, employed for considering potential adverse effects on such resources; Section 3.1.2 of the Cultural Resources Technical report contains information on potential impacts of the proposed project on such resources; and Appendices B and C of the Cultural Resources Technical Report contain information on the studies that have been, or will be, conducted as part of the assessment of adverse effects of the proposed project on such resources.

1713-4

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1713-5

Thank you for your comment. Potential socioeconomic impacts for all the alternatives, including alternatives evaluating burial, are addressed in Section 4.1.2 of the EIS, including an evaluation of construction related, and long-term operations, changes to employment, taxes, and income in New Hampshire.

It will also have significant and unreasonable adverse impacts on the value and integrity of our property as a historic site. Our home, built in approximately 1810, is one of the earliest residences in the town of Lancaster. It was depicted as the J.A. Johnson property on a late 19<sup>th</sup>-century map of the town and was owned by the Weeks family from about 1915 to 1931. Congressman John Wingate Weeks sponsored the 1911 Weeks Act that created the White Mountain National Forest and his son, Charles Sinclair Weeks, a United States senator from Massachusetts and President Eisenhower's Secretary of Commerce, maintained his summer residence at our property until he sold it in 1931. The Site Evaluation Committee should not permit the construction of an extremely unattractive above-ground transmission line in close proximity to, and in plain view from, a historic property once owned by the man who was responsible for establishing the National Forest in northern New Hampshire.

The proposed above-ground transmission line will also be bad public policy in light of a number of the factors that RSA chapter 162-H requires the Site Evaluation Committee to consider. First, it will be bad for the economies of Coos and Grafton Counties, undermine the overall economic growth of the state, adversely impact the historic sites along the proposed route, and be inimical to the welfare of the population and the State's environment. The transmission line will be a terrible eyesore on the pristine landscape of northern and central New Hampshire through which it will run. Consequently, the line will be antithetical not only to the environment but also to the tourist and recreation industries that are Coos County's best hope for the future economic growth and on which Grafton County likewise relies heavily. Moreover, the United States Department of Energy found that burial of the entire transmission line along the proposed route will create nearly twice as many annual construction jobs over three years, will have double the economic impact from construction, and will generate 97% more statewide annual property tax revenues than the proposed above-ground line. (EIS, 4-5, 4-6.)

The proposed above-ground transmission line will also be inconsistent with New Hampshire's scenic road statute, RSA 231:157-158, and its scenic and cultural byways statute, RSA 238:19-24. As the New Hampshire Supreme Court has observed, the purpose of the scenic road statute is to "encourage the tourist attractiveness of our scenic roads" and to protect and enhance the "scenic beauty" of our state. *Webster v. Town of Candia*, 146 N.H. 430, 435 - 36 (2001). Mount Prospect Road is one of five designated scenic roads in Lancaster, and there are many designated scenic roads within the Northern Pass view shed in other towns. It seems incongruous that, because Mount Prospect Road is a designated scenic road, I must obtain the town's permission to cut down certain trees in my yard but that an out-of-state utility may be allowed to erect enormous and ugly transmission towers a short distance from, and in plain view of, the designated scenic road on which I live. The proposed transmission line will also cross or come close to, in numerous spots, both of the scenic byways in the Great North Woods and all three of the scenic byways in the White Mountains that are included in the New Hampshire Scenic and Cultural Byways System. The statutory purpose of the byways system is to "provide the opportunities for residents and visitors to travel a system of byways which feature the scenic and cultural qualities of the state," to "promote retention of rural and urban scenic byways," and to "expose the unique elements of the state's beauty, culture and history." RSA 238:19, I. The Northern Pass project will adversely impact New Hampshire's scenic byways system and undermine the purposes of the statute.

Finally, for the same reasons that the proposed above-ground transmission line will have substantial and unreasonable adverse effects on our property, its aesthetics, its market value and its quality as a historic site, it will have similar unreasonable adverse impacts on hundreds of other properties within the Northern Pass view shed.

1713-6

Thank you for your comment. Impacts to national, state, and local scenic byways are analyzed in the EIS and in the Visual Impact Assessment Technical Report (see Sections 4.1.1, 4.2.1, 4.3.1, 4.4.1, and 4.5.1 of the EIS, Section 2.4.2.4 and Chapter 4 of the Visual Impact Assessment Technical Report).

Northern Pass' own reasoning for burying the additional 52 miles supports burial of the remainder of the proposed transmission line. On its website, Northern Pass argues that its recent changes to its proposed route address "inter-related concerns expressed by New Hampshire citizens about tourism, historic landscapes, property values and aesthetics" and that the "additional 52 miles of underground, for a total of 60 miles eliminates potential view-related impacts in the White Mountain National Forest, the gateway areas to the north and south, the Appalachian Trail, and other critical view sheds." (See attached screen shot of website.) I submit that the Weeks State Park view shed is just as critical and just as deserving of protection (through burial of the transmission lines) from unreasonable and adverse view-related impacts as the view sheds along the additional 52 miles of underground transmission lines. I also submit that the same inter-related concerns about tourism, historic landscapes, property values and aesthetics that require burial along this 52-mile stretch apply with equal force to the many other critical view sheds, historic landscapes, and private properties along the other 130 miles of the proposed route.

For the foregoing reasons, I request that the Site Evaluation Committee find that the proposed above-ground transmission line will have unreasonable adverse effects on our property, its aesthetics and its value as a historic site, on hundreds of other properties within the Northern Pass view shed, and on the welfare of the population, the state's environment, the overall economic growth of New Hampshire, historic sites within the view shed, and aesthetics. See RSA 162-H:1; RSA 162-H:16, IV (c). I further request that the Committee not issue a certificate unless the entire transmission line is buried. The Department of Energy's EIS has determined that extensive burial of the proposed transmission line with a 1,000 MW transmission capacity "would be practical and technically feasible." (EIS, 2-1.) Burying the transmission line would also be economically viable and would mitigate the most serious adverse economic, view-related, environmental, and historic effects of the Northern Pass. The Committee should not allow a plethora of gigantic and ugly transmission towers to cut a 130-mile swath across New Hampshire.

Sincerely,



Linda Upham-Bornstein, Ph.D.

1713-7

1713-7

Thank you for your comment. Northern Pass has applied to the Department of Energy for a Presidential permit for an HVDC transmission line that would run from Quebec, Canada to Deerfield, NH. Executive Order (EO) 10485, as amended by EO 12038, "requires that executive permission be obtained for the construction and maintenance at the borders of the United States of facilities for the exportation or importation of electric energy." DOE is authorized to "receive applications for the construction, operation, maintenance, or connection, at the borders of the United States, of facilities for the transmission of electric energy between the United States and a foreign country[,]" and "[u]pon finding the issuance of the permit to be consistent with the public interest, and, after obtaining the favorable recommendations of the Secretary of State and the Secretary of Defense thereon, to issue to the applicant, as appropriate, a permit for [the] construction, operation, maintenance, or connection." (EO 10485). DOE, however, does not have siting authority for the Project. In this case, the New Hampshire Site Evaluation Committee has siting authority for the Project in the state of New Hampshire. Additionally, the USFS has siting authority for portions of the Project located in the White Mountain National Forest. (For further discussion, see Sections 1.1-1.3 of the final EIS.) While DOE's authority is limited to the approval or denial of the amended Presidential permit application (August 2015) as requested by the Applicant, DOE's policy is to analyze not only the proposed border crossing, but also the alignment of new infrastructure required between the proposed border crossing and connection to the existing U.S. electricity system as a connected action. In keeping with this policy, DOE analyzed the potential environmental impacts of the alignment proposed by the Applicant. In addition, in response to input from Cooperating Agencies, other agencies, and extensive public comment, DOE analyzed a range of other alignments and underground and overhead configurations between the proposed border crossing and connection with the existing U.S. electricity system. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. The EIS analyzes several full-burial alternatives in detail (Alternatives 3, 4a, 4b, and 4c). The potential environmental impacts of all twelve alternatives, as well as technical constraints and costs, are discussed throughout the EIS. Additionally, seventeen alternatives were considered but eliminated from detailed analysis. Section 2.4 of the final EIS has been updated with additional information on alternatives considered but eliminated from detailed analysis. Potential impacts within the Northern Section, where Weeks State Park is located, are discussed in Section 4.2 of the EIS. Potential

impacts to visual resources, tourism, historic and cultural resources, and property values are discussed throughout the EIS for all alternatives in all geographic sections.



Figure 1 Weeks/Bornstein house c.1920



Figure 2 185 Mount Prospect Rd, 2015

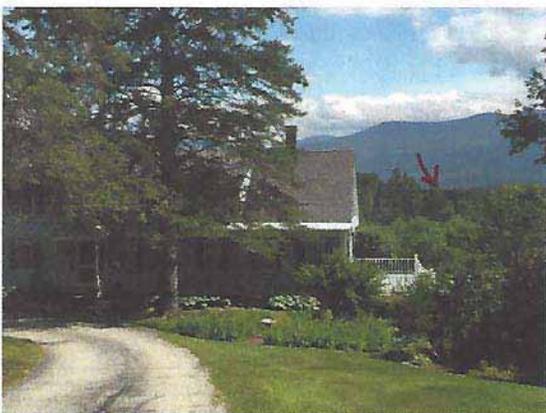
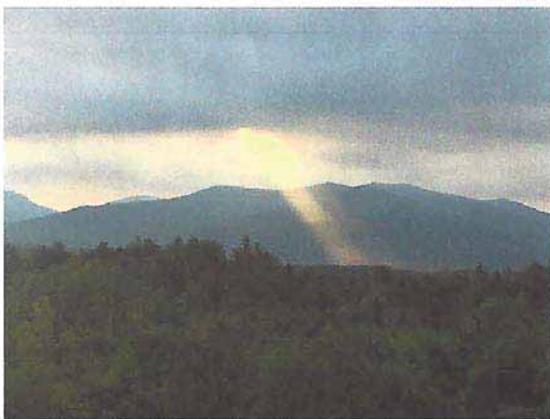
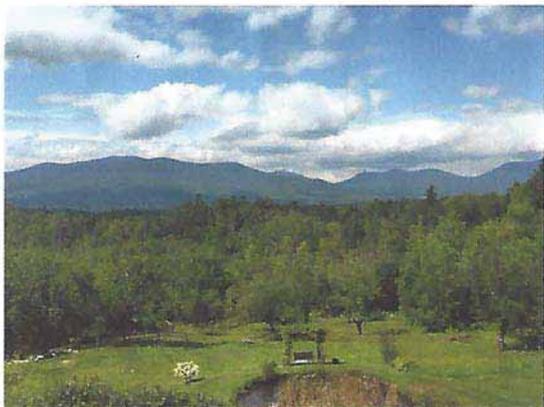


Figure 3 Front of house with view from side deck of the existing row.



Figure 4 View from back of house. The ROW runs from left to right at tree line.



---

**From:** Mike Kenney <mkenney@ussa.org>  
**Sent:** Sunday, January 03, 2016 12:11 PM  
**To:** drafteiscomments@northernpasseis.us  
**Subject:** Northern Pass

EIS Site Review Committee,

I am glad the public comment period has been extended. As a landowner on RT 116 in Easton the proposed burial route raises many unanswered questions;

-Short and long term effects of exposure to DC magnetic fields of this magnitude where the lines cross over granite river bedrock and are in close proximity to houses.

-How much land bordering the proposed road bed will be used and disturbed and taken out of future uses by the landowner.

We own property that has terrain literally to the edge of the road?

- I am strongly opposed to this latest plan by Northern Pass proponents. They do not take into consideration what the best plan is for the residents and how it will effect businesses of the region but rather how they can spend the least money with no consideration for the environment or many businesses that depend upon the pristine state of our landscapes.

-I am really tired of their rhetoric of "caring for the people and landscapes" while bringing in jobs and driving our utility prices down. I try not to listen to baloney and only rarely eat it. The majority of jobs would last 6 months and utility rates would drop for 2 years before resuming their upward trend. I would be willing to pay a little more to live in a clean non-industrialized environment.

Sincerely,

Mike and Beth Kenney  
 Easton, NH

1714-1

Thank you for your comment. Buried transmission cables will produce magnetic fields in the surrounding environment, but because the conductors are close together, the fields would be small compared to those beneath above-ground lines (see Section 4.1.4.2 in the EIS, and Section 4.1 of the Electric and Magnetic Fields Technical Report (included as Appendix B of the Public Health and Safety Technical Report). Also, the fields would be direct current fields at levels considerably lower than the Earth's magnetic field.

| 1714-1

| 1714-2

1714-2

Thank you for your comment. Section 2.3.12.5 of the final EIS has been updated to include revised assumptions regarding the installation of underground cable in roadways. In general, the cable would be installed in the shoulder or on the very edge of the roadway. Short-term disturbance for the trench and construction activities is assumed to be 10 feet (3 m) wide, with the majority of disturbance limited to the road surface (approximately 30 feet [9 m] wide) and adjacent, previously disturbed areas. General impacts to roadway corridors are analyzed in Section 4.1.6 of the EIS.

1715-1  
Thank you for your comment.

Brian Mills  
Senior Planning Advisor  
Office of Electricity Delivery and Energy  
Reliability (OE-20)  
U.S. Dept. Of Energy  
1000 Independence Ave. SW  
Washington, DC 20585

Dear Mr. Mills:

I was born and brought up in NH and I strongly feel that all energy produced or passing through the state of NH to states south should be provided to NH residents first. Not transmitted South and then sold back to NH through the highest bidder. New Hampshire should not let other states control our rates as would be the case if Northern Pass (a.k.a. Northern Trash) were to have their way and put huge power lines from one end of the state to the other!! It is my opinion that the DES and the EPA agencies are not doing the job that they are paid to do.

We have seen what has happened in Wiscasset Maine – huge power lines going overhead with much loss in the value of their property and they are now not even in use. We would not like to see this happen in scenic New Hampshire.

If Northern Pass does get permits and succeeds in being allowed to put power cables the whole length of NH please do what you can to make sure that the cables are put underground the entire length of New Hampshire.

Sincerely and Thank You,



Warren C. Leighton  
162 Creampoke Road  
Stewartstown, NH 03576

1715-1

# Northern Pass EIS Website Comment Receipt

**Refers to Comment placed on Jan 11, 2016**

**ID:** 8659

**Date Entered:** Jan 11, 2016

**Source:** Website

**Topics:** Alternatives

**Name:** Mary Anne Sullivan

**Organization:** Hogan Lovells US LLC

**Title:** Counsel to Northern Pass Transmission LLC

**Email:** maryanne.sullivan@hoganlovells.com

**Mailing Address:** 555 Thirteenth Street NW

**City:** Washington

**State:** DC

**Zip:** 20004

**Country:** US

**Comment:**

COMMENT OF NORTHERN PASS TRANSMISSION LLC  
ON DRAFT ENVIRONMENTAL IMPACT STATEMENT

In its Draft Environmental Impact Statement (“DEIS”), the U.S. Department of Energy (“DOE”) concluded that 11 alternatives warranted detailed consideration. Northern Pass Transmission LLC (“Northern Pass” or the “Project”) submits this comment for the purpose of identifying considerations that Northern Pass has determined render some of those alternatives infeasible – considerations that Northern Pass believes were not adequately weighed in DOE’s determination of which alternatives warranted detailed consideration. Accordingly, Northern Pass urges DOE to be clear in the Final Environmental Impact Statement (“FEIS”) with respect to the considerations described below that render infeasible in any practical or legal sense certain of the alternatives evaluated in the DEIS. Northern Pass notes that the alternatives that it believes have such “fatal flaws” are not alternatives that appear to enjoy any particular public support.

### Alternative 3 – Underground along the Route Analyzed Under Alternative 2

As described in the DEIS, Alternative 3 would be a completely underground alternative that would follow the same alignment as Alternative 2 except for a slight deviation to accommodate locating the converter station at the intersection of the existing PSNH transmission right-of-way (“ROW”) and North Road in Deerfield. DEIS at 2-15. The DEIS notes that this would entail underground placement along a portion of the existing PSNH ROW that is subject to 644 easements, many of which do not authorize an underground transmission line. The DEIS acknowledges that all easements that do not permit underground transmission would have to be renegotiated and suggests that this may be “challenging” to accomplish. Id. Northern Pass believes that including this option among the reasonable alternatives seriously underestimates the challenge associated with amending the easements.

Northern Pass has carefully analyzed the situation with the easements governing the ROW. It has determined that it was not the practice of PSNH or its predecessor companies to seek authorization for underground transmission in the easements it obtained prior to 1960. As a result, the overwhelming majority of the 644 easements for the ROW do not permit underground transmission lines. To renegotiate hundreds of easements, where a failure to achieve the amendment of even a single easement would preclude that alternative (and where each property owner would clearly understand the leverage he or she held) makes it very clear to Northern Pass that this alternative is not in any meaningful sense a reasonable alternative, neither practically nor economically.

### Alternatives 4A, 5A and 6A – Underground along the I-93 Corridor

Three of the 11 alternatives evaluated in the DEIS propose construction of the Project underground along the I-93 corridor, including through the White Mountain National Forest (“WMNF”) and Franconia Notch State Park. The DEIS acknowledges that burial of the cable underneath the pavement or in the median of I-93 would not be permitted, but the DEIS posits that the cable could be buried on either the east side of the northbound lane or the west side of the southbound lane. However, as far as Northern Pass can determine, the DEIS does not build into its analysis of the construction the impacts associated with the particular restrictions under federal and state law that would apply to construction along I-93. Northern Pass believes that those restrictions make the I-93 alternatives completely infeasible. Among other things, the legal and practical challenges associated with such an undertaking are insurmountable; the route entails unanalyzed, but potentially significant adverse, environmental consequences in one of New Hampshire’s most treasured locations; and the I-93 alternatives offer no offsetting environmental benefits that might make those alternatives worth the challenge of pursuing them. In short, constructing Northern Pass along the I-93 corridor is not a reasonable alternative.

The DEIS describes the anticipated approach to burial along roadways in Section 2.3.2.5. In doing so, it does not differentiate among the various roadway options it considers. Compare Sections 2.3.7.5 and 2.3.9.5 (incorporating by reference the discussion in Section 2.3.2.5). Thus, for all underground roadway options, the DEIS describes the construction process as follows:

"Short-term disturbance for the trench and construction activities is assumed to be 10 feet (3 m) wide, with the majority of disturbance limited to the road surface (approximately 30 feet [9 m] wide) and adjacent, previously disturbed areas. One lane of the road would be temporarily closed to traffic to accommodate construction activities. Construction and installation of the underground cables associated with the Project would be scheduled to meet local requirements regarding noise

1716-1

1716-1

Thank you for your comment. The Land Use analysis in the EIS and Land Use Technical Report acknowledges that the existing PSNH easements along the Project corridor do not, in many cases, permit underground transmission cables (see Sections 4.2.6.3, 4.3.6.3, 4.4.6.3, and 4.5.6.3 of the EIS). The EIS further acknowledges that in order for Alternative 3 to be implemented, the majority of these 644 easements would need to be amended through agreement with each individual land owner. However, Alternative 3 was retained for detailed analysis in the EIS because it ensures that the potential environmental impacts from any combination of above and below ground placement of the Project within the Alternative 2 route is bounded by the analysis.

1716-2

Thank you for your comment. Several alternatives analyzed in detail in the EIS include segments of underground cable within the I-93 corridor, including Alternatives 4a, 4b, 4c, 5a, 6a, and 6b. Alternatives 4a, 5a, and 6a include burial through Franconia Notch in the I-93 corridor. Construction of underground cable in the I-93 corridor is described in Section 2.3.4.5 of the EIS. Laws and regulations governing the installation of utilities in interstate highways are discussed in Section 3.1.6.4 of the EIS, and the Memorandum of Agreement (also known as the 1977 Consent Decree) related to the maintenance of I-93 within Franconia Notch State Park is acknowledged and described in Section 3.3.6.4 of the EIS. As described in Section 4.1.6.1, the Applicant would be required to obtain relevant authorizations to construct the Project in roadway corridors. A particular discussion of construction in Franconia Notch is located in Section 4.3.6.4 of the EIS. DOE has considered this comment and no change to the EIS was made.

1716-2

limitations, construction work hours, etc. and to minimize the impact on local traffic, residents, and businesses. Lane closures would be in effect for days to weeks and for short segments of road along the route."

DEIS at 2-11 emphasis added).

The DEIS also describes what would be involved for a "new transmission route (rather than within an existing roadway)," which may more accurately describe the impacts that would be involved for construction along the I-93 corridor, given that, as explained below, any such construction would have to occur at the outer edge of the I-93 Limited Access Right of Way ("LAROW"):

*"t is assumed that an area approximately 40 feet (12 m) wide would be cleared of vegetation to accommodate this construction. Future vegetation growth would need to be limited in this 40-foot-wide corridor to prevent disturbance of the cables by roots. The area of direct, short-term disturbance for installation of the trench would be 10 feet (3 m) wide."*

*Id.*

*Finally, the DEIS describes the splice pads that would be necessary for any underground installation:*

*"Cable splice pads would be utilized for the installation and joining of underground cable segments. The cable splice pads would be temporary areas within which splicing would be conducted. Upon completion of a necessary splice, the area would be backfilled and no longer present. The splice pad areas would be necessary approximately every 1,800 feet (549 m). The distance between splice pads is dependent on many factors, including: (i) local conditions, including site conditions and local road load and other limits; (ii) the maximum size of cable reels that can be transported to a particular location; and (iii) the bending radius of the cable."*

*Id.*

*In short, according to the DEIS, underground construction along roadways, including I-93, would entail short-term lane closures and significant construction activity, along with the associated disruptions to traffic. It would also entail some permanent impacts on vegetation.*

*These descriptions in the DEIS accurately capture the construction techniques and impacts associated with underground burial along most public roads and areas of new underground construction in New Hampshire. However, these descriptions do not take into account the restrictions that would apply to efforts to construct Northern Pass underground along I-93, particularly through Franconia Notch. Specifically, the DEIS assumes that: i) construction could occur in the roadways and immediately adjacent previously disturbed areas; ii) lane closures would be possible; iii) only previously disturbed areas would be involved; and iv) future vegetation could be restricted in a 40-foot wide area. Northern Pass does not believe that these assumptions can be permissibly applied to the I-93 corridor.*

*Unlike the more traditional public highways where Northern Pass proposes to construct the Project, I-93 is governed by a separate and more stringent set of principles that are applicable to longitudinal utility installations along interstate highways. While not expressly prohibiting longitudinal utility installations, if states choose to permit them within interstate highways, federal law requires approval of an "accommodation plan" from the Federal Highway Administration to insure the "safe and efficient use of the highways". 23 C.F.R. §645.209(c). Any such plan must, among other requirements, establish a utility strip "along the outer edge of the right-of-way by locating a utility access control line*

1716-2

Continued 1716-2 cont'd

between the proposed utility installation and the through roadway and ramps.” 23 C.F.R. §645.209(c)(2)(v) (emphasis added).

The New Hampshire Department of Transportation (“NHDOT”) has adopted, and the Federal Highway Administration has approved, the Utility Accommodation Manual, Bureau of Highway Design, New Hampshire Department of Transportation, February 2010 (“UAM”). This document governs the use of New Hampshire highways for utilities. The UAM makes it clear that freeways like I-93 “are dedicated to allow for optimum mobility and safety of through traffic. The basic element in the design and operation of these highways to achieve this end is the limiting of access to the highway.” UAM § XIII.A. In accordance with this objective, NHDOT has adopted strict requirements governing any proposed longitudinal use of freeways like I-93 beyond those applicable to the standards for other highways.

Addressing new underground utility installations along freeways, the UAM states clearly: “Longitudinal installations are not permitted within the LAROW lines parallel to either the through roadway or its ramps.” UAM, § XIII.B.4 (emphasis added). While the Commissioner may grant a design exception from this prohibition, to be eligible for a design exception, an applicant must demonstrate “extreme hardship.” To meet this requirement, the applicant must show, among other things, that “[a]lternate locations are not available or cannot be implemented at reasonable cost,” and that the accommodation requested “will not adversely affect the safety, design, construction, operation, maintenance, or stability of the freeway.” UAM, § XIII.B.6(a) and (c). As shown by the DEIS and by the route along state roads that Northern Pass supports, the Project plainly has other viable alternatives. Specifically, there are public roadway options other than I-93. Moreover, construction along the I-93 corridor would affect operation of the highway for the period of construction. Therefore, Northern Pass cannot plausibly meet the UAM-prescribed standard for a design exception.

Further, in the unlikely event Northern Pass were to obtain a hardship exception, NHDOT policy reflects the federal requirement that longitudinal utilities be placed at the outer limits of the ROW. The UAM states: “In general, utilities are to be located and designed in such a manner that they can be constructed and/or serviced without direct access from the through roadways or connecting ramps.” UAM, § XIII.B.6(e)(1) (emphasis added). The UAM suggests that any accommodation plan should limit access for construction and servicing to frontage roads, where available, nearby public roads and streets, or trails that connect to the outer edge of the LAROW. UAM, § XIII. B.6(e)(2). In short, the UAM prohibits access from the highway itself except in extreme circumstances.

The DEIS does not consider how feasible the approaches to construction prescribed by the UAM would be for underground construction of Northern Pass along I-93. However, having analyzed the issue, it is the strong view of Northern Pass that, along the relevant portion of I-93 through the White Mountain National Forest and Franconia State Park, the UAM-prescribed access options are not available to accommodate the kind of construction activities that would be required for Northern Pass, particularly without considerable disturbance of previously undisturbed areas that the DEIS does not evaluate and that Northern Pass deems wholly unnecessary.

More specifically, based on its visual examination of the relevant area, Northern Pass has concluded that, except for a narrow shoulder, the area between the I-93 roadway and the outer edge of the I-93 ROW is undisturbed. To construct Northern Pass in that area would require extensive tree, vegetation and ledge removal, measures that are largely unnecessary along the state roads Northern Pass has designated in its project design in the area of the WMNF. Wetland areas likewise also appear to be located along the outer edge of the LAROW and would be impacted as well. Finally, the required clearing and terrain alteration would likely permanently alter the experience of travelers along the I-93 corridor without achieving any benefits that could not be achieved using the state roads Northern

1716-2

Continued 1716-2 cont'd

Pass has proposed, where the environmental impacts would be temporary and much reduced. For these reasons, Northern Pass believes it is both unrealistic and unwise to pursue the I-93 corridor as an option for underground construction of the proposed transmission line.

Entirely separate barriers to the use of the I-93 corridor by Northern Pass that are of equal or greater significance arise under a 1977 Memorandum of Agreement (“MOA”) that led to a Stipulated Order of Dismissal in *Appalachian Mountain Club (“AMC”) v. Adams*, Case No. 74-208 (D.N.H.), a case that entailed extended litigation over the construction of I-93 through Franconia Notch. Like those posed by the state and federal regulations governing underground utility construction along I-93, the barriers to construction that are reflected in the MOA do not appear to be accounted for in the DEIS.

The MOA, which was signed by seven state and non-governmental parties, embodied an agreement for the design of I-93 through Franconia Notch State Park. Among other things, the MOA provided that “there will be no additional lanes or major construction within the Park.” MOA at ¶IV.2.2 (emphasis added). Changes as minor as the addition of a median divider, which was proposed to reduce highway fatalities along that stretch of I-93, required amendment of the MOA and judicial approval. *AMC v. Adams*, supra, Motion to Modify Stipulated Order (April 1, 1993). It is reasonable to anticipate that some of the parties to that MOA who have also been active in this NEPA process would contend that construction of an underground transmission line, even at the outer edge of the I-93 LAROW, is an activity that is not permitted under the MOA.

While Northern Pass is not a highway construction project, the parties who were important to the agreement reflected in the MOA may well contend that the MOA is not limited to highway construction projects, but rather covers all construction within the LAROW. Moreover, it is reasonable to expect that NHDOT would want to limit any amendments to the MOA to changes that support highway safety. Given these considerations and the availability of other roadway burial options for Northern Pass, there would seem to be no justification for testing the limits of the MOA, especially in light of the strong cultural and environmental values associated with Franconia Notch.

#### Alternatives 6A and 6B – Co-located AC Lines from Franklin to Deerfield

Two of the alternatives addressed in the DEIS, Alternatives 6A and 6B, involve co-locating the existing 115 kV AC line with the new 345 kV AC line from the proposed converter station at Franklin to Deerfield. The DEIS acknowledges that this approach has not undergone technical design, but “it is assumed that the structures supporting the co-located lines would generally resemble the structures in the Proposed Action, and would be of comparable height.” DEIS at 2-29. Northern Pass has likewise not performed a detailed technical analysis of such a design. However, even without such an analysis, it can identify several reliability-related concerns with such a design. More fundamentally, it does not believe that it can be assumed that the structure heights could be as indicated in Figure 2-7.

The structure drawings shown on the top right and bottom of Figure 2-7 do not appear to take into account all electrical clearances necessary for the various conditions that each circuit may encounter. In order to reduce the structure heights for the 345 kV portion of the line, Northern Pass designed the Project to relocate and rebuild the existing 115 kV line and to place the 345 kV line on H-frame structures, which permit a lower height. However, if the 345 and 115 kV lines were co-located on the same structures, at a minimum, the H-frame structures would have to be taller than the one depicted in Figure 2-7 in order to achieve the necessary electrical separation. In addition, easement restrictions applicable to certain portions of the Alternative 3 route would preclude using H-frame structures because electrical clearance requirements could not be satisfied. The taller lattice structures shown on the upper left of Figure 2-7 would likely be sufficient to accommodate the required electrical separations, although that would have to be confirmed. However, if the goal of Alternatives 6A and 6B

1716-2

Continued 1716-2 cont'd

1716-3

Thank you for your comment. These comments regarding the possible design specifications of Alternatives 6a and 6b are noted. DOE developed the preliminary design of these alternatives with the assistance of an independent engineering consultant, and DOE believes that these assumptions are reasonable and sufficient for this NEPA analysis. If either of these alternatives were selected by the New Hampshire Site Evaluation Committee and additional design detail were to become available, DOE would evaluate whether the design specifications necessitated further analysis..

1716-3

*is to reduce visibility of the Project, that will not be achievable anywhere the H-frame structures are assumed in the Northern Pass design from Franklin to Deerfield. The potentially reduced visibility of the narrower corridor permitted by co-locating circuits on a single structure will likely be more than offset by the taller structures that would be required to achieve the necessary electrical separation.*

*Co-locating two sets of AC circuits on a single structure would also affect system electrical reliability in at least two distinct ways. First, putting two circuits on any single structure results in a condition that would have to be studied by ISO-NE under the standards of the Northeast Power Coordinating Council, which is the Regional Reliability Authority. Specifically, ISO-NE would have to evaluate the simultaneous loss of two adjacent transmission circuits on a multiple circuit tower as a single event and determine the impact to the grid associated with such a design. ISO-NE has not studied this design configuration, and thus new, potentially time-consuming studies would have to be performed to determine whether additional electrical infrastructure would be required to accommodate this design.*

*Additionally, in order to protect the safety of the linemen performing maintenance on the 345 kV line, at a minimum for the lattice structure design shown on the top right of Figure 2-7 and the H-frame structure design shown on the bottom of that figure, it would likely be necessary to de-energize the 115 kV line located below it when service is being performed. Turning off the power to two different lines when only one requires service would obviously decrease the reliability of the resulting service.*

1716-3

Continued 1716-3 cont'd

1717-1

Thank you for your comment.

December 27, 2015

Mr. Brian Mills  
 Senior Planning Advisor  
 Office of Electricity Delivery and Energy  
 Reliability (OE-20)  
 U.S. Department of Energy  
 1000 Independence Ave. SW  
 Washington, DC 20585

Steven K. Hogan & Stella E. Hogan  
 66 Jane Drive  
 Candia, NH 03034-2719

Dear Mr. Mills,

We would like to comment regarding proposed high voltage transmission line through New Hampshire commonly known as Northern Pass. I would like you to know that my wife and I are life long residents of NH and own property in both the southern tier of the state namely Rockingham County, Candia also in Coos County, Clarksville NH.

We support the Northern Pass Project for the following reasons:

1. New Hampshire's electrical generation infrastructure is aging and in some cases is nearing or beyond the expected life expectancy.

Seabrook Sta.	Nuclear	1200 MW	on line 1990	25years
Newington Sta.	Oil/ Nat. Gas	550 MW	on line 1973	42years
Merrimack Sta.	Coal	575 MW	on line 1968	47years
Schiller Sta.	Coal units 4&5	120 MW	on line 1948	67years
Schiller Sta,	Wood unit 6	60 MW	on line 2007	8years
Smith Sta.	Hydro.	18 MW	on line 1948	67years
	Total	2525 MW		

Regionally we have seen the closure of Vermont Yankee. As generation facilities are retired it is imperative that new energy efficient, environmental friendly, renewable sources be built to provide reliable electrical energy for the New England Regional Power Grid.

1717-1

2. Energy costs in this region of the country are exceptionally higher than in than the rest of the continental US. This hydro-electric power project will have a direct positive impact on the cost of energy we now experience.
3. Much of the negativity associated with this project can be attributed to the towers required to support the transmission line and how it'll impact views, scenery along the transmission line path. We believe Northern Pass has done an admirable job of addressing these concerns. By proposing burying 60 miles of power line and utilizing existing transmission right of way (ROW) along the proposed 132 mile route.
4. My understanding is that to also lessen the visual effect of this power line Eversource Energy has reduced the transmission line voltage which allowed project planners to reduce the overall tower heights again lessening the visual effect.
5. Northern Pass management has made significant commitments to many interested parties. Providing jobs during the construction period, allowing right of way (ROW) usage for recreational purposes to include hiking, biking atving and snowmobiling.
6. Tax revenues generated by this project will have a long term positive effect for those communities through which it traverses.
7. Many projects that have improved New Hampshire such as the completion of I-93 through Franconia Notch, expansion of state route 101 from Manchester to the seacoast, building Seabrook Nuclear Power Station, experienced negative rhetoric from a vocal minority. To date each of these completed projects have had nothing but positive benefits for NH residents.
8. We have traveled these United States seen many projects that have effected the topography of our country including. dams, power lines, penstocks, irrigation canals, levies wind mills, solar arrays, skyscrapers, Railroads, Airports etc. Society benefits from these projects and society will benefit from Northern Pass.

1717-1  
Continued

1717-1 cont'd

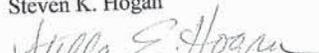
9. DOE Regulatory processes in place today adequately way the pros & cons relating to large scale power projects. Projects should be approved or denied upon their merit to society and not a minority of vocal interveners.

In our opinion this project has merits that far out way the negatives. We need regulators such as your selves to look beyond the rhetoric of those that purport "NOT IN MY BACKYARD".

Thank you for taking the time consider our comments.

Regards,

  
Steven K. Hogan

  
Stella E. Hogan

Cc: Senator Jeanne Sheehan  
Senator Kelley Ayotte

1717-1  
Continued

**From:** [Mills, Brian](#)  
**To:** [Travis Beck](#)  
**Subject:** FW: Group letter re Opposition to Northern Pass  
**Date:** Tuesday, January 5, 2016 12:34:15 PM

---

A comment

-----Original Message-----

From: Barbara Meyer [<mailto:bnmeyer7@gmail.com>]  
Sent: Tuesday, January 05, 2016 1:54 PM  
To: Mills, Brian <[Brian.Mills@hq.doe.gov](mailto:Brian.Mills@hq.doe.gov)>  
Subject: Group letter re Opposition to Northern Pass

GROUP LETTER in response to the draft EIS

We, the undersigned, are residents of Franconia and Easton and we strongly object to the currently proposed routing of the Northern Pass down Rts. 116 and 112, our home town roads.

HEALTH & SAFETY\*

We object because our homes in this area are especially close to the road and therefore highly susceptible to damage from excavation. Eversource has acknowledged that excavation involves drilling and blasting, and that they will be inspecting and photographing wells and foundations in anticipation of having to defend damage claims.

We object because routing this project through our residential neighborhood subjects us, in perpetuity, to the risk of catastrophic accidental dig-ins.

We object because of the dual-edge sword of above-ground warning signs -- requiring them runs the risk of affecting tourism while not using them increases dig-in risk.

VEGETATION\*

We object because Eversource has said that while they will try to bury the lines under the road, they will sometimes use land adjacent to the road and in those areas, the vegetation will need to be permanently removed. Residents are concerned about the loss of vegetation that now screens our homes from the road.

TAXES AND ENVIRONMENTAL JUSTICE\*

We object because Eversource is using "property tax payments" to entice local governments to approve this route. In the absence of these payments, towns involved would likely reject this project out of hand. Once the payments get large enough though, local governments can be enticed to ignore the objections of the residents affected. This arrangement allows moneyed corporate interests to take away the voice of the individual homeowner. This is all the more egregious because it is the homeowner along the route who bears the risk of construction, the effects of

1718-1

Thank you for your comment. Several sections in the EIS discuss the requirements for and evaluate the impacts of installation of transmission towers and burial of the transmission line (e.g., Sections 2.3.2.5 and 4.1.14; see specific alternatives in each geographic area). Evaluation of specific depths and the resulting impacts and mitigation at specific locations would be addressed during subsequent federal and state permitting processes, as applicable. Appendix H discusses mitigation measures intended to avoid, minimize, or mitigate impacts to geology, soils, vegetation, and wildlife.

1718-2

Thank you for your comment. As analyzed in the EIS, "underground portions of the Project would have long-term visual impacts resulting from limited vegetation removal and ongoing vegetation management required for portions of underground cable, including those located in roadway corridors" (Section 4.1.1.2). Appendix H of the EIS includes several measures intended to reduce visual impacts of the Project; however, no measures specific to underground cable are included.

1718-1

1718-2

excavation, the risk of accidental dig-ins, and the loss of property value in going from a parcel without, to a parcel with, a billion-watt transmission corridor in the front yard.

#### ALTERNATIVES\*

If this project goes forth at all, we urge the DOE, the SEC, and Eversource to instead use the I-93 alternative. The I-93 route is a shorter route through already disturbed ground. Any warning signs there would be more tolerable than in our tourism-driven community. The danger of dig-ins and concerns about EMF exposure would be reduced. Lack of pedestrians is also a plus on I-93, keeping people safe from the line and the line safe from people who might intentionally want to disrupt the grid. And using I-93 would preserve local property values.

With regard to slowing down high-speed traffic during construction on 93...traffic is slowed routinely for construction and paving, and slowed daily for toll collection. Cities have constructed light rail systems in the medians of their highways under far heavier and more dangerous traffic conditions.

I-93 already forms a de facto industrial corridor. The current Northern Pass proposal will keep the existing above-ground high-power lines through the White Mountain Forest in place, while tearing a whole new transmission project through two mountain valleys where NO transmission lines currently exist. We strongly object to sacrificing more of our home town and creating yet another industrial corridor snaking across the North Country.

\*Headings reflect categories established by the DOE for purposes of commenting on the EIS (Environmental Impact Study).

William T. Adam, Easton

Amy Bahr, Franconia

Carl Belz, Franconia

Barbara Collier, Easton

Jim Collier, Easton

Isabel Costa, Easton

Lydia Cumbee, Franconia

Russ Cumbee, Franconia

Minnie Cushing, Sugar Hill

Elizabeth E. Horan, Franconia

Stephen P. Horan, Franconia

Bryan Kelly, Franconia

1718-3

Thank you for your comment. Because an EIS is intended to inform decisionmakers and the public about potential impacts of a major federal action, DOE analyzes in detail several alternatives that involve underground cable in the I-93 corridor, including Alternatives 4a, 4b, 4c, 5a, 6a, and 6b. The regulatory framework governing utilities in roadway corridors is discussed in the Land Use Technical Report and the EIS, see Section 3.1.6.4. DOE has considered this comment and no change to the EIS was made.

1718-3

Barbara Lakes, Easton

Carl Lakes, Easton

Kathleen Mead, Franconia

Barbara Meyer, Easton

Eric Meyer, Easton

Paul Meyer, Easton

Irene Mosedale, Franconia

Ken Mosedale, Franconia

Pauline Palmer, Franconia

Tom Palmer, Franconia

Walter Palmer, Franconia

Phil Parker, Easton

Kathleen Sherburn, Franconia

Robert Sherburn, Franconia

Sabrina Sherburn, Franconia

Travis Simpson, Franconia

Leigh B. Starer, Franconia

David Starkey, Franconia

Genevieve Starkey, Franconia

Dawn Steele, Franconia

Bob Thibault, Easton

Kathy Thibault, Easton

Kathryn Ting, Franconia

Anne Whiting, Franconia

Dave Whiting, Franconia

Gregory Wolf, Franconia

Lucille Wolf, Franconia



**From:** Suzanne Steele <suzsteele0711@gmail.com>  
**Sent:** Monday, January 04, 2016 7:49 PM  
**To:** draftEIScomments@northernpasseis.us  
**Subject:** Northern Pass comments

Hello,

There are many reasons why I am not in favor of the Northern Pass project. New Hampshire is known for its beautiful countryside, lakes and mountains and this beauty is imperative for hundreds of thousands of dollars flowing into our economy through tourism. This tourism creates jobs for thousands of people in our state as well. This project, if it goes through, would forever scar our great state. Hundreds of miles would change with many vistas that are currently free from 100+ foot towers.

I am also a Wellness Consultant and am concerned about the health impacts of Northern Pass. The electromagnetic pollution from these proposed lines should be reviewed more critically than has been to this point. I would like to ask the committee to research Europe's findings and their perspective on limiting this type of energy within their borders.

I moved to Deerfield in 1993 because of the beauty of this area as well as the history of our town. We are currently celebrating our 250th Anniversary in 2016; a community steeped in history. We have a number important "centers" in our town -- several very near the new proposed expanded lines.

[http://www.townofdeerfieldnh.com/Pages/DeerfieldNH\\_Webdocs/aboutdf/townhistory](http://www.townofdeerfieldnh.com/Pages/DeerfieldNH_Webdocs/aboutdf/townhistory)

This would threaten our Historic Places. During the open forum with Eversource it was asked a number of times how much larger the Deerfield terminal would be and how much more Electromagnetic power would be surging from this building. Neither Bill Quinlan or any other spokesman answered any of these questions. As a Deerfield resident, that raised a red flag for me.

Another issue with this project is that the jobs would be temporary and it was again not clear at the open forum where the workers would come from. This is not something that would benefit NH.

One thing that was shared with at the forum was the potential savings for us as users of electricity. Mr. Quinlan said, when asked directly that the savings might be 3-5%, but he said it was undetermined whether there may be savings at all. This is definitely not a big enough benefit for me to support the downsides of this project!

1719-1

Thank you for your comment. The EIS discusses the importance of tourism to New Hampshire, businesses, and the local and regional economy. The EIS (Section 3.1.2) and the Socioeconomic Technical Report describe the methods used to analyze potential impact to tourism for this EIS. As discussed in Section 4.1.2 of the EIS, no authoritative peer-reviewed studies were identified that address impacts to tourism as a result of the construction of transmission lines, and DOE did not attempt to develop such a study. No other resources were identified to allow for quantification of potential impacts. The EIS concludes that "while it is reasonable to conclude that the Project may have some level of impact on tourism within New Hampshire and on individual locations near the Project route, these are not quantifiable." Additionally, Section 4.1.1 of the EIS addresses potential impacts to Visual Resources which may result.

1719-1

1719-2

Thank you for your comment. The commenter's concern regarding potential impacts from electro-magnetic fields is noted. Section 4.1.4.2 in the EIS addresses the potential impacts of exposure to magnetic fields. Additional discussion is provided in Section 4.1 and Appendix B of the Electric and Magnetic Fields Technical Report (included as Appendix B of the Public Health and Safety Technical Report). Analysis of European perspectives is outside the scope of this EIS.

1719-2

1719-3

Thank you for your comment. Potential impacts to historic and cultural resources in Deerfield are discussed in Section 4.4.8 of the EIS. Section 2.3 of the EIS describes the proposed projects at the Deerfield Substation.

1719-3

1719-4

Thank you for your comment. Potential socioeconomic impacts are addressed in the EIS within Section 4.1.2, including an evaluation of construction related, and long-term operations, changes to employment and income in New Hampshire.

1719-4

Burying the lines seems to be a better option; however, according to Eversource not feasible due to the cost. I don't know if there is long-term knowledge of the impacts to the land and its surroundings to this amount of power being buried for years/decades...

One of the biggest reasons why I don't support Northern Pass is that this electricity is NOT going to be used by our residents. It is going to be used by southern New England (just like the existing Northeast Utilities Transmission Line that runs through NH). We are just being used by Hydro-Quebec and Eversource to help them earn more money by scarring our beautiful state.

Please DO NOT allow this to happen.

I would be happy to discuss this further.

Thank you for your time and consideration.

Suzanne

--

**Suzanne Steele**

**Balanced Wellness LLC**

*Providing Lifestyle Solutions*

603.463.5858 h

603.505.1660 c

# Sharon H. Miller



PO Box 22, Errol, NH 03579  
smillermoneysunk@gmail.com

1720-1  
Thank you for your comment.

12/10/2015

Brian Mills  
Senior Planning Advisor  
Office of Electricity Delivery and Energy Reliability (OE-20)  
U.S. Department of Energy  
1000 Independence Ave. SW  
Washington, DC 20585

Dear Mr. Mills,

I am writing in regards to the NH Northern Pass proposed route. I am very concerned, as a NH resident in its the most northern part, that the proposed route that is overland will destroy the economic beauty of the area.

I moved to NH from Washington, DC, over 35 years ago, to live in a small farmhouse, work, enjoy the outdoors and raise a family. My neighbor is the Balsams Resort and the towers will ruin their ambience and potentially adversely affect their prosperity, as with other businesses in Northern NH. Making a living here is a struggle as we are weather and outdoor beauty dependent, which many people who do not live here fail to understand. This I believe may be true of Hydro-Quebec and Eversource who stand to gain a great deal if they are not required to bury their transmission lines.

I fell that the full burial of the transmission line is in order if you do not say no to Northern Pass.

Warm regards,  
Sharon H. Miller Ph.D.

1720-1



# Northern Pass EIS Website Comment Receipt

1721-1

Thank you for your comment.

**Refers to Comment placed on Jan 25, 2016**

**ID:** 8673

**Date Entered:** Jan 25, 2016

**Source:** Website

**Topics:** Alternatives, Design Criteria / Mitigation Measures

**Organization:** Suggested Underground Route

**Country:** US

**Comment:** If you paste this link into your browser, you will see a 194 mile path (2 miles longer than the preferred alternative) that avoids ALL LAROW highways, such as I-93. It uses secondary and tertiary roads to underground THE COMPLETE ROUTE.

<https://www.google.com/maps/dir/45.0220032,-71.4634857/42.7928989,-71.3771918/@43.902081,-72.7173584,8z/am=t/data=!4m6!1m5!3m4!1m2!1d-71.614709!2d44.7280512!3s0x4cb69f8c91b60379:0x5f1508205663806b!3m4!1m2!1d-71.5676822!2d44.4940305!3s0x4cb411c19d4b84ef:0x5e2f40540e215b24!3m4!1m2!1d-71.5608195!2d44.4867869!3s0x4cb411e64cafe2b3:0x2bc9bc734aca3428!3m4!1m2!1d-71.5645689!2d44.485599!3s0x4cb411e8a0cf3dad:0xa6745ea343a99ad2!3m4!1m2!1d-71.5667119!2d44.4854901!3s0x4cb411ef341431d5:0xfd8bf45d0d8934ed!3m4!1m2!1d-71.5687834!2d44.4850731!3s0x4cb411ef2772585d:0x732506efc6c70a5e!3m4!1m2!1d-71.6698363!2d44.2894962!3s0x4cb4702fe93521d1:0x29ab549e1027b835!3m4!1m2!1d-71.7933192!2d44.0464846!3s0x4cb485d3e8e1d991:0x2d9cb7c99e43a89d!3m4!1m2!1d-71.5967388!2d43.5102959!3s0x4cb34ac45e6e5ef5:0x3382f7f4d66a9177!3m4!1m2!1d-71.5571127!2d43.449618!3s0x89e274d93e91dae1:0x2a62fe5abe307674!3m4!1m2!1d-71.485264!2d43.407433!3s0x89e27406912f7e1b:0x2d8c35ff8c7a2613!1m0!2m1!1b1!3e0>

1721-1

# Northern Pass EIS Website Comment Receipt

## Refers to Comment placed on Feb 6, 2016

**ID:** 9337

**Date Entered:** Feb 6, 2016

**Source:** Website

**Topics:** Taxes, Economic, Quality of Life

**Name:** Alan Cote

**Organization:** homeowner

**Title:** Mr.

**Email:** arcote@comcast.net

**Mailing Address:** 488 Pingree Hill Rd

**City:** Auburn

**State:** NH

**Zip:** 03032

**Country:** US

**Comment:** Please consider the positive impacts that the Northern Pass project will have in New England. New England pays among the highest electric rates in the country. We need this project. As a property owner in both Campton, NH and Auburn, NH, I have no objection to these transmission lines. Unless you are directly under them, they disappear in the terrain quite quickly due to the topography. In addition, the clearings under the power lines provide grazing opportunities for wildlife. If this country is truly committed to reducing carbon emissions, there is no cleaner way to do that than with hydro-electric power. Please expedite the approval of this project.

1722-1

Thank you for your comment. The habitat conversion to foraging, or grazing, habitat is discussed in the Wildlife Technical Report.

| 1722-1

**From:** [Mills, Brian](#)  
**To:** [Travis Beck](#)  
**Subject:** FW: Northern Pass  
**Date:** Thursday, September 17, 2015 7:17:14 AM

---

1723-1  
Thank you for your comment.

-----Original Message-----

From: Rick McNally [<mailto:rjmcnally@charter.net>]  
Sent: Wednesday, September 16, 2015 2:55 PM  
To: Mills, Brian <[Brian.Mills@hq.doe.gov](mailto:Brian.Mills@hq.doe.gov)>  
Cc: Castro Everett <[castro.everett@gmail.com](mailto:castro.everett@gmail.com)>; French Barry <[barryfrench@yahoo.com](mailto:barryfrench@yahoo.com)>; KELLY MAUREEN <[moke1773@aol.com](mailto:moke1773@aol.com)>; Conservation Action Network AMC <[Conservation@outdoors.org](mailto:Conservation@outdoors.org)>; Labossiere Mike <[mlabossiere@fallriverma.org](mailto:mlabossiere@fallriverma.org)>; jblock@clf.org  
Subject: Northern Pass

I would like to register my objection to this power line. I live in southeastern Massachusetts where the power lines and towers from Montaup Power Plant, Somerst which shut down several years ago, are abandoned and there is no effort to protect the public from these public nuisances. Shortly, the same will be true of the high voltage power lines and towers out of Brayton Point, Somerset when it shuts down. These easements and structures lace our area and especially our Southeastern Massachusetts Bioreserve. The same can be said of the underground Spectra easement through the Bioreserve. It no longer carries any product from the terminal in the north end of Fall River and consequently the easement is not maintained and has become an avenue for vehicles to destroy the pristine forest. There is no confidence left in the general public that any utility will behave responsibly.

Very truly yours

Richard J. McNally, Westport, MA 02790

1723-1

**From:** [Lauren Kennard](mailto:Lauren_Kennard)  
**To:** [webmaster@northernpasseis.us](mailto:webmaster@northernpasseis.us)  
**Subject:** Suggestion  
**Date:** Wednesday, September 30, 2015 9:16:42 AM

---

I believe that the Northern Pass will come about. As we all know, this will disrupt the current plant life that grows along the proposed locations. I live in Strafford, Nh and near me, are some power lines, along this section of lines, there is a lot of water run off and because of this, the plant life has an abundance of variety that supports flowers, berries, greens. Quite often, I walk these lines with my camera to photograph the beauty of plant life, wild life, insects, and amphibians. If the lines were not here, this environment would not exist. ( Actually, I wish that this area had protection in place to stop ATVs and maintain the plant life at this location) In the state of NH we have endangered species issues. I believe that we could appease many wildlife lovers and encourage a healthy wildlife environment by adjusting and incorporating new plantings along the pass such as Lupine and other varieties which would support such species as the Karner Blue Butterfly and other species. Let's benefit from this opportunity and think outside the box as to the possibilities to improve upon nature. The pass will open up land to bring in new types of plantings for wildlife, picnic areas, camping ares,and vistas, ponds, all this and more could all take place along these lines. The options for great possibilities are endless that could improve and promote changes that are positive in every avenue.

Sincerely,  
Lauren Kennard  
355 Drake Hill Road  
Strafford, NH  
03884

1724-1

Thank you for your comment. Several measures described in Appendix H of the EIS relate to revegetation of disturbed areas. These measures include various requirements to revegetate disturbed areas promptly with seed mixes from sources as close as possible to the Project corridor and subject to federal and/or state agency approval.

1724-1

1725-1

Thank you for your comment. Potential impacts in Canada from the construction and operation of electricity infrastructure, including hydropower generation and transmission in Canada, are beyond the scope of this NEPA analysis. NEPA does not require an analysis of potential environmental impacts that occur within another sovereign nation that result from actions approved by that sovereign nation. Additionally, the construction and operation of Hydro-Quebec power generation projects and electricity transmission line projects in the bulk Hydro-Quebec system will occur regardless of and independent to whether DOE issues a Presidential permit for the proposed Northern Pass Project international border crossing. Specifically, Hydro-Quebec performed the required evaluation of potential mercury releases from hydroelectric reservoirs, that focused on impacts to fish, birds, animals, and human populations which included indigenous communities living around existing and developing hydroelectric facilities. Further in response to requirements, Hydro-Quebec includes obligations related to monitoring and mitigation measures to ensure that the public is not exposed to health risks (including those potential impacts from methylmercury) from hydroelectric development as a part of the Canadian government permitting and authorizations for its hydroelectric facilities. The measures are based on consumption and other exposure (i.e., reference dose) guidelines for methylmercury issued by Health Canada, as appropriate for a project authorized by the provincial and federal governments of Canada; not the reference dose for methylmercury established by the U.S. government (i.e., by the U.S. Environmental Protection agency) as suggested by the commenter. For these reasons, potential environmental impacts in Canada are not addressed in this EIS. Section 1.5.4.1 of the EIS has been updated in response to this comment.

January 31, 2017

BY ELECTRONIC & POSTAL DELIVERY

Mr. Brian Mills  
Office of Electric Delivery and Energy Reliability (OE-20)  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585

**Re: Supplemental Comments of CLF on DEIS and SDEIS, Northern Pass Transmission LLC, Presidential Permit Application, OE Docket No. PP-371**

Dear Mr. Mills:

Conservation Law Foundation submits these limited supplemental comments in OE Docket No. PP-371. In light of additional scientific data that has recently become available regarding both methylmercury and methane releases associated with hydroelectric facilities, these comments respectfully supplement the record regarding the impacts of the proposed project.

**I. DOE Must Consider, Analyze, and Address the Effects of Increased Methylmercury Releases in Canada**

As indicated in comments that Conservation Law Foundation (“CLF”) submitted in this docket on April 4, 2016, NEPA requires DOE to assess cross-border impacts that are causally linked to the project proposal under review.<sup>1</sup> In the Draft Environmental Impact Statement (“DEIS”) and Supplemental Draft Environmental Impact Statement (“SDEIS”), the Department of Energy (“DOE”) improperly omits any analysis of the impacts the proposed project will have on Canada’s environment and populations. Among these deficiencies, DOE’s analysis includes no mention of the effects methylmercury will have on Canada’s environment and indigenous populations. The proposed project will likely result in the development of new hydroelectric

1725-1

<sup>1</sup> See CLF Comments at 26-30, citing, e.g., *Border Power Plant Working Group*, 260 F. Supp. 2d at 1012-15 (environmental impacts of generating facility that will export power through international transmission line requiring Presidential Permit must be considered under NEPA).

reservoirs, and/or the expanded use of existing reservoirs.<sup>2</sup> Flooding hydroelectric reservoirs has widely been acknowledged to increase releases of carbon dioxide, methane, and methylmercury. In affected areas, methylmercury has been found to be sustained, not only in the reservoir but also areas downstream of the reservoir, for one to three decades.<sup>3</sup> A recent Harvard study of Canadian reservoirs has made new scientific data available on this subject; a report on that scientific data is attached to these comments.<sup>4</sup>

Methylmercury is a neurotoxin. It is an organic molecule produced mainly by bacteria from inorganic mercury naturally present in materials flooded during the course of reservoir creation.<sup>5</sup> When an area is flooded, microbial production is stimulated in the newly flooded soil by degradation of labile organic carbon and associated changes in geochemical conditions.<sup>6</sup> The methylmercury moves into the water and animals, magnifying as it moves up the food chain. Methylmercury is the only mercury species that biomagnifies in aquatic food webs.<sup>7</sup> This makes the toxin especially dangerous for indigenous communities living near hydroelectric projects because they tend to maintain diets rich in local fish, birds and marine mammals.<sup>8</sup>

As all Canadian hydroelectric facilities being considered for near term development are located within 161 miles of indigenous communities, increased impacts on indigenous populations are foreseeable.<sup>9</sup> Further, indigenous populations have already been substantially affected by high methylmercury levels resulting from existing hydroelectric reservoirs.<sup>10</sup> DOE's impacts analysis therefore must include an assessment of the effects the proposed project, and the intrinsically linked expansion of hydroelectric resources in Canada, on indigenous populations and natural resources, including fish. This analysis moreover should be referenced in DOE's assessment of the environmental justice impacts of the proposed project. DOE's

1725-1  
Continued

---

<sup>2</sup> As indicated in the Application, the proposed project is not just an energy source-neutral transmission line, but a transmission line specifically designed to transmit power from hydroelectric resources located in Canada. For this reason, the link between the transmission line and associated hydroelectric facilities is intrinsic.

<sup>3</sup> Ryan S.D. Calder, et. al, *Future Impact of Hydroelectric Power Development on Methylmercury Exposures of Canadian Indigenous Communities*, Environmental Science & Technology Journal 50(23), A, Nov. 9, 2016, available at <http://pubs.acs.org/doi/abs/10.1021/acs.est.6b04447> and included in Exhibit 24.

<sup>4</sup> See *id.*, Exhibit 24.

<sup>5</sup> D.M. Rosenberg, et al., Large-scale impacts of hydroelectric development, Environmental Reviews 5(1), 27, 28, March 1997, available at [https://www.researchgate.net/publication/240084662\\_Large-scale\\_impacts\\_of\\_hydroelectric\\_development](https://www.researchgate.net/publication/240084662_Large-scale_impacts_of_hydroelectric_development) and included in Exhibit 24.

<sup>6</sup> See Calder at A.

<sup>7</sup> *Id.*

<sup>8</sup> *Id.*

<sup>9</sup> *Id.* at Figure 2.

<sup>10</sup> *Id.* at A.

1725-1 cont'd

1725-2

Thank you for your comment. Potential impacts in Canada from the construction and operation of electricity infrastructure, including hydropower generation and transmission in Canada, are beyond the scope of this NEPA analysis. NEPA does not require an analysis of potential environmental impacts that occur within another sovereign nation that result from actions approved by that sovereign nation. Additionally, the construction and operation of Hydro-Quebec power generation projects and electricity transmission line projects in the bulk Hydro-Quebec system will occur regardless of and independent to whether DOE issues a Presidential permit for the proposed Northern Pass Project international border crossing. For these reasons, potential environmental impacts in Canada are not addressed in this EIS. Section 1.5.4.1 of the EIS has been updated in response to this comment. DOE appreciates and agrees with the commenter's assertion that the nature of methane as an important greenhouse gas is well-established in scientific literature. Section 4.1.10 of this EIS analyzes the potential impacts from GHG emissions, including methane, from the proposed Project and the construction and operation of the associated transmission line in the state of New Hampshire as a connected action to DOE's Presidential permit decision. No change to the EIS has been made in response to this comment.

1725-1  
Continued

1725-2

current environmental justice assessment identifies no impacted minority populations.<sup>11</sup> This omission is a result of DOE's failure to assess the foreseeable impacts of the project in Canada. In so narrowing the scope of its impacts analysis, DOE fails to properly assess impacts on Canada's indigenous populations in connection with the construction and operation of associated hydroelectric facilities.

According to Harvard scientists, over half of women of childbearing age and young children in certain indigenous communities in Canada are projected to exceed the U.S. Environmental Protection Agency's ("EPA") reference dose for methylmercury.<sup>12</sup> The EPA's oral reference dose is based on the assumption that a determined exposure amount to methylmercury, or threshold, exists in order for certain toxic effects of methylmercury to show.<sup>13</sup> Methylmercury is known to be the most poisonous among the mercury compounds.<sup>14</sup>

For these reasons, DOE must carefully assess the impacts that increased methylmercury releases associated with the hydroelectric reservoirs necessary to transmit hydroelectric power from Canada along the proposed cross-border transmission line.

## II. DOE Also Must Evaluate the Effects of Increased Methane Releases Resulting from the Proposed Project

As part of its impacts analysis, DOE likewise must evaluate the nature and effects of methane emissions from the construction and operation of the hydroelectric facilities intrinsically associated with the proposed project.<sup>15</sup> CLF's prior comments address greenhouse gas emissions (*see, e.g.*, comments filed April 4, 2016 at n. 58), thus these comments are intended only to supplement the record with regard to recent scientific analysis of methane emissions in particular.

A recent scientific study employing a more comprehensive methodology than past studies has found that methane constitutes 79 percent of carbon dioxide equivalent emissions from hydroelectric and other man-made reservoirs globally. The study is the first scientific analysis to consider methane bubbling upward from reservoir soil, also called ebullition, in models of

<sup>11</sup> DEIS S-29.

<sup>12</sup> *Id.* at A (Abstract).

<sup>13</sup> U.S. EPA, Integrated Risk Information System (IRIS) Chemical Assessment Summary: Methylmercury, 2001, 1, available at [https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance\\_nمبر=73](https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nمبر=73).

<sup>14</sup> Young-Seoub Hong, et al., Methylmercury Exposure and Health Effects, *Journal of Preventive Medicine and Public Health* 45(6), 353, Nov. 29, 2012, available at <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3514465/> and included in Exhibit 24.

<sup>15</sup> *See* discussion above and in CLF's prior comments, citing, *e.g.*, *Border Power Plant Working Group*, 260 F. Supp. 2d at 1012-18.

reservoir greenhouse gas emissions.<sup>16</sup> Its authors conclude that the estimates of methane emissions per area of reservoir are about 25 percent higher than previously thought.<sup>17</sup> The study indicates that reservoir methane production is an underappreciated source of greenhouse gases, producing the equivalent of roughly 1 gigaton of carbon dioxide per year, or 1.3 percent of all greenhouse gases produced by humans.<sup>18</sup> This is comparable to rice paddies or biomass burning, both of which are included in emission estimates of the Intergovernmental Panel on Climate Change. The analysis, published in *BioScience* and attached as an exhibit,<sup>19</sup> is the largest and most comprehensive look to date at the link between reservoirs and greenhouse gases.

The nature of methane as a highly potent greenhouse gas is well-established. Methane's lifetime in the atmosphere is much shorter than carbon dioxide, but it is more efficient at trapping radiation than carbon dioxide.<sup>20</sup> Pound for pound, the comparative impact of methane on climate change is more than 25 times greater than climate change over a 100-year period.<sup>21</sup> DOE's environmental impacts analysis must include an analysis of the climate impacts associated with methane releases from hydroelectric reservoirs in Canada that are associated with the proposed project, and that are contractually and intrinsically tied to the proposed cross-border transmission line.<sup>22</sup>

### Conclusion

CLF appreciates the opportunity to comment on the DEIS and SDEIS regarding the proposed Northern Pass electric transmission project, and we urge DOE to address the significant

1725-2  
Continued

---

<sup>16</sup> Methane bubbling, or ebullition, is the sudden release of bubbles of methane into the air. Bubbles develop as a result of methane building up over time in the soil, forming pockets of methane gas. When the pressure builds sufficiently, these bubbles pop, transporting methane rapidly upward, creating methane emissions.

<sup>17</sup> See Chris Mooney, "Reservoirs are a major source of global greenhouse gases, scientists say," *Washington Post*, Sept. 28, 2016, available at [https://www.washingtonpost.com/news/energy-environment/wp/2016/09/28/scientists-just-found-yet-another-way-that-humans-are-creating-greenhouse-gases/?utm\\_term=.bd3c41e83e6c](https://www.washingtonpost.com/news/energy-environment/wp/2016/09/28/scientists-just-found-yet-another-way-that-humans-are-creating-greenhouse-gases/?utm_term=.bd3c41e83e6c) and included in Exhibit 25.

<sup>18</sup> *Id.*

<sup>19</sup> See Bridget R. Deemer, et al., Greenhouse Gas Emissions from Reservoir Water Surfaces: a New Global Synthesis, *BioScience* 66(11), Oct. 5, 2016, available at <https://academic.oup.com/bioscience/article/66/11/949/2754271/Greenhouse-Gas-Emissions-from-Reservoir-Water> and included in Exhibit 25.

<sup>20</sup> See EPA Overview of Greenhouse Gas Emissions at <https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane>.

<sup>21</sup> *Id.*

<sup>22</sup> See *Border Power Plant Working Group*, 260 F. Supp. 2d at 1012-18. See also Council on Environmental Quality ("CEQ") Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews, Aug. 1, 2016. This Final Guidance, issued subsequent to CLF's prior comments, confirms that federal agencies should evaluate greenhouse gas emissions and climate impacts as part of the NEPA review process.



issues identified herein as well as in CLF's previously submitted comments in complying with the requirements of the National Environmental Policy Act.

Respectfully submitted,

Melissa Birchard  
Attorney for Conservation Law Foundation

Enclosures

Exhibit 24:

- Calder, R., et al., *Future Impacts of Hydroelectric Power Development on Methylmercury Exposures of Canadian Indigenous Communities*
- Rosenberg, D.M., et al., *Large-scale impacts of hydroelectric development*
- Hong, Y., et al., *Methylmercury Exposure and Health Effects*

Exhibit 25:

- Mooney, C., *Reservoirs are a major source of global greenhouse gases, scientists say*
- Deemer, B., et al., *Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis*

**EXHIBIT 24**

## Future Impacts of Hydroelectric Power Development on Methylmercury Exposures of Canadian Indigenous Communities

Ryan S. D. Calder,<sup>\*,†,‡</sup> Amina T. Schartup,<sup>†,‡</sup> Miling Li,<sup>†,‡</sup> Amelia P. Valberg,<sup>†</sup> Prentiss H. Balcom,<sup>‡</sup> and Elsie M. Sunderland<sup>†,‡</sup>

<sup>†</sup>Department of Environmental Health, Harvard T. H. Chan School of Public Health, Boston Massachusetts 02215, United States

<sup>‡</sup>Harvard John A. Paulson School of Engineering and Applied Sciences, Cambridge Massachusetts 02138, United States

### Supporting Information

**ABSTRACT:** Developing Canadian hydroelectric resources is a key component of North American plans for meeting future energy demands. Microbial production of the bioaccumulative neurotoxin methylmercury (MeHg) is stimulated in newly flooded soils by degradation of labile organic carbon and associated changes in geochemical conditions. We find all 22 Canadian hydroelectric facilities being considered for near-term development are located within 100 km of indigenous communities. For a facility in Labrador, Canada (Muskrat Falls) with planned completion in 2017, we probabilistically modeled peak MeHg enrichment relative to measured baseline conditions in the river to be impounded, downstream estuary, locally harvested fish, birds and seals, and three Inuit communities. Results show a projected 10-fold increase in riverine MeHg levels and a 2.6-fold increase in estuarine surface waters. MeHg concentrations in locally caught species increase 1.3 to 10-fold depending on time spent foraging in different environments. Mean Inuit MeHg exposure is forecasted to double following flooding and over half of the women of childbearing age and young children in the most northern community are projected to exceed the U.S. EPA's reference dose. Equal or greater aqueous MeHg concentrations relative to Muskrat Falls are forecasted for 11 sites across Canada, suggesting the need for mitigation measures prior to flooding.



### INTRODUCTION

Hydroelectric power accounts for 16.2% of global electricity generation and plans to greatly expand capacity are underway as countries seek to develop carbon neutral energy sources.<sup>1,2</sup> In Canada, 59% of the electricity supply is from hydroelectric power and expansion is a key component of meeting international agreements on carbon dioxide (CO<sub>2</sub>) reductions.<sup>3</sup> Enhanced releases of CO<sub>2</sub>, methane (CH<sub>4</sub>), and methylmercury (MeHg) that are sustained for one to three decades following flooding are widely acknowledged.<sup>1,4,5</sup> Impacts of CO<sub>2</sub> and CH<sub>4</sub> releases are global but MeHg is a neurotoxin that bioaccumulates in food webs and adversely affects individuals who rely on local ecosystems for food.<sup>6</sup> Previous studies show reservoir characteristics can be used to project MeHg levels in water<sup>7,8</sup> and fish<sup>9</sup> following flooding but a prospective analysis of risks to human health from hydroelectric power expansion is lacking.

Traditional diets of indigenous people in the Arctic and Subarctic are rich in fish, birds, seal, and whale that provide many nutritional and cultural benefits<sup>10,11</sup> but also biomagnify environmental contaminants.<sup>12,13</sup> Negative impacts of MeHg exposure on neurodevelopment are well-established and widely used as the basis for regulatory thresholds.<sup>14</sup> In northern indigenous populations, increased MeHg exposure has been

significantly associated with cardiovascular risk factors for adults such as increased resting heart rate and heart rate variability,<sup>15,16</sup> as well as increased incidence of attention deficit/hyperactivity disorder (ADHD) among children with high prenatal exposures.<sup>17</sup> Acute MeHg toxicity is associated with widespread neurological abnormalities, paresthesia and ataxia.<sup>18</sup> In Canadian indigenous communities previously impacted by hydroelectric flooding,<sup>19,20</sup> measured MeHg exposures have surpassed the lowest observed effects levels for acute MeHg toxicity.<sup>18</sup>

Inorganic mercury (Hg) is a natural component of soils and has been enriched globally by anthropogenic sources.<sup>21,22</sup> MeHg is the only Hg species that biomagnifies in aquatic food webs.<sup>23</sup> Previously, we simulated flooding using soil cores from a planned hydroelectric reservoir in Labrador, Canada and found a 14-fold MeHg enrichment in overlying water within 3 days that was increasing exponentially at the end of the five-day experimental period.<sup>24</sup> These results suggest enhanced MeHg availability to fish, birds and seals occurs almost immediately

Received: September 1, 2016

Revised: October 21, 2016

Accepted: October 21, 2016

after reservoir flooding.<sup>24</sup> Similarly, whole ecosystem experiments in Northern Ontario show MeHg production peaks within the first 1–3 years following impoundment.<sup>4,7</sup> Elevated MeHg levels in previously flooded reservoirs have gradually declined back to baseline over several decades.<sup>25</sup>

Here we quantify expected increases in MeHg exposures for three Inuit communities in Labrador, Canada surrounding a hydroelectric facility to be flooded in 2016–2017 (Muskrat Falls). Our analysis considers: (a) potential MeHg enrichment in the flooded reservoir, (b) MeHg accumulation in the downstream environment (an estuary known as Lake Melville), (c) MeHg biomagnification in country foods, and (d) shifts in MeHg exposures for Inuit individuals. We use information from the Muskrat Falls site to forecast MeHg concentrations for planned hydroelectric reservoir expansion areas across Canada and discuss potential impacts on human health and mitigation strategies.

## MATERIALS AND METHODS

Data from nine sites across three ecosystems were used to derive a relationship between soil organic carbon and peak methylmercury (MeHg) content of flooded soils.<sup>7,26–28</sup> We excluded data from sites inundated more than three decades prior to MeHg measurements because MeHg production diminishes over time and smaller increases are observed in periodically flooded environments.<sup>6,24,29</sup> For data from the Experimental Lakes Area (ELA) of Canada (boreal inceptisols soils), we used the highest MeHg concentrations following flooding for each site.<sup>7</sup> Soil organic matter was converted to organic carbon using a conversion factor of 0.58, where needed.<sup>30</sup>

Methods used to calculate peak MeHg fluxes from flooded soils into overlying reservoir waters for the Muskrat Falls, Labrador site are shown in [Supporting Information \(SI\) Table S1](#). Satellite data were used to derive the organic carbon content (%) of the upper 30 cm of soil in each planned reservoir.<sup>31,32</sup> Post-flooding peak water column MeHg concentrations were simulated probabilistically using the distributions described in [SI Table S2](#), including (1) the 90th percentile solids diameter, (2) the sediment-water partition coefficient ( $K_d$ , L kg<sup>-1</sup>) for MeHg, and (3) the MeHg fraction photochemically degraded during downstream transport.

We repeated this analysis for hydroelectric power development sites currently in the planning phase or under construction across Canada. All planned reservoirs are within 100 km of indigenous population reserves, settlements or communities, which is the approximate distance of treaty negotiated Inuit hunting and fishing territory from the Muskrat Falls facility. For all facilities, we modeled peak water column MeHg concentrations expected following flooding based on site-specific data for water discharge, flooded area, reservoir soil organic carbon, and the Muskrat Falls diffusive boundary layer estimate ([SI Table S3](#)).

For the Muskrat Falls site, downstream impacts of peak reservoir MeHg concentrations on the Lake Melville estuary were quantified using the model developed by Schartup et al.<sup>24</sup> ([SI Figure S1](#)). The estuary is permanently stratified and our previous work shows biological productivity is concentrated in the low-salinity surface layer (upper 10 m), which is the focus of this analysis. The estuarine model is based on extensive field measurements collected between 2012 and 2014 ([SI Table S4](#)). It is externally forced with probabilistically modeled freshwater MeHg inputs from the impounded river (Churchill River) from

this work, and previously characterized atmospheric deposition, and tidal inputs.<sup>24</sup> Depth-specific tidal inflows and outflows to the Lake Melville estuary are based on buoy measurements and detailed hydrodynamic modeling.<sup>33</sup> The annual mean flux of seawater from the subsurface to the surface layer ( $2.83 \times 10^9$  m<sup>3</sup> d<sup>-1</sup>) was calculated from the hydraulic budget for each vertical layer. We updated redox reactions for inorganic Hg species following the parametrization by Soerensen et al.<sup>34</sup>

Baseline MeHg concentrations in locally harvested foods from the Lake Melville region were derived with the assistance of a community-led harvesting program ([SI Table S5](#)). Local foods were selected for MeHg analysis in 2014–2015 after consulting the Community Research Advisory Committee, North West River. Fish MeHg concentrations often exhibit a relationship with length.<sup>25</sup> For this study, we separated juvenile and adult size ranges and retained those most frequently consumed by Inuit community members. All fish and shellfish samples were analyzed for total Hg/MeHg and stable isotopes of carbon, nitrogen and Hg ([SI Table S6](#)).<sup>35</sup> Locally consumed seal (*Phoca hispida hispida*) muscle, liver and kidney were obtained from Inuit hunters in the spring of 2015 and analyzed for total Hg and MeHg at Environment Canada in Burlington, Ontario (see the [Supporting Information](#) for details). Data for other birds and wildlife were obtained from Environment Canada and literature values, where applicable.

Site-specific bioaccumulation factors (BAFs) for 65 locally harvested foods including fish, birds, eggs and seal ([SI Table S5](#)) were used to link modeled MeHg increases in the Churchill River and Lake Melville estuary following flooding to changes in locally harvested food concentrations ([SI Table S7](#)). This analysis assumes steady state biological MeHg concentrations with peak MeHg fluxes from the reservoir. Data from previously flooded environments indicates up to ten years are required for biota to reach maximum MeHg levels.<sup>29,36</sup>

We calculated BAFs from measured MeHg concentrations in each locally consumed species and annual mean concentrations measured in the river, estuary and outer marine regions (i.e.,  $BAF = \text{MeHg biota}/\text{water MeHg}$ ). Exposure to aqueous MeHg for each species was calculated from the fraction of their lifespan spent in each environment (i.e., the sum product of aqueous MeHg concentration multiplied by the lifespan in each region). We estimated the predominant habitat/foraging regions of each species using  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\Delta^{199}\text{Hg}$ , and  $\delta^{202}\text{Hg}$  as tracers,<sup>35</sup> and literature information on their habitat preferences. We accounted for uncertainty in the time spent in each foraging region using uniform distributions that envelope the likely ranges for each species ([SI Table S2](#)) and probabilistically simulating MeHg increases. At previously flooded hydroelectric reservoirs, some typically herbivorous fish have been observed to eat fish stunned or killed by passage through hydroelectric turbines, effectively raising their trophic level and magnifying MeHg concentrations.<sup>37</sup> We do not include such potential effects in our enrichment calculations.

Hair samples were used as biomarkers of MeHg exposure for individuals in three Inuit communities (Happy Valley–Goose Bay, North West River, and Rigolet) downstream from the Muskrat Falls development area ([SI Figure S2](#)). Samples were obtained from the occipital region of the scalp with the assistance of 26 Inuit research assistants. Participants were recruited by the Nunatsiavut Government using membership rolls, which is limited to persons with demonstrated Inuit identity/ancestry. Samples were collected in both the June/July 2014 and September/October 2014 to account for any seasonal

variability in MeHg intake and ensure overlap with the peak harvest season for seals in the spring. 656 hair samples were analyzed across these two periods, representing 571 unique Inuit individuals and 19% of the total Inuit population in the region (SI Table S8). Total Hg was analyzed in the two-centimeter proximal end of hair using thermal decomposition, amalgamation, and atomic absorption spectrophotometry (EPA method 7473) with a Nippon MA-3000 or Milestone DMA-80 at Harvard University. Most of the Hg in hair is present as MeHg (>90%) and potential demethylation in the hair follicle means that total Hg is the best indicator of internal MeHg exposure.<sup>38</sup> At least one method blank and one certified hair reference materials (GBW-07601 and ERM-DB001) were tested every 10 samples and all recoveries were within certified ranges. Precision, calculated by replicate analysis of the duplicate hair samples (RSD) was better than 8.6%.

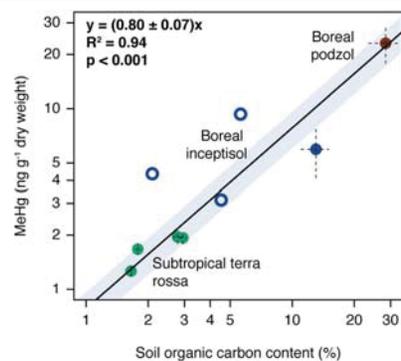
Food frequency questionnaire (FFQ) data using overlapping 24-h, 1-month and 3-month recall periods were collected in March/April 2014 concurrently with hair sampling in June/July and September/October 2014. The final FFQ survey population included 38% of Inuit individuals in the region (SI Table S9) and 1145 unique individuals. The survey included information on height, weight, sex, age. Focus group sessions were conducted with Community Research Advisory Committees to ensure comprehensiveness of country foods listed, local names and preparation methods. Interviews were conducted in-person with the use of visual aids for identification of fish meal sizes and species. Research protocols, consent procedures and the survey instrument were reviewed and approved by the Harvard Office of Human Research Administration, the Newfoundland and Labrador Health Research Ethics Authority, and the Nunatsiavut Government Research Advisory Committee prior to recruitment.

Three-month FFQ recall data from September 2014 (highest-enrollment sampling period) and the one-compartment pharmacokinetic model developed by the U.S. Environmental Protection Agency<sup>39,40</sup> were used to probabilistically model baseline MeHg exposures in the three Inuit communities prior to flooding. We chose the 3-month survey period because it most closely matches the exposure period recorded by hair samples. Variability in pharmacokinetic parameters for MeHg in the human body was probabilistically simulated following the methods outlined in Li et al.<sup>41</sup> We scaled individual fish servings to match the total meal number reported over the recall period because recall data on species-specific fish consumption tends to overestimate total consumption.<sup>41–43</sup> Lognormal or gamma distributions were developed from measured MeHg concentrations in country foods (SI Table S6) and used in probabilistic exposure simulations.<sup>44</sup> MeHg variability in store-bought foods (SI Table S10) was simulated following Carrington and Bolger.<sup>44</sup>

Modeled MeHg exposures were scaled by the ratio between measured and modeled hair Hg to ensure agreement with actual exposure levels. For individuals who did not provide hair samples, we adjusted modeled exposures by the median of these correction factors (mean = 0.96). Gender and age from 2011 census data were used to match the demographic distribution of the Inuit population in each of the three communities.<sup>45,46</sup> Shifts in exposure resulting from flooding of the Muskrat Falls reservoir were propagated from probabilistically simulated increases in MeHg concentrations in country foods in each individual's diet.

## RESULTS AND DISCUSSION

**Methylmercury Increases in Flooded Reservoirs.** We find a strong linear relationship across multiple ecosystems between MeHg concentrations in soils inundated within approximately three decades and their organic carbon content (Figure 1). This relationship is consistent with site-specific

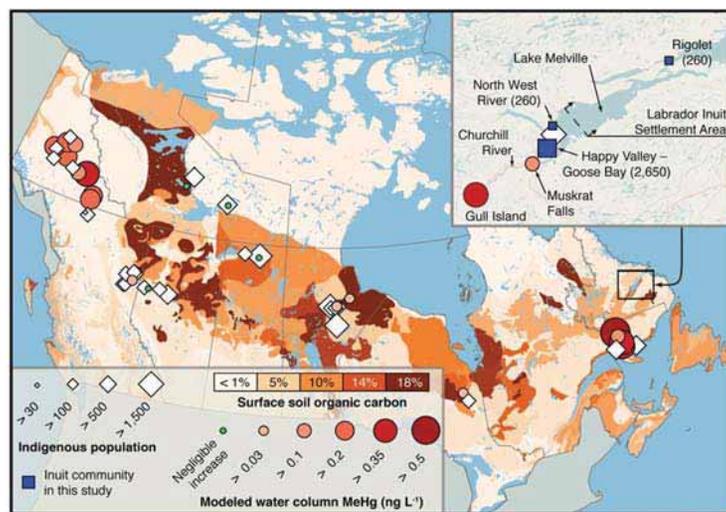


**Figure 1.** Relationship between soil organic carbon content and MeHg concentrations ( $\text{ng g}^{-1}$  dry weight) of flooded soils. Each data point represents an individual sampling location. Hatched lines indicate standard errors around the mean. Soil cores are from the Wujiang reservoir, China (subtropical terra rossa),<sup>28</sup> the Experimental Lakes Area (ELA, boreal incepsitol) in Northern Ontario, Canada,<sup>7,26</sup> and La Grande-2 (Robert Bourassa) Reservoir in Quebec, Canada.<sup>27</sup> ELA data indicate the site-wide peak in MeHg (1–2 years postflood) except for the filled circle, which represents 9-years post flooding.

results from prior work.<sup>6,7,26</sup> Labile organic carbon stimulates the activity of methylating microbes by providing substrate for respiration.<sup>4</sup> Oxygen consumed during organic carbon degradation creates optimal geochemical conditions for anaerobic microbes (mainly sulfate reducers in flooded soils),<sup>4,6</sup> thereby increasing MeHg production.

Indigenous lands are located within 100 km of all potential hydroelectric sites across Canada planned for near-term development (Figure 2). Modeled sediment-to-water MeHg fluxes across reservoirs range from 11–977  $\text{ng m}^{-2} \text{day}^{-1}$ . When normalized to soil organic carbon content, modeled fluxes (19–52  $\text{ng m}^{-2} \text{day}^{-1}$ ) are consistent with those calculated from peak water column MeHg concentrations for a whole-ecosystem flooding experiment in the Experimental Lakes Area (ELA), Canada (24–115  $\text{ng m}^{-2} \text{day}^{-1}$ ). For the Muskrat Falls reservoir, the expected mean flux (664  $\text{ng m}^{-2} \text{day}^{-1}$ ) is within the range reported for other natural systems (2–830  $\text{ng m}^{-2} \text{day}^{-1}$ ).<sup>47</sup>

Across Canada, MeHg concentrations in hydroelectric reservoirs following flooding range from negligible for generating stations and run of the river facilities to greater than 0.5  $\text{ng L}^{-1}$ . Forecasted MeHg concentrations in reservoir water for the Muskrat Falls site (0.19  $\text{ng L}^{-1}$ ) are moderate compared to other facilities across Canada due to its relatively smaller flooded area (41  $\text{km}^2$ ). Highest forecasted concentrations are for a planned facility in Quebec with a relatively large flooded area (144  $\text{km}^2$ ) (SI Table S3). Ten of the planned sites across Canada are expected to have postflooding MeHg concentrations lower than Muskrat Falls,

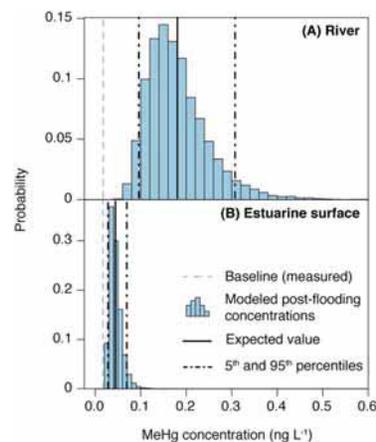


**Figure 2.** Planned locations for hydroelectric power expansion in Canada and indigenous populations with reserves or communities within 100 km of development regions (SI Table S3). Inset map shows the Muskrat Falls facility in Labrador and the three Inuit communities studied in this work. Reservoir MeHg concentrations are modeled for each site using the relationship shown in Figure 1 and site specific data on soil organic carbon content (upper 30 cm) of flooded reservoirs derived from satellite data, and the sediment-water flux parametrization shown in SI Table S1.

and 11 are expected to be higher (SI Figure S3). The four sites with highest projected MeHg concentrations ( $>0.35 \text{ ng L}^{-1}$ ) have relatively large flooded areas ( $85\text{--}144 \text{ km}^2$ ). Cumulatively, sites with projected MeHg concentrations higher than Muskrat Falls account for greater than 50% of the proposed new energy generation (SI Figure S3).

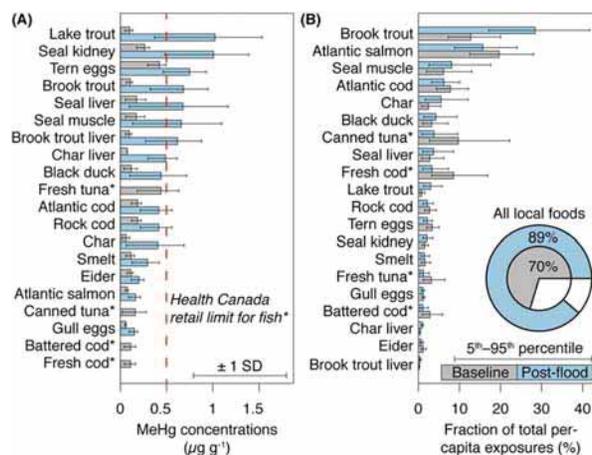
After flooding of the Muskrat Falls reservoir, the annual flow-weighted mean MeHg concentration in the Churchill River is projected to increase approximately 10-fold from a measured baseline value of  $17.5 \pm 11.5 \text{ pg L}^{-1}$  (SI Table S4) to an expected mean of  $180 \text{ pg L}^{-1}$ . The fifth and 95th percentile scenarios represent 5.5 to 17-fold enrichment ( $90\text{--}300 \text{ pg L}^{-1}$ ) relative to baseline concentrations (Figure 3). These changes represent substantial increases in MeHg concentrations in the freshwater environment that will be magnified in local food webs.

**Impacts on the Downstream Environment.** Few studies have considered the downstream impacts of enhanced MeHg concentrations in hydroelectric reservoirs. Kasper et al.<sup>48</sup> noted elevated fish MeHg concentrations up to 250 km downstream of the impoundment. However, the Muskrat Falls environmental impact assessment posited there would be no impact on a large fjord (Lake Melville) approximately 40 km downstream that contains treaty-negotiated hunting and fishing territory for Labrador Inuit, due to potential dilution throughout the water column.<sup>49</sup> By contrast, our previous research indicates the estuary is permanently stratified and freshwater inputs from the Churchill River are concentrated in the upper 10 m of the water column with limited mixing.<sup>24</sup> This concentrates riverine inputs within a relatively small volume of the estuary (the photic zone) that is most important for biological productivity, facilitating uptake at the base of estuarine food webs.<sup>24</sup>



**Figure 3.** Probabilistically modeled scenarios for MeHg increases in downstream river and estuary of the Muskrat Falls hydroelectric facility. Photochemical MeHg demethylation is assumed to occur continuously down the reach of the Churchill River into Lake Melville thus the river concentration reflects the average of reservoir concentrations and downstream inputs to Lake Melville.

Modeling conducted here indicates expected mean MeHg concentrations in Lake Melville surface waters will increase 2.6-fold following flooding of the Muskrat Falls reservoir from  $17 \text{ pg L}^{-1}$  to a peak level of  $44 \text{ pg L}^{-1}$  (Figure 3). The fifth percentile scenario suggests a lower bound increase of 1.6-fold ( $28 \text{ pg L}^{-1}$ ) and the 95th percentile scenario represents a 4-fold



**Figure 4.** Top 20 MeHg exposure sources for Inuit downstream of the Muskrat Falls hydroelectric reservoir before (measured in 2014) and after flooding (modeled peak concentration) planned for 2016–2017 (SI Table S1). Commercial species unaffected by local conditions are denoted by “\*”. Panel (A) shows MeHg concentrations in country foods relative to Health Canada retail limits for fish other than tuna ( $0.5 \mu\text{g g}^{-1}$ ).<sup>64</sup> Error bars indicate  $\pm 1$  standard deviation for baseline and postflooding (simulated) mean. Panel (B) shows relative changes in per-capita exposures based on the expected mean exposures from probabilistic simulations. Error bars indicate 5th–95th percentiles simulated for each species. Pie charts show population-wide MeHg exposure from country foods before (measured) and after (modeled) flooding, where white space corresponds to MeHg exposure from commercial foods. A complete list of MeHg concentrations in aquatic foods are available in SI Tables S6 and S11.

increase ( $69 \text{ pg L}^{-1}$ ). These results suggest substantial increases in MeHg concentrations in the downstream estuary will result from flooding of the Muskrat Falls reservoir, contrasting the results of the initial Environmental Impact Assessment.<sup>49</sup>

**Methylmercury Increases in Biota.** Impacts of enhanced aqueous MeHg concentrations in the river and estuary surrounding the Muskrat Falls site depend on the extent of bioaccumulation in local food webs. Site-specific BAFs for fish, birds, eggs and seal range from  $10^6$  to  $10^8$  (SI Table S7). Highest baseline MeHg concentrations are found in loon eggs, tern eggs, seal liver, and porpoise (literature value). Only porpoise presently exceeds the  $0.5 \mu\text{g MeHg g}^{-1}$  Canadian retail limit<sup>50</sup> for most fish (Figure 4, SI Table S6).

Modeled MeHg concentrations in the top 20 local foods contributing to Inuit MeHg exposure after flooding range from 1.3 to 10 times measured baseline concentrations (Figure 4). This is consistent with two- to 9-fold increases in fish MeHg concentrations previously reported for other Canadian reservoirs.<sup>36,51</sup> Variable impacts of flooding across species downstream of Muskrat Falls mainly reflects differences in foraging activity (i.e., time spent in the river, estuary and outer marine regions, SI Table S7). For example, brook trout are highly enriched in MeHg following flooding due to the large fraction of their lifespan spent in the freshwater environment (SI Table S11).

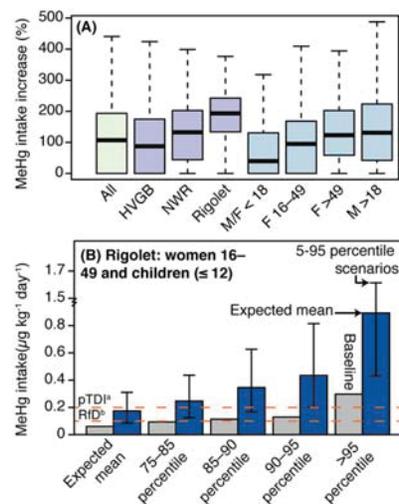
After flooding, expected mean MeHg concentrations in lake trout, seal, tern eggs, brook trout and char liver are all projected to be at or above the Canadian retail limit for MeHg (Figure 4A). Black duck, Atlantic cod and rock cod also exceed this level under the 95th percentile environmental increase scenario. After flooding, almost 90% of population-wide MeHg exposure is projected to be from locally caught foods (Figure 4B). Increasing MeHg burdens of traditional country foods consumed by Inuit will elevate their MeHg exposures and

may adversely affect local wildlife that are sensitive to high levels of MeHg exposure.<sup>52</sup>

**Inuit Exposures and Risks.** Measured hair Hg concentrations in 474 individuals from the three Inuit communities downstream of Muskrat Falls show over 90% of baseline (ca. 2014) MeHg exposures are below regulatory guidelines for MeHg in the U.S. and Canada (Figure S4). Highest exposures are found in the most northern community of Rigolet, where 24% of individuals presently exceed the U.S. Environmental Protection Agency’s (U.S. EPA) Reference Dose for MeHg (RfD,  $0.1 \mu\text{g kg}^{-1} \text{body weight day}^{-1}$ ), and 3% are above Health Canada’s (HC) provisional tolerable daily intake (pTDI,  $0.20\text{--}0.47 \mu\text{g kg}^{-1} \text{body weight day}^{-1}$ ). Mean exposure levels in Rigolet in 2014 were similar to those reported in the 2007–2008 Inuit Health Survey for other communities along the Labrador coastline.<sup>53</sup> All three Inuit communities downstream of Muskrat Falls have higher MeHg exposure levels than the general Canadian population due to greater consumption of aquatic foods.<sup>54</sup>

Following flooding of the Muskrat Falls reservoir, median MeHg exposures are expected to at least double for the majority of the downstream Inuit population (Figure 5A). Projected increases are greatest in the community of Rigolet, where the median exposure increase is projected to be almost three times baseline values. Disproportionate increases in MeHg exposures occur for individuals who are already the most highly exposed and consume the greatest quantities of country foods. For example, mean MeHg intake increases from  $0.15$  to  $0.50 \mu\text{g kg}^{-1} \text{day}^{-1}$  for individuals at the 90th percentile of postflooding exposures and this demographic accounts for nearly 60% of the total additional MeHg intake ( $\mu\text{g day}^{-1}$ ) following flooding.

Average MeHg exposure levels for women of childbearing age<sup>16–49</sup> and young children (age <12) in the community of



**Figure 5.** (a) Health Canada (HC) provisional tolerable daily intake ( $pTDI$ ); (b) U.S. EPA reference dose ( $RfD$ ) for MeHg. Modeled changes in Inuit MeHg exposures following flooding of the Muskrat Falls reservoir. Panel (A) shows exposure increases relative to measured baseline intake in 2014. Error bars indicate the 5th–95th percentile scenarios for MeHg increases in the flooded reservoir and biota based on probabilistic simulations. Panel (B) shows baseline and postflooding MeHg intake in women of childbearing age<sup>16–49</sup> and children (age <12) in the community of Rigolet. HVGB = Happy Valley–Goose Bay, NWR = North West River.

Rigolet exceed the U.S. EPA's  $RfD$  (Figure 5B) and are within 15% of Health Canada's provisional tolerable daily intake ( $pTDI$ ) level.<sup>55</sup> This demographic is most sensitive to the neurodevelopmental impacts of MeHg exposure.<sup>56</sup> Beyond the 75th percentile of this population, all individuals are above both regulatory guidelines for MeHg (Figure 5B). Grandjean and Budtz-Jorgensen<sup>57</sup> found imprecision in the biomonitoring data used to formulate the U.S. EPA's  $RfD$  led to an overestimate of 50% and proposed that a revised  $RfD$  of  $0.05 \mu\text{g kg}^{-1} \text{day}^{-1}$  ( $0.58 \mu\text{g Hg g}^{-1} \text{hair}$ ) would be more appropriate. In Rigolet, 77% of individuals exceed this level (Figure S5). Exposures are lower in the other two communities due to more limited consumption of country foods (Figure S6). Across the three communities, 41% of the total population and 28% of women of childbearing age (Figure S5) exceed the level proposed by Grandjean and Budtz-Jorgensen.<sup>57</sup>

Regulatory thresholds such as a  $RfD$  imply the existence of a safe level of chronic exposure. However, when formulating the  $RfD$ , the U.S. EPA itself acknowledged that “no evidence of a threshold arose for methylmercury-related neurotoxicity”.<sup>39</sup> Recent data from prospective birth cohorts support this conclusion.<sup>58–60</sup> For adults, the Health Canada  $pTDI$  is the least conservative across international regulatory agencies ( $0.47 \mu\text{g kg}^{-1} \text{day}^{-1}$ ). Therefore, all consumers of local foods are likely to face decreased net health benefits as a result of increased MeHg in local foods.

**Pan Canada Implications.** Modeled reservoir MeHg levels at 11 of the proposed 21 hydroelectric sites across Canada are comparable or greater than the Muskrat Falls reservoir (Figure

2). The communities of Happy Valley-Goose Bay and Northwest River consume fewer country foods than typical of most indigenous populations in Canada,<sup>53</sup> suggesting potentially greater exposures of other indigenous communities with moderate and high projected reservoir MeHg levels.

Country foods are known to confer a wide-range of nutritional and social health benefits to indigenous communities and nutritious alternative food choices are limited in the Canadian North.<sup>10,11</sup> Past studies suggest reducing or avoiding consumption of country foods may also result in substantial adverse impacts on individual health.<sup>61,62</sup> Reducing environmental MeHg concentrations associated with hydroelectric flooding should thus be prioritized as a mitigation measure. For example, soil organic carbon content could be used as a screening criterion for site selection or reservoirs could be designed to minimize flooded area. Mailman et al.<sup>63</sup> review a number of other interventions, such as the removal of organic carbon from the planned reservoir regions prior to flooding.

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.6b04447.

Details on reservoir model parameters and algorithms, characteristics of planned hydroelectric power facilities across Canada, probabilistic exposure assessment methods, dietary survey data and MeHg measurements in water column and biota are provided (PDF)

## ■ AUTHOR INFORMATION

### Corresponding Author

\*Phone: (617) 637-6484; fax: (617) 495-4551; e-mail: ry.calders@mail.harvard.edu.

### Notes

The authors declare no competing financial interest.

## ■ ACKNOWLEDGMENTS

This work was supported by the U.S. National Science Foundation (OCE 1260464 and 1130549), the Canadian Northern Contaminants Program, ArcticNet Inc., Tides Canada Oak Arctic Marine Fund Program, and the Nunatsiavut Government (NG). We thank research assistants employed by the NG for collection of dietary survey data, and Marina Biasutti-Brown, Tom Sheldon, Rodd Laing, and Trevor Bell for assistance with sample collection and human health survey work. We thank Nil Basu (McGill U.), Jane Kirk and Derek Muir (Env. Canada) for assistance with seal sample shipping and analysis and Neil Burgess (Env. Canada) for information on egg and bird Hg data and foraging behavior.

## ■ REFERENCES

- (1) Barros, N.; Cole, J. J.; Tranvik, L. J.; Prairie, Y. T.; Bastviken, D.; Huszar, V. L. M.; del Giorgio, P.; Roland, F. Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. *Nat. Geosci.* **2011**, *4* (9), S93–S96.
- (2) International Energy Agency (IEA). *Renewable Energy Essentials: Hydropower*, 2010.
- (3) Natural Resources Canada (NRCAN). About Renewable Energy. <http://www.nrcan.gc.ca/energy/electricity-infrastructure/about-electricity/7359> (accessed February 28, 2016).
- (4) St. Louis, V. L.; Rudd, J. W.; Kelly, C. A.; Bodaly, R.; Paterson, M. J.; Beaty, K. G.; Hesslein, R. H.; Heyes, A.; Majewski, A. R. The Rise

and fall of mercury methylation in an experimental reservoir. *Environ. Sci. Technol.* **2004**, *38* (5), 1348–1358.

(5) Rudd, J.; Harris, R.; Kelly, C.; Hecky, R. Are hydroelectric reservoirs significant sources of greenhouse gases? *Ambio*. **1993**, *22* (4), 246–248.

(6) Rosenberg, D. M.; Berkes, F.; Bodaly, R.; Hecky, R.; Kelly, C.; Rudd, J. W. Large-scale impacts of hydroelectric development. *Environ. Rev.* **1997**, *5* (1), 27–54.

(7) Hall, B. D.; St. Louis, V. L.; Rolfhus, K. R.; Bodaly, R. A.; Beaty, K. G.; Paterson, M. J.; Cherewyk, K. A. P. Impacts of reservoir creation on the biogeochemical cycling of methyl mercury and total mercury in boreal upland forests. *Ecosystems* **2005**, *8* (3), 248–266.

(8) Rolfhus, K.; Hurley, J.; Bodaly, R.; Perrine, G. Production and retention of methylmercury in inundated boreal forest soils. *Environ. Sci. Technol.* **2015**, *49* (6), 3482–3489.

(9) Johnston, T. A.; Bodaly, R.; Mathias, J. Predicting fish mercury levels from physical characteristics of boreal reservoirs. *Can. J. Fish. Aquat. Sci.* **1991**, *48* (8), 1468–1475.

(10) Kuhnlein, H.; Receveur, O. Local cultural animal food contributes high levels of nutrients for arctic Canadian indigenous adults and children. *J. Nutr.* **2007**, *137* (4), 1110–1114.

(11) Receveur, O.; Boulay, M.; Kuhnlein, H. V. Decreasing traditional food use affects diet quality for adult Dene/Métis in 16 communities of the Canadian Northwest Territories. *J. Nutr.* **1997**, *127* (11), 2179–2186.

(12) Donaldson, S.; Van Oostdam, J.; Tikhonov, C.; Feeley, M.; Armstrong, B.; Ayotte, P.; Boucher, O.; Bowers, W.; Chan, L.; Dallaire, F.; Dallaire, R.; Dewailly, E.; Edwards, J.; Egeland, G.; Fontaine, J.; Furgal, C.; Leech, T.; Loring, E.; Muckle, G.; Nancarrow, T.; Pereg, D.; Plusquellec, P.; Potyrala, M.; Receveur, O.; Shearer, R. Environmental contaminants and human health in the Canadian Arctic. *Sci. Total Environ.* **2010**, *408* (22), S165–S234.

(13) Stow, J.; Krümmel, E.; Leech, T.; Donaldson, S. What is the impact of mercury contamination on human health in the Arctic? In *AMAP Assessment 2011: Mercury in the Arctic*; Arctic Monitoring and Assessment Programme (AMAP): Oslo, Norway, 2011.

(14) National Research Council (NRC). *Toxicological Effects of Methylmercury*; National Academies Press: Washington, DC, 2000.

(15) Valera, B.; Dewailly, E.; Poirier, P. Impact of mercury exposure on blood pressure and cardiac autonomic activity among Cree adults (James Bay, Quebec, Canada). *Environ. Res.* **2011**, *111*, 1265–1270.

(16) Valera, B.; Dewailly, E.; Poirier, P. Association between methylmercury and cardiovascular risk factors in a native population of Quebec (Canada): A retrospective evaluation. *Environ. Res.* **2013**, *120*, 102–108.

(17) Boucher, O.; Jacobson, S.; Plusquellec, P.; Dewailly, E.; Ayotte, P.; Forget-Dubois, N.; Jacobson, J.; L, J.; Muckle, G. Prenatal methylmercury, postnatal lead exposure, and evidence of attention deficit/hyperactivity disorder among Inuit children in Arctic Quebec. *Environ. Health Perspect.* **2012**, *120* (10), 1456–1461.

(18) Clarkson, T. W.; Amin-Zaki, L.; Al-Tikriti, S. An outbreak of methylmercury poisoning due to consumption of contaminated grain. *Federation proceedings* **1976**, *35* (12), 2395–2399.

(19) Methylmercury Study Group. *McGill Methylmercury Study*. 1980.

(20) Dumont, C.; Girard, M.; Bellavance, F. O.; Noël, F. Mercury levels in the Cree population of James Bay, Quebec, from 1988 to 1993/94. *Can. Med. Assoc. J.* **1998**, *158* (11), 1439–1445.

(21) Amos, H. M.; Jacob, D. J.; Streets, D. G.; Sunderland, E. M. Legacy impacts of all-time anthropogenic emissions on the global mercury cycle. *Global Biogeochem. Cy.* **2013**, *27* (2), 410–421.

(22) Smith-Downey, N.; Sunderland, E.; Jacob, D. Anthropogenic impacts on global storage and emissions of mercury from terrestrial soils: Insights from a new global model. *J. Geophys. Res.* **2010**, *115*, G03008.

(23) Lavoie, R. A.; Jardine, T. D.; Chumchal, M. M.; Kidd, K. A.; Campbell, L. M. Biomagnification of mercury in aquatic food webs: a worldwide meta-analysis. *Environ. Sci. Technol.* **2013**, *47* (23), 13385–13394.

(24) Schartup, A. T.; Balcom, P. H.; Soerensen, A. L.; Gosnell, K. J.; Calder, R. S. D.; Mason, R. P.; Sunderland, E. M. Freshwater discharges drive high levels of methylmercury in Arctic marine biota. *Proc. Natl. Acad. Sci. U. S. A.* **2015**, *112* (38), 11789–94.

(25) Anderson, M. Duration and extent of elevated mercury levels in downstream fish following reservoir creation. *River Syst.* **2011**, *19* (3), 167–176.

(26) Rolfhus, K. R.; Hurley, J. P.; Bodaly, R. A.; Perrine, G. Production and retention of methylmercury in inundated boreal forest soils. *Environ. Sci. Technol.* **2015**, *49* (6), 3482–3489.

(27) Mucci, A.; Montgomery, S.; Lucotte, M.; Plourde, Y.; Pichet, P.; Tra, H. V. Mercury remobilization from flooded soils in a hydroelectric reservoir of northern Quebec, La Grande-2: results of a soil resuspension experiment. *Can. J. Fish. Aquat. Sci.* **1995**, *52* (11), 2507–2517.

(28) Meng, B.; Feng, X.; Qiu, G.; Li, Z.; Yao, H.; Shang, L.; Yan, H. The impacts of organic matter on the distribution and methylation of mercury in a hydroelectric reservoir in Wujiang River, Southwest China. *Environ. Toxicol. Chem.* **2016**, *35* (1), 191–199.

(29) Schetagne, R.; Verdon, R. Post-impoundment evolution of fish mercury levels at the La Grande Complex, Québec, Canada (from 1978 to 1996). In *Mercury in the Biogeochemical Cycle*; Lucotte, M. et al., Eds.; Springer, 1999; pp 235–258.

(30) Qian, Y.; Follett, R. Carbon Dynamics and Sequestration in Urban Turfgrass Ecosystems. In *Carbon Sequestration in Urban Ecosystems*; Lal, R.; Augustin, B., Eds.; Springer, 2012, 161–172.

(31) European Soil Data Centre (ESDAC). *Global Soil Organic Carbon Estimates*, 2015.

(32) Périé, C.; Ouimet, R. Organic carbon, organic matter and bulk density relationships in boreal forest soils. *Can. J. Soil Sci.* **2008**, *88* (3), 315–325.

(33) Lu, Z.; DeYoung, B.; Banton, S. *Analysis of Physical Oceanographic Data from Lake Melville, Labrador, September 2012 - July 2013*; Memorial University of Newfoundland: St. John's, Newfoundland, 2014.

(34) Soerensen, A. L.; Jacob, D. J.; Schartup, A. T.; Fisher, J. A.; Lehnher, I.; Louis, V. L.; St; Heimbürger, L. E.; Sonke, J. E.; Krabbenhoft, D. P.; Sunderland, E. M. A mass budget for mercury and methylmercury in the Arctic Ocean. *Global Biogeochem. Cy.* **2016**, *30* (4), 560–575.

(35) Li, M.; Schartup, A. T.; Valberg, A. P.; Ewald, J. D.; Krabbenhoft, D. P.; Yin, R.; Balcom, P. H.; Sunderland, E. M. Environmental Origins of Methylmercury Accumulated in Subarctic Estuarine Fish Indicated by Mercury Stable Isotopes. *Environ. Sci. Technol.* **2016**. DOI: 10.1021/acs.est.6b03206.

(36) Verdon, R.; Brouard, D.; Demers, C.; Lalumière, R.; Laperle, M.; Schetagne, R. Mercury evolution (1978–1988) in fishes of the La Grande hydroelectric complex, Quebec, Canada. *Water, Air, Soil Pollut.* **1991**, *56*, 405–417.

(37) Brouard, D.; Doyon, J.-F.; Schetagne, R. Amplification of Mercury Concentrations in Lake Whitefish (*Coregonus clupeaformis*) Downstream from the La Grande 2 Reservoir, James Bay, Quebec. In *Mercury Pollution Integration and Synthesis*; Watras, C. J.; Huckabee, J. W., Eds.; CRC Press, 1994.

(38) Berglund, M.; Lind, B.; Bjornberg, K. A.; Palm, B.; Einarsson, O.; Vahter, M. Inter-individual variations of human mercury exposure biomarkers: a cross-sectional assessment. *Environ. Health* **2005**, *4*, 20.

(39) United States Environmental Protection Agency (US EPA). Methylmercury (MeHg); CASRN 22967-92-6. In *Integrated Risk Information System (IRIS)*, 2002.

(40) World Health Organization (WHO). *Methylmercury*, 1990.

(41) Li, M.; von Stackelberg, K.; Rheinberger, C. M.; Hammitt, J. K.; Krabbenhoft, D. P.; Yin, R.; Sunderland, E. M. Insights from mercury stable isotopes into factors affecting the internal body burden of methylmercury in frequent fish consumers. *Elementa*. **2016**, *4*, 000103.

(42) Lincoln, R. A.; Shine, J. P.; Chesney, E. J.; Vorhees, D. J.; Grandjean, P.; Senn, D. B. Fish consumption and mercury exposure among Louisiana recreational anglers. *Environ. Health Perspect.* **2011**, *119* (2), 245–251.

- (43) Dong, Z.; Jim, R. C.; Hatley, E. L.; Backus, A. S.; Shine, J. P.; Spengler, J. D.; Schaidler, L. A. A longitudinal study of mercury exposure associated with consumption of freshwater fish from a reservoir in rural south central USA. *Environ. Res.* **2015**, *136*, 155–62.
- (44) Carrington, C. D.; Bolger, M. P. An exposure assessment for methylmercury from seafood for consumers in the United States. *Risk Anal* **2002**, *22* (4), 689–699.
- (45) Statistics Canada. 2011 National Household Survey. 2013.
- (46) Statistics Canada. 2011 Census. 2012.
- (47) Gill, G. A.; Bloom, N. S.; Cappellino, S.; Driscoll, C. T.; Dobbs, C.; McShea, L.; Mason, R.; Rudd, J. W. Sediment-water fluxes of mercury in Lavaca Bay, Texas. *Environ. Sci. Technol.* **1999**, *33* (5), 663–669.
- (48) Kasper, D.; Forsberg, B. R.; Amaral, J. O. H.; Leitão, R. P.; Py-Daniel, S. S.; Bastos, W. R.; Malm, O. Reservoir Stratification Affects Methylmercury Levels in River Water, Plankton, and Fish Downstream from Balbina Hydroelectric Dam, Amazonas, Brazil. *Environ. Sci. Technol.* **2014**, *48* (2), 1032–1040.
- (49) Nalcor Energy. *Biophysical Assessment*, 2009.
- (50) Health Canada. *Health Canada's Maximum Levels for Chemical Contaminants in Foods*. <http://www.hc-sc.gc.ca/fn-an/securit/chem-chim/contaminants-guidelines-directives-eng.php> (accessed August 16, 2016).
- (51) Harris, R.; Hutchinson, D. *Assessment of the Potential for Increased Mercury Concentrations*. 2008.
- (52) Depew, D. C.; Basu, N.; Burgess, N. M.; Campbell, L. M.; Devlin, E. W.; Drevnick, P. E.; Hammerschmidt, C. R.; Murphy, C. A.; Sandheinrich, M. B.; Wiener, J. G. Toxicity of dietary methylmercury to fish: derivation of ecologically meaningful threshold concentrations. *Environ. Toxicol. Chem.* **2012**, *31* (7), 1536–1547.
- (53) Chan, H. M. L. *Contaminant Assessment in Nunatsiavut*. 2011.
- (54) Lye, E.; Legrand, M.; Clarke, J.; Probert, A. Blood total mercury concentrations in the Canadian population: Canadian health measures survey cycle 1, 2007–2009. *Can. J. Public Health.* **2013**, *104* (3), E246–E251.
- (55) Health Canada. *Mercury: Your Health and the Environment: A Resource Tool*, 2004.
- (56) Mahaffey, K. R.; Sunderland, E. M.; Chan, H. M.; Choi, A. L.; Grandjean, P.; Mariën, K.; Oken, E.; Sakamoto, M.; Schoeny, R.; Weihe, P.; Yan, C.-H.; Yasutake, A. Balancing the benefits of n-3 polyunsaturated fatty acids and the risks of methylmercury exposure from fish consumption. *Nutr. Rev.* **2011**, *69* (9), 493–508.
- (57) Grandjean, P.; Budtz-Jørgensen, E. Total imprecision of exposure biomarkers: implications for calculating exposure limits. *Am. J. Ind. Med.* **2007**, *50* (10), 712–719.
- (58) Rice, G. E.; Hammitt, J. K.; Evans, J. S. A probabilistic characterization of the health benefits of reducing methyl mercury intake in the United States. *Environ. Sci. Technol.* **2010**, *44* (13), S216–S224.
- (59) Karagas, M.; Choi, A. L.; Oken, E.; Horvat, M.; Schoeny, R.; Kamai, E.; Grandjean, P.; Korrick, S. Evidence on the human health effects of low level methylmercury exposure. *Environ. Health Perspect.* **2012**, *120* (6), 799–806.
- (60) Roman, H. A.; Walsh, T. L.; Coull, B. A.; Dewailly, E.; Guallar, E.; Hattis, D.; Marien, K.; Schwartz, J.; Stern, A. H.; Virtanen, J. K.; Rice, G. Evaluation of the cardiovascular effects of methylmercury exposures: current evidence supports development of a dose-response function for regulatory benefits analysis. *Environ. Health Perspect.* **2011**, *119* (5), 607–14.
- (61) Wheatley, B.; Paradis, S. Balancing human exposure, risk and reality: questions raised by the Canadian aboriginal methylmercury program. *Neurotoxicology.* **1996**, *17* (1), 241–249.
- (62) Furgal, C.; Powell, S.; Myers, H. Digesting the message about contaminants and country foods in the Canadian North: a review and recommendations for future research and action. *Arctic* **2005**, *58*, 103–114.
- (63) Mailman, M.; Stepnuk, L.; Cicek, N.; Bodaly, R. A. Strategies to lower methyl mercury concentrations in hydroelectric reservoirs and lakes: A review. *Sci. Total Environ.* **2006**, *368* (1), 224–235.
- (64) Health Canada. *Updating the Existing Risk Management Strategy for Mercury in Retail Fish*, 2007.

## Supporting Information

### Future Impacts of Hydroelectric Power Development on Methylmercury Exposures of Canadian Indigenous Communities

Ryan S.D. Calder<sup>a,b\*</sup>, Amina T. Schartup<sup>a,b</sup>, Miling Li<sup>a,b</sup>, Amelia P. Valberg<sup>a</sup>, Prentiss Balcom<sup>b</sup>, and Elsie M. Sunderland<sup>a,b</sup>

<sup>a</sup> Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston MA, 02215, USA

<sup>b</sup> Harvard John A. Paulson School of Engineering and Applied Sciences, Cambridge MA, 02138, USA

\*Corresponding author: 29 Oxford St., Cambridge MA, 02138, United States. T: (617) 637-6484; F: (617) 495-4551. [ry.calder@mail.harvard.edu](mailto:ry.calder@mail.harvard.edu)

## Contents

Supplemental Information on Seal Mercury Analyses . . . . .10

## Tables

Table S1. Methods used to calculate transport of MeHg from sediment into the water column . . . . .	2
Table S2. Distribution of parameters for MeHg flux from sediments to water column . . . . .	3
Table S3. Characteristics of planned hydroelectric power projects across Canada . . . . .	4
Table S4. Measured methylmercury concentrations in the Churchill River between 2012-2015 . . . . .	6
Table S5. Community-based monitoring of fish species from the Lake Melville region . . . . .	7
Table S6a. MeHg concentrations in aquatic species harvested from the Lake Melville region . . . . .	8
Table S6b. . . . .	9
Table S7a. MeHg bioaccumulation factors, concentrations and lifetime habitat fractions . . . . .	11
Table S7b. . . . .	12
Table S8. Hair mercury analyses of Inuit individuals . . . . .	14
Table S9. Food frequency questionnaire (FFQ) data collected from Inuit . . . . .	15
Table S10. MeHg concentrations in aquatic foods harvested outside the Lake Melville region . . . . .	16
Table S11a. Modeled MeHg concentrations in country foods after flooding . . . . .	18
Table S11b. . . . .	19

## Figures

Figure S1. Schematic of model for mercury cycling the Lake Melville estuary . . . . .	5
Figure S2. Map of the Labrador Inuit Settlement Area . . . . .	13
Figure S3. Number of proposed hydroelectric sites with reservoir MeHg concentrations . . . . .	17
Figure S4. Measured concentrations of total Hg in hair from three Inuit communities . . . . .	20
Figure S5. Baseline and post-flooding MeHg intake relative to intake levels . . . . .	21
Figure S6. Fraction of population exceeding exposure thresholds at baseline . . . . .	22

**Table S1.** Methods used to calculate sediment-water exchange of MeHg.

$J$ (ng m <sup>-2</sup> s <sup>-1</sup> )	Flux of MeHg into the water column based on the mass transfer formulation of Steinberger and Hondzo (1)	$J = \frac{C_{pw} - C_w}{\delta_d} D$
$D$ (m <sup>2</sup> s <sup>-1</sup> )	Molecular diffusivity for MeHg (2)	2x10 <sup>-10</sup> (macromolecular organic complexes)
$dC_w/dt$ (ng L <sup>-1</sup> s <sup>-1</sup> )	Rate of change of MeHg concentration in the water column determined by flux from flooded soil and outflow from river	$\frac{1}{V} \left( \frac{C_{pw} - C_w}{\delta_d} D A_f - Q C_w + Q C_{wb} \right) 10^3 \frac{L}{m^3}$
$C_w$ (ng L <sup>-1</sup> )	Steady state ( $dC_w/dt = 0$ ) concentrations of MeHg in reservoir water	$\frac{C_{pw} \cdot D \cdot A_f}{D \cdot A_f + \delta_d \cdot Q} + C_{wb}$
$C_{pw}$ (ng L <sup>-1</sup> )	Concentration of MeHg in interstitial waters	Derived from empirical relationship in Figure 1 and $K_d$
$C_{wb}$ (ng L <sup>-1</sup> )	Pre-impoundment riverine MeHg (3)	0.0175
$\log K_d$ [L kg <sup>-1</sup> ]	Sediment-water partition coefficient based on measurements (3)	2.93±0.16
$A_f$ (m <sup>2</sup> )	Land area flooded	Table S2
$Q$ (m <sup>3</sup> s <sup>-1</sup> )	River flow	Table S2
$\delta_d$ (m)	Thickness of the diffusive sublayer controlled by turbulent action based on Peterson (4)	$v^{1-\frac{1}{n}} \cdot \frac{1}{\sqrt{\tau/\rho}} \cdot D^{\frac{1}{n}} \cdot c^{-\frac{1}{n}}$
$\nu$ (m <sup>2</sup> s <sup>-1</sup> )	Kinematic viscosity of water	1.3x10 <sup>-6</sup>
$\rho$ (kg m <sup>-3</sup> )	Density of water	10 <sup>3</sup>
$C$ (unitless)	Coefficient	0.000463
$n$ (unitless)	Coefficient	3.38
$\tau$ (N m <sup>-2</sup> )	Post-impoundment shear stress at the sediment-water interface based on Wilcock (5)	$\left[ U \cdot \kappa / \ln \left( \frac{h}{e \cdot a \cdot \frac{d_{90}}{30}} \right) \right]^2 \rho$
$U$ (m s <sup>-1</sup> )	Average current velocity based on Muskrat Falls facility (6)	0.1
$\kappa$ (unitless)	von Karman constant	0.41
$d_{90}$ (mm)	90 <sup>th</sup> percentile solids diameter based on the predominant soil type in the Muskrat Falls reservoir area (7, 8)	0.2
$a$ (unitless)	Constant	2.85
$h$ (m)	Height of the channel based on Muskrat Falls facility	16.8
$e$ (unitless)	Base of the natural logarithm	2.718

**Table S2.** Distributions of uncertain parameters used to simulate MeHg enrichment in water and biota in flooded reservoirs. Table S1 contains the complete parameterization for sediment-to-water fluxes of MeHg.

Parameter	Distribution
90 <sup>th</sup> percentile solids diameter in reservoir ( $d_{90}$ , mm) <sup>a</sup>	Triangular: min = 0.005, max = 1, mode = 0.2
Sediment-water partition coefficient ( $\log K_d$ , L kg <sup>-1</sup> ) <sup>b</sup>	Normal: $\mu = 2.96$ , $\sigma = 2.54$
Degradation of MeHg during downstream transport to estuary (fraction lost) <sup>c</sup>	Uniform: min = 0.3, max = 0.5
Fraction of excess riverine MeHg demethylatable in Lake Melville <sup>d</sup>	Uniform: min = 0, max = 1
Estuarine fraction of lifespan for key marine species <sup>e</sup>	Uniform: min = 0, max = 0.5
Estuarine fraction of lifespan for key bird species <sup>f</sup>	Uniform: min = 0.5, max = 1
Riverine fraction of lifespan for seals <sup>g</sup>	Uniform: min = 0, max = 0.25

<sup>a</sup> Mode based on the dominant soil type (podzol) in the Muskrat Falls region (7); minimum and maximum values represent ranges across a variety of soil types (8).

<sup>b</sup> Probability distribution for site-wide mean derived from measurements (5).

<sup>c</sup> Maximum degradation is based on upper limit suggested by Schartup et al. (3); minimum is based on degradation rate measured by Jonsson et al. (9).

<sup>d</sup> MeHg complexed to terrestrial organic ligands may be resistant to degradation (9).

<sup>e</sup> Fraction of MeHg obtained from the estuarine environment during foraging and/or spawning is uncertain for Atlantic cod, Atlantic salmon, and rock cod.

<sup>f</sup> Seabirds (eider, tern, guillemot and gull) are found in both the marine and estuarine environments. Some birds consumed by Inuit may spend their entire life history foraging in the estuary (maximum) or in outer marine areas (minimum).

<sup>g</sup> Inuit hunters report seasonal seal foraging in the freshwater environment.

**Table S3.** Characteristics of planned hydroelectric power projects across Canada.

Hydroelectric Project (River, Province/Territory)	Flow (m <sup>3</sup> s <sup>-1</sup> )	Flood area (km <sup>2</sup> )	Post-flood MeHg (ng L <sup>-1</sup> )	Capacity (MW)	Indigenous populations within 100 km <sup>a</sup>
False Canyon (Liard, YT) <sup>b</sup>	151	160	0.24	58	Liard
Middle Canyon (Liard, YT) <sup>b</sup>	160	90	0.21	38	Liard, Dease
Detour Canyon (Pelly, YT) <sup>b</sup>	257	135	0.22	65	Selkirk, Little Salmon
Granite Canyon (Pelly, YT) <sup>b</sup>	362	170	0.21	254	
Hoole Canyon (Pelly, YT) <sup>b</sup>	97	25	0.13	13	Ross River
Slate Rapids (Pelly, YT) <sup>b</sup>	53	136	0.35	42	
Fraser Falls (Stewart, YT) <sup>b</sup>	359	570	0.29	300	Nacho Nyak Dun, Selkirk
Two Mile Canyon (Stewart, YT) <sup>b</sup>	166	105	0.18	53	Nacho Nyak Dun
La Martre (La Martre, NT) <sup>c</sup>	31	0	•	13	Whati
Lutselk'e (Snowdrift, NT) <sup>c</sup>	42	0	•	1	Lutsel K'e Dene
Site C (Peace, BC) <sup>d</sup>	1251	53	0.04	1100	West Moberly, Saulteau, Doig River, Halfway River, Blueberry River
Amisk (Peace, AB) <sup>e</sup>	1600	8	•	330	Duncan's, Horse Lake, Peavine Metis
Tazi Twé (Fond du Lac, SK) <sup>f</sup>	304	0	•	50	Black Lake, Fond du Lac
Keeyask (Nelson, MB) <sup>g</sup>	3100	45	0.06	695	Fox Lake, War Lake, York Factory, Tataskweyak, Bunibonibee
Conawapa (Nelson, MB) <sup>h</sup>	3100	5	0.04	500	Fox Lake
New Post Creek (Abitibi, ON) <sup>i</sup>	42	2	0.04	25	Taykwa Tagamou
Romaine 1 (La Romaine, QC) <sup>j</sup>	291	12	0.35	270	Quebec Innu (Ekuanitshit, Nutashkuan)
Romaine 2 (La Romaine, QC) <sup>j</sup>	291	85	0.38	640	
Romaine 3 (La Romaine, QC) <sup>j</sup>	291	37	0.20	395	
Romaine 4 (La Romaine, QC) <sup>j</sup>	291	144	0.55	245	
Muskkrat Falls (Churchill, NL) <sup>k</sup>	1829	41	0.19	824	Labrador Inuit, Innu and Metis
Gull Island (Churchill, NL) <sup>k</sup>	1829	85	0.37	2250	

• Negligible increase from baseline.

<sup>a</sup> First Nations unless otherwise specified. Locations on Figure 2 are centroids of traditional lands (10, 11). First Nations populations are those living on their respective reserves and unceded lands (12).

<sup>b</sup> Comparative feasibility assessment ongoing (13).

<sup>c</sup> Under review (14).

<sup>d</sup> Construction began in 2015 and will continue through 2024 (15, 16).

<sup>e</sup> Permitting process ongoing. Peavine settlement is 169 km from project but traditional lands review is ongoing (17).

<sup>f</sup> Permitting process ongoing (18).

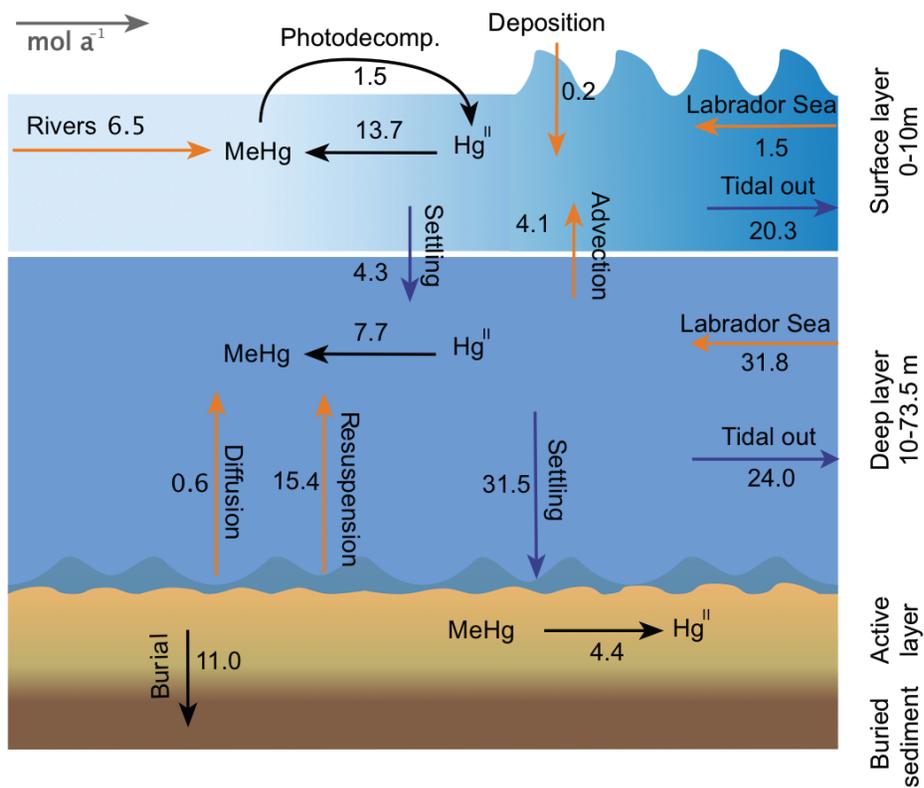
<sup>g</sup> Construction began in 2014 and will continue through 2021 (19, 20).

<sup>h</sup> Planning activities suspended pending results of resources planning review (21).

<sup>i</sup> Construction began in 2015 and will continue through 2018 (22).

<sup>j</sup> Construction began in 2009 and will continue through 2017 (Romaine 3) – 2020 (Romaine 4). Construction complete on Romaine 1 and 2. Nutashkuan (132 km from Romaine 1) and Ekuanitshit and are the indigenous communities found to use the land impacted by the development (23).

<sup>k</sup> Construction of Muskkrat Falls began in 2013 and will continue through 2017 (24). A construction timetable for Gull Island has not been released. Labrador Metis (NunatuKavut) is not plotted on Figure 2 because it does not have a recognized land claim.



**Figure S1.** Schematic of model for mercury cycling the Lake Melville estuary Labrador adapted from Schartup et al. (3) for this analysis. Hydrodynamic data used to calculate mixing are from Lu et al. (25).

**Table S4.** Measured MeHg concentrations in the Churchill River between 2012-2015. Analytical procedures are described in Schartup et al. (3).

Season	Month - Year	Churchill River discharge (m <sup>3</sup> day <sup>-1</sup> )	MeHg (pg L <sup>-1</sup> )	<i>n</i>	Weighted mean (pg L <sup>-1</sup> )	Weighted SD (pg L <sup>-1</sup> )
Winter					26.53	1.66
	Dec	1.56E+08	27.49 <sup>a</sup>	–		
	Jan-15	1.56E+08	27.49	1		
	Feb-15	1.57E+08	24.62	1		
Spring					26.36	12.76
	Mar-15	1.47E+08	23.21	1		
	Apr-14	1.35E+08	11.83	1		
	May-14	2.31E+08	36.91	1		
Summer					4.99	1.15
	Jun-13/14	2.03E+08	5.91	2		
	Jul-14	1.45E+08	5.01	1		
	Aug-14	1.36E+08	3.61	1		
Fall					11.22	–
	Sep-12/14	1.32E+08	11.20	2		
	Oct	1.45E+08	11.20 <sup>a</sup>	–		
	Nov	1.53E+08	11.20 <sup>a</sup>	–		
<b>Annual</b>					<b>17.94</b>	<b>11.46</b>

<sup>a</sup>No data were available for this month so MeHg concentrations are based on a month with similar water discharges.

**Table S5.** Community-based monitoring of fish species from the Lake Melville region between 2014-2015. Analytical methods for total Hg and MeHg analysis are provided in Li et al. (26)

Sample	Location	Date	<i>n</i>	Sampled By
Smelt	Churchill River	September 2014	7	Inuit residents of North West River and Rigolet
Brook Trout	Lake Melville		20	Inuit residents of North West River and Rigolet
Lake Trout	Churchill River	June-July 2014	13	Field Research Coordinator
Stickleback	Churchill River and Lake Melville	July-Sept 2014	30	Field Research Coordinator
Salmon	Lake Melville (Rigolet area)	July 2014	3	Rigolet fishers
Long Nose Sucker	Lake Melville (between NWR/Rigolet)	July-Aug 2014	20	Inuit fishers, North West River and Rigolet
Whitefish	Lake Melville (between NWR/Rigolet)	July-Aug 2014	20	Inuit fishers, North West River and Rigolet
Flatfish	Lake Melville (between NWR/Rigolet)	July-Aug 2014	20	Inuit fishers, North West River and Rigolet
Pike	Churchill River	July-Aug 2014 August 2015	13	Inuit fishers (HVGB)
Arctic Char	20 miles East of Rigolet	August 2015	10	Inuit fisher (Rigolet)
Atlantic Cod	St. Lewis Bay	September 2014	5	Labrador fisher
Mussels	Rigolet and NWR areas	June 2015	10	Inuit hunter
Misc. river fish	Churchill River above Muskrat Falls	August 2015	10	Inuit fishers

**Table S6a.** MeHg concentrations in aquatic species harvested from the Lake Melville region. Fish and bird concentrations are for fillets/muscle unless noted.

Species	MeHg ( $\mu\text{g g}^{-1}$ ) Mean $\pm$ SD	n	Data Source
Seal ( <i>Phoca hispida</i> ) <1 year (80%) <sup>a</sup>			
Muscle	0.11 $\pm$ 0.09	34	This study
Liver	0.13 $\pm$ 0.16	50	This study
Kidney	0.24 $\pm$ 0.12	14	This study <sup>b</sup>
Seal 1-4 years (10%) <sup>a</sup>			
Muscle	0.21 $\pm$ 0.17	18	This study, Brown et al. (27)
Liver	0.28 $\pm$ 0.29	n/a	Mean of age classes < 1 year and > 4 years.
Kidney	0.31 $\pm$ 0.15	n/a	
Seal > 4 years (10%) <sup>a</sup>			
Muscle	0.39 $\pm$ 0.51	68	This study, Brown et al. (27)
Liver	0.43 $\pm$ 0.37	3	This study
Kidney	0.38 $\pm$ 0.17	3	This study <sup>b</sup>
Atlantic Salmon ( <i>Salmo salar</i> )			
Fillet	0.07 $\pm$ 0.02	12	Li et al. (26)
Roe	0.01 $\pm$ 0.004	n/a	This study <sup>c</sup>
Liver	0.09 $\pm$ 0.02	n/a	This study <sup>d</sup>
Atlantic cod ( <i>Gadus morhua</i> )	0.19 $\pm$ 0.06	5	Li et al. (26)
Arctic char ( <i>Salvelinus alpinus</i> )			
Fillet	0.06 $\pm$ 0.04	4	Li et al. (26)
Roe	0.01	n/a	This study <sup>c</sup>
Liver	0.08	n/a	This study <sup>d</sup>
Sculpin ( <i>Myoxocephalus scorpius</i> )			
Fillet	0.23 $\pm$ 0.09	10	Li et al. (26)
Liver	0.11 $\pm$ 0.11	10	This study <sup>e</sup>
Brook trout ( <i>Salvelinus fontinalis</i> )			
Fillet	0.10 $\pm$ 0.03	48	Li et al. (26)
Liver	0.10 $\pm$ 0.03	18	This study <sup>f</sup>
Roe	0.05 $\pm$ 0.02	17	This study
Ouananiche ( <i>Salmo salar m. sebago</i> )	0.15 $\pm$ 0.11	18	Jacques Whitford Environment Ltd (28)
Lake trout ( <i>Salvelinus namaycush</i> )	0.99 $\pm$ 0.46	28	Jacques Whitford Environment Ltd (28)

<sup>a</sup> Fraction of total seal harvest in each age class estimated by Inuit seal hunters in 2015.

<sup>b</sup> Fraction of total Hg as methylmercury in kidney estimated as 26% from Northern Quebec ringed seals; moisture content estimated as 29% (29).

<sup>c</sup> Estimated from salmon fillet:roe ratio (30).

<sup>d</sup> Estimated from salmon fillet:liver ratio (30).

<sup>e</sup> Estimated as 50% MeHg as a fraction of total Hg from literature values (31).

<sup>f</sup> Estimated 62% MeHg as a fraction of total Hg based on salmon liver (30).

<sup>d</sup> Estimated from salmon fillet:liver ratio (30).

<sup>e</sup> Based on 44% MeHg as a fraction of total Hg as for molluscs (32).

<sup>f</sup> Converted from dry weight using moisture content from gull samples.

**Table S6b.** MeHg concentrations in aquatic species harvested from the Lake Melville region. Fish and bird concentrations are for fillets/muscle unless noted.

Species	MeHg ( $\mu\text{g g}^{-1}$ ) Mean $\pm$ SD	<i>n</i>	Data Source
Flatfish ( <i>Pleuronectoide sp.</i> )	0.07 $\pm$ 0.04	20	Li et al. (26)
Capelin ( <i>Mallotus villosus</i> )			
Fillet	0.02 $\pm$ 0.002	6	Li et al. (26)
Roe	0.002 <sup>a</sup>		
Rainbow smelt ( <i>Osmerus mordax</i> )	0.11 $\pm$ 0.05	18	Li et al. (26)
Mussels ( <i>Mytilus edulis</i> )	0.004 $\pm$ 0.0005	6	Li et al. (26)
Porpoise ( <i>Phocoena phocoena</i> )			
Muscle	0.60 $\pm$ 0.06 <sup>b</sup>	20	Das et al. (33) (Atl. Norway)
Liver	1.22 $\pm$ 0.87 <sup>b,c</sup>	21	Das et al. (33) (Atl. Norway)
Rock cod ( <i>Gadus ogac</i> )			
Fillet	0.19 $\pm$ 0.06		Assumed equal to cod
Liver	0.23 <sup>d</sup>		
Green sea urchin ( <i>Strongylocentrotus droebachiensis</i> )	0.04	8	Noël et al. (34)
Periwinkle ( <i>Littorina littorea</i> )	0.04	40	Noël et al. (34)
Clams ( <i>Arctica islandica</i> )	0.01 $\pm$ 0.01	15	US FDA (35)
Scallops ( <i>Amusium laurenti</i> )	0.01 <sup>e</sup>	200	Karimi et al. (36)
Gull ( <i>Rissa tridactyla</i> )			
Muscle	0.23 $\pm$ 0.27	7	Lavoie et al. (37)
Eggs	0.06 $\pm$ 0.01	20	Lavoie et al. (38)
Tern ( <i>Sterna paradisaea</i> )			
Muscle	0.23 $\pm$ 0.25 <sup>f</sup>	12	Clayden et al. (39)
Eggs	0.42 $\pm$ 0.25 <sup>f</sup>	17	Clayden et al. (39)
Guillemot ( <i>Cepphus grylle</i> )			
Muscle	0.27 $\pm$ 0.07	3	Braune et al. (40) (Nfld.)
Eggs	0.21 $\pm$ 0.01	20	Lavoie et al. (38)
Black duck ( <i>Anas rubripes</i> )			
Muscle	0.11 $\pm$ 0.08	12	Braune et al. (40) (Nfld. + Labrador)
Eggs	0.03 $\pm$ 0.003		Schwarzbach and Adelsbach (41) – mallards, CA.
Eider ( <i>Somateria mollissima</i> )			
Muscle	0.11 $\pm$ 0.03	8	Braune et al. (40) (Nfld. + Labrador)
Loon ( <i>Gavia immer</i> )			
Eggs	0.90 $\pm$ 1.88	29	Evers et al. (42) (Maritimes)
Sandpiper ( <i>Calidris pusilla</i> )			
Muscle	0.07 $\pm$ 0.01	19	Burger et al. (2014)

<sup>a</sup> Estimated from salmon fillet:roe ratio (30).

<sup>b</sup> Converted from dry weight using moisture content from seal.

<sup>c</sup> Based on 29% MeHg as a fraction of total Hg (43).

<sup>d</sup> Estimated from salmon fillet:liver ratio (30).

<sup>e</sup> Based on 44% MeHg as a fraction of total Hg as for molluscs (32).

<sup>f</sup> Converted from dry weight using moisture content from gull samples.

### **Supplemental Information on Seal Mercury Analyses**

MeHg concentrations in seal liver and muscle were measured at the Environment Canada laboratory in Burlington, Ontario. Samples were freeze dried and homogenized, then digested with 5N HNO<sub>3</sub> solution at 55 °C overnight. Digested samples were buffered with acetate and ethylated using sodium tetraethylborate (NaTEB). Ethylated MeHg was purged onto a Tenax packed column, separated by gas chromatography, and detected by cold vapor atomic fluorescence spectroscopy using a Brooks Rand MERX automated MeHg analyzer following established methods (44, 45). The average recovery for the DOLT 5 Certified Reference Material (CRM) included in each digestion cycle was 96.8±5.6% (SD; *n*=8). Precision, estimated by replicate analysis of duplicate samples was on average 6% (*n*=6).

**Table S7a.** Bioaccumulation factors (BAFs) between aquatic MeHg concentrations and measured concentrations in biota and the estimated fraction of lifespan for each species spent in the freshwater environment (River), Lake Melville (Estuary) and outer marine regions (Marine).

Species	log BAF	River	Estuary	Marine	References
Arctic char		0.5	0.5	0	Dunbar (46), Bradbury et al. (47) <sup>a,b</sup>
Muscle	6.6				
Liver	6.6				
Roe	5.6				
Atlantic cod	7.7	0	0–0.50	0–0.50	Li et al. (26) <sup>c,d</sup>
Atlantic salmon		0	0–0.50	0–0.50	Li et al. (26) <sup>c,d</sup>
Muscle	7.3				
Liver	7.4				
Roe	6.4				
Brook trout		0.5	0.5	0	Backus (48), Pilgrim et al. (49) <sup>a,e</sup>
Muscle	6.8				
Liver	6.7				
Roe	6.5				
Capelin		0	0.25	0.75	Li et al. (26) <sup>c</sup>
Muscle	6.0				
Roe	5.1				
Clams	5.8	0	1	0	Harvest location <sup>f</sup>
Black duck		0.5	0.5	0	Longcore et al. (50) <sup>g</sup>
Muscle	6.8				
Eggs	6.2				
Eider		0	0.5–1	0.5–1	BirdLife International (51) <sup>d,g</sup>
Muscle	6.9				
Flatfish	6.6	0	1	0	Armstrong and Starr (52) <sup>a</sup>
Green sea urchin	6.4	0	1	0	Harvest location <sup>f</sup>
Guillemot		0	0.5–1	0.5–1	Butler et al. (53) <sup>d</sup>
Muscle	7.4				
Eggs	7.2				
Gull		0	0.5–1	0.5–1	Baird et al. (54) <sup>g</sup>
Muscle	7.3				
Eggs	6.7				

<sup>a</sup> Stable Hg isotopes suggest mixed habitat (26).

<sup>b</sup> Time spent in open ocean is short (several weeks per year) (46, 47).

<sup>c</sup> Habitat is predominantly offshore and fish migrate into the estuary to feed and/or spawn.

<sup>d</sup> Habitats modeled probabilistically (see Table 2). Reported BAF is expected value.

<sup>e</sup> Habitat is predominantly freshwater. Radiotelemetry monitoring in the Churchill River revealed short (90% < 10 km) seasonal displacements (55).

<sup>f</sup> Sessile and low-motility species are based on predominant fishing location.

<sup>g</sup> Increased MeHg following flooding is scaled by time spent in region (0.5) for migratory species.

**Table S7b.** Bioaccumulation factors (BAFs = MeHg biota/aqueous MeHg) and the estimated fraction of lifespan for each species spent in the freshwater environment (river), Lake Melville (estuary) and outer marine regions (marine).

Species	log BAF	River	Estuary	Marine	Reference
Lake trout	6.8	1	0	0	Black et al. (56)
Loon		0.5	0.5	0	McIntyre et al. (57) <sup>a</sup>
Eggs	7.7				
Mussels	5.3	0	1	0	Harvest location <sup>b</sup>
Ouananiche	6.9	1	0	0	Bradbury et al. (47)
Periwinkles	6.4	0	1	0	Harvest location <sup>b</sup>
Porpoise		0	0.25	0.75	Read and Westgate (58) <sup>c</sup>
Muscle	8.1				
Liver	8.4				
Rainbow smelt	6.8	0	1	0	FishBase (59) <sup>d</sup>
Rock cod		0	0–0.50	0–0.50	Ferguson et al. (60) <sup>e,f</sup>
Muscle	7.7				
Liver	7.5				
Sandpiper	6.6	0.5	0.5	0	Gratto-Trevor et al. (61) <sup>a</sup>
Scallops	6.1	0	1	0	Harvest location <sup>b</sup>
Sculpin		0	0.25	0.75	Li et al. (26) <sup>c</sup>
Muscle	7.7				
Liver	7.2				
Seal		0–0.25	0.5–0.75	0.25	Sikumiut Environmental Management Ltd. (62) <sup>f,g</sup>
Muscle	7.1				
Liver	7.1				
Kidney	7.3				
Tern		0	0.5–1	0.5–1	Hatch et al. (63) <sup>a,f</sup>
Muscle	7.3				
Eggs	7.5				

<sup>a</sup> Increased MeHg following flooding is scaled by time spent in region (0.5) for migratory species.

<sup>b</sup> Sessile and low-motility species are based on predominant fishing location.

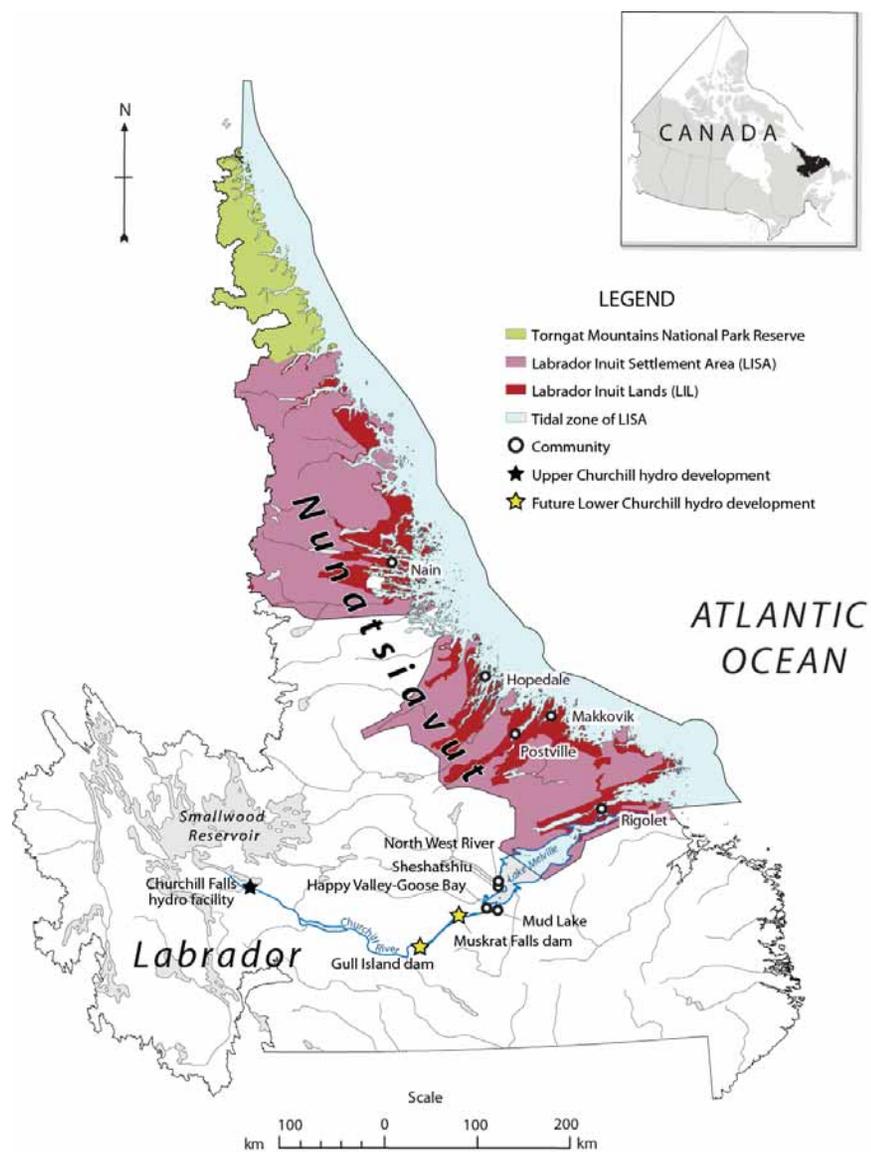
<sup>c</sup> Habitat is predominantly offshore and fish migrate into the estuary to feed and/or spawn. Habitat fraction is modeled probabilistically (see Table S2). Reported BAF is expected mean.

<sup>d</sup> Hg isotope signature in adults indicates mixed habitat (26).

<sup>e</sup> Same  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  stable isotope signature as Atlantic cod.

<sup>f</sup> Habitat fraction modeled probabilistically (see Table S2). Reported BAF is expected mean.

<sup>g</sup> Pups are found in sea ice in estuarine environment.



**Figure S2.** Map of the Labrador Inuit Settlement Area, existing and future hydroelectric developments on the Churchill River, and locations of indigenous communities. Source: Durkalec et al. (64). Reprinted with permission from Nunatsiavut Government.

**Table S8.** Hair mercury sampling from Inuit individuals in the communities downstream of the Muskrat Falls reservoir in June/July (spring/summer) and September/October (fall) 2014.

Demographic Group	Spring/ Summer (n)	Fall (n)	Total (n)	Unique Individuals (Percent Inuit Population <sup>a</sup> )
All individuals	157	499 <sup>b</sup>	656 <sup>b</sup>	571 <sup>b</sup>
Non-Inuit household members <sup>c</sup>	21	84	105	94
Inuit individuals	136	412	548	474 (19%)
<i>Communities</i>				
Happy Valley–Goose Bay <sup>d</sup>	96	265	361	325 (13%)
North West River	37	133	170	139 (37%)
Rigolet	24	101	125	107 (40%)
<i>Demographic Group<sup>e</sup></i>				
Women of childbearing age (16-49) <sup>f</sup>	52	149	201	173
Children ≤ 12 years	15	29	44	40
Women of childbearing age (16-49 & children ≤ 12 in Rigolet	12	36	48	39
All male >12 years	56	174	230	200
All female >49 years	27	140	167	147

<sup>a</sup> Hair was collected for some individuals during both sampling periods. Total Inuit population is based on the 2011 Census and National Household Survey (65, 66).

<sup>b</sup> Including three individuals who did not report Inuit status

<sup>c</sup> Hair samples were collected from non-Inuit individuals if they shared a residence with registered Inuit beneficiary identified by the Nunatsiavut Government.

<sup>d</sup> Includes the nearby community of Mud Lake (n=22).

<sup>e</sup> Combined data for all three communities.

<sup>f</sup> As defined by the U.S. National Health and Nutrition Examination Survey (67).

**Table S9.** Food frequency questionnaire (FFQ) data collected from Inuit individuals from the communities downstream from the Muskrat Falls reservoir in March/April (winter), June/July (spring/summer) and September/October (fall) 2014. Dietary survey data collection overlapped with hair sampling (Table S8) in the spring and fall.

Demographic Group	Winter (n)	Spring/ Summer (n)	Fall (n)	Total (n)	Unique Individuals (Percent Inuit Population <sup>a</sup> )
All individuals	231	294	1054 <sup>b</sup>	1579 <sup>b</sup>	1145 <sup>b</sup>
Non-Inuit household <sup>c</sup> members	34	49	167	250	188
Inuit individuals	197	245	882	1324	952 (38%)
<i>Communities</i>					
Happy Valley-Goose Bay <sup>d</sup>	170	217	667	1054	745 (31%)
North West River	30	34	158	222	167 (43%)
Rigolet	31	43	229	303	233 (87%)
<i>Demographic Group<sup>e</sup></i>					
Women of childbearing age (16-49)	59	77	278	414	306
Children ≤12 years	55	59	166	280	179
Women of childbearing age (16-49 & children ≤ 12 in Rigolet	15	19	100	134	101
All male >12 years	74	108	387	569	406
All female > 49 years <sup>f</sup>	28	37	191	256	200

<sup>a</sup> Data from some individuals are for multiple survey periods. Total Inuit population is based on the 2011 Census and National Household Survey (65, 66).

<sup>b</sup> Total includes three individuals who did not report Inuit status.

<sup>c</sup> Non-Inuit individuals who share a household with a registered Inuit beneficiary identified by the Nunatsiavut Government were included in the survey.

<sup>d</sup> Includes the nearby community of Mud Lake (n=22).

<sup>e</sup> Combined data for all three communities.

<sup>f</sup> As defined by the U.S. National Health and Nutrition Examination Survey (67).

**Table S10.** MeHg concentrations in aquatic foods harvested outside the Lake Melville region. Commercial market categories rather than species names are listed for store-bought seafood.

Species	MeHg ( $\mu\text{g g}^{-1}$ ) Mean $\pm$ SD	<i>n</i>	Data Source
Minke whale ( <i>Balaenoptera acutorostrata</i> ) <sup>a</sup>	0.075 $\pm$ 0.021	4	Riget et al. (68)
Polar bear ( <i>Ursus maritimus</i> )	0.07 $\pm$ 0.05	23	Woshner et al. (69)
Cod	0.11 $\pm$ 0.07	115	US FDA (35)
Clams	0.01 $\pm$ 0.002	15	US FDA (35)
Scallops	0.02 $\pm$ 0.01 <sup>b</sup>	200	Karimi et al. (36)
Mussels	0.02 $\pm$ 0.01 <sup>b</sup>	134	Karimi et al. (36)
Catfish	0.04 $\pm$ 0.02 <sup>b</sup>	103	Karimi et al. (36)
Crab	0.06 $\pm$ 0.03 <sup>b</sup>	151	Karimi et al. (36)
Haddock	0.06 $\pm$ 0.03 <sup>b</sup>	78	Karimi et al. (36)
Herring	0.02 $\pm$ 0.01 <sup>b</sup>	115	Karimi et al. (36)
Lobster	0.04 $\pm$ 0.02 <sup>b</sup>	149	Karimi et al. (36)
Oysters (canned)	0.003 $\pm$ 0.003 <sup>b,c</sup>	361	Karimi et al. (36)
Pollock (fish sticks)	0.02 $\pm$ 0.01 <sup>b</sup>	131	Karimi et al. (36)
Brook trout	0.09 $\pm$ 0.04 <sup>b,d</sup>	44	Karimi et al. (36)
Rainbow trout	0.03 $\pm$ 0.02 <sup>b</sup>	71	Karimi et al. (36)
Sardines	0.03 $\pm$ 0.02 <sup>b</sup>	246	Karimi et al. (36)
Shrimp	0.03 $\pm$ 0.02 <sup>b</sup>	361	Karimi et al. (36)
Skate	0.12 $\pm$ 0.05 <sup>b</sup>	13	Karimi et al. (36)
Sole	0.10 $\pm$ 0.04 <sup>b</sup>	51	Karimi et al. (36)
Tilapia	0.02 $\pm$ 0.01 <sup>b</sup>	114	Karimi et al. (36)
Fresh Tuna	0.44 $\pm$ 0.25 <sup>d</sup>	295	US FDA (35)
Canned tuna	0.16 $\pm$ 0.13 <sup>e</sup>	1002	US FDA (35)
Fresh salmon	0.04 $\pm$ 0.02 <sup>b</sup>	504	Karimi et al. (36)
Canned salmon	0.04 $\pm$ 0.04 <sup>f</sup>	61	Karimi et al. (36) <sup>e</sup>

<sup>a</sup> Converted from dry weight using moisture content from seal muscle.

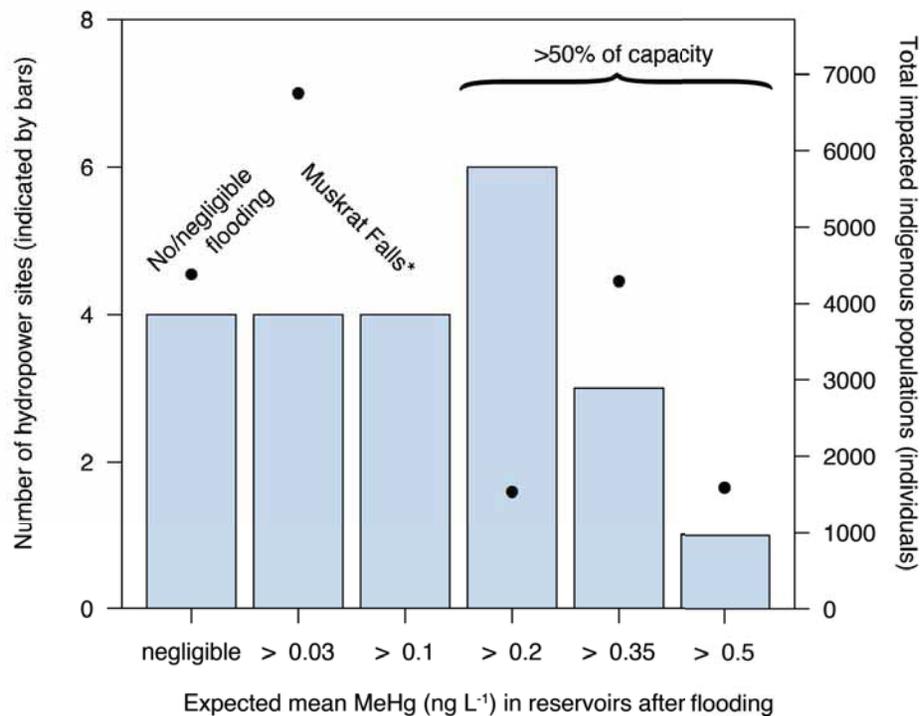
<sup>b</sup> Standard deviation of distribution modeled following Carrington and Bolger (70).

<sup>c</sup> Based on all market oysters.

<sup>d</sup> Based on all unspecified freshwater.

<sup>e</sup> Yellowfin, bigeye and albacore weighted according to relative landings reported by Sunderland (71).

<sup>f</sup> Relative consumption of light and white canned tuna calculated from Sunderland (71).



**Figure S3.** Number of planned hydroelectric power sites with forecasted reservoir MeHg concentrations above and below the Muskrat Falls reservoir and corresponding indigenous populations potentially impacted (circles). \* Inuit population downstream from Muskrat Falls is included in the >0.35 bin because it is also potentially impacted by planned Gull Island facility.

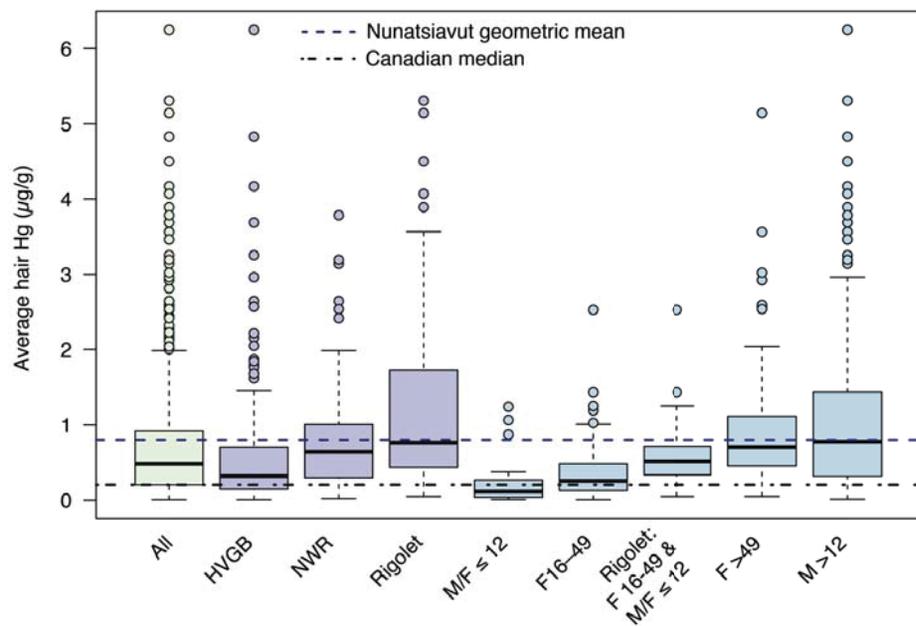
**Table S11a.** Modeled MeHg concentrations in country foods after flooding of the Muskrat Falls reservoir.

Species	Post-flooding distribution of values			
	Expected mean	75 <sup>th</sup> percentile	90 <sup>th</sup> percentile	95 <sup>th</sup> percentile
Arctic char				
Muscle	0.41	0.51	0.78	1.0
Liver	0.49	0.58	0.70	0.80
Roe	0.05	0.06	0.07	0.08
Atlantic cod	0.41	0.50	0.65	0.76
Atlantic salmon				
Muscle	0.16	0.20	0.25	0.29
Liver	0.20	0.23	0.28	0.31
Roe	0.020	0.023	0.027	0.031
Black duck				
Muscle	0.44	0.55	0.83	1.1
Eggs	0.11	0.13	0.16	0.18
Brook trout				
Muscle	0.68	0.84	1.1	1.3
Liver	0.62	0.76	1.0	1.2
Roe	0.34	0.42	0.58	0.70
Capelin				
Muscle	0.04	0.05	0.06	0.07
Roe	0.01	0.01	0.01	0.01
Clams	0.03	0.03	0.04	0.04
Eider				
Muscle	0.20	0.24	0.30	0.34
Flatfish	0.17	0.22	0.32	0.40
Green sea urchin	0.10	0.12	0.14	0.16
Guillemot				
Muscle	0.68	0.82	1.0	1.2
Eggs	0.53	0.61	0.74	0.84
Gull				
Muscle	0.41	0.46	0.54	0.59
Eggs	0.15	0.18	0.21	0.24
Lake trout	1.0	1.3	1.8	2.2
Loon				
Eggs	5.6	5.7	13.3	20.9
Minke whale	0.07	0.09	0.10	0.11
Mussels	0.01	0.01	0.01	0.01
Ouananiche	1.5	1.9	3.0	3.9
Periwinkles	0.10	0.12	0.14	0.16

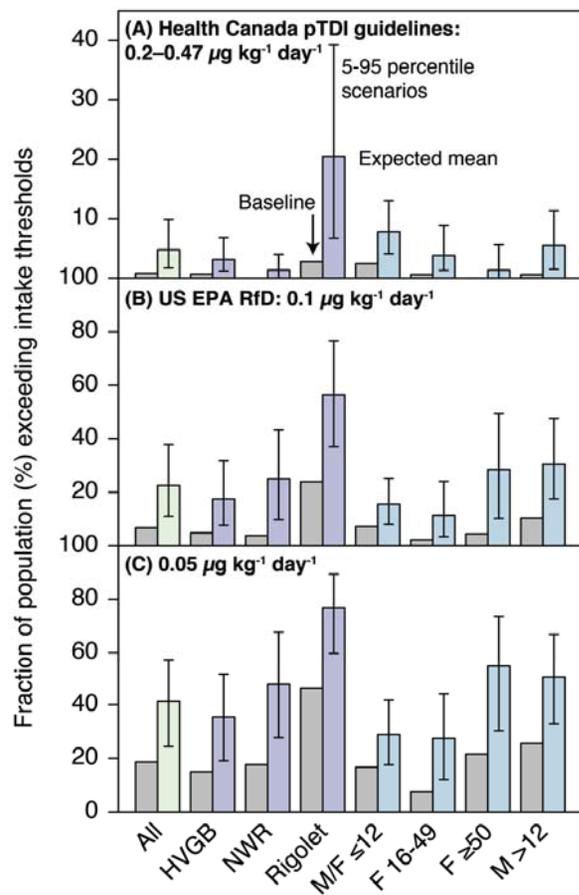
**Table S11b.** Modeled MeHg concentrations in country foods after flooding of the Muskrat Falls reservoir

Species	Post-flooding distribution of values			
	Expected mean	75 <sup>th</sup> percentile	90 <sup>th</sup> percentile	95 <sup>th</sup> percentile
Porpoise				
Muscle	1.4	1.8	2.7	3.5
Liver	2.8	3.6	5.2	6.8
Rock cod				
Muscle	0.42	0.50	0.65	0.77
Liver	0.50	0.58	0.70	0.79
Sandpiper	0.26	0.30	0.37	0.42
Scallops	0.06	0.07	0.08	0.09
Sculpin				
Muscle	0.54	0.66	0.88	1.0
Liver	0.20	0.24	0.42	0.58
Seal <sup>a</sup>				
Muscle	0.66	0.82	1.3	1.6
Liver	0.67	0.84	1.3	1.7
Kidney	1.0	1.2	1.6	1.9
Smelt	0.29	0.36	0.48	0.58
Tern	0.41	0.50	0.86	1.2

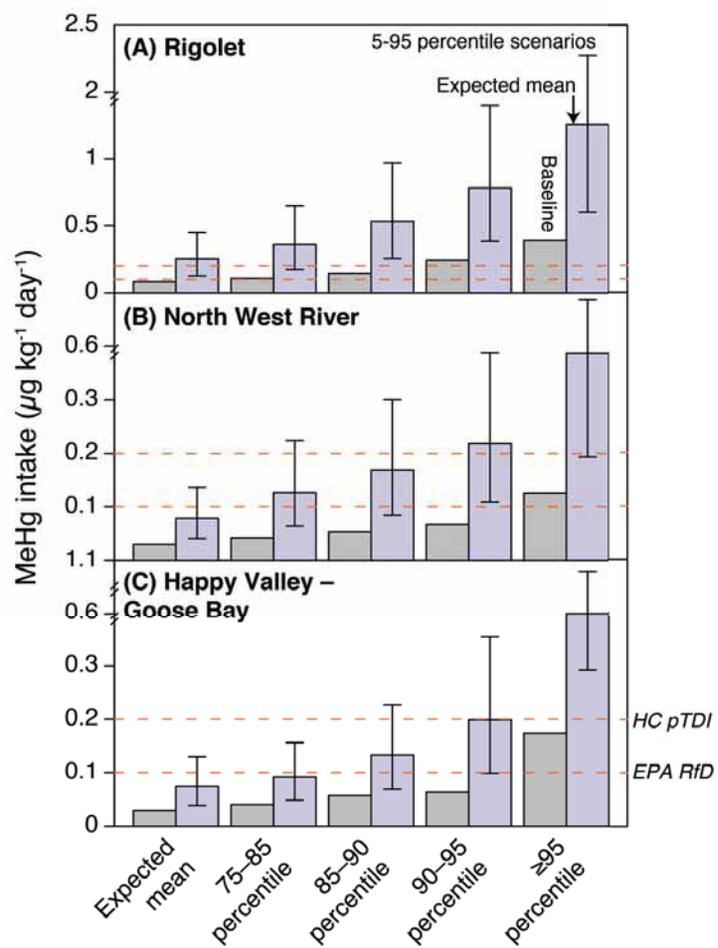
<sup>a</sup> Weighted by age range (Table S6a).



**Figure S4.** Measured concentrations of total Hg in hair samples from individuals in three Inuit communities downstream from the Muskrat Falls hydroelectric facility (HVGB = Happy Valley – Goose Bay; NWR = North West River) and among demographic groups (all communities together). Canadian median (6–79 years old) (72) and Nunatsiavut mean (73) are estimated using a mean blood-to-hair partition coefficient of  $250 \text{ L g}^{-1}$  (74). Most of the Hg in hair is present as MeHg (>90%) and potential demethylation in the hair follicle means that total Hg is the best indicator of internal MeHg exposure (75). At least one method blank and one certified hair reference materials (GBW-07601 and ERM-DB001) were tested every 10 samples and all recoveries were within certified ranges. Precision, calculated by replicate analysis of the duplicate hair samples (RSD) was better than 8.6%.



**Figure S5.** Fraction of population exceeding exposure thresholds in 2014 (measured) and post-flooding (modeled) by community (HVGB = Happy Valley – Goose Bay, NWR = North West River) and age/gender. Panel (A) shows the population that exceeds Health Canada provisional tolerable daily intake (pTDI) guidelines for MeHg of  $0.20 \mu\text{g kg}^{-1} \text{day}^{-1}$  for women of childbearing age and children 12 years and under and  $0.47 \mu\text{g kg}^{-1} \text{day}^{-1}$  for others (76). Panel (B) shows the population that exceeds the U.S. Environmental Protection Agency's Reference Dose (RfD) (77), and panel (C) indicates the proportion of the population exceeding the RfD calculated based on more recent epidemiological research on neurotoxicity (78, 79).



**Figure S6.** Baseline (measured) and post-flooding (modeled) MeHg intake relative to the Health Canada (HC) provisional tolerable daily intake (pTDI) and the U.S. EPA reference dose (RfD) for the communities of (A) Rigolet, the largest per-capita consumer of country foods, (B) North West River and (C) Happy Valley – Goose Bay

## References

1. Steinberger, N.; Hondzo, M. Diffusional mass transfer at sediment-water interface. *J Environ Eng.* **1999**, *125* (2), 192-200.
2. Sunderland, E. M.; Dalziel, J.; Heyes, A.; Branfireun, B. A.; Krabbenhoft, D. P.; Gobas, F. A. Response of a macrotidal estuary to changes in anthropogenic mercury loading between 1850 and 2000. *Environ Sci Technol.* **2010**, *44* (5), 1698-1704.
3. Schartup, A. T.; Balcom, P. H.; Soerensen, A. L.; Gosnell, K. J.; Calder, R. S. D.; Mason, R. P.; Sunderland, E. M. Freshwater discharges drive high levels of methylmercury in Arctic marine biota. *P Natl Acad Sci USA*, **2015**, *112* (38), 11789-11794.
4. Peterson, E. L. Benthic shear stress and sediment condition. *Aquacult Eng.* **1999**, *21* (2), 85-111.
5. Wilcock, P. R. Estimating Local Bed Shear Stress from Velocity Observations. *Water Resour Res.* **1996**, *32* (11), 3361-3366.
6. AMEC. Lower Churchill Hydroelectric Development Freshwater Fish Habitat Compensation Plan: Muskrat Falls. **2013**.
7. Soil Landscapes of Canada Working Group (SLCWG). Soil Landscapes of Canada v. 3.2. Agriculture and Agri-Food Canada. **2011**.
8. Chan, T. P.; Govindaraju, R. S. Estimating Soil Water Retention Curve from Particle-Size Distribution Data Based on Polydisperse Sphere Systems. *Vadose Zone J.* **2004**, *3* (4), 1443-1454.
9. Jonsson, S.; Skjyllberg, U.; Nilsson, M. B.; Lundberg, E.; Andersson, A.; Bjorn, E. Differentiated availability of geochemical mercury pools controls methylmercury levels in estuarine sediment and biota. *Nat Commun.* **2014**, *5*, 4624.
10. Natural Resources Canada (NRCAN). *Data – Canada Lands Surveys*. <http://www.nrcan.gc.ca/earth-sciences/geomatics/canada-lands-surveys/11092>. Accessed July 2, 2016.
11. Metis Settlements General Council. *Peavine Metis Settlement*. <http://www.msgc.ca/communities/peavine-metis-settlement>. Accessed July 3, 2016.
12. Aboriginal Affairs and Northern Development Canada (AANDC). *First Nation Profiles*.
13. Midgard Consulting Inc. Yukon Next Generation Hydro and Transmission Viability Study: Site Screening Inventory. **2015**.
14. Government of the Northwest Territories. *Northwest Territories Energy Report*. **2011**.
15. BC Hydro. Preliminary Construction Schedule. **2015**.
16. Klohn Crippen Berger; SNC-Lavalin. *Hatch Peace River Site C Clean Energy Project*. **2011**.
17. AHP Development Corporation. *Project Description: Amisk Hydroelectric Project: Executive Summary*. **2015**.
18. Canadian Environmental Assessment Agency. *Tazi Twé Hydroelectric Project Draft Environmental Assessment Report*. **2015**.
19. Keeyask Hydropower LP. *Keeyask Generation Project Year in Review 2014-2015*. **2015**.
20. Manitoba Hydro-Electric Board; Tataskweyak Cree Nation; War Lake First Nation; York Factory First Nation; Fox Lake Cree Nation. *Keeyask Project: Project Description*. **2009**.
21. Manitoba Hydro. *Conawapa Generating Station*. <https://www.hydro.mb.ca/projects/conawapa/index.shtml>. Accessed March 28, 2016.
22. Northern Ontario Business Staff. *Construction begins on \$300-million hydro project*. Northern Ontario Business, 2015.
23. Ministère du Développement durable, de l'Environnement et des Parcs. *Rapport d'analyse environnementale pour le projet d'aménagement du complexe hydroélectrique de la rivière Romaine sur le territoire de la municipalité régionale de comté de Minganie par Hydro-Québec*. **2009**.

24. Ernst & Young LLP. *Muskkrat Falls Project: Review of Project Cost, Schedule and Related Risk Interim Report*. **2016**.
25. Lu, Z.; DeYoung, B.; Banton, S. *Analysis of physical oceanographic data from Lake Melville, Labrador, September 2012 - July 2013*; Memorial University of Newfoundland: St. John's, Newfoundland. **2014**.
26. Li, M.; Schartup, A. T.; Valberg, A. P.; Ewald, J. D.; Krabbenhoft, D. P.; Yin, R.; Balcom, P. H.; Sunderland, E. M. Environmental Origins of Methylmercury Accumulated in Subarctic Estuarine Fish Indicated by Mercury Stable Isotopes. *Environ Sci Technol*. **2016**. In press. DOI: 10.1021/acs.est.6b03206
27. Brown, T. M.; Fisk, A. T.; Wang, X.; Ferguson, S. H.; Young, B. G.; Reimer, K. J.; Muir, D. C. Mercury and cadmium in ringed seals in the Canadian Arctic: Influence of location and diet. *Sci Total Environ*. **2016**, 545-546, 503-511.
28. Jacques Whitford Environment Ltd. *Statistical Analysis of Mercury Data from Churchill Falls (Labrador) Corporation Reservoirs*. **2006**.
29. Lemire, M.; Kwan, M.; Laouan-Sidi, A. E.; Muckle, G.; Pirkle, C.; Ayotte, P.; Dewailly, E. Local country food sources of methylmercury, selenium and omega-3 fatty acids in Nunavik, Northern Quebec. *Sci Total Environ*. **2015**, 509-510, 248-259.
30. Zhang, X.; Naidu, A. S.; Kelley, J. J.; Jewett, S. C.; Dasher, D.; Duffy, L. K. Baseline concentrations of total mercury and methylmercury in salmon returning via the Bering Sea (1999-2000). *Mar Poll Bull*. **2001**, 42 (10), 993-997.
31. Harley, J.; Lieske, C.; Bhojwani, S.; Castellini, J. M.; López, J. A.; O'Hara, T. M. Mercury and methylmercury distribution in tissues of sculpins from the Bering Sea. *Polar Biol*. **2015**, 38 (9), 1535-1543.
32. Claisse, D.; Cossa, D.; Bretaudeau-Sanjuan, J.; Touchard, G.; Bombled, B. Methylmercury in Molluscs Along the French Coast. *Mar Poll Bull*. **2001**, 42 (4), 329-332.
33. Das, K.; Siebert, U.; Fontaine, M.; Jauniaux, T.; Holsbeek, L.; Bouquegneau, J. M. Ecological and pathological factors related to trace metal concentrations in harbour porpoises *Phocoena phocoena* from the North Sea and adjacent areas. *Mar Ecol Prog Ser*. **2004**, 281, 283-295.
34. Noël, L.; Testu, C.; Chafey, C.; Velge, P.; Guérin, T. Contamination levels for lead, cadmium and mercury in marine gastropods, echinoderms and tunicates. *Food Control*. **2011**, 22 (3-4), 433-437.
35. United States Food and Drug Administration (US FDA), Mercury Levels in Commercial Fish and Shellfish (1990-2010). **2014**.
36. Karimi, R.; Fitzgerald, T. P.; Fisher, N. S. A quantitative synthesis of mercury in commercial seafood and implications for exposure in the United States. *Environ Health Perspect*. **2012**, 120 (11), 1512-1519.
37. Lavoie, R. A.; Hebert, C. E.; Rail, J. F.; Braune, B. M.; Yumvihoze, E.; Hill, L. G.; Lean, D. R. Trophic structure and mercury distribution in a Gulf of St. Lawrence (Canada) food web using stable isotope analysis. *Sci Total Environ*. **2010**, 408 (22), 5529-5539.
38. Lavoie, R. A.; Champoux, L.; Rail, J. F.; Lean, D. R. Organochlorines, brominated flame retardants and mercury levels in six seabird species from the Gulf of St. Lawrence (Canada): relationships with feeding ecology, migration and molt. *Environ Pollut* **2010**, 158 (6), 2189-2199.
39. Clayden, M. G.; Arsenault, L. M.; Kidd, K. A.; O'Driscoll, N. J.; Mallory, M. L. Mercury bioaccumulation and biomagnification in a small Arctic polynya ecosystem. *Sci Total Environ* **2015**, 509-510, 206-215.

40. Braune, B. M.; Malone, B.; Burgess, N. M.; Elliott, J.; Garrity, N.; Hawkings, J.; Hines, J.; Marshall, H.; Marshall, W.; Rodrigue, J.; Wakeford, B.; Wayland, M.; Weseloh, D.; Whitehead, P. *Chemical Residues in Waterfowl and Gamebirds Harvested in Canada, 1987-95*, **1999**.
41. Schwarzbach, S.; Adelsbach, T. *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed*. **2003**.
42. Evers, D. C.; Burgess, N. M.; Champoux, L.; Hoskins, B.; Major, A.; Goodale, W. M.; Taylor, R. J.; Poppenga, R.; Daigle, T. Patterns and Interpretation of Mercury Exposure in Freshwater Avian Communities in Northeastern North America. *Ecotoxicology*. **2005**, *14* (1-2), 193-221.
43. Joiris, C. R.; Holsbeck, L.; Bolba, D.; Gascard, C.; Stanev, T.; Komakhidze, A.; Baumgärtner, W.; Birkun, A. Total and organic mercury in the Black Sea harbour porpoise *Phocoena phocoena relicta*. *Marine Poll Bull.* **2001**, *42* (10), 905-911.
44. Lehnher, I.; St. Louis, V. L.; Emmerton, C. A.; Barker, J. D.; Kirk, J. L., Methylmercury cycling in High Arctic wetland ponds: Sources and sinks. *Environ Sci Technol.* **2012**, *46* (19), 10514-10522.
45. Hintelmann, H.; Nguyen, H. T., Extraction of methylmercury from tissue and plant samples by acid leaching. *Anal Bioanal Chem.* **2005**, *381* (2), 360-365.
46. Dunbar, M. J., The Sea Waters surrounding the Québec-Labrador peninsula. *Cahiers de géographie du Québec*. **1965**, *10* (19), 13.
47. Bradbury, C.; Roberge, M.; Minns, C. *Life History Characteristics of Freshwater Fishes Occurring in Newfoundland and Labrador, with Major Emphasis on Lake Habitat Requirements*. Fisheries and Oceans Canada. **1999**.
48. Backus, R. The Fishes of Labrador. *Bulletin of the American Museum of Natural History*. **1957**, *113* (4).
49. Pilgrim, B. L.; Perry, R. C.; Keefe, D. G.; Perry, E. A.; Dawn Marshall, H., Microsatellite variation and genetic structure of brook trout (*Salvelinus fontinalis*) populations in Labrador and neighboring Atlantic Canada: evidence for ongoing gene flow and dual routes of post-Wisconsinan colonization. *Ecol Evol.* **2012**, *2* (5), 885-898.
50. Longcore, J. R.; McAuley, D. G.; Hepp, G. R.; Rhymer, J. M.; Poole, A.; Gill, F. American Black Duck (*Anas rubripes*). *The Birds of North America Online*. **2000**.
51. BirdLife International *Somateria mollissima*. <http://www.iucnredlist.org/details/22680405/0>. Accessed July 19, 2016.
52. Armstrong, M. P.; Starr, B. A. Reproductive Biology of the Smooth Flounder in Great Bay Estuary, New Hampshire. *T Am Fish Soc.* **1994**, *123* (1), 112-114.
53. Butler, R. G.; Buckley, D. E.; Poole, A.; Gill, F. Black Guillemot (*Cepphus grylle*). *The Birds of North America Online*. **2002**.
54. Baird, P. H.; Poole, A.; Gill, F. Black-legged Kittiwake (*Rissa tridactyla*). *The Birds of North America Online*. **1994**.
55. Nalcor Energy. *Biophysical Assessment*. **2009**.
56. Black, G. A.; Dempson, J. B.; Bruce, W. J. Distribution and postglacial dispersal of freshwater fishes of Labrador. *Can J Zool.* **1986**, *64* (1), 21-31.
57. McIntyre, J. W.; Barr, J. F.; Poole, A.; Gill, F. Common Loon (*Gavia immer*). *The Birds of North America Online*. **1997**.
58. Read, A. J.; Westgate, A. J., Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. *Mar Biol.* **1997**, *130* (2), 315-322.
59. FishBase. *Osmerus mordax* (Mitchill, 1814). <http://www.fishbase.org/summary/253>. Accessed July 19, 2016.

60. Ferguson, S. H.; Loseto, L. L.; Mallory, M. L. *A Little Less Arctic: Top Predators in the World's Largest Northern Inland Sea, Hudson Bay*. Springer Netherlands. **2010**.
61. Gratto-Trevor, C. L.; Poole, A.; Gill, F. Semipalmated Sandpiper (*Calidris pusilla*). *The Birds of North America Online*. **1992**.
62. Sikumiut Environmental Management Ltd. *Seal Abundance and Distribution*. **2007**.
63. Hatch, J. J.; Poole, A.; Gill, F., Arctic Tern (*Sterna paradisaea*). *The Birds of North America Online*. **2002**.
64. Durkalec, A.; Sheldon, T.; Bell, T. E., Eds. Scientific Report. **2016**.
65. Statistics Canada, 2011 National Household Survey. **2013**.
66. Statistics Canada, 2011 Census. **2012**.
67. McDowell, M. A.; Dillon, C. F.; Osterloh, J.; Bolger, P. M.; Pellizzari, E.; Fernando, R.; Montes de Oca, R.; Schober, S. E.; Sinks, T.; Jones, R. L.; Mahaffey, K. R. Hair Mercury Levels in U.S. Children and Women of Childbearing Age: Reference Range Data from NHANES 1999-2000. *Environ Health Perspect*. **2004**, *112* (11), 1165-1171.
68. Riget, F.; Moller, P.; Dietz, R.; Nielsen, T. G.; Asmund, G.; Strand, J.; Larsen, M. M.; Hobson, K. A. Transfer of mercury in the marine food web of West Greenland. *J Environ Monit*. **2007**, *9* (8), 877-883.
69. Woshner, V. M.; O'Hara, T. M.; Bratton, G. R.; Beasley, V. R. Concentrations and interactions of selected essential and non-essential elements in ringed seals and polar bears of arctic Alaska. *J Wildl Dis* **2001**, *37* (4), 711-721.
70. Carrington, C. D.; Bolger, M. P. An exposure assessment for methylmercury from seafood for consumers in the United States. *Risk Anal*. **2002**, *22* (4), 689-699.
71. Sunderland, E. M., Mercury exposure from domestic and imported estuarine and marine fish in the U.S. seafood market. *Environ Health Perspect*. **2007**, *115* (2), 235-42.
72. Lye, E.; Legrand, M.; Clarke, J.; Probert, A. Blood total mercury concentrations in the Canadian population: Canadian health measures survey cycle 1, 2007-2009. *Can J Public Health*. **2013**, *104* (3), E246-E251.
73. Chan, H. M. L. Contaminant Assessment in Nunatsiavut. **2011**.
74. World Health Organization (WHO) Methylmercury. **1990**.
75. Berglund, M.; Lind, B.; Bjornberg, K. A.; Palm, B.; Einarsson, O.; Vahter, M., Inter-individual variations of human mercury exposure biomarkers: a cross-sectional assessment. *Environ Health*. **2005**, *4*, 20.
76. Health Canada Updating the Existing Risk Management Strategy for Mercury in Retail Fish; **2007**.
77. United States Environmental Protection Agency (US EPA), Reference Dose for Methylmercury. In Federal Register, 2000; Vol. 65, pp 64702-64703.
78. Bellanger, M.; Pichery, C.; Aerts, D.; Berglund, M.; Castano, A.; Cejchanova, M.; Crettaz, P.; Davidson, F.; Esteban, M.; Fischer, M. E.; Gurzau, A. E.; Halzlova, K.; Katsonouri, A.; Knudsen, L. E.; Kolossa-Gehring, M.; Koppen, G.; Ligocka, D.; Miklavcic, A.; Reis, M. F.; Rudnai, P.; Tratnik, J. S.; Weihe, P.; Budtz-Jorgensen, E.; Grandjean, P.; Demo/Cophes, Economic benefits of methylmercury exposure control in Europe: monetary value of neurotoxicity prevention. *Environ Health* **2013**, *12*, 3.
79. Grandjean, P.; Budtz-Jorgensen, E., Total imprecision of exposure biomarkers: implications for calculating exposure limits. *Am J Ind Med*. **2007**, *50* (10), 712-719.

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/240084662>

# Large-scale impacts of hydroelectric development

Article in *Environmental Reviews* · March 1997

DOI: 10.1139/er-5-1-27

---

CITATIONS

187

---

READS

138

6 authors, including:



**Carol A. Kelly**

R&K Research Inc., Canada

70 PUBLICATIONS 6,057 CITATIONS

SEE PROFILE



**John W M Rudd**

103 PUBLICATIONS 8,340 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Penobscot River Mercury Study [View project](#)



Methane cycling in lakes [View project](#)

All content following this page was uploaded by [Carol A. Kelly](#) on 19 November 2015.

The user has requested enhancement of the downloaded file.

# Large-scale impacts of hydroelectric development

D.M. Rosenberg,<sup>1</sup> F. Berkes, R.A. Bodaly, R.E. Hecky, C.A. Kelly, and J.W.M. Rudd

**Abstract:** The substantial size of some hydroelectric projects and the extensive total surface area covered by reservoirs globally require that research determining the impacts of these developments be done at ever-increasing spatial and temporal scales. As a consequence of this research, new views are emerging about the spatial extent and longevity of the environmental and social impacts of such developments. New findings challenge the notion of hydroelectric development as a benign alternative to other forms of power generation. This review examines the intertwined environmental and social effects of methylmercury bioaccumulation in the food web, emission of greenhouse gases from reservoirs, downstream effects of altered flows, and impacts on biodiversity, each of which operates at its own unique spatial and temporal scales. Methylmercury bioaccumulation occurs at the smallest spatial and temporal scales of the four impacts reviewed, whereas downstream effects usually occur at the largest scales. Greenhouse gas emissions, the newest surprise connected with large-scale hydroelectric development, are relatively short term but eventually may have important global-scale consequences. Limitation of biodiversity by hydroelectric development usually occurs at intermediate spatial and temporal scales. Knowledge developed from working at expanded spatial and temporal scales should be an important part of future decision making for large-scale hydroelectric development.

*Key words:* hydroelectric development, large-scale, environmental impacts, social impacts.

**Résumé :** La dimension considérable de certains projets hydroélectriques et les vastes surfaces totales globalement couvertes par les réservoirs nécessitent que la recherche menée pour déterminer les impacts de ces développements soit conduite à des échelles d'espace et de temps de plus en plus grandes. Comme conséquence de cette recherche, de nouvelles perceptions prennent naissance concernant l'ampleur spatiale et la longévité des impacts sociaux et environnementaux, suite à ces développements. De nouvelles constatations mettent en doute la notion que le développement hydroélectrique serait une alternative bénigne par rapport à d'autres formes de production d'énergie. Dans cette revue, les auteurs examinent les effets sociaux et environnementaux intercroisés de la bioaccumulation du mercure méthylé dans la chaîne alimentaire, de l'émission de gaz à effet serre à partir des réservoirs, des conséquences en aval des perturbations des rivières ainsi que des impacts sur la biodiversité, lesquels agissent chacun à leurs échelles spatiales et temporelles. Parmi les quatre impacts considérés, la bioaccumulation du mercure méthylé survient aux échelles spatiales et temporelles les plus petites, alors que les perturbations en aval des cours d'eau surviennent aux échelles les plus grandes. Les émissions de gaz à effet serre, la dernière surprise reliée aux développements hydroélectriques sur de grandes surfaces, sont de durée relativement courte mais pourraient éventuellement avoir des conséquences importantes à l'échelle globale. La limitation de la biodiversité par le développement hydroélectrique se manifeste habituellement à des échelles spatiales et temporelles intermédiaires. La connaissance provenant du travail à des échelles spatiales et temporelles plus vastes devrait jouer un rôle importante dans les processus futures de prise de décision lors des développements hydroélectriques à grande échelle.

*Mots clés :* développement hydroélectrique, grande échelle, impacts sociaux, impacts environnementaux.  
[Traduit par la rédaction]

## Introduction

Contemporary research on the environmental effects of hydroelectric development is pursued at a variety of spatial and temporal scales. These scales extend from short-term studies following formation of single, small reservoirs (e.g., Aggus 1971; Bass 1992; Koskeniemi 1994) to studies of huge reservoir and water-diversion complexes drawn from decades

of data (e.g., Pligin and Yemel'yanova 1989; Rozengurt and Hedgpeth 1989; Marchand 1990). At the very largest scales, Chao (1991, 1995) reported that worldwide impoundment of water has reduced sea levels by 3 cm, and the concentration of reservoirs built in the last 40 years at high latitudes has caused the earth to spin faster!

The global extent of reservoirs, including hydroelectric facilities is enormous. There are ~39 000 large dams in the

Received 17 July 1996. Accepted 6 February 1997.

D.M. Rosenberg,<sup>2</sup> R.A. Bodaly, R.E. Hecky,<sup>3</sup> and J.W.M. Rudd. Freshwater Institute, 501 University Crescent, Winnipeg, MB R3T 2N6, Canada.

F. Berkes. Natural Resources Institute, University of Manitoba, Winnipeg, MB R3T 2N2, Canada.

C.A. Kelly. Department of Microbiology, University of Manitoba, Winnipeg, MB R3T 2N2, Canada.

<sup>1</sup> The following coauthors are arranged in alphabetical order.

<sup>2</sup> Author to whom all correspondence should be addressed (e-mail: rosenbg@cc.umanitoba.ca).

<sup>3</sup> Present address: Canada Centre for Inland Waters, 867 Lakeshore Road, Burlington, ON L7R 4A6, Canada.

**Table 1.** Selected estimates of regional spatial coverage by reservoirs (estimates may not agree).

Region	Types of reservoirs	Area covered (km <sup>2</sup> )	Ref.
Global	Hydroelectric	600 000 (larger than the North Sea)	Pearce 1996
	All types and sizes	500 000 (~2× the Laurentian Great Lakes)	Kelly et al. 1994
	All types, large (>10 <sup>8</sup> m <sup>3</sup> of water)	California or France	Dynesius and Nilsson 1994
Canada	Hydroelectric, five, extant, large (≥1000 MW of power)	~20 000 (Lake Ontario)	Rosenberg et al. 1987
United States	Hydroelectric, new, planned for northern Québec	~10 000 (~1/2 covered by forest)	Rougerie 1990
	All types and sizes (>100 000; 5500 are large, i.e., dams ≥15 m height)	New Hampshire and Vermont	Devine 1995
India	All types and sizes (>1550 are large; >100 000 are medium and small; meaning of size not specified)	Large, >14 500; medium and small, >11 000	Foote et al. 1996

world (World Register of Dams 1988, in Dynesius and Nilsson 1994); some 5500 of these (≥15 m height) are in the United States (Devine 1995) and 618 (≥10 m) are in Canada (Environment Canada 1990). The usable man-made reservoir capacity is ~9% of the annual global river runoff (Dynesius and Nilsson 1994). The present storage capacity of large dams amounts to 5500 km<sup>3</sup> (Postel et al. 1996). Of this, 3500 km<sup>3</sup> are actively used in regulating river runoff; by 2025 another ~1200 km<sup>3</sup> will have been added to active storage (Postel et al. 1996). It has been estimated that reservoirs of all types and sizes occupy 500 000 km<sup>2</sup> globally, an area approximately twice that of the Laurentian Great Lakes (Kelly et al. 1994). Table 1 summarizes some regional estimates of the areal extents of reservoirs and Table 2 presents the extent of local flooding caused by selected major hydroelectric developments.

Projects like La Grande River development in Canada (Berkes 1981), the Sardar Sarovar development in India (Morse and Berger 1992), and the Three Gorges development in China (Fearnside 1988) indicate continuing global interest in the construction of megaprojects that produce significant amounts of power (i.e., ≥1000 MW), although Postel et al. (1996) contend that the average number of large dams (≥15 m) constructed in the world is dropping and will continue to do so into the next century (see also Majot 1996). In Canada, hydroelectric development over the past few decades has moved from relatively contained project configurations in the populated south of the country to relatively uncontained configurations in the sparsely populated north, which indicates that the best (i.e., most cost effective) sites have been used (see Devine 1995 for a similar comment about the United States). Some large-scale Canadian hydroelectric projects are reviewed in Rosenberg et al. (1987).

Past and present development of hydroelectric megaprojects has required environmental and social researchers to work at ever-increasing spatial and temporal scales. This review will deal with these expanded scales rather than with the smaller scale, in-reservoir and immediately downstream processes (e.g., changes in sedimentation regime, primary productivity, and faunal populations) of more traditional reviews (e.g., Baxter 1977; Baxter and Glaude 1980). Research at larger scales has begun to lead to new views about the spatial extent and longevity of the environmental and social effects of such projects, and cumulative effects on a global basis. These findings challenge the notion of hydroelectric development as a relatively benign form of power generation and raise questions

about whether hydroelectric projects can ever be made environmentally sustainable (Goodland et al. 1993).

This review will focus on four, large-scale impacts attributable to hydroelectric developments, each of which operates at its own unique spatial and temporal scales (Fig. 1): (i) methylmercury bioaccumulation; (ii) emissions of greenhouse gases; (iii) downstream effects; and (iv) limitation of biodiversity. Each of these impacts have environmental and social effects, both of which are considered in this review, although environmental effects receive more emphasis. We have chosen to interweave the presentation of environmental and social effects to emphasize the linkages between them. The material presented concentrates on Canadian experiences, but examples from elsewhere in the world are used to demonstrate that broadly applicable principles are involved. This review will not address alternative energy sources to hydroelectric generation or hydroelectric conservation programs, which are both subjects broad enough to deserve separate attention.

### Methylmercury bioaccumulation

Methylmercury bioaccumulation by fish and the consequent consumption of fish by humans is of concern in the creation of reservoirs. Methylmercury is an organic molecule produced mainly by bacteria (Berman and Bartha 1986) from inorganic mercury naturally present in materials flooded during the course of reservoir creation (Bodaly et al. 1984a; Hecky et al. 1991; Kelly et al. 1997). Methylmercury is a neurotoxin to which the human fetus is particularly sensitive (e.g., Weihe et al. 1996).

Methylmercury bioaccumulation is the most spatially restricted of the four environmental impacts being reviewed (Fig. 1). Methylmercury problems in fish are confined to the reservoirs themselves and short (<100 km) distances downstream. Temporally, methylmercury contamination in reservoirs can last 20–30 years or more; for example, methylmercury levels in predatory fish in boreal reservoirs of Canada and Finland can be expected to return to background levels 20–30 years after impoundment (Bodaly et al. 1997).

### Environmental effects

The first indication that methylmercury was a problem in new reservoirs came from South Carolina (Abernathy and Cumbie 1977). Alerted by the American experience, researchers elsewhere began reporting similar occurrences (Table 3). Research on northern reservoirs, especially in Canada and Finland, has

**Table 2.** Extent of flooding involved in selected major hydroelectric developments.

Project and location	Total surface area of impounded water (km <sup>2</sup> )	Area of newly flooded land (km <sup>2</sup> )	Comments	Ref.
<b>Canada</b>				
Kemano, Phase I, B.C.	890	NA	Includes the Nechako Reservoir	Rosenberg et al. 1987
Williston Reservoir, B.C.	1645	NA	Involves Peace River	Peace–Athabasca Delta Project Group 1972
Churchill–Nelson, Man.	3299	~750	Includes Southern Indian Lake (SIL), Notigi, and Stephens Lake reservoirs; preimpoundment surface area of SIL, 1977 km <sup>2</sup>	Newbury et al. 1984; Rosenberg et al. 1987, 1995
Manic 5, Qué.	2072	NA	—	R. Harris, personal communication
La Grande, Phase I, Qué.	11 345	9675	Includes La Grande (LG) 2, 3, and 4, Opinaca, and Caniapiscou reservoirs. DesLandes et al. (1995) report that Phase 1 covers a total area of 13 520 km <sup>2</sup>	Berkes 1988
La Grande, Phase II, Qué	~2000	NA	Includes Laforge-1 and Eastmain-1 reservoirs	A. Penn, personal communication
Churchill Falls, Labrador	6705	NA	Includes Smallwood, Ossokmanuan, and Jacopie Lake reservoirs	Rosenberg et al. 1987
<b>United States</b>				
Missouri mainstem reservoirs, Mont., N.Dak., S.Dak., Nebr.	6260	NA	Includes Lake Ft. Peck (991 km <sup>2</sup> ), Lake Sakakawea (3060 km <sup>2</sup> ), Lake Francis Case (420 km <sup>2</sup> ), Lewis and Clark Lake (113 km <sup>2</sup> ), Lake Oahe (1450 km <sup>2</sup> ), and Lake Sharpe (226 km <sup>2</sup> ) reservoirs	Rosenberg et al. 1987
<b>Russian Federation</b>				
Volga River	26 010	50–69% of area inundated was highly fertile cropland	Includes 11 reservoirs, 8 in the Volga River catchment and 3 in the Kama River catchment. The largest of these are Kuibyshevskaya (6450 km <sup>2</sup> ) and Rybinskaya (4550 km <sup>2</sup> ) reservoirs, both in the Volga catchment. Poddubny and Galat (1995) report the following total : shallow-water areas (km <sup>2</sup> ) for the four reservoirs of the Upper Volga River: Ivankova, 327:156; Uglich, 249:89; Rybinsk, 4450:950; Gorky, 1591:368	Rozengurt and Hedgpeth 1989
River Don	5500	NA	>130 reservoirs in the catchment	Volovik 1994
<b>Ukraine</b>				
Dnieper River	~7000	NA	Dnieper reservoir cascade. Exact number of reservoirs involved is not given	Romanenko and Yevtushenko 1996
<b>South America</b>				
Balbina Reservoir, Amazonas State, Brazil	2360–4000	NA	Exact size is not known because of survey's margin of error	Fearnside 1989
	3147	3108	Columns 7 and 8 of Table III in Fearnside 1995	Fearnside 1995
Tucurui Reservoir, Pará State, Brazil	2160	NA	—	Monosowski 1984
	2247	1926	Columns 7 and 8 of Table III in Fearnside 1995	Fearnside 1995

Table 2 (concluded).

Project and location	Total surface area of impounded water (km <sup>2</sup> )	Area of newly flooded land (km <sup>2</sup> )	Comments	Ref.
	2830	NA	Tocantins–Araguaia catchment, the southeasternmost Amazonian tributary, integrates the seasonally dry Cerrados with the hot humid Amazonian rain forest	Ribeiro et al. 1995
Itaipu, Brazil and Paraguay	1350	NA	—	Goldsmith and Hildyard 1984
Guri, Venezuela	3280	NA	—	Goldsmith and Hildyard 1984
<b>Africa</b>				
Lake Kariba Reservoir, Zimbabwe and Zambia	5364	NA	Dam on middle part of Zambezi River at Kariba Gorge; forested and savannah regions	Balon 1978; Obeng 1981
Volta Lake Reservoir, Ghana	8500	NA	Dam on Volta River at Akosombo. Reservoir occupies two climatic zones: forest in south and savannah–woodland in north	Petr 1971; Obeng 1977, 1981
Lake Kainji, Nigeria	1280	NA	Dam on Niger River at Bussa; forested and savannah regions	Obeng 1981
High Dam at Aswan, Egypt and Sudan	3000–6000	NA	Dam on Nile River. Reservoir is known as Lake Nasser (Egyptian part) and Lake Nubia (Sudanese part)	White 1988
Cabora Bassa Dam, Mozambique	6276	NA	Reservoir lies in desert region	Obeng 1981
	3800		Dam on lower Zambezi River at Cabora Bassa Gorge	Goldsmith and Hildyard 1984; Bolton 1984
<b>Middle East</b>				
Southeast Anatolia Project, Turkey	1857	NA	Euphrates River development: Keban Dam (680 km <sup>2</sup> ), Karakoya Dam (300 km <sup>2</sup> ), and Ataturk Dam (877 km <sup>2</sup> ); other smaller developments on Euphrates. Developments on Tigris are planned	Hillel 1994
<b>Southeast Asia</b>				
Brokopondo, Suriname	1500	NA	—	Goldsmith and Hildyard 1984
Kabalebo, Suriname	1450	NA	—	Goldsmith and Hildyard 1984
<b>China</b>				
Three Gorges Reservoir, Yangtze River	1150	632	Mostly in mountainous terrain	Chau 1995
Danjiangkou Reservoir, Han River	745–1000	NA	Largest extant reservoir in China	Zhong and Power 1996

Note: NA, not available.

been extensive; fewer reports come from temperate and tropical reservoirs. However, the problem appears to be less severe in warmer areas (Yingcharoen and Bodaly 1993).

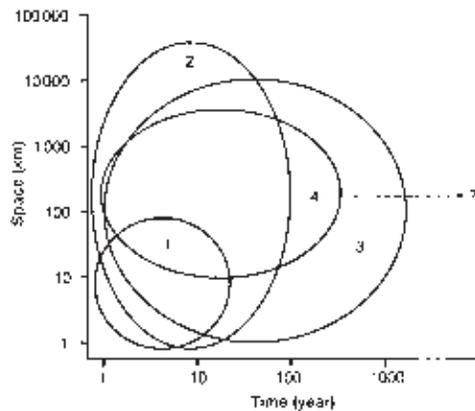
Research in northern Canadian reservoirs has revealed the following characteristics of methylmercury in fish.

(1) It can reach very high levels. For example predatory fish (pike: *Esox lucius*; walleye: *Stizostedion vitreum*) in La Grande (LG) 2 Reservoir in the James Bay region of Québec reached approximately six times background levels or more than seven times the Canadian marketing limit of 0.5 µg/g (Verdon et al. 1991). Mean concentrations in predatory fish almost always exceed 1.0 µg/g in northern reservoirs (Bodaly et al. 1997).

(2) Levels in predatory fish usually remain elevated for 2–3 decades following impoundment, whereas levels in water and zooplankton remain elevated for 10 and 10–15 years, respectively (Bodaly et al. 1997). The difference between fish and lower trophic levels is probably the result of a longer half-life of methylmercury in fish and a slower turnover of fish populations. Methylmercury levels in predatory fish from the LG2 Reservoir and from reservoirs in northern Manitoba remain above marketing levels 10–20 years after reservoir creation (Strange et al. 1991; James Bay Mercury Committee 1995; Bodaly et al. 1997). Average levels in LG2 were still >3.0 µg/g 13 years after flooding.

**Table 3.** Examples of elevated methylmercury levels in fish from new reservoirs.

Location	Species	Ref.
<b>Boreal zone</b>		
Northern Manitoba	<i>Stizostedion vitreum</i> (walleye), <i>Esox lucius</i> (northern pike), and <i>Coregonus clupeaformis</i> (lake whitefish)	Bodaly et al. 1984a
Northern Québec	As for northern Manitoba plus <i>Catostomus catostomus</i> (longnose sucker) and <i>Salvelinus namaycush</i> (lake trout)	Boucher et al. 1985
Labrador	<i>Esox lucius</i> , <i>Salvelinus namaycush</i> , and <i>Coregonus clupeaformis</i>	Bruce and Spencer 1979
Finland	<i>Esox lucius</i> and <i>Coregonus lavaretus</i> (whitefish)	Lodeniuss et al. 1983
<b>Temperate areas</b>		
Southern Saskatchewan	<i>Stizostedion vitreum</i> and <i>Castostomus commersoni</i> (common sucker)	Waite et al. 1980
Illinois	<i>Micropterus salmoides</i> (largemouth bass)	Cox et al. 1979
South Carolina	<i>Micropterus salmoides</i> , <i>Morone chrysops</i> (white bass), and <i>Perca flavescens</i> (yellow perch)	Abernathy et al. 1985
<b>Tropical area</b>		
Thailand	<i>Pristolepis fasciatus</i> , <i>Puntiploites procozyron</i> , <i>Hampala macrolepidota</i> , and <i>Morulus chrysophekadion</i>	Yingcharoen and Bodaly 1993

**Fig. 1.** Spatial and temporal scales at which impacts resulting from large-scale hydroelectric development manifest themselves. 1 = methylmercury bioaccumulation; 2 = emission of greenhouse gases; 3 = downstream effects; 4 = limitation of biodiversity. (Note that axes are in log scales.)

(3) Methylmercury can be elevated in biota downstream of reservoirs. For example, fish downstream of dams have higher methylmercury concentrations than fish in the reservoir upstream, because the downstream fish feed on fish that are injured passing through the turbines (Brouard et al. 1994). Fish and invertebrates downstream of reservoirs also can have elevated methylmercury concentrations in the absence of generating stations (Johnston et al. 1991; Bodaly et al. 1997), apparently because of the transport of methylmercury in water and invertebrates. This second kind of downstream transport of methylmercury probably extends for <100 km but may be a more common occurrence than elevated levels caused by fish feeding on injured fish.

Why is methylmercury a by-product of flooding and how is it bioaccumulated by fish? At the outset, methylmercury elevation in fish is related to the degree of flooding of terrestrial areas involved in reservoir creation. A high proportion of land flooded to the final surface area of the reservoir produces higher methylmercury levels than when a low proportion of the surface area is flooded land (Bodaly et al. 1984a; Johnston et al. 1991). This relationship appears to explain why fish methylmercury levels in the LG2 reservoir, which was created by flooding a river valley, were so much higher than those in Southern Indian Lake (SIL), Manitoba, an already existing lake whose water level was raised 3 m (Verdon et al. 1991; cf. Strange et al. 1991). Linear models developed by Johnston et al. (1991) can be used to predict fish methylmercury levels in boreal reservoirs based on the ratios of flooded terrestrial area to water volume of the reservoir itself (within-lake effects) and of flooded terrestrial area to water volume of inflowing waters (upstream effects). Models developed by Hydro-Québec (1993a) also depend on the terrestrial area flooded but include data on reservoir volume and flushing rate, decomposable organic matter, and methylmercury dynamics in fish.

Experimental studies done in mesocosms demonstrated that methylmercury accumulating in fish originates by microbial transformation of inorganic mercury naturally present in the soil and vegetation that are flooded (Hecky et al. 1987, 1991). All organic materials (moss, spruce boughs, and prairie sod) added to the mesocosms stimulated methylmercury bioaccumulation by yellow perch (*Perca flavescens*). Hecky et al. (1991) also demonstrated greatly enhanced rates of conversion from inorganic mercury to methylmercury in newly flooded sediments of reservoirs compared with natural lake sediments.

Methylmercury production and uptake into the aquatic food web are being examined by the Experimental Lakes Area Reservoir Project (ELARP) in northwestern Ontario (Kelly et al. 1997). Natural wetlands in the northern boreal ecotone are sites of methylmercury production and important sources of methylmercury to downstream ecosystems (St. Louis et al. 1994, 1996). Boreal wetlands flooded to form reservoirs become even larger sources of methylmercury because of

increased methylmercury production in flooded vegetation and peat. This problem was studied in an experimentally flooded wetland in which methylmercury production increased 35-fold (to  $\sim 6 \mu\text{g}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ ) after flooding (Kelly et al. 1997). Bacteria converted inorganic mercury (present prior to flooding) to methylmercury in the process of decomposing flooded vegetation. The system responded within weeks to the increased methylmercury production. Concentrations of methylmercury in surface water and peat increased  $\sim 10$ -fold (to  $\sim 1 \text{ ng/L}$  and  $10 \text{ ng/g}$  dry weight, respectively); the proportion of methylmercury to total mercury in water increased from  $\sim 5$  to  $>30\%$ . Methylmercury concentrations also increased after flooding in zooplankton (to  $\sim 340 \text{ ng/g}$  dry weight (10-fold); M.J. Paterson, personal communication); predatory shoreline insects (to  $\sim 180 \text{ ng/g}$  dry weight (2-fold); footnote 4); caged floater mussels (*Pyganodon grandis*; Malley et al. 1996); finescale dace (*Phoxinus neogaeus*; to  $\sim 0.30 \mu\text{g/g}$  wet weight (3-fold); Kelly et al. 1997); and 18-day old nestling tree swallows (*Tachycineta bicolor*; to  $\sim 100 \text{ ng/g}$  dry weight (2-fold); V. St. Louis, personal communication). In addition, an experiment done in nearby reference Lake 240 showed that food was the dominant pathway of methylmercury uptake by fish (*P. neogaeus*; 85 versus 15% by passive uptake from water) at natural levels of methylmercury (Hall et al. 1997). It will be important to determine the duration of elevated rates of methylmercury production in the experimental reservoir. Methylation rates still remain high 3 years after flooding.

The link between newly flooded organic matter, the stimulation of methylmercury production, and increased methylmercury bioaccumulation in fish has led to an obvious recommendation for remediation: removal, burning, or covering of vegetation and soil organic matter before flooding to reduce the severity of the mercury problem. However, this recommendation has not been experimentally verified and, in any case, is impractical to carry out in large reservoirs. For example, the SIL reservoir has a shoreline length of 3788 km (Newbury et al. 1984). Alternatives would be to minimize the area flooded when creating reservoirs and avoid flooding natural wetland areas (Kelly et al. 1997).

It is not clear whether concentrations of methylmercury in predatory fish from reservoirs are sufficiently high to affect their populations (Niimi and Kissoon 1994; Wiener and Spry 1996). However, the main concern has been the effect of consumption of these fish on human populations.

#### Social effects

Canada has been a focus for the study of social impacts of methylmercury bioaccumulation resulting from hydroelectric development. The movement of large-scale hydroelectric development into Canada's subarctic boreal forest region has put at risk residents of the area, who are mainly aboriginal and live in small villages that are usually located on major rivers and lakes. The villages are characterized by mixed subsistence-based economies and rely on access to the fish and wildlife resources of customary territories that range in size from thousands to tens of thousands of square kilometres of land and water (Usher and Weinstein 1991). The term subsistence

refers to the production of local renewable resources for non-market home and community use. Subsistence in contemporary northern aboriginal communities is integrated at the household level with wage labor, commercial resource harvesting, and other economic activities (Wolfe and Walker 1987; Usher and Weinstein 1991; Berkes et al. 1994).

Large-scale hydroelectric development in northern Canada has entailed relocation of some communities away from flooded zones, encroachment by outsiders on traditional territories, harvest disruption caused by the physical and biological effects of the projects, and methylmercury contamination (Rosenberg et al. 1995; Berkes and Fast 1996). All of these events affect subsistence-based economies in often complex ways. The problem of methylmercury contamination, and resultant closed fisheries, in northern communities is particularly serious (Bodaly et al. 1984a; Boucher et al. 1985; Anonymous 1987; Berkes 1988), although to date no medically documented cases are available of mercury poisoning caused by eating fish from new reservoirs (e.g., Wheatley and Paradis 1995). In addition, the social impact of elevated mercury levels is difficult to distinguish from impacts of a range of social changes caused by hydroelectric development (Waldrum 1985; Niezen 1993).

Research reported in Rosenberg et al. (1995) and Berkes and Fast (1996) indicated that approximately one quarter to one third of the wild food harvested by Cree communities in northern Manitoba, Ontario, and Québec came from fishing; residents of these communities routinely caught and ate large quantities of fish over extended periods of the year. A public health strategy that advised native people not to eat contaminated fish also advised them not to fish, which is a common activity of great economic and cultural importance (e.g., Wheatley and Paradis 1995). In addition, the substitution of natural food with store-bought food posed its own threats to the health of native populations (Szathmary et al. 1987; Thouez et al. 1989). Last, the pervasive effects of methylmercury contamination on the social and mental well-being of natives and communities at risk needs to be mentioned. Whether or not individuals were exposed to or actually ingested injurious levels of methylmercury, the threat alone caused anxiety and the native communities suffered adverse social and psychological effects (Usher 1992; Wheatley and Paradis 1995).

#### Greenhouse gases

The release of greenhouse gases ( $\text{CH}_4$  and  $\text{CO}_2$ ) caused by the flooding of organic matter such as in forested peatlands may be the newest surprise connected with reservoir creation (Rudd et al. 1993). The problem is reasonable to expect given the considerable decomposition of flooded organic material and frequent oxygen depletion that usually accompany reservoir creation.

Bacterial decomposition of flooded organic material is at the base of both the methylmercury bioaccumulation problem discussed above and greenhouse gas emissions. On a temporal scale, greenhouse gas emissions from northern boreal reservoirs should slow with time but may last longer than 100 years where peat has been flooded, whereas the process should be faster in tropical areas because they have no peat tied up as organic carbon in soils and have higher year-round temperatures

<sup>4</sup> B.D. Hall, D.M. Rosenberg, and A.P. Wiens. Methylmercury in aquatic insects from an experimental reservoir. In preparation.

**Table 4.** Possible rates of greenhouse gas produced and energy generated by (i) fossil-fuel generation, and reservoirs having a (ii) low and (iii) high ratio of flooded area to energy produced.\*

Site used in estimation	Category of energy generated	Ratio of flooded area to energy produced $\left(\frac{\text{km}^2}{\text{TWh}\cdot\text{year}^{-1}}\right)$	Rate of greenhouse gas production (equiv. Tg CO <sub>2</sub> ·TWh <sup>-1</sup> )
<b>(A) Manitoba (details given in Rudd et al. 1993)</b>			
Coal-fired generation	<i>i</i>	—	0.4–1.0
Churchill-Nelson diversion	<i>ii</i>	88	0.04–0.06
Grand Rapids (Cedar Lake)	<i>iii</i>	710	0.3–0.5
<b>(B) Brazil (details given in Fearnside 1995)</b>			
Manaus fossil fuel	<i>i</i>	—	1.30
Tucurai	<i>ii</i>	64	0.58
Balbina reservoir	<i>iii</i>	1437	26.20

Note: TWh = terawatt hours; Tg = teragrams; T = 10<sup>12</sup>.

\*Caution should be used in comparing the results of Rudd et al. (1993) and Fearnside (1995) because of differences in (a) calculating the global warming potential of CH<sub>4</sub>; (b) considering indirect and direct effects of CH<sub>4</sub>; and (c) time scales used. In addition, Fearnside (1995) relied on modeling, whereas Rudd et al. (1993) took direct measurements.

(Fig. 1). Spatially, greenhouse gas emissions probably represent the most extensive impact of large-scale hydroelectric development, as they may contribute to global climate change (see below).

#### Environmental effects

The net greenhouse effect in natural boreal forests is about zero: peatlands are natural sinks for CO<sub>2</sub>, but they are slight sources of CH<sub>4</sub> to the atmosphere, and forests are slight sinks for CH<sub>4</sub>, but they are neutral for CO<sub>2</sub> (Rudd et al. 1993). The flooding of forests in the course of reservoir creation upsets these natural balances and results in a flux of greenhouse gases to the atmosphere. Estimates of greenhouse gas emissions from northern Canadian and Brazilian reservoirs indicate that some reservoirs with a high ratio of surface area to energy produced can approximate (Table 4A) or greatly exceed (Table 4B) emissions from power plants using fossil fuels. Conversely, run-of-the-river installations may be much less polluting than power plants run by fossil fuels.

The dramatic difference in greenhouse gas emissions between Cedar Lake Reservoir in Manitoba and Balbina Reservoir in the Brazilian Amazon (Table 4) is probably real. The much higher emissions calculated for Balbina are a result of recent flooding in a tropical setting (see below). There is a need for more of these kinds of geographic comparisons and research to explain the differences.

The following factors may be involved in regulating the intensity and duration of greenhouse gas emissions after reservoir creation (Kelly et al. 1994).

(1) The amount of flooding involved. Extensive flooding of terrestrial areas will lead to large releases of gases (e.g., Table 4), a factor also important in determining bioaccumulation of methylmercury in fish (see above).

(2) The age of the reservoir. Decomposition rates appear to decrease with time, as indicated by data on oxygen depletion (Baxter and Glaude 1980; Schetagne 1989). An initial period of rapid decomposition of easily degraded organic material probably will be followed by a period of slower decomposition of more refractory organic material. The slowing of rates means that

the longer the life of a reservoir, the lower will be the average flux per year of gases. However, even after decomposition of organic material is complete, greenhouse gas emissions will be similar to the rates produced by natural lakes, which are greater than estimated fluxes for the original, undisturbed, terrestrial system (Rudd et al. 1993).

(3) The amount of plant biomass and soil carbon flooded. Plant biomass varies in different ecosystems (e.g., 0.7 kg C/m<sup>2</sup> in grasslands to 20 kg C/m<sup>2</sup> in tropical rain forests; boreal ecosystems are approximately midway in this range) and so does soil carbon (low in the tropics to high in boreal peatlands) (Kelly et al. 1994). Flooding of peatlands is of special concern because the large amount of carbon stored in them could produce greenhouse gases for decades.

(4) The geographic location of a reservoir. Temperature will vary with location, and temperature will affect the rate of decomposition and the ratio of CH<sub>4</sub>:CO<sub>2</sub> that is released. Tropical reservoirs will have high water temperatures and fast decomposition, which tend to produce anoxic conditions and a high proportion of CH<sub>4</sub> (Fearnside 1995). The global-warming potential of CH<sub>4</sub> is 20–40 times that of CO<sub>2</sub> (per g basis), so the percentage of CH<sub>4</sub> released is important.

The magnitude and extent of the potential greenhouse gas emission problem is currently being examined along with methylmercury bioaccumulation in the ELARP experiment in northwestern Ontario (see above). Flux of CH<sub>4</sub> to the atmosphere after flooding of the experimental reservoir increased by about 20-fold (to 11 g C·m<sup>-2</sup>·year<sup>-1</sup>); Kelly et al. 1997). Prior to flooding, the wetland was a net sink for CO<sub>2</sub> (8.2 g C·m<sup>-2</sup>·year<sup>-1</sup>) because of fixation of CO<sub>2</sub> as organic carbon by plant photosynthesis. After flooding, the wetland became a large CO<sub>2</sub> source (>170 g C·m<sup>-2</sup>·year<sup>-1</sup>). These postflooding changes were caused by the death of vegetation, which eliminated the photosynthetic CO<sub>2</sub> sink and stimulated the production of CO<sub>2</sub> and CH<sub>4</sub> by decomposition of plant tissue. The increased flux of CH<sub>4</sub> was also caused by an increased level of anoxia in the reservoir and decreased CH<sub>4</sub> oxidation, which reduced the proportion of CH<sub>4</sub> that was consumed by bacteria before it could escape from the reservoir.

Postflood fluxes of CO<sub>2</sub> from the experimental reservoir were similar to measured fluxes of CO<sub>2</sub> from large hydroelectric reservoirs in northern Québec (Kelly et al. 1997). Fluxes of CH<sub>4</sub> from the experimental reservoir at the Experimental Lakes Area (ELA) were faster than from the Québec reservoirs but much slower than the very high rates predicted for tropical reservoirs. Measured fluxes of greenhouse gases from the experimental reservoir were similar to rates predicted by Rudd et al. (1993) and are within a range that is significant in some types of hydroelectric developments. The level of concern is related to the ratio of electricity produced per unit of land flooded; presently available data indicate that greenhouse gas fluxes from northern hydroelectric developments that produce <1 MW of electricity/km<sup>2</sup> of land flooded may be of concern in proposals for new reservoir development (C.A. Kelly, unpublished data). The global significance of reservoirs as sources of greenhouse gases is related to the total area of all types of reservoirs and to fluxes from the major types; however, the global surface area of reservoirs is poorly known and flux measurements are available for only a few locations.

As for the methylmercury problem discussed above, possible remediation would require removal of organic matter from the area to be flooded, an improbable task given the extent of forest flooded in today's large-scale hydroelectric developments. Minimizing the area flooded and avoiding wetlands are possible alternatives (see above).

#### Social effects

The social effects of greenhouse gas emissions from reservoirs are entwined in the greater problem of global climate warming. The social effects of global climate change are complex and, until recently, somewhat speculative. For example, everyone is familiar with the claim that climate warming will eventually cause rising sea levels, which will inundate low-lying cities (e.g., Gribbin and Gribbin 1996). However, recent news stories indicate that insurance companies worldwide are concerned about the increasing incidence of extreme weather events, thought to be tied to climate warming (e.g., Sterling 1996; Redekop 1996). The above examples indicate that the social effects of climate warming will occur at much broader spatial and temporal scales than, say, elevated methylmercury levels.

A major problem in public perception is the lack of a measurable link between specific greenhouse gas emissions (greenhouse gases are produced by a variety of human activities) and any subsequent environmental or social damage. This strongly contrasts with other local and regional effects of hydroelectric development for which cause and effect are often obvious.

The role played by greenhouse gas emissions from hydroelectric development will be difficult to identify. The overall contribution of greenhouse gas emissions from reservoirs to global climate warming is thought to be small when compared with other major sources of greenhouse gases, such as the burning of fossil fuels (C.A. Kelly and J.W.M. Rudd, unpublished data). Certainly, little evidence exists in the current energy policy literature indicating that reservoir greenhouse gas emissions are deemed to be important (e.g., Goodland 1994–1995). However, Pearce (1996) estimated that CO<sub>2</sub> emissions from reservoirs globally amount to 7% of total, man-made emissions of CO<sub>2</sub>. He used a total global reservoir surface area of 600 000 km<sup>2</sup> and Canadian rates of emission (presumably based on Rudd et al. 1993). Canadian reservoirs

would add 12% to total Canadian greenhouse gas emissions over the next 50 years if Rudd et al.'s (1993) estimates are correct (Pearce 1996). This source of greenhouse gases may become increasingly important in time as the burning of fossil fuels decreases. Determination of the importance of hydroelectric developments as contributors of greenhouse gases on a global level is an important future research endeavor.

Greenhouse gas emissions from reservoirs may assume greater future importance at the local level as nations move toward CO<sub>2</sub> accounting. Decisions can be made at the local level; tools are available (e.g., Rudd et al. 1993; Fearnside 1995) to choose among alternative hydroelectric development possibilities to minimize greenhouse gas production.

#### Downstream effects

Proponents of large-scale hydroelectric development often claim that water flowing freely to the ocean is wasted (e.g., Bourassa 1985; White 1988). Ironically, changes in the natural hydrological cycle as a result of water storage for power production and interbasin water diversion ultimately cause downstream freshwater and marine resources to be wasted. This impact can operate at the scale of thousands of kilometres from the source of the problem (Fig. 1), although some predicted effects on marine currents and changes in climate (see below) expand the spatial scale even more. Temporally, changes to downstream areas can be regarded as very long term, unless some effort is made to operate upstream facilities in a way that mimics natural hydrological flows.

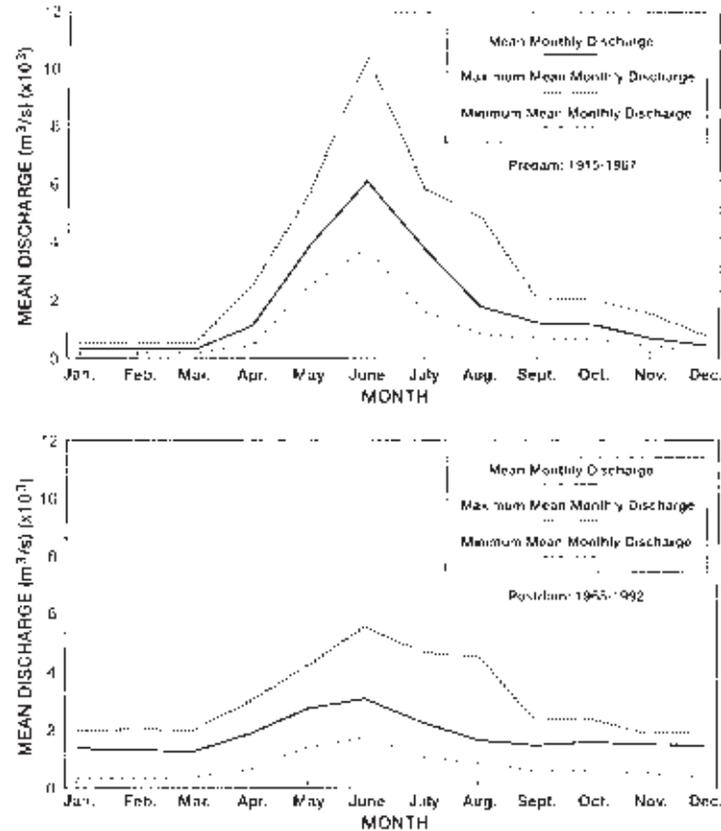
#### Environmental effects

Natural seasonal runoff patterns influence heavily the ecology of downstream deltaic, estuarine, and marine coastal areas (e.g., Neu 1982a, 1982b; Rozengurt and Hedgpeth 1989; Rozengurt and Haydock 1993). These downstream areas are cradles of biological productivity because of the delivery of nutrients to them by freshwater runoff and because, at least in the north-temperate zone, freshwater runoff entering the ocean causes mixing and entrainment of deep, nutrient-rich ocean water into the surface layer (Neu 1982a; Milko 1986; Rozengurt and Haydock 1993). Nearshore biological processes such as primary productivity and fish feeding, growth, migration, and spawning are attuned to these seasonal dynamics of flow. In the case of a large, northern freshwater delta like the Peace–Athabasca in Alberta, natural seasonal cycles of flooding maintain the delta vegetation in an early successional stage of high productivity, which leads to a diverse and productive wildlife community (Rosenberg 1986).

Hydroelectric developments on north-temperate rivers characteristically trap high spring flows for storage in reservoirs and release higher-than-normal flows in winter when the power is needed (Fig. 2; see also Fig. 3 of Bergström and Carlsson 1994 for the Luleälven River, Sweden). Thus, the normal hydrograph is attenuated in spring and enhanced in winter (e.g., Devine 1995; see Dudgeon 1992 for different flow modification in tropical Asian rivers). Ecologically, runoff is transferred from the biologically active period of the year to the biologically inactive: it is like watering your garden in the winter (Neu 1982a).

Neu (1982b) neatly expressed the magnitude of the problem for Canada. All rivers on earth at any one time contain

**Fig. 2.** Effect of flow control on the natural hydrograph of a north-temperate river, the Peace at the town of Peace River, Alta. (reprinted from Shelast et al. 1994, p. 26, with permission of Sentar Consultants Ltd., Calgary, Alta.). The Bennett Dam is situated upstream in British Columbia (see Rosenberg 1986).



~1300 km<sup>3</sup> of water, which is approximately the same amount of existing artificial (i.e., reservoir) storage in Canada. Canada's rivers annually discharge ~1500–2000 km<sup>3</sup>, a value slightly above existing artificial storage. If the live storage amounts to one quarter to one third of this amount, then ~400 km<sup>3</sup> of water is shifted annually from spring to winter. In other words, before any regulation, the spring and winter volumes were 1600 and 400 km<sup>3</sup>, respectively; after extensive regulation, the volumes became 1200 and 800 km<sup>3</sup>, respectively.

Bergström and Carlsson (1994) documented changes of river runoff into the northern basins of the Baltic Sea as a result of hydropower development. Seasonally, the Bothnian Bay and the Bothnian Sea receive increased winter discharge and decreased discharge at other times of the year. On a monthly basis, both of these areas show evidence of increasing base-flow levels over time.

Physical/chemical changes to downstream areas resulting

from significant alteration of seasonal flows include (i) desiccation of wetlands, increased offshore salinity, and upstream saltwater intrusion because of reduced flows; (ii) collapse of natural deltaic levees and subsidence of coastal deltaic areas because of reduced sediment inputs; and (iii) overall reduction of spring nutrient inputs to estuaries (e.g., Rozengurt and Hedgpeth 1989; Rozengurt and Haydock 1993). Northern areas are particularly affected by the loss of buoyancy flux provided by freshwater inputs and the resulting stable layer that enables high, offshore primary productivity. On an even larger scale, the reduction of river inputs of sediments to the sea because of dam construction has reduced "...the input of natural ballasts which are instrumental in carbon removal and preservation. By changing the sediment load of rivers we are changing biogeochemical cycling of elements in regions where more than 80% of organic carbon is being removed today..." (Ittekkot and Haake 1990).

Biological changes involve (i) lowered spring primary productivity because of decreased nutrient inputs and loss of stratification; (ii) lowered benthic invertebrate productivity because of changes in primary productivity and increased salinity; and (iii) deleterious effects on the most valuable commercial fisheries because of changes in fish-food organisms, nursery grounds, spring spawning, and migration (Rozengurt and Hedgpeth 1989; Rozengurt and Haydock 1993; Attrill et al. 1996).

Changes to ocean currents and climate as a result of large-scale hydroelectric development (e.g., Neu 1982a) and water diversions (e.g., Gribbin 1979; Micklin 1985; Milko 1986) can also be considered downstream effects, albeit of the largest possible extent. However, predictions of such changes and their ecological meanings are uncertain at this point, and the proposed, massive water diversion projects that would cause them are not yet a reality.

Several case histories of downstream effects are available that demonstrate the adverse ecological consequences of grossly altered seasonal water flows, as described above (Table 5). The Aral Sea has not been included because its desiccation is related to upstream irrigation practises rather than hydroelectric development. Nevertheless, it is an excellent example of the ultimate effect of extreme water abstraction on downstream areas (e.g., see Micklin 1988; Ellis and Turnley 1990; Kotlyakov 1991; Precoda 1991; Levintanus 1992; Glantz et al. 1993; Pearce 1995b). In addition, Löffler (1993) reviewed irrigation problems of lakes in developing countries, Mirza and Ericksen (1996) described the environmental and social impacts of flood-control/irrigation projects in Bangladesh, and Nichols et al. (1986) described effects of extensive upstream water withdrawal for irrigation on the estuary of San Francisco Bay.

Predicting the cumulative effects on Hudson and James bays of large-scale hydroelectric development in their catchments is a problem currently being faced in Canada (Rosenberg et al. 1995). Major developments exist on the Churchill and Nelson rivers in Manitoba, the Moose River in Ontario, and La Grande River in Québec, and others have been proposed (see Table 4 of Rosenberg et al. 1995). Concerted efforts at cumulative impact assessment on Hudson Bay will be hampered by the meager data base available (especially for the winter period), poor knowledge of ranges of natural variability, incomplete understanding of natural processes, and lack of political will to improve these deficiencies (Rosenberg et al. 1995).

#### Social effects

Numerous benefits and disbenefits of large-scale hydroelectric development on downstream uses of water have been documented. Benefits may include flood control (e.g., Fearnside 1988; White 1988; Hillel 1994; Chau 1995; Dudgeon 1995; Losos et al. 1995); provision of irrigation water (e.g., White 1988; Hillel 1994; Dudgeon 1995; Losos et al. 1995; Romanenko and Yevtushenko 1996; Zhong and Power 1996); and provision of urban and industrial water supplies (e.g., Hillel 1994; Romanenko and Yevtushenko 1996; Zhong and Power 1996). Disbenefits may include the loss of water for irrigation and urban needs; loss of soil fertility because of elimination of normal flood periods (e.g., White 1988; Hillel 1994); and reduction of productivity of fish and wildlife

(e.g., Berkes 1982; Gaboury and Patalas 1984; Ebel et al. 1989; Hesse et al. 1989; Usher and Weinstein 1991). In general, any impacts on mangrove areas, floodplains, wetlands, and deltas will also affect human uses that depend on these productive ecosystems or on high water quality.

Perhaps the most dramatic social consequence of altering natural flows to downstream areas is the reduction or collapse of the commercial fisheries in these areas. The declines in commercial fish catches from 1950 to 1970 to 1990 in the four great inland seas of the former Soviet Union and the eastern Mediterranean off the coast of Egypt are shown in Table 6. Rozengurt and Haydock (1994) attribute these declines to impoundment of major river systems, but other anthropogenic activities such as overfishing and chemical pollution are almost certainly also involved. The ensuing hardship on fishers has been mentioned explicitly for the Azov Sea (Rozengurt and Haydock 1993) and the Danube Delta (Pringle et al. 1993). However, similar effects probably resulted from the precipitous decline of commercial fisheries in the Caspian Sea (Rozengurt and Hedgpeth 1989) and the Black Sea (Tolmazin 1979). Construction of the High Dam at Aswan in Egypt has been implicated in the serious decline of the sardine fishery in the eastern Mediterranean, but cause-and-effect has been difficult to prove (White 1988).

Several hydroelectric projects in the Canadian north have documented negative impacts on downstream aboriginal communities (Rosenberg et al. 1995). For example, the Peace-Athabasca Delta in northern Alberta is located 700 km downstream of the Bennett Dam in British Columbia. The Delta, one of the largest inland deltas in the Western Hemisphere, provided productive muskrat, fish, and waterfowl habitat, which supported the aboriginal economy of Ft. Chipewyan (Peace-Athabasca Delta Project Group 1973). Reduced spring flooding in the Delta as a result of the upstream dam (Table 5) negatively affected the harvest of muskrat, and some species of fish and waterfowl, with consequent adverse effects on the aboriginal community. The damage was only partially remedied by mitigative measures (Dirschl et al. 1993).

A subsistence fishery at Chisasibi on La Grande River downstream of the LG2 Reservoir in northern Québec declined when the river was blocked in 1978 to allow filling of the Reservoir (Berkes 1982). However, the effect was short lived and the fishery recovered, only to be closed later because of high methylmercury levels (Berkes 1988). A number of other problems at the mouth of La Grande resulted from hydroelectric development upstream: (i) upstream movement of saline water from James Bay, which affected the local water supply; (ii) debris in the river, which affected the fishery; and (iii) problems of access to the north shore of the river because of unpredictable ice conditions resulting from operation of the LG2 Reservoir (Berkes 1981, 1982, 1988). The last problem was solved by building a road across the recently completed LG1 Dam (Anonymous 1995). Similar problems were encountered by the Inuit of Kuujuaq (Fort Chimo) at the mouth of the Koksoak River following blockage of the Caniapiscou River in 1982 to fill the Caniapiscou Reservoir: (i) increased salinity of the drinking water; (ii) fouling of nets by algae, which limited fishing; and (iii) difficult access and navigation because of glacial boulders exposed at low water (Bissonnette and Bouchard 1984).

### Limitation of biodiversity

“River systems and their riparian zones play key roles in the regulation and maintenance of biodiversity in the landscapes.” (Dynesius and Nilsson 1994)

“Loss of biodiversity compromises the structure and function of ecosystems, which can in turn compromise the economic well-being of human populations.” (Coleman 1996)

Biodiversity can be defined as “...the variety and variability among living organisms and the ecological complexes in which they occur” (OTA 1987, in Angermeier and Karr 1994). More simply put, biodiversity is “...the variety of life and its processes” (Hughes and Noss 1992). These definitions encompass a number of different levels of biological organization, including genes, species, communities, ecosystems, and landscapes (Hughes and Noss 1992; Biodiversity Science Assessment Team 1994). These definitions also involve components of composition, structure, and function (Hughes and Noss 1992).

Although the idea of impacts on biodiversity caused by large-scale hydroelectric development is quite new, the hydroelectric industry in North America has recognized it as a serious issue (e.g., Mattice et al. 1996). The concern is that these kinds of development may cause losses of biodiversity well in excess of natural, background losses (Coleman 1996). For example, the reduction or extirpation of native species through alteration of physical habitat or introduction of exotic species is a form of biodiversity loss connected with large-scale hydroelectric development (Power et al. 1996).

Impacts to biodiversity can occur over extensive spatial scales (several 1000 km<sup>2</sup> in the case of chains of reservoirs operated as a single unit; e.g., see Rancourt and Parent 1994 for La Grande River development) and over extended periods of time (Fig. 1). In fact, species extinctions (see below), an extreme form of biodiversity limitation, are permanent.

### Environmental effects

The degree of biodiversity loss from all anthropogenic causes in fresh waters is not fully known but must be substantial because of the extent of physical impact of man on streams and rivers, especially in developed countries such as the United States (Hesse et al. 1989; Benke 1990; Allan and Flecker 1993; Dynesius and Nilsson 1994; Devine 1995). For example, a survey of the species listed under the Endangered Species Act in the United States done by Losos et al. (1995) indicated that water development projects affected higher numbers of species (256 or ~30%) than any other resource-extraction activity. Water-flow disruption and water diversion were among the most disruptive categories of water development. Animals were affected more than plants; water developments endangered ~95% of listed clam and mussel species (see also Devine 1995), and ~85% of listed fish species (Losos et al. 1995).

Nehlsen et al. (1991) identified 214 native, naturally spawning stocks of Pacific salmon, steelhead, and sea run cutthroat (*Oncorhynchus* spp.) from the Pacific northwest that are endangered (1 stock), are facing high (101 stocks) or moderate risk (58 stocks) of extinction, or are of special concern (54 stocks). Eighteen of the high-risk stocks may already be extinct. The chief causes of the plight of these stocks were (i) habitat loss or damage, impeded movement, and low flows (caused by hydroelectric development, agriculture, logging, etc.); (ii) overfishing; and (iii) negative interactions with other

species of fish, including hatchery stocks. Seventy-six of these at-risk stocks originated from the Columbia River catchment, which has undergone extensive hydroelectric development (see below). At least 106 major populations of salmon and steelhead on the West Coast are extinct; one of the major reasons is dam construction (Nehlsen et al. 1991). “With the loss of so many populations prior to our knowledge of stock structure, the historic richness of the salmon and steelhead resource of the West Coast will never be known. However, it is clear that what has survived is a small proportion of what once existed, and what remains is substantially at risk” (Nehlsen et al. 1991).

Slaney et al. (1996) extended the Nehlsen et al. (1991) study to British Columbia and the Yukon Territory in Canada. Status classifications were possible for 5491 stocks or 57% of the stocks identified. Of these, 932 stocks were at high (11.4%) or moderate (1.4%) risk of extinction, or were of special concern (4.2%). An additional 142 stocks (2.6% of those classified) were driven to extinction in this century mainly because of logging, urbanization, and hydroelectric power development. Major rivers in British Columbia that support anadromous salmon do not have mainstream dams, but dams on the Columbia River in the United States have caused the extinction of various stocks in the Canadian portion of the Columbia catchment (Slaney et al. 1996). Hydroelectric development has also led to stock losses on smaller British Columbia rivers. Conflicts between water requirements for power and fisheries have led to stock depressions in a number of British Columbia and Yukon Territory rivers (Slaney et al. 1996).

### Landscape and ecosystem levels

Habitat alteration or destruction affects all levels of biodiversity. The flooding of vast areas of land in the creation of reservoirs, dewatering of water bodies by diversion, and erosion caused by increased flows have their initial effects on landscape and ecosystem levels. As mentioned above, it has been estimated that reservoirs of all sizes and types now occupy 500 000 km<sup>2</sup> globally (Kelly et al. 1994). Up-to-date data on the total surface area occupied by major hydroelectric developments in various countries or ecological zones are not easily available; however, large areas of landscape-level habitat alteration are involved in major projects (Table 2).

At the ecosystem level, perhaps the greatest cost of changing the nature of a river by turning it into chains of reservoirs is the interruption of energy flow into the system from allochthonous and autochthonous sources. Biotic communities are probably structured along resource gradients and downstream communities at least partly depend on upstream processes (Vannote et al. 1980; Johnson et al. 1995). Impoundments along river courses can interrupt natural longitudinal gradients, causing longitudinal shifts in physical and chemical variables, which in turn cause biotic shifts (Ward and Stanford 1983). This reset mechanism ultimately affects biodiversity (e.g., Lehmkuhl 1972; Harding 1992). For example, transport of sediment and organic matter to downstream reaches is interrupted by reservoirs (especially by erosion control measures in them) and this probably affects carbon and nutrient cycling (e.g., see Hesse et al. 1989 for the Missouri River, U.S.A.). Furthermore, intermittent and permanent aquatic habitats outside the main channel are also important to normal river functioning; the predictable advance and retreat of water onto the floodplain are thought to control adaptations of most of the

**Table 5.** Selected examples of the downstream effects of altered flows caused by large-scale hydroelectric development. (Note this table reads across facing pages and continues on the following two facing pages.)

Area affected	Upstream development	Physical effects
Gulf of St. Lawrence, Canada	Hydroelectric development in the St. Lawrence catchment	>8000 m <sup>3</sup> /s of spring discharge withheld (~1/4–1/3 of peak discharge) Twenty to thirty percent reduction in normal spring quantity of nutrients
Peace–Athabasca Delta, Alta.	W.A.C. Bennett Dam and Williston Reservoir, Peace River, B.C.	Williston Reservoir filled with 62 km <sup>3</sup> of Peace River water (1968–1971); normal Peace River flows (4000–9000 m <sup>3</sup> /s) reduced to 280 m <sup>3</sup> /s during filling; flood flows of Peace River adjacent to Peace–Athabasca Delta reduced by as much as 5600 m <sup>3</sup> /s; water levels in Peace River dropped 3–3.5 m below normal; Lake Athabasca waters flowed out of the Delta without causing flooding Forty percent decrease in shorelines and surface areas of perched basins; 500 km <sup>2</sup> of mud flats of larger lakes desiccated; computer simulations using operating conditions of the Dam predicted: continued marked departures from natural flow patterns (reduced peak flows), continued drying of perched basins, and accelerated ageing of the Delta
Danube Delta, Romania and The Ukraine	Hydroelectric development (>30 dams and other engineering works along the mainstem); water removal for drinking, irrigation, and industrial processing; transportation; disposal of municipal and industrial wastes	Floodplain reduced by 290 000 ha because of hydrologic modifications to mainstem (e.g., embankments); resulting loss of 4.3 km <sup>3</sup> of water retention capacity so nutrients and heavy metals are carried straight to Delta Severe coastal erosion (up to 17 m/year) because dams and other hydrologic changes have reduced transport of sediments
Volga Delta and Caspian Sea	Major water users in the Caspian catchment: (i) agriculture, (ii) hydroelectric power plants, (iii) industry, (iv) municipal government, (v) shipping, and (vi) commercial fisheries Volga–Kama catchment: 11 large hydropower stations (most built in period 1955–1965); 200 small and large reservoirs inundating ≈ 26 000 km <sup>2</sup> of the catchment (≈50–69% of this was highly fertile cropland)	190–200 km <sup>3</sup> /year of water accumulated to form reservoirs; freshwater flows to Caspian significantly reduced Spring flows reduced as much as 37% (98.9 cf. 155.8 km <sup>3</sup> ; 1967–1979); 1051 km <sup>3</sup> of spring flows retained over period 1961–1979 (= 4× normal annual runoff from Volga); regulated releases showed deviations of 30–50% below normal natural mean flows (cf. ±10–15% for normal, natural spring flows) Regulated winter runoff increased to 2.2× normal Mean annual salinities of north basin of Caspian increased from 8 to 11 ppt since 1955; estuarine mixing zone compressed and moved up Delta; extent of brackish water increased because of excessive water removal and dry years of 1973–1977 Reduced sediment load (2–4× less than normal); stability of river banks and levees affected Nutrient fluxes increased by 10–35% in winter and decreased by 25–40% in spring; annual amount of inorganic and organic phosphorus delivered to Caspian decreased by 1.5–2.0×, reducing primary production in north basin of Caspian by 50%; organic nitrogen (industrial and municipal sources) increased >2.5×

Biological effects	Comments	Ref.
<p>Drastic decline in fish catches in the late 1960s and early 1970s corresponding to a period of naturally low discharges and increased regulation (4000 to 8000 m<sup>3</sup>/s); mid-1970s recovery corresponding to a period of increased natural discharge; quantitative proof difficult because of the many other variables involved</p>	<p>The article is speculative</p>	<p>Neu 1982a, 1982b</p>
<p>Muskrat (<i>Ondatra zibethicus</i>) numbers harvested declined from 144 000 (winter 1965–1966) to &lt;2000 (winter 1971–1972); vegetational succession continued unchecked (creating new meadow and willow communities); computer simulations (under operating conditions) predicted: continued vegetational succession, 20–25% reduction in duck production, and 40–60% reduction of fall muskrat populations; other studies indicated reduced spawning success of walleye (<i>Stizostedion vitreum</i>) but no effects on goldeye (<i>Hiodon alosoides</i>) and lake trout (<i>Salvelinus namaycush</i>)</p>	<p>Despite remedial efforts, the Delta continues to desiccate and will disappear within 50 years unless new management approaches are adopted</p>	<p>Townsend 1975; Rosenberg 1986; Nichol 1991; Rosenberg et al 1995</p>
<p>Decline in commercial fish catches (1970–1990) from 7000–9000 to 4000–5000 tons/year; "...attributed to the loss of fish habitat and the general deterioration of water quality..."</p> <p>Increased eutrophication and turbidity in Delta waters caused by increasing input of nutrients, metals, and pesticides in combination with changes of surface water flow and sediment loading; reductions in biodiversity, major shifts of ecosystem primary productivity (from rooted macrophytes to phytoplankton), and large declines in fish yields caused by degradation of water quality</p> <p>Bird populations much reduced over historical levels because of degraded habitat; impoundments partly to blame</p> <p>Declining water quality of Black Sea partly because of eutrophication of the Danube; valuable fisheries destroyed because chemocline has ascended from 170 to 110 m (see also Tolmazin 1979)</p>	<p>Causes of biological effects in the Delta are difficult to disentangle. Hydropower development is thought to be at least partly responsible for those listed here</p>	<p>Pringle et al 1993</p>
<p>Area of nursery grounds of semianadromous fish able to tolerate salinity fluctuations of 0.2–5 ppt during spawning and up to 8 ppt during feeding decreased from 25 000 (1959–1971) to 6200 km<sup>2</sup> (1977); optimum salinity of 2 ppt for mussels (important food for semianadromous fish) reduced to 30% of historical area, leading to large declines of mussels; biomass of phytoplankton, zooplankton, and zoobenthos in north basin of Caspian decreased by as much as 2.5×</p> <p>Catches of commercially important fish species declined by almost an order of magnitude from 1930 to 1972; commercial fishery became dominated by the less valuable sprat (<i>Clupeonella delicatula</i>), which increased 107× between 1930 and 1972; Volga – North Caspian endemic herring <i>Alosa kessleri volgensis</i> virtually disappeared (1913–1916, 130 000–160 000 t; 1960s, 5000–6000 t; 1969–1972, 10 t); similar patterns of reduction in commercial fishery reported from other parts of Caspian catchment that also suffered alterations in water flow; declines of commercially valuable fish attributed to (i) chronic water shortages and acute temperature fluctuations in Volga Delta nursery area, which negatively affected spawning, food supply, and feeding; and (ii) inadequate water supply during spring, which hindered spawning activities and migration of juveniles</p>	<p>More than 300 rivers exist in the Caspian Sea catchment, but the Volga River exercises major control over the physical and chemical oceanography and biological productivity of the Sea, because the Volga's catchment represents 40% of the total Caspian catchment and provides 85% of the natural historical average annual discharge of 300 km<sup>3</sup>. Water levels of the Caspian Sea have been rising since 1977, perhaps because of a natural increase in the volume of water discharged by the Volga River (Williams 1996)</p>	<p>Rozengurt and Hedgpeth 1989</p>

Table 5 (concluded).

Area affected	Upstream development	Physical effects
Azov Sea, Russian Federation	On the River Don: hydroelectric facilities, heavy industry, and irrigation; >130 reservoirs containing 37 km <sup>3</sup> of water and covering 5500 km <sup>2</sup>	Average water flow reduced to 21.4 km <sup>3</sup> /year or 76% of normal (pre-1952); spring flow (March–May) normally 70% of annual flow and now 37%; flow during other seasons increased 2.5–3.0×; floodplain spawning grounds reduced from 950 to 270 km <sup>2</sup> ; flood period reduced from 49 to 11 days; changes in mineral fluxes in River Don Delta (e.g., total phosphorus decreased from 11.3 × 10 <sup>3</sup> to 2.3 × 10 <sup>3</sup> tons/year, total suspended solids decreased from 3.6 × 10 <sup>6</sup> to 1.1 × 10 <sup>6</sup> tons/year, sulphate increased from 1860 × 10 <sup>3</sup> to 3550 × 10 <sup>3</sup> tons/year, chloride increased from 970 × 10 <sup>3</sup> to 2650 × 10 <sup>3</sup> tons/year)
Nile Delta, Egypt	High Dam at Aswan is the major problem; built to control floods, to store water to allow “water security” for year-round agricultural production, and to generate hydroelectric power	High Dam designed to store average flow of 84 km <sup>3</sup> /year so no excess flow would exist beyond needs of 55.5 km <sup>3</sup> Downstream turbidity dropped from 30–3000 to 15–40 mg/L and from characteristic seasonal peak during flood season to regular level throughout the year; lowest levels at time of incoming flood Total dissolved solids increased from 110–180 to 120–230 mg/L, with similar change in seasonal distribution described for turbidity; salt burden increased; increased volume of water delivered to perennial irrigation systems resulted in large return flow through cultivated soil, which led to increased burden of dissolved salts in receiving drains and canals; more salt reached the Delta than before construction of the Dam, but less reached Mediterranean Sea; result is average annual accumulation of chlorides and sodium in the Delta soils; potential water quality problems not anticipated Widespread coastal erosion because of (i) silt deprivation from upstream, although the vast system of irrigation canals in the Delta itself may be to blame (Stanley 1996); (ii) removal of Delta sediment by marine waves and currents; and (iii) subsidence and rising sea level over low-lying northern areas of the Delta; areas of northern Delta threatened by increased salinization of groundwater and incursion of salt water; Nile water reaching the coast highly polluted by agricultural runoff and industrial municipal waste; Delta constitutes two thirds of Egypt’s habitable land, so losses are critical

biota (Johnson et al. 1995). Prevention of this natural flooding would, therefore, constitute a disturbance (Bayley 1995). For example, channel-bed degradation below mainstem dams in the Missouri River has eliminated many of the backwater and subsidiary channels, which provided much of the river’s autochthonous primary and secondary production. Loss of these habitat types has had a major impact on energy flow to higher trophic levels (Hesse et al. 1989; see also Power et al. 1996). Alienating sections of floodplains or reducing the frequency of flood recurrence may seriously affect the substantial stores of resting-stage invertebrates in dry floodplain sediments, thus removing a potentially important food source for juvenile fish (Boulton and Lloyd 1992). Hesse (1995) discusses alternative plans to restore natural functioning of the Missouri River ecosystem by operating mainstem dams to approximate the pre-regulation hydrograph (see below).

Still in the context of function, Hydro-Québec (1993b) has

argued that the replacement of northern boreal forest by large expanses of reservoir results in a net gain of productivity (as the production of fish biomass) over what is provided (as terrestrial fauna) by pre-existing forest habitat. However, this “more-is-better” argument does not account for changes in biodiversity involved in conversion from a terrestrial to an aquatic system, and ignores the many natural services provided by the boreal forest as a carbon sink (Gorham 1991; Mackenzie 1994; Kelly et al. 1997) and as a source of food and fur for aboriginal communities (Charest 1982; Berkes et al. 1994).

#### *Community, species, and genetic levels*

The effects of large-scale hydroelectric development on biodiversity can also be manifested at community, species, and genetic levels. Habitat alterations create the main effects, but the introduction of non-native biota by water diversions and stocking activities is also important.

Biological effects	Comments	Ref.
<p>Terrestrial and aquatic plants: general decrease of native species; increased number of introduced species and weedy plants characteristic of disturbed environments</p> <p>Many native mammal, bird, reptile, fish, and insect species almost extinct or endangered</p> <p>Only 3 years out of last 50 have been good for reproduction of fishes</p> <p>Blue-green algae and diatoms increased, whereas green algae declined in the lower Don; overall phytoplankton biomass increased from 0.45 (1960) to 2.9 g/m<sup>3</sup> (1980–1990); biomass of zooplankton decreased from 1.15 g/m<sup>3</sup> (pre-1952) to 17–25 mg/m<sup>3</sup> (1980–1991)</p> <p>Before 1952, &gt;20 commercial fish species and catches ≥ 75 000 tons/year in the Azov–Don fishery; by 1991, 6 commercial fish species and catches of 3000–5000 tons/year</p>	<p>Greatest changes in River Don catchment occurred from the 1930s–1960s with the construction of large hydroelectric facilities and damming of rivers. The River Don system is polluted by oil, metals, and pesticides, among others, from industries, agriculture, and municipalities. Major water regulation schemes have also affected the Black Sea and its commercial fishery (Tolmazin 1979)</p>	<p>Tolmazin 1979; Volovik 1994</p>
<p>Downstream phytoplankton density increased from 160 to 250 mg/L because of reduced levels of silt in the water</p> <p>Commercial fishery affected: (i) number of species, number of fish, and average size declined at two locations in Delta, although numbers and size increased at a third; (ii) sardine fishery in eastern Mediterranean declined probably because of water quality problems rather than overfishing; (iii) shrimp catches declined after closure of the Dam, partly because of overfishing of immatures in north Delta lakes; (iv) demersal fish catches declined after closure, but then partly rebounded probably because of increase in motorized boats in decade after 1970; and (v) accelerated migration of Red Sea fish into the Mediterranean that began with the Suez Canal but that had been prevented by flow of Nile into the Sea</p>	<p>Nile River water has been manipulated historically. Changes immediately following the commissioning of the High Dam included (i) reduction of nutrient concentrations reaching the Mediterranean Sea; (ii) failure of phytoplankton blooms to develop; (iii) drop in sardine (<i>Sardinella</i>) catches; and (iv) decline in fisheries in brackish Delta lakes (for further details see Aleem 1972). Authors on the subject of the effects of the High Dam usually are careful to point out the benefits that accrued from the development: (i) control over water supplies that allowed perennial agriculture; (ii) flood control; and (iii) contribution to Egypt's national electrical grid. Many of the disbenefits are surrounded by controversy because of a lack of comprehensive study. As White (1988) commented: the Aswan High Dam "...demonstrates the difficulty on scientific grounds of making a definitive evaluation of the full consequences of a massive, unique intervention in physiological, biological, and human systems"</p>	<p>White 1988; Stanley and Warne 1993; Pearce 1994</p>

**Habitat alterations:** Several kinds of habitat alterations act together to limit biodiversity. Blockages preventing migration, habitat simplification, and unnatural discharge regimes are all characteristic of large-scale hydroelectric development. Examples of each are given in Table 7.

The fragmentation of river systems by the construction of hydroelectric dams (other blockages such as irrigation or navigation barrages have the same effect (see Natarajan 1989; Reeves and Leatherwood 1994)) impedes the free passage of fauna and its use of various kinds of habitat (Table 7). This can lead to the diminished abundance or even extirpation of species over wide areas (Table 8).

Extinction of species means the loss of a unique genetic base that has probably evolved over a very long time (Meffe 1986). A more subtle threat is the erosion of genetic diversity that underpins long-term persistence and adaptability

**Table 6.** Commercial fishery catches in 1950, 1970, and 1990 in the four great inland seas of the former Soviet Union and in the eastern Mediterranean off the coast of Egypt (data from Fig. 6 of Rozengurt and Haydock 1994).

Location	Catches (× 10 <sup>3</sup> tons)		
	1950	1970	1990
Western Black Sea	200	75	5
Sea of Azov	300	36	2
Caspian Sea	400	100	10
Aral Sea	50	18	0
Mediterranean – Egypt	40	6	7

**Table 7.** Limitation of biodiversity by habitat alterations resulting from large-scale hydroelectric development.

Type of habitat alteration	Location	Effects	Comments
Blockage by dams/habitat fragmentation	Columbia River, U.S.A.	<p>Reduced numbers of anadromous salmonids (Ebel et al. 1989), as follows</p> <p>Salmon and steelhead runs reduced from <math>10 \times 10^6</math> – <math>16 \times 10^6</math> fish/year in the 1880s (before major development in the catchment) to an average of <math>2.5 \times 10^6</math> fish/year in the 1980s (Ebel et al. 1989; Meffe 1992); by 1990, only <math>1.2 \times 10^6</math> salmon and steelhead returned to the Columbia, of which only 25% were wild stocks (Feldman 1995)</p> <p>Snake River (a major tributary): <math>&gt;1.5 \times 10^6</math> spring, summer, and fall chinook salmon adults returned annually during the 1800s; only 1800 returned in 1994 (Williams and Williams 1995); sockeye nearby extirpated (probably past reasonable hope); steelhead numbers declining fast (Williams and Williams 1995)</p> <p>Compensation for losses led to extensive hatchery-rearing programs; these have negatively affected wild stocks (Ebel et al. 1989; Meffe 1992)</p>	<p>Hydropower development is the major cause, although other developments (e.g., agriculture, irrigation, logging, mining, water pollution) also helped alter the river ecosystem (McIntosh et al. 1994; Rhodes 1994; Feldman 1995). Mortalities of upstream and downstream migrants at dams are one of the main causes of the declines in anadromous runs (Devine 1995; Losos et al. 1995). Mortality of juvenile fish moving downstream in the regulated Columbia system is ~77–96%, whereas mortality of adult fish moving upstream is ~37–51% (Wissmar et al. 1994). Meffe (1992) warned about negative genetic changes to natural populations of Pacific salmon as a result of major, hatchery-rearing programs meant to replace wild stocks diminished by hydroelectric and other impacts on large rivers. Resident (nonanadromous) fish are also affected (Geist et al. 1996). Possibilities of operating the Columbia system in a more benign way are currently being examined (e.g., Wernstedt and Paulsen 1995; Geist et al. 1996)</p>
	Tucurai Dam, Tocantins River, Brazil	<p>Interrupted upstream, reproductive migrations of long-distance migratory species (e.g., large catfishes: <i>Brachyplatystoma flavicans</i>, <i>Brachyplatystoma filamentosum</i>; characins: <i>Prochilodus nigricans</i>, <i>Anodus elongatus</i>); populations of these species negatively affected in lower Tocantins, downstream of dam (Ribeiro et al. 1995)</p>	<p>“The impacts of current basin-wide developments on biodiversity is [sic] difficult to assess for there are both direct and indirect effects and monitoring is not being carried out” (Ribeiro et al. 1995)</p>
	Upper Volga River, Russian Federation	<p>Changes to fish fauna following construction of four major reservoirs (Poddubny and Galat 1995): number of species increased from 44 before regulation to 46 after; 7 species (mainly anadromous rheophils) disappeared, and 9 species immigrated or were introduced; none of these 9 are reproducing naturally and will probably disappear because stocking discontinued; 39 species currently resident</p>	
Habitat simplification	Missouri River, U.S.A.	<p>“Transformation of the Missouri River into a single channel has resulted in the elimination of most side channels, islands, backwater areas, and sloughs which are important feeding, nursing, resting, and spawning areas for fish and wildlife” (Hesse et al. 1989)</p> <p>“...changes in basin and floodplain physiography and channel morphology have reduced commercial fish harvest by more than 80% and are implicated in the demise of native species” (Hesse et al. 1989)</p>	<p>The Missouri River is 3768 km long; 1233 km of the mainstem is impounded, and another 1333 km is semi-free flowing (i.e., usually downstream from large dams; Hesse 1995). The river has been channelized 75 km downstream from the last large dam (Gavins Point) for 1202 km to its confluence with the Mississippi River (Hesse 1995). Effects described are the result of overall river development and operation, of which hydroelectric generation is a part</p>

Table 7 (concluded).

Type of habitat alteration	Location	Effects	Comments
	Columbia River, U.S.A.	Lower yields of white sturgeon ( <i>Acipenser transmontanus</i> ) populations in reservoirs in the lower Columbia River than in unimpounded part because control of annual floods and creation of homogeneous reservoirs reduced habitat diversity and dams prevent movement among many different riverine habitats normally used (see above) (Beamesderfer et al. 1995)	Only ~75 out of ~950 km of the Columbia River between the ocean and the Canadian border remain lotic; the remainder have been transformed into reservoirs (Devine 1995). The resident <i>Acipenser transmontanus</i> has been listed as endangered under the U.S.A. Endangered Species Act (Geist et al. 1996)
	Upper Volga River, Russian Federation	Limited bioproductivity in reservoirs because of considerable changes in major biotopes after reservoir construction (Poddubny and Galat 1995): "Typical riverine fish habitats...remain only in the upper reaches of tributaries and in the forewaters of dams and account for no more than 1% of the total water surface area"	Poddubny and Galat (1995) recommended a number of habitat improvements to foster greater fish production
	River Rhine, Lower Rhône River, Europe	Impoverishment of benthic invertebrate species in River Rhine (Broseliske et al. 1991) and reduced biodiversity of benthic invertebrates, fish, and water birds in Lower Rhône (Fruget 1992), partly because of habitat simplification as a result of river regulation	The Rhine and the Rhône rivers have responded similarly to regulation and pollution (Fruget 1992)
Unnatural discharge regimes	Colorado River, U.S.A.	Elimination of 2 year classes of endemic Colorado squawfish ( <i>Pteichocheilus lucius</i> ) from its most productive remaining nursery habitats in the Green River catchment, perhaps because of extreme flow fluctuations and alteration of seasonal flow regimes (Jones and Tyus 1985, in Carlson and Muth 1989)	The operation of Colorado River dams has shown little regard for the minimum flow needs of fish fauna (Carlson and Muth 1989)
	Moose River system, Ont.	Low lake sturgeon ( <i>Acipenser fulvescens</i> ) populations in Mattagami River probably because of commercial overharvesting and negative effects on spawning of water-level fluctuations caused by power generation: (i) low water conditions after spawning expose eggs to variable water temperatures, low oxygen concentrations, and desiccation; (ii) fry trapped in shallow pools and exposed to predation, high temperatures, and oxygen depletion (Brousseau and Goodchild 1989)	Lake sturgeon populations appear to be healthy in the Frederick House, Abitibi, and Groundhog rivers (Brousseau and Goodchild 1989). Random water fluctuations and winter drawdown of some lakes for low-flow augmentation of power production also negatively impact fish in the system (Brousseau and Goodchild 1989)

(Vrijenhoek et al. 1985; Meffe 1986). Habitat fragmentation, as occurs when a number of dams are built along a river system, has the potential to subdivide species into small, isolated local populations (Humpesch 1992; Dynesius and Nilsson 1994) that may lose genetic variability through inbreeding and genetic drift. Erosion of genetic variability may further reduce fitness and adaptive potential. Among populations, loss of genetic variability leads to convergence to one type and a narrow range of options for that species.

Habitat simplification seriously threatens the native fish and other fauna of major river systems that have had extensive hydroelectric development (e.g., Brousseau and Goodchild 1989; Carlson and Muth 1989; Ebel et al. 1989; Hesse et al. 1989;

Natarajan 1989; Fruget 1992; Beamesderfer et al. 1995; Geist et al. 1996; Table 7). Other kinds of river development are usually also involved, but hydroelectric development is a major contributor to the problem.

Unnatural discharge regimes downstream of major dams involve both extreme fluctuations and alteration of normal seasonal flow regimes (Table 7). Both conditions can severely affect biodiversity of lotic communities (e.g., Blinn et al. 1995) because these communities have adapted over eons to the natural pattern of discharge. For example, Power et al. (1996) discuss the many ways that natural flushing flows maintain riverine biota.

Unfortunately, water releases from dams generally only

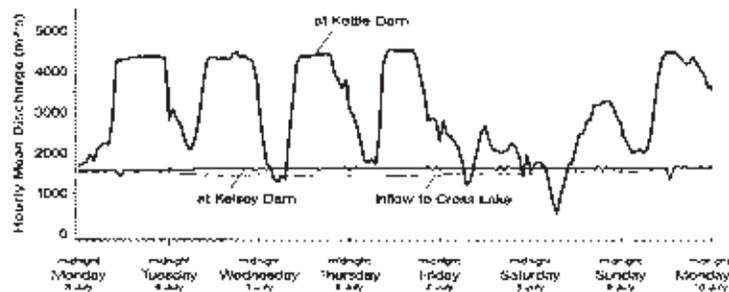
**Table 8.** Selected examples of species affected by habitat fragmentation resulting from hydroelectric development on river systems.

Species	Developments	Comments	Ref.
<b>River dolphins</b>			
<i>Platanista minor</i> (Indus dolphin)	Dams and barrages on the Indian subcontinent	Now exists as a metapopulation of four to five artificially isolated subpopulations	Reeves and Leatherwood 1994
<i>Platanista gangetica</i> (Ganges dolphin)		Only a few subpopulations remain: (i) confined to upstream ends of Ganges tributaries; (ii) population in lower Ganges also partitioned; and (iii) subpopulation entrapped in a reservoir on the Karnapuli River, Bangladesh	Reeves and Leatherwood 1994
		Dolphins were abundant in the Narayani River, Nepal, in the past, but they are disappearing from the upstream parts of the river; disappearance attributed to a variety of causes, including blockage of migration by (irrigation) barrages	Shrestha 1993
<i>Lipotes vexillifer</i> (Yangtze dolphin)	Dams and floodgates that interrupt flow between the Yangtze River and adjoining lakes	<200 remain; Three Gorges Dam will further degrade habitat	Reeves and Leatherwood 1994
	Gezhouba Dam	The number of dolphins between Ouchikou and Chenglingji declined from nine groups and 43 individuals (1986) to three groups and 11 individuals (1991)	Zhong and Power 1996
<b>Fish</b>			
<i>Hilsa ilisha</i>	Farakka Barrage, Ganges River, India	Riverine fishery upstream of barrage virtually eliminated; new remedial construction unlikely to restore hilsa fishery to earlier importance; yield of major carp species in lower Ganges also reduced (50% of 1964 levels); the Ganges suffers from other impact, too (see also Dudgeon (1992, 1995) for multiple impacts in other tropical Asian rivers)	Natarajan 1989
<i>Macrura reevesii</i> (Chinese shad), <i>Clupanodon thrissa</i> (gizzard shad)	Dams in lower reaches and reservoirs in the upper reaches of the East River, tributary to the Pearl River, China	Migratory pathways blocked; the fish virtually disappeared from the river by 1970; fry of Chinese carps (many species of Cyprinidae, especially <i>Cirrhinus molitorella</i> ) also affected	Liao et al. 1989
<i>Macrura reevesii</i>	Fuchunjiang and Hunanzhen dams, Qiantang River, China	Drastically reduced and finally eliminated from the river; the number of fish species in the region of the Xinanjiang Reservoir on the Qiantang River decreased from 107 to 66–83 because migration was blocked by the Xinanjiang Dam	Zhong and Power 1996
<i>Acipenser sinensis</i> (Chinese sturgeon), <i>Myxocyprinus asiaticus</i> (Chinese sucker), <i>Psephurus gladius</i> (white sturgeon), <i>Coreius guichenoti</i>	Gezhouba Dam, Yangtze River, China	Spawning runs detained below Dam and these species were endangered by overfishing; many <i>Acipenser sinensis</i> were hurt or killed trying to ascend Dam; <i>Acipenser sinensis</i> and <i>Myxocyprinus asiaticus</i> now artificially bred and released into river each year	Zhong and Power 1996
<i>Probarbus jullieni</i> (giant cyprinid)	Chenderoh Dam, Perak River, Malaysia	Declines partly a result of blockage of migration routes by the Dam	Dudgeon 1992
<i>Alosa</i> spp. (mostly <i>fallax</i> ) (shad)	Dams on the lower Rhône River	Only 15% of the mainstem remains accessible; shad catches have declined from 53 t in 1927 (before development) to ~8 t in the early 1970s (cf. shad in the River Rhine, which have completely disappeared)	Fruget 1992
<i>Petromyzon marinus</i> (sea lamprey), <i>Acipenser sturio</i> (sturgeon), <i>Alosa alosa</i> (allis shad), <i>Alosa fallax</i> (twait shad), <i>Anguilla anguilla</i> (eel), Mugilidae (mulletts)	Dams on major rivers in Spain	All anadromous and catadromous fishes are considered “threatened” in Spanish and Portuguese Red Books; range distributions of the species shown have been reduced by an average of 50–100% along the lengths of major Spanish rivers	Nicola et al. 1996

Table 8 (concluded).

Species	Developments	Comments	Ref.
<b>Aquatic invertebrates</b>			
<i>Zelandobius</i> (two species, stoneflies), Eriopterini (two species, crane flies)	Dams for hydropower generation in river systems in New Zealand	Populations of stoneflies and crane flies substantially reduced below impoundments; populations of the snail <i>Potamopyrgus antipodarum</i> significantly enhanced	Harding 1992
<i>Leptestheria dahalacensis</i> , <i>Eoleptestheria ticinensis</i> , <i>Imnadia yeyetta</i> (clam shrimps)	Hydropower development on the Danube River, Austria	Local extirpation of clam shrimp habitats is caused by changes in hydrologic regimes; operation of new hydroelectric plants on the Danube prevents inundation by the River of astatic pools; these species are considered to be endangered	Hödl and Eder 1996
<i>Leptodea fragilis</i> (fragile papershell mussel), <i>Potamilus alatus</i> (pink heelsplitter mussel)	Dams on five river systems in the American midwest	Upstream distribution stops at dams; dams are a barrier to the fish (freshwater drum: <i>Aplodinotus grunniens</i> ) that hosts the glochidia of these mussel species; other unionid species may also be limited by dams in these river systems: <i>Potamilus ohioensis</i> (pink papershell), <i>Truncilla donaciformis</i> (fawnsfoot), <i>Truncilla truncata</i> (deertoe), <i>Quadrula quadrula</i> (mapleleaf), and <i>Epioblasma triquetra</i> (snuffbox)	Watters 1996; see also Bogan 1993
<i>Simulium garipeense</i> (black fly)	Impoundments in the Orange River, South Africa	This South African endemic, nonpest species appears to be affected by reduced turbidity and peak flows, especially because the Orange River flows through arid areas, which minimizes the potential for colonization from tributaries; the Orange River system may be the only remaining area in which the species is found	Palmer and Palmer 1995

Fig. 3. Hourly mean discharge for the Nelson River, 1984. The large day-to-day fluctuations at Kettle Dam do not occur at Kelsey Dam or the inflow to Cross Lake (Jenpeg Dam), which are upstream installations (reprinted from Environment Canada and Department of Fisheries and Oceans 1992, p. 2.15).



satisfy power generation requirements (but see Olmsted and Bolin 1996 for a dissenting view). For example, in the Missouri River, "...water management within the reservoirs for fish and wildlife occurs only when interference with other purposes does not exist" (Hesse et al. 1989). In the Columbia River, "It is apparent from our modeling that existing operations (represented by the base-case alternatives) are not beneficial to fish and wildlife resources, but are beneficial to power and irrigation interests. This points to an increased urgency to develop alternative ways to operate the Columbia River hydropower system" (Geist et al. 1996).

Very little is known about the ecological effects of extreme fluctuations in daily discharge in the lower Nelson River, northern Manitoba (Fig. 3). Daily discharge fluctuations at

Kettle Dam for the period 1979–1988 amounted to  $>2000 \text{ m}^3/\text{s}$  in winter and  $\sim 3000 \text{ m}^3/\text{s}$  in summer; mean natural river discharge at that location is  $2170 \text{ m}^3/\text{s}$  (Environment Canada and Department of Fisheries and Oceans 1992). The abnormal patterns of discharge in the highly regulated lower Nelson are tied to weekly energy use in Manitoba. Daily discharge coincides with power demand: it is raised each morning during workdays and lowered again at night. Discharge is lowered over the weekend and begins its daily workday cycle again on Monday morning.

Many of the negative impacts of habitat alteration on the biodiversity of communities, populations, and genes could be ameliorated if the operation of hydroelectric facilities more closely mimicked natural flow regimes (Devine 1995; Feldman 1995; Hesse 1995; Zhong and Power 1996). For example, lake

sturgeon spawning activity in the Sturgeon River, Michigan, responded positively to a change in operation of the Prickett hydroelectric facility to near run-of-the-river flows (Auer 1996), and Zhong and Power (1996) showed that Chinese low-head, run-of-the-river projects have lesser impacts than high-head dams on aquatic environments, including fish and fisheries. An ecologically based, water-regulation procedure for lakes affected by hydroelectric power production has been developed in Finland (Hellsten et al. 1996).

*Introduction of non-native biota:* Exotic species can be introduced by intercatchment water diversions that are part of hydroelectric development or by stocking of hydroelectric reservoirs. Specific examples of the former are difficult to find, perhaps because of a lack of study. The McGregor Diversion, a proposed hydroelectric project in British Columbia, necessitated the mixing of waters from the Peace, an Arctic-draining river, and the Fraser, a Pacific-draining river. The project was cancelled because of the fear of introducing potential harmful fish parasites from the Pacific into the Arctic drainage (Seigel 1987).

The problem of species introductions caused by artificial interconnections among major rivers is apparently widespread in southern Africa (Bruton and van As 1986). These water diversions may involve hydroelectric generation, but their main functions are flood control and agricultural, domestic, and industrial water supply (Cambray et al. 1986). For example, Cambray and Jubb (1977) documented the survival of five species of fish that passed through the Orange-Fish tunnel in South Africa, which diverts irrigation water out of the Orange River system (Atlantic Ocean drainage) into the Great Fish and Sundays rivers (Indian Ocean drainage). The more permanent flow and increased erosional areas in the Great Fish River led to a change in the species composition of the macroinvertebrate fauna, including replacement of the pretransfer dominant black flies *Simulium adersi* and *Simulium nigritarse* by the pest species *Simulium chutteri* (Davies et al. 1993). Intercatchment transfers of water are also common in China, but little information appears to exist on the introduction of exotic species as a result (Dudgeon 1995). Most such transfers are done primarily to satisfy water-supply problems rather than for hydroelectric generation.

Nonindigenous fish and crustaceans were introduced to the Missouri River numerous times to fill new niches and habitats in impoundments, but the consequences to native ichthyofauna were rarely analyzed (Hesse et al. 1989). Stocking activities in Colorado River reservoirs were part of the overall, river-development assault (Table 7) on the unique, endemic fish fauna of this river system (Carlson and Muth 1989). As a result of river development, approximately 100 species of fish are now present; some 67 non-native species have been introduced since the turn of the century and are now predominant in most fish communities. Seventeen of 54 native species are threatened, endangered, or extinct, and the abundance and distribution of most have been drastically reduced (Carlson and Muth 1989).

#### Social effects

Limitation of cultural diversity by habitat destruction has been observed in a number of communities that lay in the path of major hydroelectric development. Canadian examples reveal a close connection between habitat destruction and negative so-

cial impacts in four major ways: (i) mercury contamination (see above); (ii) relocation; (iii) encroachment; and (iv) harvest disruption (Rosenberg et al. 1995; Berkes and Fast 1996).

#### Relocation

Major hydroelectric development often necessitates the relocation of large numbers of people (Table 9) and results in harmful social effects (Table 10). Much of the international literature focuses on involuntary resettlement, not only as the major social impact of dams but perhaps as the single most serious issue of large-scale hydroelectric development (e.g., Scudder 1973; Goodland 1994–1995). In Canada, relocations caused by hydroelectric developments such as the Kemano in British Columbia and Grand Rapids in Manitoba (see below) continue to be a source of grievance and social costs even after half a century (Royal Commission on Aboriginal Peoples 1996). Studies of northern Canadian developments, which involved moving relatively small numbers of people by international standards (hundreds versus tens of thousands; see Table 9), have provided insights into these impacts.

Relocations allow governments to “modernize” traditional aboriginal communities. However, residents of affected villages do not necessarily view the acquisition of new houses and village infrastructure in a positive light. Settlement patterns, which are based on kinship relations and access to shorelines, are disrupted and costs are added to hunting and fishing (Loney 1987; Waldram 1988). Relocation experiences in the Canadian north are similar to those reported elsewhere in the world as a result of large-scale hydroelectric development (Table 10).

#### Encroachment

Large-scale hydroelectric projects in remote areas involve the encroachment by outsiders into traditional aboriginal territories, whether in the Canadian north, the Brazilian Amazon, or elsewhere. Encroachment is facilitated by new roads and airfields constructed as part of the infrastructure needed for such projects.

In the Canadian north, the Cree land-tenure system is family based, and it is officially recognized through trapline registration. Newly constructed roads often result in an influx of outsiders. External encroachment disrupts the tenure system and the abundance and distribution of fish and wildlife upon which the tenure system is based (Berkes 1981). The consequence is adverse social impacts, which may persist for generations (Niezen 1993; Preston et al. 1995).

The plight of the Waimiri-Atroari tribe in central Amazonia, Brazil, is described by Fearnside (1989). Encroachment has played a large role in reduction of the numbers of this tribe from 6000 at the turn of the century to 3500 by 1973, 1100 by 1979, and 374 by 1986. These effects cannot be attributed to hydroelectric development but nonetheless exemplify what can result from infrastructure development of the land associated with hydroelectric development (e.g., road construction). Flooding of part of the Waimiri-Atroari tribe's reserve by the Balbina Reservoir added another stress connected with modernization of the remote area in which they live.

#### Harvest disruption

Harvest disruption is a serious and often permanent impairment to the life of aboriginal communities, especially where

**Table 9.** Selected examples of major relocations of people to make way for reservoir creation (see also Goodland 1994–1995).

Project	Approximate number of people involved	Comments	Ref.*
Volga River, Russian Federation	>300 000	—	Marchand 1990
Sanmenxia Dam, Yellow River, China	300 000	—	Pearce 1991
Three Gorges Dam, Yangtze River, China	>1 000 000	Project under construction	Fearnside 1988; Pearce 1995 <sup>a</sup>
	1 131 800	Relocation by 2008; estimate is conservative because of illegal immigration into the area and high natural rate of population increase <sup>†</sup>	Chau 1995
Lake Kariba, Zambezi River, Zimbabwe and Zambia	>50 000	Tongans affected	Balon 1978
	86 000	—	Obeng 1981
Volta Lake (Akosombo Dam), Volta River, Ghana	80 000	—	Obeng 1981
Lake Kainji, River Niger, Nigeria	50 000	—	Obeng 1981
Lesotho Highlands Water Project, Lesotho, Africa	20 000	Primary aim of project is to export water to Johannesburg and Pretoria; hydroelectric generation for Lesotho is a minor aim; mountain people have been flooded out rather than resettled; subsequent phases of the development will affect even larger numbers of people	Horta 1995
High Dam at Aswan, Nile River, Egypt and Sudan	≥100 000	Nubians affected, ~1/2 in Egypt and ~1/2 in Sudan	Walton 1981; Pearce 1994; White 1988
	120 000	—	Obeng 1981
	120 000	30 000 Sudanese	Goldsmith and Hildyard 1984
	>50 000	Sudanese villagers displaced; Egyptians not mentioned	Hillel 1994
Sardar Sarovar Dam, Narmada River, India	>100 000	Additional 140 000 farmers will be affected by canal and irrigation system; project currently being built <sup>‡</sup>	Morse and Berger 1992
Sobradinho Dam, São Francisco River, Brazil	70 000	—	Pearce 1992
Itaparica Dam, São Francisco River, Brazil	40 000	—	Pearce 1992
Southeast Anatolia Project, Turkey	250 000	Tigris and Euphrates rivers	Hillel 1994
Tabqa Dam, Lake Assad, Syria	~70 000	Euphrates River; Bedouins displaced	Hillel 1994

\*Some authors provide information on social impacts.

<sup>†</sup>Water conservancy projects undertaken in China since 1949 have involved the resettlement of >10 000 000 people (Chau 1995; Dudgeon 1995).

<sup>‡</sup>The entire Narmada Basin Development Programme is expected to displace >1 000 000 people over the next 40 years (U.S. Government Printing Office 1990, in Foote et al. 1996).

the resource base is largely aquatic (Rosenberg et al. 1995). The physical and biological effects of Canadian boreal projects have affected the availability of important species and access to them (Berkes 1981; Usher and Weinstein 1991). For example, fisheries in northern Manitoba have been affected by fluctuating water levels (Gaboury and Patalas 1984) and the blockage of fish migration by a water-control structure (Bodaly et al. 1984b; Barnes and Bodaly 1994). Available data indicate declines in per-capita, subsistence catches and for commercial catches in some or all of the communities affected by the Churchill–Nelson diversion (Usher and Weinstein 1991).

In the Grand Rapids project area in Manitoba, previously self-reliant aboriginal communities became dependent on the outside. Social problems such as crime and family violence escalated. The amount of food obtained from the surrounding area declined by a factor of 10 after damming and relocation as compared with before (Loney 1987).

In northern Québec, Cree hunters reported diminished har-

vests since 1979 of valuable food and fur species from wetland habitats in the lower La Grande River (Berkes 1988). Hunters blamed reduced habitat and feeding areas, loss of riparian productivity, and drowning and freezing-out of several species in winter. Also, many trappers lost their territories to flooding. Six major reservoirs built between 1940 and 1972 in the vast Montagnais territory east of the James Bay catchment caused most hunting/trapping areas to be abandoned by their users because of partial flooding and water-level fluctuations. For example, 47 out of 87 hunting/trapping areas belonging to the community of Bersimis were affected; of those, 24 did not produce any fur in 1975–1976 (Charest 1982).

Increased discharge, unstable ice conditions, or debris resulting from shoreline erosion make access to resources difficult or impossible in many areas affected by hydroelectric development. Operation of upstream reservoirs created winter and spring travel problems across La Grande River (Berkes 1988), the Moose River (Preston et al. 1995), and in many

**Table 10.** Selected examples of social impacts of relocation necessitated by large-scale hydroelectric development.

Development	Relocation	Comments
Diversion of the Churchill River into the Nelson River and the flooding of Southern Indian Lake, northern Manitoba (Newbury et al. 1984)	The old settlement of South Indian Lake, which was flooded by impoundment, was moved to a new, modern town built nearby	The move was associated with social disruption and disintegration (Waldram 1987; Krotz 1991): former kin-group arrangement of families was not retained in new housing; cheaply built new houses soon deteriorated; electric heat in new houses was too expensive for most villagers; and hauling water from the Lake was a problem, especially for elderly
La Grande River, northern Québec (Berkes 1981)	Erosion caused by increased river discharge threatened the town of Ft. George on the estuary of La Grande River, so the people were moved into the new town of Chisasibi upstream	Move associated with social stress (see Dwyer 1992 for an anecdotal account)
Volta Lake, Ghana (Obeng 1981)	80 000 people from 700 villages, representing 1% of the population of the Volta River catchment, were flooded out by creation of Volta Lake. Most (69 000) were relocated in 52 new towns specially built for them	Relocation brought trauma associated with abandonment of familiar lands, ancestral resting places, farms, and homes; different social conditions/need to preserve cultural identities; the need to learn new skills to survive; and exposure to schistosomiasis (Obeng 1981) Similar difficult relocation described by Balon (1978) for 50 000 Tonga people displaced by creation of Lake Kariba, Zimbabwe and Zambia
High Dam at Aswan, Egypt and Sudan (White 1988)	50 000 – 60 000 Nubians in the Egyptian part of the Lake Nasser Reservoir were moved to new villages 20 km north of Aswan  53 000 Nubians in the Sudanese part of the Lake Nasser Reservoir were moved to the Kashm el-Girba region to the southeast	Serious problems developed because of new agricultural conditions and practices, and inappropriate, nontraditional housing provided (Goldsmith and Hildyard 1984) By 15–18 years after move, the health of people overall had improved, handicraft industry developed, agricultural production remained modest, and many people longed to return to their old homes (Walton 1981; White 1988); many people did return (Goldsmith and Hildyard 1984)  Social structure of many of the old villages was severely disrupted (Goldsmith and Hildyard 1984): three different ethnic groups were settled together, and aside from cultural differences, agricultural practices of pastoralists (grazing) were incompatible with those of farmers (cultivation); design of housing "...paid little heed to the social needs of the uprooted settlers" (Goldsmith and Hildyard 1984)

other northern Canadian rivers affected by hydroelectric development (Berkes and Fast 1996). In northern Manitoba, extensive shoreline erosion resulted in reservoirs containing hazardous debris and inaccessible shorelines; it also caused the fouling of fish nets (Newbury and McCullough 1984; G.K. McCullough, personal communication). Local hydrology and fish behavior were so changed and access to well-known fishing areas were so impaired that traditional knowledge was no longer a guide for fishing success (Rosenberg et al. 1995). Costs increased and catches per unit of effort decreased in both the subsistence and commercial fisheries (Usher and Weinstein 1991).

## Conclusions

"Large dams are among the most awe-inspiring monuments to modern society." (Pearce 1991)

"Few creations of big technology capture the imagination like giant dams." (Anonymous 1992)

The fascination of politicians with hydro megaprojects at least

partly explains why these projects are built. The politician's job is mostly done after the switch is thrown to start electrical generation at a massive new dam, but the work of the environmental and social scientists responsible for postaudits has just begun. It is regrettable that so little support is usually available for the postaudit part of a project compared with its planning and construction phases (White 1988). Even given adequate support, the task of disentangling impacts of a project from the natural variability of ecosystems can be difficult (e.g., Gribbin 1979).

This review has addressed the need for considering large spatial and temporal scales in assessing the cumulative effects of hydroelectric development, and in so doing, has revealed the interconnections between environmental and social impacts. For example, habitat alteration or destruction lies at the base of the four large-scale impacts examined. Environmental changes resulting from habitat destruction lead to the social and economic problems experienced by communities dependent on local natural resources. A holistic view is therefore needed to discern these interconnections.

We are at an early stage in our understanding of large-scale impacts. What needs to be done to further this understanding?

Mercury research requires more spatial and temporal data from reservoirs that flood different land types with different vegetation, especially in temperate and tropical areas. Emphasis is needed on the time course of microbial production of methylmercury and its uptake by lower trophic levels. It would also be useful to determine the important factors involved in downstream transport and bioaccumulation of methylmercury, and to establish the exact spatial extent of this phenomenon. A thorough understanding of microbial methylation/demethylation processes would, perhaps, enable effective mitigation of mercury contamination by either uncoupling methylation or enhancing demethylation.

More comparative data from temperate and tropical zones are needed to determine the global significance of greenhouse gas emissions from reservoirs, especially data on the relative durations and amounts of CH<sub>4</sub> and CO<sub>2</sub> emitted in the different settings. In this context, it is important to have adequate data on the surface area of reservoirs and to know the proportion of this surface area that is flooded land. Better understanding of greenhouse gas fluxes under different geographic/climatic conditions combined with better estimates of the world's surface area occupied by reservoirs would enable estimation of the contribution made by reservoirs to global climate warming. Mathematical models calibrated by data collected in the field appear to hold the most promise for predicting the generation of both greenhouse gases and methylmercury in reservoirs.

Better understanding is needed of the effects of interference with freshwater flows to the ocean by upstream reservoir developments that involve substantial discharge regulation. A prime example is Canada's Hudson Bay, which is surrounded by large-scale hydroelectric development (Rosenberg et al. 1995). However, Neu (1982b) warns, "The problem is so large and complex that it would take years, even decades, of intensive studies before some of the elements given in this analysis could be verified in detail." An improved understanding of physical/chemical and geomorphic changes would lead to better explanations of changes in the biota of areas downstream of large-scale hydroelectric development.

Research into effects on biodiversity is initially limited by poor, general inventories of different levels of biodiversity (e.g., Savage 1995). Such inventories need to be improved on a world-wide basis. Furthermore, few large-scale hydroelectric developments have tried to document, even partially, structural and functional changes in biodiversity after completion of a project. The task is daunting because of the number of biodiversity levels potentially involved, and because disturbed ecosystems take a long time to reach new equilibria (Dynesius and Nilsson 1994). Yet, only after such an accounting is done can we hope to understand biodiversity losses and gains resulting from such developments.

Postaudits of large-scale hydroelectric developments require more support because they provide a storehouse of information and experience that may be usefully applied to future projects. The need for long-term monitoring is especially important with respect to social impacts, not only to understand the mechanisms of change but also for the adaptive management and mitigation of impacts. Experiences such as with La Grande River project in Canada indicate that many of the combined environmental and social impacts are unpredictable and become apparent only after a time lag (Berkes 1988). Much can be learned from the accumulated literature of social impact

assessments (e.g., Scudder 1973). Such assessments can be improved by the following: (i) more focused investigation of linked social-environmental systems, with appropriate attention to cross-scale effects in both space and time; (ii) identification of key ecosystem processes; and (iii) development of testable hypotheses as opposed to the generation of merely descriptive social and economic data.

Finally, decision makers need a better understanding of the environmental and social problems surrounding large-scale hydroelectric development. Although prevailing political philosophies and values of decision makers in developed and developing countries are not likely to support the necessary time and work needed to study large-scale impacts, the continued effort by environmental and social scientists in trying to understand and describe these impacts, as evidenced by the studies cited in this review, may eventually contribute to more enlightened decision-making for hydroelectric development.

### Acknowledgments

We thank D. Allan, B. Chao, B. Davies, and A. Flecker for providing information useful in the review. The comments of D. Malley, V. St. Louis, P. Welborn, and D. Windsor greatly improved the manuscript. D. Laroque and C. Catt patiently word-processed the many different drafts, and A. Wiens helped in many facets of producing the manuscript.

### References

- Abernathy, A.R., and Cumbie, P.M. 1977. Mercury accumulation by largemouth bass (*Micropterus salmoides*) in recently impounded reservoirs. *Bull. Environ. Contam. Toxicol.* **17**: 595-602.
- Abernathy, A.R., Newman, M.E., and Nicholas, W.D. 1985. Mercury mobilization and biomagnification resulting from the filling of a Piedmont reservoir. Water Resources Research Institute, Clemson, S.C. Rep. No. 119 (Tech. Completion Rep. G-932-07).
- Aggus, L.R. 1971. Summer benthos in newly flooded areas of Beaver Reservoir during the second and third years of filling 1965-1966. *In* Reservoir fisheries and limnology. Edited by G.E. Hall. American Fisheries Society, Washington, D.C. Spec. Publ. 8. pp. 139-152.
- Aleem, A.A. 1972. Effect of river outflow management on marine life. *Mar. Biol.* **15**: 200-208.
- Allan, J.D., and Flecker, A.S. 1993. Biodiversity conservation in running waters. *BioScience*, **43**: 32-43.
- Angermeier, P.L., and Karr, J.R. 1994. Biological integrity versus biological diversity as policy directives. *BioScience*, **44**: 690-697.
- Anonymous 1987. Summary report. Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion. Canada-Manitoba Agreement, Winnipeg, Man.
- Anonymous 1992. Inheritance of the dammed. *New Sci.* **136**(1845): 3.
- Anonymous 1995. Special report. Spotlight on La Grande-1 project. Completed July 1995. Hydro-Québec brings on-line 1368 megawatts at James Bay. *Hydro Rev.* **14**(7): SR1-SR15.
- Attrill, M.J., Rundle, S.D., and Thomas, R.M. 1996. The influence of drought-induced low freshwater flow on an upper-estuarine macroinvertebrate community. *Water Res.* **30**: 261-268.
- Auer, N.A. 1996. Response of spawning lake sturgeons to change in hydroelectric facility operation. *Trans. Am. Fish. Soc.* **125**: 66-77.
- Balon, E.K. 1978. Kariba: the dubious benefits of large dams. *Ambio*, **7**: 40-48.
- Barnes, N.E., and Bodaly, R.A. 1994. Origin and abundance of lake whitefish (*Coregonus clupeaformis*) congregating below a hydro-

- electric control dam in northern Canada. *Regul. Rivers Res. Manage.* **9**: 295–302.
- Bass, D. 1992. Colonization and succession of benthic macroinvertebrates in Arcadia Lake, a south-central USA reservoir. *Hydrobiologia*, **242**: 123–131.
- Baxter, R.M. 1977. Environmental effects of dams and impoundments. *Annu. Rev. Ecol. Syst.* **8**: 255–283.
- Baxter, R.M., and Glaude, P. 1980. Environmental effects of dams and impoundments in Canada: experience and prospects. *Can. Bull. Fish. Aquat. Sci.* **205**: 1–34.
- Bayley, P.B. 1995. Understanding large river-floodplain ecosystems. *BioScience*, **45**: 153–158.
- Beamesderfer, R.C.P., Rien, T.A., and Nigro, A.A. 1995. Differences in the dynamics and potential production of impounded and unimpounded white sturgeon populations in the lower Columbia River. *Trans. Am. Fish. Soc.* **124**: 857–872.
- Benke, A.C. 1990. A perspective on America's vanishing streams. *J. North Am. Benthol. Soc.* **9**: 77–88.
- Bergström, S., and Carlsson, B. 1994. River runoff to the Baltic Sea: 1950–1990. *Ambio*, **23**: 280–287.
- Berkes, F. 1981. Some environmental and social impacts of the James Bay hydroelectric project, Canada. *J. Environ. Manage.* **12**: 157–172.
- Berkes, F. 1982. Preliminary impacts of the James Bay hydroelectric project, Québec, on estuarine fish and fisheries. *Arctic*, **35**: 524–530.
- Berkes, F. 1988. The intrinsic difficulty of predicting impacts: lessons from the James Bay hydro project. *Environ. Impact Assess. Rev.* **8**: 201–220.
- Berkes, F., and Fast, H. 1996. Aboriginal peoples: the basis for policy-making towards sustainable development. *In* Achieving sustainable development. *Edited by* A. Dale and J.B. Robinson. University of British Columbia Press, Vancouver, B.C. pp. 204–264.
- Berkes, F., George, P.J., Preston, R.J., Hughes, A., Turner, J., and Cummins, B.D. 1994. Wildlife harvesting and sustainable regional native economy in the Hudson and James Bay lowland, Ontario. *Arctic*, **47**: 350–360.
- Berman, M., and Bartha, R. 1986. Levels of chemical versus biological methylation of mercury in sediments. *Bull. Environ. Contam. Toxicol.* **36**: 401–404.
- Biodiversity Science Assessment Team. 1994. Biodiversity in Canada. A science assessment for Environment Canada. Environment Canada, Ottawa, Ont..
- Bissonnette, A., and Bouchard, S. 1984. Répercussions sociales et économiques du détournement de la Caniapiscou sur les activités de chasse et de pêche de la population de Kuujjuaq: point en vue des utilisateurs. Centre de recherches et d'analyse en sciences humaines, Société d'énergie de la baie James, Montréal, Qué.
- Blinn, D.W., Shannon, J.P., Stevens, L.E., and Carder, J.P. 1995. Consequences of fluctuating discharge for lotic communities. *J. North Am. Benthol. Soc.* **14**: 233–248.
- Bodaly, R.A., Hecky, R.E., and Fudge, R.J.P. 1984a. Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. *Can. J. Fish. Aquat. Sci.* **41**: 682–691.
- Bodaly, R.A., Johnson, T.W.D., Fudge, R.J.P., and Clayton, J.W. 1984b. Collapse of the lake whitefish (*Coregonus clupeaformis*) fishery in Southern Indian Lake, Manitoba, following lake impoundment and river diversion. *Can. J. Fish. Aquat. Sci.* **41**: 692–700.
- Bodaly, R.A., St. Louis, V.L., Paterson, M.J., Fudge, R.J.P., Hall, B.D., Rosenberg, D.M., and Rudd, J.W.M. 1997. Bioaccumulation of mercury in the aquatic food chain in newly flooded areas. *In* Mercury and its effects on environment and biology. *Edited by* H. Sigel and A. Sigel. Marcel Dekker, New York. pp. 259–287.
- Bogan, A.E. 1993. Freshwater bivalve extinctions (Mollusca: Unionoida): a search for causes. *Am. Zool.* **33**: 599–609.
- Bolton, P. 1984. Mozambique's Cabora Bassa project: an environmental assessment. *In* The social and environmental effects of large dams. Vol. 2. *Edited by* E. Goldsmith and N. Hildyard. Wadebridge Ecological Centre, Camelford, Cornwall, U.K. pp. 156–167.
- Boucher, R., Schetagne, R., and Magnin, E. 1985. Teneur en mercure des poissons des réservoirs la Grande 2 et Opinaca (Québec, Canada) avant et après la mise en eau. *Rev. Fr. Sci. Eau*, **4**: 193–206.
- Boulton, A.J., and Lloyd, L.N. 1992. Flooding frequency and invertebrate emergence from dry floodplain sediments of the River Murray, Australia. *Regul. Rivers Res. Manage.* **7**: 137–151.
- Bourassa, R. 1985. Power from the north. Prentice Hall, Scarborough, Ont.
- Broseliske, G.H., de Jong, J., and Smit, H. 1991. Historical and present day management of the River Rhine. *Water Sci. Technol.* **23**: 111–120.
- Brouard, D., Doyon, J.-F., and Schetagne, R. 1994. Amplification of mercury concentrations in lake whitefish (*Coregonus clupeaformis*) downstream from the La Grande 2 Reservoir, James Bay, Québec. *In* Mercury pollution: integration and synthesis. *Edited by* C.J. Watras and J.W. Huckabee. Lewis Publishers, Boca Raton, Fla. pp. 369–379.
- Brousseau, C.S., and Goodchild, G.A. 1989. Fisheries and yields in the Moose River basin, Ontario. *Can. Spec. Publ. Fish. Aquat. Sci.* **106**: 145–158.
- Bruce, W.J., and Spencer, K.D. 1979. Mercury levels in Labrador fish, 1977–78. *Can. Ind. Rep. Fish. Aquat. Sci.* **111**: 1–12.
- Bruton, M.N., and van As, J. 1986. Faunal invasions of aquatic ecosystems in southern Africa, with suggestions for their management. *In* Ecology and management of biological invasions in southern Africa. *Edited by* I.A.W. MacDonald, F.J. Kruger, and A.A. Ferrar. Oxford University Press, New York. pp. 47–61.
- Cambay, J.A., and Jubb, R.A. 1977. Dispersal of fishes via the Orange-Fish tunnel, South Africa. *J. Limnol. Soc. South. Afr.* **3**: 33–35.
- Cambay, J.A., Davies, B.R., and Ashton, P.J. 1986. The Orange-Vaal River system. *In* The ecology of river systems. *Edited by* B.R. Davies and K.F. Walker. Junk Publishers, Dordrecht, the Netherlands. pp. 89–122.
- Carlson, C.A., and Muth, R.T. 1989. The Colorado River: lifeline of the American southwest. *Can. Spec. Publ. Fish. Aquat. Sci.* **106**: 220–239.
- Chao, B.F. 1991. Man, water, and global sea level. *EOS, Trans. Am. Geophys. Union*, **72**: 492.
- Chao, B.F. 1995. Anthropogenic impact on global geodynamics due to reservoir water impoundment. *Geophys. Res. Lett.* **22**: 3529–3532.
- Charest, P. 1982. Hydroelectric dam construction and the foraging activities of eastern Quebec Montagnais. *In* Politics and history in band societies. *Edited by* E. Leacock and R. Lee. Cambridge University Press, Cambridge. pp. 413–426.
- Chau, K.C. 1995. The Three Gorges Project of China: resettlement prospects and problems. *Ambio*, **24**: 98–102.
- Coleman, W.G. 1996. Biodiversity and industry ecosystem management. *Environ. Manage.* **20**: 815–825.
- Cox, J.A., Carnahan, J., DiNunzio, J., McCoy, J., and Meister, J. 1979. Source of mercury in fish in new impoundments. *Bull. Environ. Contam. Toxicol.* **23**: 779–783.
- Davies, B.R., O'Keeffe, J.H., and Snaddon, C.D. 1993. A synthesis of the ecological functioning, conservation and management of South African river ecosystems. Water Research Commission, Pretoria, Republic of South Africa. Rep. No. TT62/93.
- DesLandes, J.-C., Guénette, S., Prairie, Y., Roy, D., Verdon, R., and Fortin, R. 1995. Changes in fish populations affected by the construction of the La Grande complex (Phase 1), James Bay region, Quebec. *Can. J. Zool.* **73**: 1860–1877.
- Devine, R.S. 1995. The trouble with dams. *Atl. Mon.* **276**(2): 64–74.
- Dirschl, H.J., Novakowski, N.S., and Sadar, M.H. 1993. Environmental auditing. Evolution of environmental impact assessment

- as applied to watershed modification projects in Canada. *Environ. Manage.* **17**: 545–555.
- Dudgeon, D. 1992. Endangered ecosystems: a review of the conservation status of tropical Asian rivers. *Hydrobiologia*, **248**: 167–191.
- Dudgeon, D. 1995. River regulation in southern China: ecological implications, conservation and environmental management. *Regul. Rivers Res. Manage.* **11**: 35–54.
- Dwyer, A. 1992. The trouble at Great Whale. *Equinox*, **11**(61): 28–41.
- Dynesius, M., and Nilsson, C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* (Washington, D.C.), **266**: 753–762.
- Ebel, W.J., Becker, C.D., Mullan, J.W., and Raymond, H.L. 1989. The Columbia River—toward a holistic understanding. *Can. Spec. Publ. Fish. Aquat. Sci.* **106**: 205–219.
- Ellis, W.S., and Turnley, D.C. 1990. The Aral. A Soviet sea lies dying. *Nat. Geogr. Mag.* **177**(2): 73–93.
- Environment Canada. 1990. A primer on water. Questions and answers. Minister of the Environment, Ottawa, Ont.
- Environment Canada and Department of Fisheries and Oceans. 1992. Federal Ecological Monitoring Program. Final Report. Vol. 1. FEMP, Winnipeg, Man.
- Fearnside, P.M. 1988. China's Three Gorges Dam: "fatal" project or step toward modernization? *World Dev.* **16**: 615–630.
- Fearnside, P.M. 1989. Brazil's Balbina Dam: environment versus the legacy of the Pharaohs in Amazonia. *Environ. Manage.* **13**: 401–423.
- Fearnside, P.M. 1995. Hydroelectric dams in the Brazilian Amazon as sources of "greenhouse" gases. *Environ. Conserv.* **22**: 7–19.
- Feldman, M.D. 1995. Planning adequate streamflows for anadromous fish in the Columbia River Basin Fish and Wildlife Program. *Rivers*, **5**: 208–215.
- Foote, A.L., Pandey, S., and Krogman, N.T. 1996. Processes of wetland loss in India. *Environ. Conserv.* **23**: 45–54.
- Fruget, J.F. 1992. Ecology of the Lower Rhône after 200 years of human influence: a review. *Regul. Rivers Res. Manage.* **7**: 233–246.
- Gaboury, M.N., and Patalas, J.W. 1984. Influence of water level drawdown on the fish populations of Cross Lake, Manitoba. *Can. J. Fish. Aquat. Sci.* **41**: 118–125.
- Geist, D.R., Vail, L.W., and Epstein, D.J. 1996. Analysis of potential impacts to resident fish from Columbia River system operation alternatives. *Environ. Manage.* **20**: 275–288.
- Glantz, M.H., Rubinstein, A.Z., and Zohn, I. 1993. Tragedy in the Aral Sea basin. Looking back to plan ahead? *Global Environ. Change*, **3**: 174–198.
- Goldsmith, E., and Hildyard, N. 1984. The social and environmental effects of large dams, Vol. 1. Wadebridge Ecological Centre, Camelford, Cornwall, U.K.
- Goodland, R. 1994–1995. Environmental sustainability and the power sector. Part 2: Sustainability in the power sector. *Impact Assess.* **12**: 409–470.
- Goodland, R.J.A., Juras, A., and Pachauri, R. 1993. Can hydro-reservoirs in tropical moist forests be environmentally sustainable? *Environ. Conserv.* **20**: 122–130.
- Gorham, E. 1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. *Ecol. Appl.* **1**: 182–195.
- Gribbin, J. 1979. Climatic impact of Soviet river diversions. *New Sci.* **84**(1184): 762–765.
- Gribbin, J., and Gribbin, M. 1996. The greenhouse effect. *New Sci.* (Inside Sci. No. 92), **151**(2037).
- Hall, B.D., Bodaly, R.A., Fudge, R.J.P., Rudd, J.W.M., and Rosenberg, D.M. 1997. Food as the dominant pathway of methylmercury uptake by fish. *Water Air Soil Pollut.* In press.
- Harding, J.S. 1992. Discontinuities in the distribution of invertebrates in impounded South Island rivers, New Zealand. *Regul. Rivers Res. Manage.* **7**: 327–335.
- Hecky, R.E., Bodaly, R.A., Ramsey, D.J., Ramlal, P.S., and Strange, N.E. 1987. Evolution of limnological conditions, microbial methylation of mercury and mercury concentrations in fish in reservoirs of northern Manitoba. A summary report for Project 2.4 of the Canada-Manitoba Agreement of the Study and Monitoring of Mercury in the Churchill River Diversion. Technical Appendices to the Summary Report, Canada-Manitoba Mercury Agreement, Winnipeg, Man.
- Hecky, R.E., Ramsey, D.J., Bodaly, R.A., and Strange, N.E. 1991. Increased methylmercury contamination in fish in newly formed freshwater reservoirs. *In* *Advances in mercury toxicology*. Edited by T. Suzuki, N. Imura, and T.W. Clarkson. Plenum, New York. pp. 33–52.
- Hellsten, S., Marttunen, M., Palomäki, R., Riihimäki, J., and Alasaarela, E. 1996. Towards an ecologically based regulation practice in Finnish hydroelectric lakes. *Regul. Rivers Res. Manage.* **12**: 535–545.
- Hesse, L.W. 1995. Water allocation for ecosystem management of the Missouri River. *Regul. Rivers Res. Manage.* **11**: 299–311.
- Hesse, L.W., Schmulbach, J.C., Carr, J.M., Keenlyne, K.D., Unkenholz, D.G., Robinson, J.W., and Mestl, G.E. 1989. Missouri River fishery resources in relation to past, present, and future stresses. *Can. Spec. Publ. Fish. Aquat. Sci.* **106**: 352–371.
- Hillel, D. 1994. *Rivers of Eden. The struggle for water and the quest for peace in the Middle East.* Oxford University Press, New York.
- Hödl, W., and Eder, E. 1996. Rediscovery of *Leptostheria dahalacensis* and *Eoleptostheria ticinensis* (Crustacea: Branchiopoda: Spinicaudata): an overview on presence and conservation of clam shrimps in Austria. *Hydrobiologia*, **318**: 203–206.
- Horta, K. 1995. The mountain kingdom's white oil. The Lesotho Highlands Water Project. *Ecologist*, **25**: 227–231.
- Hughes, R.M., and Noss, R.F. 1992. Biological diversity and biological integrity: current concerns for lakes and streams. *Fisheries* (Bethesda), **17**(3): 11–19.
- Humpesch, U.H. 1992. Ecosystem study Altenwörth: impacts of a hydroelectric power-station on the River Danube in Austria. *Freshwater Forum*, **2**: 33–58.
- Hydro-Québec. 1993a. Grande-Baleine complex. Feasibility study. Part 2: Hydroelectric complex. Book 6: Mercury. Hydro-Québec, Montréal, Qué.
- Hydro-Québec. 1993b. Grande-Baleine complex. Feasibility study. Part 2: Hydroelectric complex. Book 8: Key issues. Hydro-Québec, Montréal, Qué.
- Ittekkot, V., and Haake, B. 1990. The terrestrial link in the removal of organic carbon in the sea. *In* *Facets of modern biogeochemistry*. Edited by V. Ittekkot, S. Kempe, W. Michaelis, and A. Spitz. Springer-Verlag, Berlin. pp. 318–325.
- James Bay Mercury Committee. 1995. Report of activities, 1993–1994. James Bay Mercury Committee, Montréal, Qué.
- Johnson, B.L., Richardson, W.B., and Naimo, T.J. 1995. Past, present, and future concepts in large river ecology. *BioScience*, **45**: 134–141.
- Johnston, T.A., Bodaly, R.A., and Mathias, J.A. 1991. Predicting fish mercury levels from physical characteristics of boreal reservoirs. *Can. J. Fish. Aquat. Sci.* **48**: 1468–1475.
- Kelly, C.A., Rudd, J.W.M., St. Louis, V., and Moore, T. 1994. Turning attention to reservoir surfaces, a neglected area in greenhouse studies. *EOS, Trans. Am. Geophys. Union*, **75**: 332–333.
- Kelly, C.A., Rudd, J.W.M., Bodaly, R.A., Roulet, N.T., St. Louis, V.L., Heyes, A., Moore, T.R., Schiff, S., Warner, B., and Dyck, B. 1997. Effects of flooding on CO<sub>2</sub>, CH<sub>4</sub> and methyl mercury fluxes in an experimental reservoir. *Environ. Sci. Technol.* **31**. In press.
- Koskenniemi, E. 1994. Colonization, succession and environmental conditions of the macrozoobenthos in a regulated, polyhumic reservoir, western Finland. *Int. Rev. Gesamten Hydrobiol.* **79**: 521–555.
- Kotlyakov, V.M. 1991. The Aral Sea basin. A critical environmental zone. *Environment*, **33**(1): 4–9, 36–39.
- Krotz, L. 1991. Dammed and diverted. *Can. Geogr.* **111**(1): 36–44.

- Lehmkuhl, D.M. 1972. Change in thermal regime as a cause of reduction of benthic fauna downstream of a reservoir. *J. Fish. Res. Board Can.* **29**: 1329–1332.
- Levintanus, A. 1992. Saving the Aral Sea. *J. Environ. Manage.* **36**: 193–199.
- Liao, G.Z., Lu, K.X., and Xiao, X.Z. 1989. Fisheries resources of the Pearl River and their exploitation. *Can. Spec. Publ. Fish. Aquat. Sci.* **106**: 561–568.
- Lodenius, M., Seppänen, A., and Herranen, M. 1983. Accumulation of mercury in fish and man from reservoirs in northern Finland. *Water Air Soil Pollut.* **19**: 237–246.
- Löffler, H. 1993. The future of large lakes in the third world. *Mem. Ist. Ital. Idrobiol.* **52**: 27–38.
- Loney, M. 1987. The construction of dependency: the case of the Grand Rapids hydro project. *Can. J. Native Stud.* **7**: 57–78.
- Losos, E., Hayes, J., Phillips, A., Wilcove, D., and Alkire, C. 1995. Taxpayer-subsidized resource extraction harms species. *Double jeopardy. BioScience.* **45**: 446–455.
- Mackenzie, D. 1994. Where has all the carbon gone? *New Sci.* **141**(1907): 30–33.
- Majot, J. 1996. Risky business. Is the dam industry a dinosaur in the age of privatization? *World Rivers Rev.* **10**(4): 8–9.
- Malley, D.F., Stewart, A.R., and Hall, B.D. 1996. Uptake of methyl mercury by the floater mussel, *Pyganodon grandis* (Bivalvia, Unionidae), caged in a flooded wetland. *Environ. Toxicol. Chem.* **15**: 928–936.
- Marchand, P. 1990. Les variations de niveau des réservoirs de la Volga et leurs conséquences sur l'environnement. *Rev. Sci. Eau.* **3**: 3–20.
- Mattice, J., Fraser, M., Ragone, S., Wisniewski, J., and Wisniewski, J. (Editors). 1996. Managing for biodiversity: emerging ideas for the electric utility industry. *Environ. Manage.* **20**: 777–974.
- McIntosh, B.A., Sedell, J.R., Smith, J.E., Wissmar, R.C., Clarke, S.E., Reeves, G.H., and Brown, L.A. 1994. Historical changes in fish habitat for select river basins of eastern Oregon and Washington. *Northwest Sci.* **68**(Spec. Issue): 36–53.
- Meffe, G.K. 1986. Conservation genetics and the management of endangered fishes. *Fisheries* (Bethesda), **11**(1): 14–23.
- Meffe, G.K. 1992. Techno-arrogance and halfway technologies: salmon hatcheries on the Pacific coast of North America. *Conserv. Biol.* **6**: 350–354.
- Micklin, P.P. 1985. The vast diversion of Soviet rivers. *Environment*, **27**(2): 12–20, 40–45.
- Micklin, P.P. 1988. Desiccation of the Aral Sea: a water management disaster in the Soviet Union. *Science* (Washington, D.C.), **241**: 1170–1176.
- Milko, R. 1986. Potential ecological effects of the proposed GRAND Canal diversion project on Hudson and James bays. *Arctic*, **39**: 316–326.
- Mirza, M.M.Q., and Ericksen, N.J. 1996. Impact of water control projects on fisheries resources in Bangladesh. *Environ. Manage.* **20**: 523–539.
- Monosowski, E. 1984. Brazil's Tucurui Dam: development at environmental cost. *In* The social and environmental effects of large dams. Vol. 2. Edited by E. Goldsmith and N. Hildyard. Wadebridge Ecological Centre, Camelford, Cornwall, U.K. pp. 191–198.
- Morse, B., and Berger, T.R. 1992. Sardar Sarovar. Report of the independent review. Resource Futures International, Ottawa, Ont.
- Natarajan, A.V. 1989. Environmental impact of Ganga basin development on gene-pool and fisheries of the Ganga River system. *Can. Spec. Publ. Fish. Aquat. Sci.* **106**: 545–560.
- Nehlsen, W., Williams, J.E., and Lichatowich, J.A. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* (Bethesda), **16**(2): 4–21.
- Neu, H.J.A. 1982a. Man-made storage of water resources—a liability to the ocean environment? Part I. *Mar. Pollut. Bull.* **13**: 7–12.
- Neu, H.J.A. 1982b. Man-made storage of water resources—a liability to the ocean environment? Part II. *Mar. Pollut. Bull.* **13**: 44–47.
- Newbury, R.W., and McCullough, G.K. 1984. Shoreline erosion and restabilization in the Southern Indian Lake reservoir. *Can. J. Fish. Aquat. Sci.* **41**: 558–566.
- Newbury, R.W., McCullough, G.K., and Hecky, R.E. 1984. The Southern Indian Lake impoundment and Churchill River diversion. *Can. J. Fish. Aquat. Sci.* **41**: 548–557.
- Nichol, P. 1991. Bleak future predicted for delta. *Fort McMurray Today*, December 16, 1991, p. 1.
- Nichols, F.H., Cloern, J.E., Luoma, S.N., and Peterson, D.H. 1986. The modification of an estuary. *Science* (Washington, D.C.), **231**: 567–573.
- Nicola, G.G., Elvira, B., and Almodóvar, A. 1996. Dams and fish passage facilities in the large rivers of Spain: effects on migratory species. *Arch. Hydrobiol. Suppl.* **113**(Large Rivers 10): 375–379.
- Niezen, R. 1993. Power and dignity: the social consequences of hydro-electric development for the James Bay Cree. *Can. Rev. Sociol. Anthropol.* **30**: 510–529.
- Niimi, A.J., and KISSOON, G.P. 1994. Evaluation of the critical body burden concept based on inorganic and organic mercury toxicity to rainbow trout (*Oncorhynchus mykiss*). *Arch. Environ. Contam. Toxicol.* **26**: 169–178.
- Obeng, L. 1977. Should dams be built? The Volta Lake example. *Ambio*, **6**: 46–50.
- Obeng, L.E. 1981. Man's impact on tropical rivers. *In* Perspectives in running water ecology. Edited by M.A. Lock and D.D. Williams. Plenum, New York. pp. 265–288.
- Olmsted, L.L., and Bolin, J.W. 1996. Aquatic biodiversity and the electric utility industry. *Environ. Manage.* **20**: 805–814.
- Palmer, R.W., and Palmer, A.R. 1995. Impacts of repeated applications of *Bacillus thuringiensis* var. *israelensis* de Barjac and temephos, used in blackfly (Diptera: Simuliidae) control, on macroinvertebrates in the middle Orange River, South Africa. *South. Afr. J. Aquat. Sci.* **21**: 35–55.
- Peace–Athabasca Delta Project Group. 1972. The Peace–Athabasca Delta. A Canadian resource. Summary report, 1972. A report on low water levels in Lake Athabasca and their effects on the Peace–Athabasca Delta. Environment Ministers of Canada, Alberta and Saskatchewan, Edmonton, Alta.
- Peace–Athabasca Delta Project Group. 1973. The Peace–Athabasca Delta Project. Technical Report. A report on low water levels in Lake Athabasca and their effects on the Peace–Athabasca Delta. Environment Ministers of Canada, Alberta and Saskatchewan, Edmonton, Alta.
- Pearce, F. 1991. A dammed fine mess. *New Sci.* **130**(1767): 36–39.
- Pearce, F. 1992. World Bank projects punished the poor. *New Sci.* **135**(1830): 5.
- Pearce, F. 1994. High and dry in Aswan. *New Sci.* **142**(1924): 28–32.
- Pearce, F. 1995a. The biggest dam in the world. *New Sci.* **145**(1962): 25–29.
- Pearce, F. 1995b. Poisoned waters. The Aral Sea has all but vanished, but its legacy is destroying the health of more than a million people. *New Sci.* **148**(2000): 29–33.
- Pearce, F. 1996. Trouble bubbles for hydropower. *New Sci.* **150**(2028): 28–31.
- Petr, T. 1971. Lake Volta—a progress report. *New Sci. Sci. J.* **49**: 178–182.
- Pligin, Yu.V., and Yemel'yanova, L.V. 1989. Acclimatization of Caspian invertebrates in Dnieper reservoirs. *Hydrobiol. J.* **25**(1): 1–9.
- Poddubny, A.G., and Galat, D.L. 1995. Habitat associations of upper Volga River fishes: effects of reservoirs. *Regul. Rivers Res. Manage.* **11**: 67–84.
- Postel, S.L., Daily, G.C., and Ehrlich, P.R. 1996. Human appropriation of renewable fresh water. *Science* (Washington, D.C.), **271**: 785–788.

- Power, M.E., Dietrich, W.E., and Finlay, J.C. 1996. Dams and downstream aquatic biodiversity: potential food web consequences of hydrologic and geomorphic change. *Environ. Manage.* **20**: 887–895.
- Precoda, N. 1991. Requiem for the Aral Sea. *Ambio*, **20**: 109–114.
- Preston, R.J., Berkes, F., and George, P.J. 1995. Perspectives on sustainable development in the Moose River basin. *In* Papers of the 26th Algonquin Conference. *Edited by* D.H. Pentland. University of Manitoba Press, Winnipeg, Man. pp. 379–393.
- Pringle, C., Vellidis, G., Heliotis, F., Bandacu, D., and Cristofor, S. 1993. Environmental problems of the Danube Delta. *Am. Sci.* **81**: 350–361.
- Rancourt, M., and Parent, L. 1994. Special report: project profile. Moving into the future with James Bay: Laforce-1 meets the challenges. *Hydro Rev.* **13**(7): SR2–SR15.
- Redekop, B. 1996. Rate storm in the forecast. Past year's wild weather may give insurers cold feet. *Winnipeg Free Press*, October 27, 1996. pp. A1–A2.
- Reeves, R.R., and Leatherwood, S. 1994. Dams and river dolphins: can they co-exist? *Ambio*, **23**: 172–175.
- Rhodes, J.J. 1994. Environmental history of river basins in eastern Oregon and Washington. *Northwest Sci.* **68** (Spec. Issue): i–ii.
- Ribeiro, M.C.L.B., Petre, M., Jr., and Juras, A.A. 1995. Ecological integrity and fisheries ecology of the Araguaia-Tocantins River basin, Brazil. *Regul. Rivers Res. Manage.* **11**: 325–350.
- Romanenko, V.D., and Yevtushenko, N.Yu. 1996. International cooperation in protecting the waters of the Dnieper basin. *Hydrobiol. J.* **32**(1): 28–32.
- Rosenberg, D.M. 1986. Resources and development of the Mackenzie system. *In* The ecology of river systems. *Edited by* B.R. Davies and K.F. Walker. Junk Publishers, Dordrecht, the Netherlands. pp. 517–540.
- Rosenberg, D.M., Bodaly, R.A., Hecky, R.E., and Newbury, R.W. 1987. The environmental assessment of hydroelectric impoundments and diversions in Canada. *In* Canadian aquatic resources. *Edited by* M.C. Healey and R.R. Wallace. *Can. Bull. Fish. Aquat. Sci.* **215**. pp. 71–104.
- Rosenberg, D.M., Bodaly, R.A., and Usher, P.J. 1995. Environmental and social impacts of large-scale hydroelectric development: who is listening? *Global Environ. Change*, **5**: 127–148.
- Rougerie, J.-F. 1990. James Bay development project. Hydroelectric development in northwestern Québec. *Can. Water Watch*, **3**: 56–58.
- Royal Commission on Aboriginal Peoples. 1996. Report of the Royal Commission on Aboriginal Peoples, Vol. 1. Ministry of Supply and Services, Ottawa, Ont.
- Rozenfurt, M., and Haydock, I. 1993. Freshwater flow diversion and its implications for coastal zone ecosystems. *Trans. N. Am. Wildl. Nat. Resour. Conf.* **58**: 287–295.
- Rozenfurt, M.A., and Haydock, I. 1994. The role of inland water development in the systemic alteration of the coastal zone environment. *In* Proceedings, Watershed '93. A National Conference on Watershed Management, 21–24 March 1993, Alexandria, Va. pp. 755–759.
- Rozenfurt, M.A., and Hedgpeth, J.W. 1989. The impact of altered river flow on the ecosystem of the Caspian Sea. *Rev. Aquat. Sci.* **1**: 337–362.
- Rudd, J.W.M., Harris, R., Kelly, C.A., and Hecky, R.E. 1993. Are hydroelectric reservoirs significant sources of greenhouse gases? *Ambio*, **22**: 246–248.
- Savage, J.M. 1995. Systematics and the biodiversity crisis. *BioScience*, **45**: 673–679.
- Schetagne, R. 1989. Qualité de l'eau. Régions de La Grande 2 et Opinaca. Interprétation des données de 1988. Réseau de suivi environnemental du complexe La Grande, phase 1. Service Recherches en Environnement et Santé Publique, Vice-présidence Environnement, Hydro-Québec, Montréal, Qué.
- Scudder, T. 1973. The human ecology of big projects: river basin development and resettlement. *Annu. Rev. Anthropol.* **2**: 45–61.
- Seagel, G.C. 1987. Pacific to Arctic transfer of water and biota. The McGregor diversion project in British Columbia, Canada. *In* Proceedings of the Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada. *Edited by* W. Nicholaichuk and F. Quinn. Environment Canada, Saskatoon, Sask. pp. 431–438.
- Shelast, B.M., Luoma, M.E., Brayford, K.T., Martin, J.A., and Tarpey, T. 1994. Pre-design study. Environmental effects monitoring. Daishowa-Marubeni International Ltd., Peace River, Alta. Sentar Consultants, Calgary, Alta., and Daishowa-Marubeni International Ltd., Peace River, Alta. Proj. No. 09–638–01–01.
- Shrestha, T.K. 1993. Status, ecology and behaviour of Gangetic dolphin in the Narayani River of Nepal. *J. Freshwater Biol.* **5**: 365–377.
- Slaney, T.L., Hyatt, K.D., Northcote, T.G., and Fielden, R.J. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. *Fisheries (Bethesda)*, **21**(10): 20–35.
- Stanley, D.J. 1996. Nile delta: extreme case of sediment entrapment on a delta plain and consequent coastal land loss. *Mar. Geol.* **129**: 189–195.
- Stanley, D.J., and Warne, A.G. 1993. Nile delta: recent geological evolution and human impact. *Science (Washington, D.C.)*, **260**: 628–634.
- Sterling, H. 1996. IJC faint shadow of its potential. *Winnipeg Free Press*, September 20, 1996. p. A9.
- St. Louis, V.L., Rudd, J.W.M., Kelly, C.A., Beaty, K.G., Bloom, N.S., and Flett, R.J. 1994. Importance of wetlands as sources of methyl mercury to boreal forest ecosystems. *Can. J. Fish. Aquat. Sci.* **51**: 1065–1076.
- St. Louis, V.L., Rudd, J.W.M., Kelly, C.A., Beaty, K.G., Flett, R.J., and Roulet, N.T. 1996. Production and loss of methylmercury and loss of total mercury from boreal forest catchments containing different types of wetlands. *Environ. Sci. Technol.* **30**: 2719–2729.
- Strange, N.E., Bodaly, R.A., and Fudge, R.J.P. 1991. Mercury concentrations in fish in Southern Indian Lake and Issett Lake, Manitoba, 1975–88: the effect of lake impoundment and Churchill River diversion. *Can. Tech. Rep. Fish. Aquat. Sci.* **1824**: 1–36.
- Szathmary, E., Rittenbaugh, C., and Goodby, C.M. 1987. Dietary changes and plasma glucose levels in an Amerindian population undergoing cultural transition. *Soc. Sci. Med.* **24**: 791–804.
- Thouez, J.P., Rannou, A., and Foggin, P. 1989. The other face of development: native population health status and indicators of malnutrition. The case of the Cree and Inuit of northern Québec. *Soc. Sci. Med.* **29**: 965–974.
- Tolmazin, D. 1979. Black Sea—dead sea? *New Sci.* **84**(1184): 767–769.
- Townsend, G.H. 1975. Impact of the Bennett Dam on the Peace-Athabasca delta. *J. Fish. Res. Board Can.* **32**: 171–176.
- Usher, P.J. 1992. Socio-economic effects of elevated mercury levels in fish on sub-arctic native communities. *In* Contaminants in the Marine Environment of Nunavik, Proceedings of the Conference, Montréal, Qué. Université Laval, Québec. pp. 45–50.
- Usher, P.J., and Weinstein, M.S. 1991. Towards assessing the effects of Lake Winnipeg regulation and Churchill River diversion on resource harvesting in native communities in northern Manitoba. *Can. Tech. Rep. Fish. Aquat. Sci.* **1794**: 1–69.
- Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and Cushing, C.E. 1980. The River Continuum Concept. *Can. J. Fish. Aquat. Sci.* **37**: 130–137.
- Verdon, R., Brouard, D., Demers, C., Lalumière, R., Laperle, M., and Schetagne, R. 1991. Mercury evolution (1978–1988) in fishes of the La Grande hydroelectric complex, Québec, Canada. *Water Air Soil Pollut.* **56**: 405–417.

- Volovik, S.P. 1994. The effects of environmental changes caused by human activities on the biological communities of the River Don (Azov Sea basin). *Water Sci. Technol.* **29**(3): 43–47.
- Vrijenhoek, R.C., Douglas, M.E., and Meffe, G.K. 1985. Conservation genetics of endangered fish populations in Arizona. *Science* (Washington, D.C.), **229**: 400–402.
- Waite, D.T., Dunn, G.W., and Stedwill, R.J. 1980. Mercury in Cookson Reservoir (East Poplar River). *Saskatchewan Environment*, Regina, Sask. WPC–23.
- Waldram, J.B. 1985. Hydroelectricity development and dietary delocalization in northern Manitoba, Canada. *Hum. Organ.* **44**: 41–49.
- Waldram, J.B. 1987. Relocation, consolidation, and settlement pattern in the Canadian subarctic. *Hum. Ecol.* **15**: 117–131.
- Waldram, J.B. 1988. As long as the rivers run. Hydroelectric development and native communities in western Canada. University of Manitoba Press, Winnipeg, Man.
- Walton, S. 1981. Egypt after the Aswan Dam. *Environment*, **23**(4): 30–36.
- Ward, J.V., and Stanford, J.A. 1983. The serial discontinuity concept of lotic ecosystems. In *Dynamics of lotic ecosystems*. Edited by T.D. Fontaine and S.M. Bartell. Ann Arbor Science, Ann Arbor, Mich. pp. 29–42.
- Watters, G.T. 1996. Small dams as barriers to freshwater mussels (*Bivalvia*, *Unionoida*) and their hosts. *Biol. Conserv.* **75**: 79–85.
- Weihe, P., Grandjean, Ph., Debes, F., Sorensen, N., and White, R.F. 1996. Neurotoxic potential of prenatal exposure to methylmercury: a cohort study in the Faroe Islands. In *Book of abstracts: program changes, revisions etc.* 4th International Conference on Mercury as a Global Pollutant, 4–8 August 1996, Hamburg, Germany. Edited by R. Ebinghaus, G. Petersen, and U. von Tümpling. p. 32.
- Wernstedt, K., and Paulsen, C.M. 1995. Economic and biological analysis to aid system planning for salmon recovery in the Columbia River basin. *J. Environ. Manage.* **43**: 313–331.
- Wheatley, B., and Paradis, S. 1995. Exposure of Canadian aboriginal peoples to methylmercury. *Water Air Soil Pollut.* **80**: 3–11.
- White, G.F. 1988. The environmental effects of the High Dam at Aswan. *Environment*, **30**(7): 5–11, 34–40.
- Wiener, J.G., and Spry, D.J. 1996. Toxicological significance of mercury in freshwater fish. In *Environmental contaminants in wildlife: interpreting tissue concentrations*. Edited by W.N. Beyer, G.H. Heinz, and A.W. Redmond-Norwood. Special Publication of the Society of Environmental Toxicology and Chemistry. Lewis Publishers, Boca Raton, Fla. pp. 297–339.
- Williams, J.E., and Williams, C.D. 1995. Who speaks for the Snake River salmon? *Fisheries* (Bethesda), **20**(11): 24–26.
- Williams, W.D. 1996. What future for saline lakes? *Environment*, **38**(9): 12–20, 38–39.
- Wissmar, R.C., Smith, J.E., McIntosh, B.A., Li, H.W., Reeves, G.H., and Sedell, J.R. 1994. A history of resource use and disturbance in riverine basins of eastern Oregon and Washington (early 1800s–1990s). *Northwest Sci.* **68**(Spec. Issue): 1–35.
- Wolfe, R.J., and Walker, R.J. 1987. Subsistence economies in Alaska: productivity, geography, and development impacts. *Arct. Anthropol.* **24**: 56–81.
- Yingcharoen, D., and Bodaly, R.A. 1993. Elevated mercury levels in fish resulting from reservoir flooding in Thailand. *Asian Fish. Sci.* **6**: 73–80.
- Zhong, Y., and Power, G. 1996. Environmental impacts of hydroelectric projects on fish resources in China. *Regul. Rivers Res. Manage.* **12**: 81–98.

## Methylmercury Exposure and Health Effects

Young-Seoub Hong<sup>1</sup>, Yu-Mi Kim<sup>1</sup>, Kyung-Eun Lee<sup>2</sup>

<sup>1</sup>Department of Preventive Medicine, Dong-A University College of Medicine, Busan; <sup>2</sup>Department of Clinical Laboratory Science, Catholic University of Pusan College of Health Science, Busan, Korea

Methylmercury is a hazardous substance that is of interest with regard to environmental health, as inorganic mercury circulating in the general environment is dissolved into freshwater and seawater, condensed through the food chain, ingested by humans, and consequently affects human health. Recently, there has been much interest and discussion regarding the toxicity of methylmercury, the correlation with fish and shellfish intake, and methods of long-term management of the human health effects of methylmercury. What effects chronic exposure to a low concentration of methylmercury has on human health remains controversial. Although the possibility of methylmercury poisoning the heart and blood vessel system, the reproductive system, and the immune system is continuously raised and discussed, and the carcinogenicity of methylmercury is also under discussion, a clear conclusion regarding the human health effects according to exposure level has not yet been drawn. The Joint FAO/WHO Expert Committee on Food Additives proposed to prepare additional fish and shellfish intake recommendations for consumers based on the quantified evaluation of the hazardousness of methylmercury contained in fish and shellfish, methylmercury management in the Korea has not yet caught up with this international trend. Currently, the methylmercury exposure level of Koreans is known to be very high. The starting point of methylmercury exposure management is inorganic mercury in the general environment, but food intake through methylation is the main exposure source. Along with efforts to reduce mercury in the general environment, food intake management should be undertaken to reduce the human exposure to methylmercury in Korea.

**Key words:** Methylmercury, Health effect, Toxicity, Human exposure, Epidemiology

### INTRODUCTION

Methylmercury, which is known to be the most poisonous among the mercury compounds is created when inorganic mercury circulating in the general environment is dissolved into freshwater and seawater. It is known to become condensed

through the ecological food chain and ingested into humans [1]. Accordingly, methylmercury can be ingested through food intake by people whose occupations are not directly related to mercury exposure, and this can affect human health. Therefore, methylmercury is a hazardous material that deserves the attention of environmental health experts. In air, most mercury exists in the form of inorganic mercury, while it is organic mercury that occupies most of the mercury content in human bodies. 80% to 90% of organic mercury in a human body is from fish and shellfish intake, and 75% to 90% of organic mercury existing in fish and shellfish is methylmercury. It was reported that 75% of blood mercury resulted from fish and shellfish intake for more than 30 days [2]. In recent years, extensive studies on the dose-response assessment of methylmercury have been performed, and the concentration of meth-

Received: September 21, 2012 Accepted: October 17, 2012

**Corresponding author:** Kyung-Eun Lee, PhD

57 Oryundae-ro, Geumjeong-gu, Busan 609-757, Korea

Tel: +82-51-510-0562, Fax: +82-51-510-0568

E-mail: kelee@cup.ac.kr

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

ylmercury which is considered safe for human exposure is decreasing as new data are gathered.

Methylmercury is highly poisonous and the toxicity varies according to its form, inflow path, exposure amount, and individual susceptibility. When a pregnant woman is exposed to methylmercury, it may increase the risk of silent birth and the birth of babies with deformities or severe nervous system diseases, even when the mother does not show any symptoms of poisoning [3,4]. Accordingly, most developed countries including the US, Canada, and Japan, set and manage recommendation standards for fish and shellfish intake as a part of the protection of vulnerable classes such as pregnant women and infants from methylmercury. In Korea, however, special recommendations for fish and shellfish intake do not exist, with the exception of freshwater fish, although there is a standard allowance for the mercury concentration in fish and shellfish. Furthermore, sufficient data on health disorders occurring in the normal population because of chronic exposure to low concentrations of methylmercury and various effects of poisoning on susceptible classes such as pregnant women and fetuses have not been gathered.

Recently, there has been a great deal of interest in and discussion about the toxicity of methylmercury, its correlation with fish and shellfish intake, and how to manage its effects on human health. In this study, we examined the characteristics, toxicity, and exposure levels of methylmercury, along with examining research trends and proposing a management plan.

## OVERVIEW OF THE HEALTH RISKS OF METHYLMERCURY

### Characteristics of Methylmercury

Mercury is classified as metal mercury, inorganic mercury, and organic mercury. The compounds composed of the combination of hydrogen and carbon are called organic mercury compounds. Organic mercury compounds are classified as allylmercury and alkylmercury compounds. Phenylacetate mercury (an agricultural chemical) and mercurochrome (an anti-septic) are allylmercury compounds and methylmercury and ethylmercury are alkyl mercury compounds [5]. Monomethylmercury and dimethylmercury, which are frequently found in ecological systems, may cause severe contamination to marine ecology. Minamata disease in Japan, which resulted from the intake of mercury-contaminated fish and shellfish, is a famous example [6].

People can be exposed to mercury through air, food, drink, and amalgam-treated teeth. From mercury flowing into the human body, methylmercury is known to have the strongest toxicity to humans, showing a high rate of human residues, such as 95% in one study [6]. The concentration of total mercury in the air is known to be  $<10 \text{ ng/m}^3$ , 22% of which is monomethylmercury and dimethylmercury. However, the average amount of methylmercury that people take in from the air is  $<0.04 \text{ } \mu\text{g/d}$ , so it can be said that air is not a major exposure source of methylmercury. On the other hand, mercury that has flowed into seas, rivers, and stream forms ligand combinations with various organic materials and exists in stabilized forms. Methylmercury is not created until inorganic mercury is methylated by microorganisms. Once produced, this methylmercury disperses to pelagic organisms very quickly and is then condensed in the pelagic organisms. It is known that methylmercury accumulates in humans who ingest these pelagic organisms [6]. The concentration of total mercury in most foods other than fish and shellfish is very low, at  $<0.01 \text{ } \mu\text{g/g}$ , and most mercury exists in the form of inorganic mercury. However, seafood, such as fish and shellfish, contains much higher quantities of mercury and 90% of mercury exists in the form of methylmercury. Although the concentration of methylmercury in most fishes is reported to be as low as  $<0.4 \text{ } \mu\text{g/g}$ , predatory fishes such as sword fish and shark are reported to contain one to two digits  $\mu\text{g/g}$  of mercury [6,7]. As such, predators that are larger, live longer, and are located high on the food chain have higher quantities of mercury [1,6,7].

Inorganic mercury discharged from various contaminants flows into seas, rivers, and streams, is converted to methylmercury by bacteria and plankton in water, is accumulated in pelagic organisms including fish and shellfish, and flows into humans through fish and shellfish intake by humans [1,6]. When methylmercury flows into the human body, it produces disulfides with a high chemical affinity to sulfhydryl groups from proteins. Disulfides make protein structures and enzyme functions nonspecific and cause poisoning [8,9]. Because of this, people who live in mercury-contaminated areas suffer from acute or chronic mercury poisoning without occupational exposure.

### Toxicokinetics

#### Absorption

While the absorption rate of inorganic mercury is not more than 2% to 38%, organic mercury is absorbed nearly complete-

ly and flows into the blood [10]. When people ingest methylmercury-contaminated food, methylmercury is separated by gastric acid. It combines with cysteine among the amino acids in the duodenum and almost 100% of the mercury is absorbed. Afterwards, it combines with the hemoglobin of red blood cells through the portal vein, is accumulated in the central nervous system, and causes disorders of the neurons [11]. In an animal experiment, up to 95% of methylmercury was absorbed by the lungs. As it is easily dissolved in fat and absorbed in the digestive tract quickly, methylmercury showed 17 to 35 times faster absorption than inorganic mercury. The maximum blood methylmercury concentration was found 6 hours after food exposure, and 95% of intake was absorbed [12].

#### **Distribution**

Methylmercury has high affinity with the sulfhydryl protein group. When it is ingested into the human body, it combines with glutathione to make methylmercury-glutathione compound and is distributed to various tissues and organs through the blood vessels [9,13]. It easily crosses the blood-brain barrier and placenta and is accumulated in the brain of fetuses more than in mothers [5]. The concentration of methylmercury in organisms is relatively stable proportional to the blood concentration and 90% of methylmercury is distributed in red blood cells. Accordingly, if we measure the blood methylmercury concentration, we can infer the concentration in the organs. When methylmercury was injected into pregnant mice, a 1.7 to 4.8 times higher mercury concentration was detected in the brain of the fetus than in that of the mother [12]. As methylmercury is fat-friendly, it crosses the cell membrane very easily. Although the placenta cross rate of methylmercury is 10 times higher than other mercury compounds, the transition from blood methylmercury to breast milk was lower than that from inorganic mercury [12]. It is known that when people are exposed to methylmercury, blood mercury moves to the follicle in the hair growth stage and is accumulated there. It has also been shown that the mercury concentration in hair is proportional to the blood concentration [12].

#### **Metabolism**

It is known that methylmercury is converted to bivalence inorganic mercury and undergoes oxidation and reduction [10]. Methylmercury releases oxygen radicals at decomposition and the released oxygen radical causes severe damage to cells by activating the chain of lipid peroxidation of the cell membrane

[13]. It has been proven that methylmercury has high fat solubility, is toxic to the central nervous system which has a high fat content [13].

#### **Excretion**

The main excretion paths of methylmercury are known to be the bile and feces. Methylmercury is excreted in the bile, but a part of it is reabsorbed through enterohepatic cycling and flows to the liver [6,10]. Most methylmercury is dissolved by demethylation and excreted to the feces in ion form. In case of applicant subject who was exposed to a methylmercury application once, excretion through the feces occupied 90% of total mercury excretion [10]. As methylmercury excretion via the urine is very slight, methylmercury concentration is not detected accurately in the urine because of the existence of inorganic mercury. Therefore, the concentration of mercury in the urine cannot be a good index for measuring the body's accumulation of methylmercury or its concentration in major organs [13]. The half-life period of methylmercury, that is, the time in which the content of methylmercury in the body is reduced to half through excretion, is 70 days on average. Additionally, organic mercury can be excreted through breast milk and the half-life period of methylmercury in breast feeding women is much shorter than in other women [6].

### **Health Effects of Methylmercury**

#### **Neurotoxicity**

The neurotoxicity of methylmercury is well known through worldwide intoxication incidents and studies regarding low concentration exposure. Methylmercury is a strong toxin that influences enzymes, cell membrane function, and neuron delivery materials; causes oxidative stress, lipid peroxidation, and mitochondria dysfunction; and distracts synapse transmission, microtubule composition, amino acid transport, and cellular migration in growing brains [14]. It is reported that there are motor disturbances such as ataxia and trembling, and dysesthesia such as impaired vision [5].

It was first discovered that methylmercury had fatal effects on the brain development of fetuses through mercury poisoning incidents in Minamata, Japan in the 1950s [6]. While there were only trivial or no symptoms of intoxication in mothers, infants showed central nervous disturbances such as paralysis and intelligence disorders. In the hair of Minamata residents, 280 to 760 ppm of mercury was detected [11]. Considering that the hair mercury concentration of normal people is 2 ppm,

5 mg/70 kg is defined as mercury poisoning, and 150 to 300 mg/70 kg is a lethal dose; it is a very high concentration [11]. All the children with Minamata disease suffered from mental retardation, cerebellar ataxia, physical growth disorder, dysarthria, and limb deformities. Most of them showed hyperkinesia, hypersalivation, seizures, and strabismus [6,12].

In Iraq in the early 1970s, there was an incident in which 6350 people were poisoned by mercury by eating bread made of grain containing chemicals including mercury. Of them, 409 died [6]. As it was caused by an acute exposure to a higher concentration of mercury than in the Minamata area, the poisoned children showed dysesthesia, paralysis, cerebral palsy and mental disorder symptoms. Those who were measured as having 25 mg of methylmercury showed dysesthesia at first; 50 mg, dysbasia; 90 mg balbuties; 180 mg, hearing disorders; and those who were measured at 200 mg died. On the other hand, it is estimated that when methylmercury is ingested constantly at a rate of 50 µg per day, the risk of dysesthesia will increase by 0.3%, and at 200 µg per day, the risk will increase by 8% [6].

Although children in New Zealand and the Faroe Islands were exposed to remarkably lower concentrations of methylmercury than in the Japan and Iraq poisoning incidents, they showed disorders in intelligence quotient, language, visual-spatial skills, gross motor skills, memory, and concentration [15-18]. However, a recent study regarding the effects of methylmercury exposure because of food intake after birth on the central nervous system did not prove a clear cause-effect relationship although several correlations in neurological examination were found [19]. In the same study, it is reported that recent methylmercury exposure had effects on the ability to perform addition, and a signal and number matching test, but it did not have effects on simple response time or selection response time tests [19].

In Korea, blood mercury concentration was measured in 1778 six- to ten-year-old children and no special correlation with attention deficit hyperactivity disorder (ADHD) prevalence was found [20]. On the other hand, in China and Hong Kong, it was reported that ADHD prevalence increased with increasing blood mercury concentration [21], and it was also reported that the hair mercury concentration of Spanish children was correlated with their visual-spatial skills [22]. It is thought that extensive study on complicated exposure including various concentrations and various metals should be performed in the future.

### **Reproductive effects**

The reproductive toxicity of methylmercury has been confirmed. In several studies, the correlation between chromosomal anomaly and sister-chromatid exchange according to methylmercury exposure was identified [23]. The reproductive toxicology shown in experimental animals exposed to high concentration methylmercury for a short period included reduced number of sperms, testicular atrophy, reduced size of infants in one birth, reduced survival rate of fetuses, and fetus deformity [24]. When injecting 0.4 to 0.8 mg/kg methylmercury dicyandiamide into the stomach cavity of mice at the seventh, ninth, and twelfth day of pregnancy, growing fetuses showed the greatest sensitivity to methylmercury toxicity [25]. To distinguish the influence of the exposure before and after birth on two variables, survival and weight gain, surrogate nurturing and cross nurturing were performed right after the birth. The death rate because of exposure before birth was 2 times higher than that because of exposure after birth, and the influence was greatest at the end of organogenesis. The effects on mother animals were not conspicuous, but it was found that methylmercury exposure in the womb could be much more dangerous to children than the exposure after birth through breast milk [25]. However, further studies regarding the reproductive toxicology of humans exposed to low concentration methylmercury should be performed.

### **Immunotoxicity**

The immunotoxicity of methylmercury on humans have not been confirmed. According to animal experiments, a mouse which had been fed feed containing 3.2 mg/kg of methylmercury did not show any changes in body weight or weight of the kidney, liver and spleen but the weight of the thymus and the number of thymocytes were reduced by 22% and 50%, respectively. While the lymph cell proliferation response against T cell and B cell mitogen increased in the thymus and spleen, NK cell activation was reduced by 44% in the spleen, and by 75% in the blood [12]. Additionally, methylmercury caused the malfunction of mastocytes in rodents [26].

According to a report of the National Research Council (NRC) [23], people exposed to high concentration methylmercury such as those who live near the Amazon River and eat fish as a staple food and those who work in gold mines, have been observed to have an increased frequency of antinuclear autoantibodies, changes in serum cytokine levels, and an increased risk of malaria infection [27,28].

Recently, it was reported that atopic dermatitis increased when the mercury concentration was high [29], but there have not been study results that could prove the effects of methylmercury on human immunity in Korea. However, considering the result of animal experiments, the possibility of immunotoxicity of methylmercury on human bodies cannot be ignored, so further studies should be performed.

#### **Carcinogenicity**

No epidemiological study on human beings has clearly shown a relationship between methylmercury exposure and cancer occurrence in an. Although one study has raised the possibility of leukemia because of mercury exposure, it could not clearly show the relationship between them because of factors such as limited population. It was reported that factory workers in a chloralkali plant in Sweden had two times higher risks of obtaining lung cancer, and the risk of brain cancer and kidney cancer were higher, but statistical significance was not observed [12]. In animal experiments, in mice fed with 10 mg/kg of methylmercury, chronic kidney failure, adenoma, and carcinoma were observed. In other words, it was reported that rodents exposed to methylmercury chloride showed a higher incidence of kidney cancer [12]. The International Agency for Research on Cancer judged that there is sufficient evidence of the carcinogenicity of methylmercury chloride on experimental animals and designated methylmercury as a Group 2B material (possibly carcinogenic to humans) [30], while the US Environmental Protection Agency designated it as a Group C material (possible human carcinogen) because it believed that evidence of the carcinogenicity of methylmercury in humans was insufficient and the rationale of the carcinogenicity in experimental animals was restricted [24].

#### **Cardiovascular effects**

Up to now, the relationship between methylmercury and cardiovascular toxicity has not been clearly identified through limited studies. However, the probability of the correlation between methylmercury exposure and cardiovascular toxicity has been raised consistently through some studies. It is known that mercury promotes the creation of free radicals, and that methylmercury disturbs the anti-oxidation effects of glutathione and catalase as it has a high affinity with the thiol group, causes lipid peroxidation, promotes platelet aggregation and blood coagulation, causes sclerosis of the arteries, and raises the blood pressure [31,32]. Consequently, the risk of myocar-

dial infarction is increased, and the danger of death is increased because of coronary heart disease and cardiovascular diseases [32]. Methylmercury shows fatal toxicity to the brains of children, whose brains are still developing, on the other hand, exposure shows a higher toxicity to adults than to children with regard to the incidence of cardiovascular diseases.

In Denmark, a case was reported in which children exposed to mercury showed increased blood pressure, both systolic and diastolic, and a reduced heart rate variability when they became 7 years old [33], and reduced sympathetic and parasympathetic nerve functions of the heart as heart rate variability values in both low frequency areas and high frequency areas decreased when they became 14 years old [34]. In a study researching the effects of low mercury exposure on the cardiovascular system in Finland, when male adults were traced for 14 years, it was found that death from coronary heart disease and incidence of acute myocardial infarction became twice as high as hair mercury concentration increased by 2 µg/g after correction for selenium, docosahexaenoic acid, docosapentanoic acid and vitamin E ingestion and other cardiovascular disease incurring risk factors [31,32]. Rissanen et al. [35] reported that fish oil-derived fatty acids reduced the risk of acute coronary events. But Virtanen et al. [32] reported that increased mercury exposure was associated with increased risk of acute coronary events and cardiovascular mortality. It is interpreted that mercury weakened the positive effects of fish.

The NRC concluded that mercury exposure would have effects on cardiovascular diseases, reporting that methylmercury's toxic effects include increased blood pressure as it was accumulated in heart, and noting that in mercury poisoning incidents, abnormal heartbeats, abnormal electrocardiogram, and myocarditis were reported [23]. In Korea, it was reported that elementary school students with higher urine mercury concentration showed a significantly higher blood cholesterol level, and proposing the possibility that mercury might affect the cardiovascular system, as the group with higher blood pressure in the relaxation period showed a relatively higher urine mercury concentration than the group with normal blood pressure [36]. Another study reported that hair mercury concentration had significant positive correlation with age, blood pressure in the contraction and relaxation period, total cholesterol, neutral fat, low density lipid protein cholesterol, and body mass index, while it had a significant negative correlation with standard deviation of the NN intervals, total power, low frequency, and high frequency (HF) values in heart rate,

high density lipid protein cholesterol, and heart rate variability tests [37]. Additionally, it reported that even after the correction of cardiovascular disease risk factors such as age and gender, when the hair mercury concentration increased by 1 ppm, the heart rate decreased by 2.6 beats/min, the Ln (HF) decreased by 0.131 ms, and the HF norm decreased by 2.550 [37]. This can be interpreted as a confirmation of the effects of mercury exposure on the parasympathetic nerve system of the heart. However, from some other perspectives, the heart protection effects of omega-3 and selenium contained in fish are proposed. Therefore, it is judged that the positive effects of such content in fish should be considered together, when the cardiovascular toxicity of methylmercury is analyzed.

### Human Epidemiological Studies of Methylmercury

Minamata disease and the Iraq grain contamination incident are the most famous environmental contamination incidents by food contaminated by methylmercury. They showed the extreme effects of acute and extensive exposure to methylmercury on humans. Three epidemiological studies to evaluate the effects of low concentration or medium concentration of methylmercury exposure on human bodies, the studies in the Faroe Islands, Seychelles, and New Zealand, are long-term observation studies regarding the health effects by fish intake under conditions without special contaminants.

In New Zealand in 1978, the first cohort study on pregnant women was performed. When analyzing the hair mercury concentration of 1000 pregnant women, 73 pregnant women were found to have a hair mercury concentration of more than 6 µg/g. In the follow up observation, children whose mothers' hair mercury concentration was 13 to 15 µg/g during pregnancy showed low intelligence. Although the contribution rate of methylmercury was low, there were significant effects according to the children's racial differences [16,38,39]. In the Faroe Island study, the pilot whale that residents frequently ate contained methylmercury at the level of 2 mg/kg. When tracing the birth cohort group in this area for 7 years, children whose mothers were exposed to mercury much showed disorders in concentration, memory, and speech capabilities [40]. In the preliminary study for the Seychelles study, the correlation between methylmercury exposure in prenatal life and neurotoxic anomalies was observed, but these were not interpreted as clear effects of mercury exposure. In the present study, the effects of methylmercury exposure on neurological,

cognitive, and behavioral disorders were not observed [17,19]. On the other hand, in the Faroe Islands and New Zealand studies, the correlation between neuropsychological effects and exposure dose was observed. In particular, the Faroe Island study evaluated the neurotoxicity of methylmercury exposure during the period of growth, and the New Zealand study provided information on how to establish a reduction plan to prevent children from methylmercury exposure from the perspective of public health. However, in the Faroe Islands study, simultaneous exposure to polychlorinated biphenyls and other materials as well as to mercury made the result controversial [15]. Furthermore, because the cultural differences between areas were not taken into account, for example, the intake of pilot whale on the Faroe Islands is very high although their fish intake is low, while residents in Seychelles eat fish nearly every day, reevaluation was performed in 2002 [17,19].

The study results in the Faroe Islands, Seychelles, and New Zealand were used in reevaluation of the hazardousness of mercury [26]. In the Seychelles study, the hair mercury concentration of mothers corresponding to no-observed-effect-level in the nervous tissues was identified and in the Faroe Islands and New Zealand studies, the results were used to fix a benchmark dose limit (BMDL) through mathematical analysis of the relationship between doses and symptoms [26]. However, in the New Zealand study, one of the 237 mothers showed 86 mg/kg of hair mercury concentration, which is nearly four times higher than the second highest mother. Accordingly, if this case is excluded, the BMDL is 7.4 to 10 mg/kg, but if this case is included, the BMDL becomes 17 to 24 mg/kg. As the inclusion of the case influences the BMDL too much, in the evaluation of data in the New Zealand study, the case was excluded. The study results in the Faroe Islands and Seychelles showed that the hair mercury concentration of the mother which did not cause any side effects in children was 14 mg/kg; the average of two experiments was used. In many studies, the hair and blood mercury concentration ratio was reported to be 140:370, and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) calculated the blood mercury concentration of 56 µg/L using the total average ratio (250) from the hair mercury concentration. Additionally, to convert the blood mercury concentration to daily intake, JECFA used a one-compartment model. It applied 0.014 day<sup>-1</sup> as the internal removal rate, 5.85 L as the blood volume, 0.95 as the internal absorption rate, 0.05 as the blood absorption rate, and 65 kg as the average weight. Daily ingestion calculated as such was 1.5 µg/

kg body weight per day. This value represents the maximum blood mercury concentration of the mother when there are no side effects at all. By applying an uncertainty factor of 6.4 against 1.5 µg/kg body weight per day, which is the calculated daily ingestion, the provisional tolerable weekly intake (PTWI) was reevaluated to be 1.6 µg/kg body weight per week [41,42].

In Korea, most studies on mercury in the human body have addressed blood mercury concentration, and epidemiological studies analyzing blood methylmercury concentration are very limited. The reasons are because blood mercury concentration has a significant correlation with methylmercury concentration, and because it is very difficult to measure methylmercury in the blood compared to total mercury in the blood. However, the toxic effects of mercury differ according to its properties and the ratio of methylmercury to total mercury varies according to the population and occupational exposure. Therefore, it is necessary to measure methylmercury in the blood directly and perform epidemiological investigations utilizing the measured value.

In Korea, an epidemiological study evaluating blood methylmercury was first performed on pregnant women. It is known that pregnant women are vulnerable to methylmercury exposure and a high blood mercury concentration in pregnant women may cause irreversible damage to children, including developmental disorders, by influencing the cerebral nerves of fetuses, although a small amount and low concentration of mercury does not cause any symptoms in mothers. Furthermore, that the mercury concentration of cord blood is higher than the blood mercury concentration of the pregnant woman [4], and that methylmercury concentration of cord blood is approximately two times higher than the blood methylmercury concentration of the mother is a very serious problem [43]. Lee et al. [44] observed that the average mercury concentration in cord blood was 1.72 times higher, at 5.43 ppb, than the average mercury concentration of maternal blood of 3.16 ppb in a study on 59 pregnant women. Additionally, the cord blood high risk group exceeding 5 µg/L of human biomonitoring I values (HBM-I) [45] was high, at 49.2%. Methylmercury was 85% of total mercury in maternal blood and 90.4% in cord blood. The correlation coefficient of total mercury and methylmercury was observed to be 0.937 and 0.978 in maternal blood and cord blood, respectively. The difference in the mercury concentration between the mother's blood and cord blood is because as the methylmercury moves through the human body by combining with hemoglobin and glutathione, fetuses

have higher hemoglobin values and because the half-life of methylmercury is long, it accumulates in the human body for a long period of time. Therefore, as the total mercury concentration of the mother increases, the blood mercury concentration of the newborn infant increases, which means an increasing possibility of neurological and developmental disorders because of mercury. You et al. [46] analyzed the blood concentration of total mercury and methylmercury in 400 residents in 30 areas of Busan, Ulsan and Gyeongsangnam-do province in Korea. They reported that the concentration of methylmercury was 4.05 µg/L, which was 78.53% of the total mercury concentration (5.27 µg/L), that males showed a higher methylmercury concentration than females, that the blood methylmercury concentration increased significantly as the total mercury concentration increased, and that the methylmercury concentration had a significant correlation with fish intake. In sum, methylmercury management is the most important strategy for reducing the blood mercury concentration, as it occupies the largest proportion of total mercury in blood.

In Korea, blood methylmercury has not been directly analyzed. Most of the studies have analyzed total mercury in the blood. They have been performed as nationwide exposure status surveys of the general public, high risk area surveys, and high risk subject surveys from the perspective of environmental health. Table 1 shows the results of a meta-analysis of blood mercury concentration of a survey of the general public in Korea from 2005 to 2010. The average blood mercury concentration in Korea was 3.80 µg/L, which is 4 to 7 times higher than in the USA (0.98 µg/L) and Germany (0.58 µg/L). It should be taken seriously that the high risk group, that is, those exceeding the standard of HBM-I (5 µg/L), make up approximately 40% of the total. Additionally, as there is no conspicuous reduction trend in the blood mercury concentration, the Ministry of Environment has prepared Comprehensive Mercury Countermeasures and has initiated an effort to reduce the high risk group to 15% by 2015. In addition, the Mothers and Children's Environmental Health Study on high risk groups such as pregnant women and infants [47] and the Children's Health and Environmental Research study on children and youths are being performed in Korea using a cohort research design. It is expected that they will be able to evaluate the health effects of low concentration methylmercury chronic exposure.

**Table 1.** Summary measures of blood mercury concentration in Koreans

Year	Survey	Sex	n	GM	95% LC	95% UC
2007	The second Korean National Human Exposure and Bio-monitoring Examination	Total	2276	3.8	3.66	3.93
		M	797	4.94	4.66	5.24
		F	1531	3.27	3.13	3.42
2008	The third Korean National Human Exposure and Bio-monitoring Examination	Total	5129	3	2.93	3.07
		M	1580	3.87	3.71	4.04
		F	3549	2.68	2.6	2.75
2009	Korea National Environmental Health Survey	Total	2102	3.93	3.85	4.02
2010	Korea National Environmental Health Survey	Total	2114	2.88	2.8	2.97
2005	Korea National Health and Nutritional Examination	Total	2000	4.34	4.21	4.48
		M	1001	5.01	4.8	5.22
		F	999	3.76	3.6	3.93
2008	Korea National Health and Nutritional Examination	Total	2006	4.71	4.6	4.83
		M	1000	5.55	5.37	5.75
		F	1006	4	3.88	4.13
2009	Korea National Health and Nutritional Examination	Total	1991	4.28	4.17	4.39
		M	995	5.17	4.98	5.37
		F	996	3.54	3.43	3.66
Pooled summary		Total	17 618	3.80	3.76	3.84
		M	5373	4.95	4.86	5.04
		F	8081	3.35	3.30	3.40

GM, geometric mean; LC, lower confidence; UC, upper confidence.

## CONCLUSION

Given that methylmercury can have various effects on human health, not only through high concentration acute exposure, but also by low concentration chronic exposure, more active management of mercury is required. The starting point of methylmercury exposure is inorganic mercury in the general environment. However, because food intake through the methylation process is the main exposure path, dietary management countermeasures are needed along with the effort to reduce mercury in the general environment.

As the long-term birth cohort tracing studies on low concentration chronic exposure to mercury in the Faroe Islands, Seychelles, and New Zealand where high fish intake exists without other forms of exposure to contaminants showed, children whose mother had a high mercury exposure were observed to have disorders in concentration, memory, and speech. However, because of the beneficial nutrients of fish and shellfish that accompany exposure to methylmercury's

toxicity, fish and shellfish intake recommendations should be developed more precisely through quantified evaluation of methylmercury instead of simply warning against ingesting fish and shellfish.

Major countries have established daily ingestion tolerances for mercury along with fish and shellfish intake recommendations. The US has prepared fish consumption advisories in 48 states and state governments have made proactive advertisements to their citizens. Japan investigated the mercury concentration of various fishes, prepared national fish intake recommendations to restrict the number of instances of intake and the volume of many species of predatory fish for pregnant women and fertile women, and advertised the recommendations through the mass media. On the other hand, Korea does not have recommended standards on much consumed sea fishes including tuna sashimi, presenting recommendations on freshwater fish only. Therefore, countermeasures are needed.

The CODEX Alimentarius concluded that embryos and fetuses are the most vulnerable to methylmercury exposure based on various study results. Therefore, it claimed that to reduce the methylmercury exposure level, it would be more important to have proactive communication on the hazardousness of mercury for the high risk group, in other words, fertile women or pregnant women, than setting general fish intake guidelines and communicating the hazard to the general public. In Korea, in a study on the total mercury concentration of the mother's blood and the cord blood of mothers registered in the mother cohort study from 2005 to 2010, it was observed that the increased total mercury concentration of cord blood would reduce the weight of a newborn. However, the information was not sufficient to reveal the precise relationship between them. Thus, a further long-term observational study is needed. Considering this, an effort should be made to reduce mercury concentration by preparing locally suitable fish and shellfish intake recommendations and enforcing the advertisement of the hazardousness of mercury to prevent incidents in advance. Thus, to minimize health damage by low concentration methylmercury chronic exposure, a national environmental health policy is needed so that related authorities such as the Ministry of Environment, Korean Food and Drug Administration, Ministry of Health and Welfare, and Ministry of Agriculture, Fisheries and Food can collaborate to prepare countermeasures and enforce them.

## ACKNOWLEDGEMENTS

This research was supported by a grant (10162KFDA994) from Korea Food and Drug Administration in 2012.

## CONFLICT OF INTEREST

The authors have no conflicts of interest with the material presented in this paper.

## REFERENCES

1. US Environmental Protection Agency. Mercury study report to Congress [cited 2012 Oct 2]. Available from: <http://www.epa.gov/hg/report.htm>.
2. Mahaffey KR, Clickner RP, Bodurow CC. Blood organic mercury and dietary mercury intake: National Health and Nutrition Examination Survey, 1999 and 2000. *Environ Health Perspect* 2004;112(5):562-570.
3. Fuyuta M, Fujimoto T, Hirata S. Embryotoxic effects of methylmercuric chloride administered to mice and rats during organogenesis. *Teratology* 1978;18(3):353-366.
4. Tsuchiya H, Mitani K, Kodama K, Nakata T. Placental transfer of heavy metals in normal pregnant Japanese women. *Arch Environ Health* 1984;39(1):11-17.
5. Agency for Toxic Substances and Disease Registry. Toxicological profile for mercury [cited 2012 Oct 2]. Available from: <http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=115&tid=24>.
6. International Program on Chemical Safety. Environmental methylmercury: health criteria 101. Geneva: World Health Organization; 1990 [cited 2012 Oct 2]. Available from: <http://www.inchem.org/documents/ehc/ehc/ehc101.htm>.
7. Grandjean P, White RF, Weihe P, Jørgensen PJ. Neurotoxic risk caused by stable and variable exposure to methylmercury from seafood. *Ambul Pediatr* 2003;3(1):18-23.
8. Hughes WL. A physicochemical rationale for the biological activity of mercury and its compounds. *Ann N Y Acad Sci* 1957; 65(5):454-460.
9. Kim DS, Kim GB, Park KH, Kang TS, Lee JH, Nam SH, et al. A study on exposure and health effect of mercury (II). Incheon: National Institute of Environmental Research; 2006, p. 1-115 (Korean).
10. Abernethy DR, Destefano AJ, Cecil TL, Zaidi K, Williams RL; USP Metal Impurities Advisory Panel. Metal impurities in food and drugs. *Pharm Res* 2010;27(5):750-755.
11. Lee C, Cho SD, Chang DS, Shin DH, Oh DH, Whang I, et al. Food safety guidelines for consumer. *Safe Food* 2006;1(4):31-43 (Korean).
12. World Health Organization. Safety evaluation of certain food additives and contaminants: methylmercury [cited 2012 Oct 2]. Available from: [http://whqlibdoc.who.int/publications/2011/9789241660648\\_eng.pdf](http://whqlibdoc.who.int/publications/2011/9789241660648_eng.pdf).
13. Korea Food and Drug Administration. Hazardous substances-21 series: what is methylmercury in food? Seoul: Korea Food and Drug Administration; 2007, p. 1-68 (Korean).
14. Sager PR, Matheson DW. Mechanisms of neurotoxicity related to selective disruption of microtubules and intermediate filaments. *Toxicology* 1988;49(2-3):479-492.
15. Grandjean P, Weihe P, White RF, Debes F, Araki S, Yokoyama K, et al. Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. *Neurotoxicol Teratol* 1997;19(6): 417-428.
16. Crump KS, Kjellström T, Shipp AM, Silvers A, Stewart A. Influence of prenatal mercury exposure upon scholastic and psychological test performance: benchmark analysis of a New Zealand cohort. *Risk Anal* 1998;18(6):701-713.
17. Myers GJ, Davidson PW, Cox C, Shamlaye CF, Palumbo D, Cernichiari E, et al. Prenatal methylmercury exposure from ocean fish consumption in the Seychelles child development study. *Lancet* 2003;361(9370):1686-1692.
18. Debes F, Budtz-Jørgensen E, Weihe P, White RF, Grandjean P. Impact of prenatal methylmercury exposure on neurobehavioral function at age 14 years. *Neurotoxicol Teratol* 2006;28(3): 363-375.
19. Myers GJ, Thurston SW, Pearson AT, Davidson PW, Cox C, Shamlaye CF, et al. Postnatal exposure to methyl mercury from fish consumption: a review and new data from the Seychelles Child Development Study. *Neurotoxicology* 2009;30(3):338-349.
20. Ha M, Kwon HJ, Lim MH, Jee YK, Hong YC, Leem JH, et al. Low blood levels of lead and mercury and symptoms of attention deficit hyperactivity in children: a report of the children's health and environment research (CHEER). *Neurotoxicology* 2009; 30(1):31-36.
21. Cheuk DK, Wong V. Attention-deficit hyperactivity disorder and blood mercury level: a case-control study in Chinese children. *Neuropediatrics* 2006;37(4):234-240.
22. Torrente M, Colomina MT, Domingo JL. Metal concentrations in hair and cognitive assessment in an adolescent population. *Biol Trace Elem Res* 2005;104(3):215-221.
23. National Research Council. Toxicological effects of methylmer-

- cury [cited 2012 Oct 2]. Available from: [http://www.nap.edu/openbook.php?record\\_id=9899&page=147/](http://www.nap.edu/openbook.php?record_id=9899&page=147/).
24. Environmental Protection Agency. Methylmercury (MeHg) (CASRN 22967-92-6); 2009 [cited 2012 Nov 8]. Available from: <http://www.epa.gov/iris/subst/0073.htm>.
  25. Spyker DA, Spyker JM. Response model analysis for cross-fostering studies: prenatal versus postnatal effects on offspring exposed to methylmercury dicyandiamide. *Toxicol Appl Pharmacol* 1977;40(3):511-527.
  26. World Health Organization. Evaluation of certain food additives and contaminants: sixty-first report of the joint FAO/WHO Expert Committee on Food Additives [cited 2012 Oct 2]. Available from: [http://whqlibdoc.who.int/trs/WHO\\_TRS\\_922.pdf](http://whqlibdoc.who.int/trs/WHO_TRS_922.pdf).
  27. Crompton P, Ventura AM, de Souza JM, Santos E, Strickland GT, Silbergeld E. Assessment of mercury exposure and malaria in a Brazilian Amazon riverine community. *Environ Res* 2002;90(2):69-75.
  28. Gardner RM, Nyland JF, Silva IA, Ventura AM, de Souza JM, Silbergeld EK. Mercury exposure, serum antinuclear/antinuclear antibodies, and serum cytokine levels in mining populations in Amazonian Brazil: a cross-sectional study. *Environ Res* 2010;110(4):345-354.
  29. Park H, Kim K. Association of blood mercury concentrations with atopic dermatitis in adults: a population-based study in Korea. *Environ Res* 2011;111(4):573-578.
  30. Beryllium, cadmium, mercury, and exposures in the glass manufacturing industry. Working Group views and expert opinions. Lyon, 9-16 February 1993. *IARC Monogr Eval Carcinog Risks Hum* 1993;58:1-415.
  31. Salonen JT, Seppänen K, Nyyssönen K, Korpela H, Kauhanen J, Kantola M, et al. Intake of mercury from fish, lipid peroxidation, and the risk of myocardial infarction and coronary, cardiovascular, and any death in eastern Finnish men. *Circulation* 1995;91(3):645-655.
  32. Virtanen JK, Voutilainen S, Rissanen TH, Mursu J, Tuomainen TP, Korhonen MJ, et al. Mercury, fish oils, and risk of acute coronary events and cardiovascular disease, coronary heart disease, and all-cause mortality in men in eastern Finland. *Arterioscler Thromb Vasc Biol* 2005;25(1):228-233.
  33. Sørensen N, Murata K, Budtz-Jørgensen E, Weihe P, Grandjean P. Prenatal methylmercury exposure as a cardiovascular risk factor at seven years of age. *Epidemiology* 1999;10(4):370-375.
  34. Grandjean P, Murata K, Budtz-Jørgensen E, Weihe P. Cardiac autonomic activity in methylmercury neurotoxicity: 14-year follow-up of a Faroese birth cohort. *J Pediatr* 2004;144(2):169-176.
  35. Rissanen T, Voutilainen S, Nyyssönen K, Lakka TA, Salonen JT. Fish oil-derived fatty acids, docosahexaenoic acid and docosapentaenoic acid, and the risk of acute coronary events: the Kuopio ischaemic heart disease risk factor study. *Circulation* 2000;102(22):2677-2679.
  36. Kim DS, Lee EH, Yu SD, Cha JH, Ahn SC. Heavy metal as risk factor of cardiovascular disease: an analysis of blood lead and urinary mercury. *J Prev Med Public Health* 2005;38(4):401-407 (Korean).
  37. Lim S, Choi MC, Joh KO, Paek D. The health effects of mercury on the cardiac autonomic activity according to the heart rate variability. *Korean J Occup Environ Med* 2008;20(4):302-313 (Korean).
  38. Kjellstrom T, Kennedy P, Wallis S, Stewart A, Friberg L, Lind B, et al. Physical and mental development of children with prenatal exposure to mercury from fish: stage 2, interviews and psychological tests at age 6. Solna, Sweden: National Swedish Environmental Protection Board; 1989, p. 1-112.
  39. Choi AL, Grandjean P. Methylmercury exposure and health effects on humans. *Environ Chem* 2008;5:112-120.
  40. Steuerwald U, Weihe P, Jørgensen PJ, Bjerve K, Brock J, Heinzow B, et al. Maternal seafood diet, methylmercury exposure, and neonatal neurologic function. *J Pediatr* 2000;136(5):599-605.
  41. Food Safety Commission of Japan. Food safety risk assessment related to methylmercury in seafood; 2005 [cited 2012 Nov 8]. Available from: [http://www.fsc.go.jp/english/topics/methylmercury\\_e1.html](http://www.fsc.go.jp/english/topics/methylmercury_e1.html) (Japanese).
  42. United Nations Environment Programme; World Health Organization; Inter-Organization Programme for the Sound Management of Chemicals. Guidance for identifying populations at risk from mercury exposure [cited 2012 Oct 2]. Available from: <http://www.who.int/foodsafety/publications/chem/mercuryexposure.pdf>.
  43. Vahter M, Akesson A, Lind B, Björs U, Schütz A, Berglund M. Longitudinal study of methylmercury and inorganic mercury in blood and urine of pregnant and lactating women, as well as in umbilical cord blood. *Environ Res* 2000;84(2):186-194.
  44. Lee KE, Hong YS, Kim DS, Han MS, Yu BC, Kim YW, et al. Mercury concentrations of maternal and umbilical cord blood in Korean pregnant women: preliminary study. *Korean J Occup Environ Med* 2007;19(4):268-275 (Korean).
  45. Umwelt Bundes Amt. Health and environmental hygiene: German Environmental Survey 1998 (GerES III); 2005 [cited 2012 Nov 8]. Available from: <http://www.umweltbundesamt.de/>

- gesundheit-e/survey/us98/uprog.htm.
46. You CH, Kim BG, Jo EM, Kim GY, Yu BC, Hong MG, et al. The relationship between the fish consumption and blood total/methyl-mercury concentration of costal area in Korea. *Neurotoxicology* 2012;33(4):676-682.
47. Kim BM, Ha M, Park HS, Lee BE, Kim YJ, Hong YC, et al. The Mothers and Children's Environmental Health (MOCEH) study. *Eur J Epidemiol* 2009;24(9):573-583.

**EXHIBIT 25**

# Reservoirs are a major source of global greenhouse gases, scientists say

---

By **Chris Mooney** September 28, 2016

Countries around the world are trying to get their greenhouse gas emissions under control — to see them inch down, percentage point by percentage point, from where they stood earlier in the century. If everybody gets on board, and shaves off enough of those percentage points, we just might be able to get on a trajectory to keep the world from warming more than 2 degrees Celsius above the temperature where it stood prior to industrialization.

But if a new study is correct, there's a big problem: There might be more greenhouse gases going into the atmosphere than we thought. That would mean an even larger need to cut.

The new paper, slated to be published next week in *BioScience*, confirms a significant volume of greenhouse gas emissions coming from a little-considered place: Man-made reservoirs, held behind some 1 million dams around the world and created for the purposes of electricity generation, irrigation, and other human needs. In the study, 10 authors from U.S., Canadian, Chinese, Brazilian, and Dutch universities and institutions have synthesized a considerable body of prior research on the subject to conclude that these reservoirs may be emitting just shy of a gigaton, or billion tons, of annual carbon dioxide equivalents. That would mean they contributed 1.3 percent of the global total.

Moreover, the emissions are largely in the form of methane, a greenhouse gas with a relatively short life in the atmosphere but a very strong short-term warming effect. Scientists are increasingly finding that although we have begun to curb some emissions of carbon dioxide, the principal greenhouse gas, we are still thwarted by methane, which comes from a diversity of sources that range from oil and gas operations to cows.

The new research concludes that methane accounted for 79 percent of carbon dioxide equivalent emissions from reservoirs, while the other two greenhouse gases, carbon dioxide and nitrous oxide, accounted for 17 percent and 4 percent.

“There's been kind of an explosion in research into efforts to estimate emissions from reservoirs,” said Bridget Deemer, the study's first author and a researcher with Washington State University. “So we synthesized all known estimates from reservoirs globally, for hydropower and other functions, like flood control and irrigation.”

“And we found that the estimates of methane emissions per area of reservoir are about 25 percent higher than previously thought, which we think is significant given the global boom in dam construction, which is currently underway,” she continued.

As Deemer’s words suggest, the study does not single out dams used to generate electricity — it focuses on all reservoirs, including those that are created for other purposes. It drew on studies on 267 reservoirs around the world, which together have a surface area of close to 30,000 square miles, to extrapolate global data.

Reservoirs are a classic instance of how major human alteration’s to the Earth’s landscape can have unexpected effects. Flooding large areas of Earth can set off new chemical processes as tiny microorganisms break down organic matter in the water, sometimes doing so in the absence of oxygen — a process that leads to methane as a byproduct. One reason this happens is that the flooded areas initially contain lots of organic life in the form of trees and grasses.

Meanwhile, as nutrients like nitrogen and phosphorus flow into reservoirs from rivers — being poured in by human agriculture and waste streams — these can further drive algal growth in reservoirs, giving microorganisms even more material to break down. The study finds that for these reasons, reservoirs emit more methane than “natural lakes, ponds, rivers, or wetlands.”

“If oxygen is around, then methane gets converted back to CO<sub>2</sub>,” said John Harrison, another of the study’s authors, and also a researcher at Washington State. “If oxygen isn’t present, it can get emitted back to the atmosphere as methane.” And flooded areas, he said, are more likely to be depleted of oxygen. A similar process occurs in rice paddies, which are also a major source of methane emissions.

In fact, Harrison said that based on the new study, it appears that reservoir emissions and rice paddy emissions are of about the same magnitude on a global scale — but rice paddy emissions have been taken into account for some time. Reservoir emissions often have not.

“There are inventory compilers in each country that are responsible for compiling information about greenhouse gases to the atmosphere,” Harrison explained. “The [United Nations’ Intergovernmental Panel on Climate Change] writes the guidance, the cookbook that’s supposed to be used by these inventory compilers, and that guidance currently includes reservoirs only as an appendix, not an official part of any nation’s inventory. But that is likely to change as those guidelines get revised over the next two years.”

The research, said Deemer, complicates the idea that hydropower is a carbon-neutral source of energy, although she stresses that the authors aren’t saying that they’re against using large bodies of water to generate energy through dams. Rather, they’re arguing that the greenhouse gas calculus has to be included in evaluating such projects.

This problem is not an entirely new one: A major 2000 study in BioScience raised this issue, and the International Hydropower Association on its website [acknowledges](#) that “While hydropower is a very low-carbon technology, it is known

that some reservoirs in certain conditions can release quantities of methane, a greenhouse gas. Reservoirs can also, in other circumstances, act as carbon sinks.”

But what is new about the current study is its synthesis of a large number of studies since 2000, and the determination that these emissions add up to something that is big enough to be taken seriously as part of the global carbon budget. It also finds that while some reservoirs are indeed “sinks” for carbon dioxide or nitrous oxide — meaning, they take up more of these gases than they emit — that was not true for methane.

---

**Energy and Environment newsletter**[Sign up](#)

The science and policy of environmental issues.

---

The authors acknowledge the study does not represent a full “life cycle analysis” of reservoirs, taking into account how much carbon was stored (or emitted from) lands prior to their being flooded, and also what happens after reservoirs are decommissioned. Nor does it attempt to weigh the methane emissions from reservoirs used to generate hydropower against the amount of greenhouse gas emissions that would presumably be created if that electricity was instead generated by burning coal or natural gas.

But it clearly suggests a need to take these emissions seriously, and conduct further research.

“We’re trying to provide policymakers and the public with a more complete picture of the consequences of damming a river,” said Harrison.

*Correction: A prior title of this article suggested that methane emissions from reservoirs are a “key new source of greenhouse gases.” In fact, scientific budgets of global methane emissions have included reservoir emissions in the category of lakes and rivers, according to Harrison. The new research, however, does suggest that reservoir emissions may have been underestimated in such budgets.*

**Read more at Energy & Environment:**

[The Arctic is being utterly transformed — and we’re just beginning to grasp the consequences](#)

[Scientists may have solved a key riddle about Antarctica — and you’re not going to like the answer](#)

[The Pacific ‘blob’ caused an ‘unprecedented’ toxic algal bloom — and there’s more to come](#)

*For more, you can sign up for our weekly newsletter [here](#), and follow us on Twitter [here](#).*

# Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis

BRIDGET R. DEEMER, JOHN A. HARRISON, SIYUE LI, JAKE J. BEAULIEU, TONYA DELSONTRO, NATHAN BARROS, JOSÉ F. BEZERRA-NETO, STEPHEN M. POWERS, MARCO A. DOS SANTOS, AND J. ARIE VONK

*Collectively, reservoirs created by dams are thought to be an important source of greenhouse gases (GHGs) to the atmosphere. So far, efforts to quantify, model, and manage these emissions have been limited by data availability and inconsistencies in methodological approach. Here, we synthesize reservoir CH<sub>4</sub>, CO<sub>2</sub>, and N<sub>2</sub>O emission data with three main objectives: (1) to generate a global estimate of GHG emissions from reservoirs, (2) to identify the best predictors of these emissions, and (3) to consider the effect of methodology on emission estimates. We estimate that GHG emissions from reservoir water surfaces account for 0.8 (0.5–1.2) Pg CO<sub>2</sub> equivalents per year, with the majority of this forcing due to CH<sub>4</sub>. We then discuss the potential for several alternative pathways such as dam degassing and downstream emissions to contribute significantly to overall emissions. Although prior studies have linked reservoir GHG emissions to reservoir age and latitude, we find that factors related to reservoir productivity are better predictors of emission.*

*Keywords: reservoir, methane, greenhouse gas, eutrophication, ebullition*

## The construction and operation of over 1 million dams

globally (Lehner et al. 2011) has provided a variety of services important to a growing human population (e.g., hydropower, flood control, navigation, and water supply), but has also significantly altered water, nutrient, and ecosystem dynamics and fluxes in river networks. Much attention has been paid to negative impacts of dams on fish and other riverine biota, but the indirect effects on biogeochemical cycling are also important to consider. Although reservoirs are often thought of as “green” or carbon-neutral sources of energy, a growing body of work has documented their role as greenhouse gas (GHG) sources. Artificial reservoirs created by dams are distinct from natural systems in a number of key ways that may enhance GHG emissions from these systems. First, the flooding of large stocks of terrestrial organic matter may fuel microbial decomposition, converting the organic matter stored in above and below ground biomass to carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). Second, reservoirs often experience greater fluctuations in water level than natural lakes. Drops in hydrostatic pressure during water level drawdowns can enhance CH<sub>4</sub> bubbling (e.g., ebullition) rates at least over the short term (Maeck et al. 2014). This enhanced ebullition may then decrease the fraction of CH<sub>4</sub> that is oxidized to CO<sub>2</sub>, a less potent GHG,

by methane oxidizing microbes (Kiene 1991). Finally, the high catchment area-to-surface area ratios and close proximity to human activities (Thornton et al. 1990) characteristic of many reservoirs are likely to increase the delivery of organic matter and nutrients from land to water (relative to natural lakes), potentially fueling additional decomposition.

St. Louis and colleagues (2000) raised the possibility that reservoir GHG emissions contribute significantly to global budgets (table 1). Since that influential review appeared, and in part because of the attention it generated, researchers have quantified GHG fluxes from more than 200 additional reservoirs, and have synthesized regional emissions (Demarty and Bastien 2011, Li et al. 2015) and emissions from particular types of reservoirs (i.e., hydroelectric; Barros et al. 2011, Hertwich 2013) paving the way for a new synthesis of global reservoir GHG emissions. In the sections that follow, we revisit the global magnitude and controls on reservoir GHGs presented by St. Louis and colleagues (2000). This includes (a) explicit incorporation of reservoir CH<sub>4</sub> ebullition measurements, (b) updated global estimates of the magnitude of GHG emissions from reservoir water surfaces including the first global estimates of reservoir N<sub>2</sub>O emissions, (c) a discussion of the environmental controls on CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions

BioScience 66: 949–964. © The Author(s) 2016. Published by Oxford University Press on behalf of the American Institute of Biological Sciences. This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact [journals.permissions@oup.com](mailto:journals.permissions@oup.com)  
doi:10.1093/biosci/biw117

Advance Access publication 5 October 2016

**Table 1. The global surface area and GHG flux estimates from reservoirs compared with those of other freshwater ecosystems and other anthropogenic activities.**

System Type	Surface Area (x 10 <sup>6</sup> km <sup>2</sup> )	Annual teragrams (Tg) C or N (Tg per year)			Areal Rates (milligrams per square meter per day)			Annual CO <sub>2</sub> Equivalents (Tg CO <sub>2</sub> Eq per year)			
		CH <sub>4</sub> -C	CO <sub>2</sub> -C	N <sub>2</sub> O-N	CH <sub>4</sub> -C	CO <sub>2</sub> -C	N <sub>2</sub> O-N	CH <sub>4</sub>	CO <sub>2</sub>	N <sub>2</sub> O	Total
All Reservoirs (This Study)	0.31 <sup>a</sup>	13.3	36.8	0.03	120	330	0.30	606.5	134.9	31.7	773.1
All Reservoirs (Other Work)	0.51–1.5 <sup>b,c</sup>	15–52.5 <sup>b,d</sup>	272.7 <sup>b</sup>	–	82–96	498	–	680–2380	1000	–	–
Hydroelectric Reservoirs	0.34 <sup>e</sup>	3–14 <sup>e,f</sup>	48–82 <sup>e,f</sup>	–	24–112	386–660	–	136–635	176–301	–	–
Lakes	3.7–4.5 <sup>e,g,h</sup>	53.7 <sup>d</sup>	292 <sup>e</sup>	–	40	216	–	2434	1071	–	–
Ponds	0.15–0.86 <sup>i</sup>	12 <sup>i</sup>	571 <sup>i</sup>	–	27 <sup>i</sup>	422 <sup>i</sup>	–	544	2094	–	–
Rivers	0.36–0.65 <sup>d,g</sup>	1.1–20.1 <sup>d,j</sup>	1800 <sup>g</sup>	–	6–98 <sup>j</sup>	7954	–	50–911	6600	–	–
Wetlands	8.6–26.9 <sup>k</sup>	106–198 <sup>k</sup>	–	0.97 <sup>l</sup>	15–63 <sup>k</sup>	–	0.1–0.31	4805–8976	–	908	–
Other Anthropogenic Emissions (2000s)	N.A.	248 <sup>m</sup>	9200 <sup>m</sup>	6.9 <sup>m</sup>	–	–	–	11243	33733	6462	51438

Note: The values presented are mean estimates; the ranges of mean values are reported when there are multiple relevant models. In cases in which the areal rates are not referenced, they were derived from dividing annual teragrams (Tg) of C or N by the global surface-area estimate. The annual CO<sub>2</sub> equivalents were calculated by multiplying the mass-based flux (in units of Tg CH<sub>4</sub>, CO<sub>2</sub> or N<sub>2</sub>O per year) by the 100-year global warming potential of each gas (1 for CO<sub>2</sub>, 34 for CH<sub>4</sub> and 298 for N<sub>2</sub>O). <sup>a</sup> (Lehner et al. 2011), <sup>b</sup> (St. Louis et al. 2000), <sup>c</sup> (Downing and Duarte 2009), <sup>d</sup> (Bastviken et al. 2011), <sup>e</sup> (Barros et al. 2011), <sup>f</sup> (Li and Zhang 2014), <sup>g</sup> (Raymond et al. 2013), <sup>h</sup> (Verpoorter et al. 2014), <sup>i</sup> (Holgerson and Raymond 2016), <sup>j</sup> (Stanley et al. 2016), <sup>k</sup> (Melton et al. 2013), <sup>l</sup> (Tian et al. 2015), <sup>m</sup> (Ciais et al. 2013).

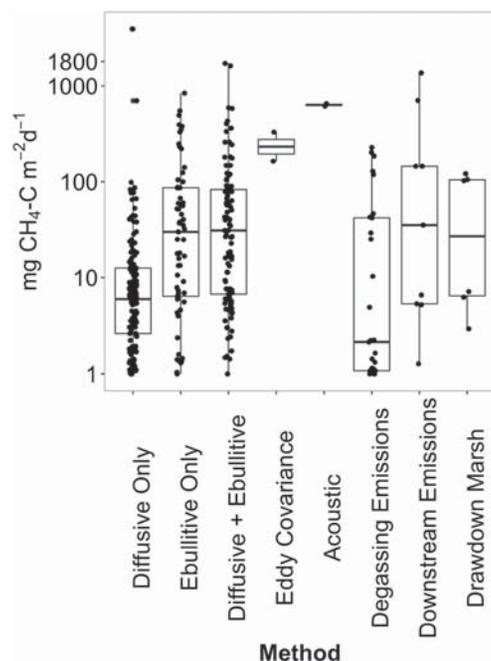
from reservoir water surfaces, (d) a discussion of the policy implications of these new findings, and (e) recommendations regarding fruitful avenues for future research. Although this synthesis focuses on GHG emissions from reservoir water surfaces, we also describe and discuss several important alternative pathways that can contribute significantly to reservoir GHG budgets (figure 1, supplemental table S1). Given the limited number of studies characterizing these pathways, we do not include them in this global analysis, but stress the need for additional study and eventual incorporation of relevant sources in future global analyses. Finally, we stress that the GHG emissions from reservoir water surfaces synthesized here represent gross fluxes such that CO<sub>2</sub> and CH<sub>4</sub> emissions should be considered alongside estimates of reservoir carbon burial for the purposes of carbon budgeting exercises.

From a GHG-management perspective, it is crucial to understand the relative role of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions as CH<sub>4</sub> and N<sub>2</sub>O are more powerful GHGs than CO<sub>2</sub> (34 and 298 times the global warming potential on a 100-year timescale, respectively; Myhre et al. 2013). To describe the relative contribution of various GHG emissions to global warming, emissions were converted to CO<sub>2</sub> equivalents, a metric that relates the radiative forcing caused by 1 mass unit of trace GHG to that caused by the emission of 1 mass unit of CO<sub>2</sub> over a given time span. Although CH<sub>4</sub> emissions from reservoirs have been implicated as a particularly important source of CO<sub>2</sub> equivalents (Giles 2006), constraining and modeling these fluxes is complicated by the fact that common methodological approaches, which

are effective for CO<sub>2</sub> and N<sub>2</sub>O emissions, do not capture an important fraction of overall CH<sub>4</sub> flux: bubble-based (ebullitive) CH<sub>4</sub> emissions. Our synthesis confirms that CH<sub>4</sub> emissions are responsible for the majority of the radiative forcing from reservoir water surfaces (approximately 80% over the 100-year timescale and 90% over the arguably more policy-relevant 20-year timescale) and that modeling approaches that ignore ebullitive CH<sub>4</sub> flux may fail to accurately quantify the magnitude of fluxes. We find that more productive, nutrient-rich reservoirs tend to emit more CH<sub>4</sub> than their less productive, nutrient-poor counterparts. Our global estimates support previous assertions (e.g., St. Louis et al. 2000) that GHG fluxes from reservoirs are globally important (approximately 1.3% of anthropogenic CO<sub>2</sub> equivalent emissions over the 100-year timespan), with CH<sub>4</sub> emissions from reservoir water surfaces comparable to those from rice paddies or from biomass burning. Therefore, we suggest the utility of incorporating reservoir CH<sub>4</sub> emissions into Intergovernmental Panel on Climate Change (IPCC) budgets.

#### Why methods matter

Aquatic GHG fluxes are measured using a variety of techniques (e.g., floating chambers, thin boundary methods, eddy covariance towers, acoustic methods, and funnels; supplemental figure S1) that provide varying degrees of spatial and temporal coverage and accuracy (St. Louis et al. 2000). Many commonly employed techniques for measuring aquatic GHG emissions focus on quantifying the diffusive flux of gases across the air–water interface. For CO<sub>2</sub> and N<sub>2</sub>O, which are



**Figure 1.** Areal  $\text{CH}_4$  fluxes associated with reservoir: diffusive-only fluxes (via thin boundary layer and floating chamber with  $R^2$  cutoff values  $> 0.85$ ,  $n = 151$ ), ebullitive-only fluxes (via funnels and floating chamber by subtraction,  $n = 58$ ), diffusive + ebullitive fluxes (via traditional methods  $n = 89$ ), total  $\text{CH}_4$  emission via eddy covariance ( $n = 2$ ), ebullitive emissions via acoustic measurements ( $n = 2$ ), degassing emissions ( $n = 22$ ), downstream emissions ( $n = 6$ ), and drawdown marsh fluxes ( $n = 6$ , 5 from Three Gorges Reservoir). Each dot represents the mean flux from a single published paper. The lines within the boxes indicate median fluxes. The boxes demarcate the twenty-fifth and seventy-fifth percentiles; the whiskers demarcate the 95% confidence intervals.

quite soluble in water (mole fraction solubility of  $7.07 \times 10^{-4}$  and  $5.07 \times 10^{-4}$  respectively at  $20^\circ\text{C}$ ), this is the dominant flux pathway, moving gasses to the atmosphere across the air–water interface. In contrast,  $\text{CH}_4$  is relatively insoluble in water (mole fraction solubility of  $2.81 \times 10^{-5}$  at  $20^\circ\text{C}$ ), and is often emitted in the form of bubbles that rise directly from the sediments (Kiene 1991, Bastviken et al. 2004). Several common measurement methods do not capture ebullition (e.g., combining estimates of air–water gas exchange with measurements of dissolved GHG concentrations), whereas others may exclude ebullition events because they interfere with the linear accumulation of  $\text{CH}_4$  within a sampling chamber (e.g., floating chambers; supplemental figure S2).

A second important challenge for accurate measurements of aquatic  $\text{CH}_4$  ebullition is that fluxes are often highly variable in both time and space (Wik et al. 2016). Ebullition is most commonly measured using inverted funnel traps, which float beneath the surface of the water and capture bubbles as they rise through the water column. These funnel traps are typically deployed for relatively short periods of time (minutes to hours) in a relatively small number of locations (generally fewer than 10 sites per reservoir), making it difficult to capture the spatial and temporal variability of fluxes (see the Hot Spots and Hot Moments section below).

Several recent method developments improve the spatial and/or temporal resolution of  $\text{CH}_4$  ebullition measurements in lakes and reservoirs. Modified funnel trap designs can support longer-term, temporally resolved data by (a) incorporating an airtight housing equipped with a differential pressure sensor or optical bubble size sensor for automated, high temporal resolution measurements of ebullition fluxes (Varadharajan et al. 2010, Delwiche et al. 2015), and (b) installing an electronic unit to empty the trap once it reaches full capacity so that traps don't fill faster than they can be sampled (cited in Maeck et al. 2014). Acoustic techniques can support higher spatial and temporal resolution ebullition measurements without the cumbersome and invasive field deployments associated with funnel traps. Following calibration of acoustic signal with bubble size (Ostrovsky et al. 2008), an echosounder can be mounted to a boat to estimate ebullition flux at a greater spatial resolution, or mounted to a stationary object for greater temporal resolution. Repeat daily or subdaily echosounder surveys provide a much higher degree of spatiotemporal coverage than that achieved via traditional methods, allowing for more accurate ebullitive flux estimates in survey zones (DelSontro et al. 2015). Still, echosounders are only effective within a certain depth range that depends on transducer frequency, beam angle, and survey boat speed (but generally ranges from 1 to 100 meters), provide no information about bubble  $\text{CH}_4$  concentrations without ancillary measurements, and can also be cost prohibitive and challenging to calibrate (Ostrovsky et al. 2008, DelSontro et al. 2015). Eddy covariance techniques, which calculate GHG fluxes on the basis of mean air density and instantaneous deviations in vertical wind speed and gas concentrations, can also overcome some of the difficulty of capturing spatially and temporally variable emissions although they cannot zero in on hot spots for release unless combined with other methods. Currently, the use of eddy covariance systems over lakes and reservoirs is relatively new and poses several challenges. These challenges include (a) high instrument cost, (b) poor sensor performance during wet conditions, and (c) difficulty associated with estimating measurement footprints, especially in small, heterogeneous areas (Fassbinder et al. 2013, Peltola et al. 2013).

Of the studies compiled here, ebullition was measured in only 52% of cases in which reservoir  $\text{CH}_4$  emissions were reported (figure 1). In the majority of cases, ebullition was measured with funnels or was lumped with diffusive flux via

floating chamber measurements; however, in two studies, researchers estimated methane fluxes via eddy covariance (Eugster et al. 2011, Deshmukh et al. 2014), and in another two studies, researchers estimated ebullitive flux via acoustic methods (DelSontro et al. 2011, 2015). Mean ebullition + diffusion fluxes were over double that of diffusion-only fluxes (103 versus 43 mg CH<sub>4</sub>-C per square meter, m<sup>2</sup>, per day) and CH<sub>4</sub> fluxes varied significantly on the basis of whether or not ebullition was included (Kruskal Wallis test,  $\chi^2 = 52.7, p < .001$ ; figure 1, supplemental table S2). On average ebullition contributed 65% of total diffusive + ebullitive flux ( $n = 56$ , standard deviation [SD] = 33.5). This is consistent with natural lakes where between 40% and 60% of CH<sub>4</sub> flux generally occurs via ebullition (Bastviken et al. 2004). The relative contribution of CH<sub>4</sub> ebullition to overall CH<sub>4</sub> flux was also highly variable, constituting anywhere from 0% to 99.6% of total CH<sub>4</sub> flux. This highlights how crucial it is to measure both types of CH<sub>4</sub> emission in order to estimate the total flux from reservoir surface waters. Although we did not explicitly address the temporal or spatial resolution of emission data from each system, it is notable that the few published acoustic and eddy covariance-based reservoir CH<sub>4</sub> flux estimates are quite high compared to the median CH<sub>4</sub> flux estimates from less temporally and/or spatially integrated measurement techniques (figure 1). Given the importance of CH<sub>4</sub> ebullition to overall CH<sub>4</sub> fluxes, we only use CH<sub>4</sub> emission estimates that incorporate both ebullition and diffusion in further sections of this article (i.e., to estimate the magnitude and controls on fluxes).

As with CH<sub>4</sub>, many studies of CO<sub>2</sub> and N<sub>2</sub>O emissions from reservoir water surfaces also suffer from low spatial and temporal resolution (therefore reducing the accuracy of emission estimates). Of the GHG estimates synthesized here, less than 25%, 3%, and 26% of temperate reservoir CH<sub>4</sub>, CO<sub>2</sub>, and N<sub>2</sub>O emission estimates covered 6 months or more of the year. The majority of studies also had fewer than 10 sampling sites and measured fluxes over short periods of time (minutes to hours), often neglecting night sampling in favor of daytime measurements. A more extensive characterization of the spatial and temporal resolution of reservoir GHG sampling was beyond the scope of this analysis, but the role of sampling bias in upscaling efforts is discussed further below (see the section on Hot Spots and Hot Moments).

#### Patterns in areal fluxes

In total, we assembled areal CH<sub>4</sub>, CO<sub>2</sub>, and N<sub>2</sub>O flux estimates from 161, 229, and 58 systems respectively, although only 75 reservoirs with CH<sub>4</sub> data met the methodological criteria for inclusion in our analyses (figure 2). In contrast to other recent reservoir GHG syntheses (Barros et al. 2011, Demarty and Bastien 2011, Hertwich 2013, Li et al. 2015), we include both hydroelectric and nonhydroelectric systems such as those used for flood control, irrigation, navigation, or recreation. Whereas previous synthesis efforts have lacked measurements from temperate and subtropical systems, our data set addresses this gap by including a number of recent GHG flux

estimates from US, European, Australian, and Asian temperate and subtropical reservoirs (figure 2, table 2). This is important given a large number of dams that are either planned or under construction in temperate and subtropical zones (Zarfl et al. 2015). Several alternative flux pathways were not included in the areal flux estimates or the regression analysis, but are reported when available (see supplemental discussion and the Alternative Flux Pathways section below).

Here, we report mean areal (per unit surface area) CH<sub>4</sub> fluxes from reservoir water surfaces that are approximately 25% larger than previous estimates (120.4 mg CH<sub>4</sub>-C per m<sup>2</sup> per day, SD = 286.6), CO<sub>2</sub> flux estimates that are approximately 30% smaller than previous estimates (329.7 mg CO<sub>2</sub>-C per m<sup>2</sup> per day, SD = 447.7), and the first-ever global mean estimate of reservoir N<sub>2</sub>O fluxes (0.30 mg N<sub>2</sub>O-N per m<sup>2</sup> per day, SD = 0.9; table 1). The mean areal N<sub>2</sub>O emissions reported here are approximately an order of magnitude less than those estimated for US reservoirs (Baron et al. 2013) and are consistent with the areal fluxes reported by Yang and colleagues (2014). 16% of reservoirs were net CO<sub>2</sub> sinks and 15% of reservoirs were net N<sub>2</sub>O sinks, whereas all systems were either CH<sub>4</sub> neutral or CH<sub>4</sub> sources (figure 2). The average areal CH<sub>4</sub> emissions that we report from reservoirs are higher than average fluxes from natural lakes, ponds, rivers, or wetlands (table 1). On the basis of the mean areal GHG fluxes in our data set, the majority (79%) of CO<sub>2</sub> equivalents from reservoirs occurred as CH<sub>4</sub>, with CO<sub>2</sub> and N<sub>2</sub>O responsible for 17% and 4% of the radiative forcing, respectively, over the 100-year timespan.

The higher mean CH<sub>4</sub> emissions reported here are likely due to the exclusion of diffusive-only estimates and a preponderance of high CH<sub>4</sub> flux estimates in the recent literature. Particularly high CH<sub>4</sub> flux estimates have been reported for some temperate reservoirs (Maeck et al. 2013, Beaulieu et al. 2014) and subtropical reservoirs (Grinham et al. 2011, Sturm et al. 2014) that were not included in previous global estimates (St. Louis et al. 2000, Barros et al. 2011, Bastviken et al. 2011), indicating that midlatitude reservoirs can emit as much CH<sub>4</sub> as tropical systems. In fact, we found that CH<sub>4</sub> fluxes from Amazonian reservoirs were statistically indistinguishable from reservoir CH<sub>4</sub> fluxes in other regions (Mann Whitney test,  $p = 0.25$ ; supplemental figure S3). These findings run counter to the common view that low latitude reservoirs (and Amazonian reservoirs in particular) support greater CH<sub>4</sub> emission rates than temperate systems (Barros et al. 2011), but are consistent with the recent influx of higher emission estimates from subtropical and temperate ecosystems mentioned above.

#### Previous efforts to identify predictors of reservoir GHGs

Reservoir age (Barros et al. 2011, UNESCO-IHA 2012, Hertwich 2013) and latitude (Barros et al. 2011) have been suggested as predictors of CO<sub>2</sub> and CH<sub>4</sub> flux from hydroelectric reservoirs. Elevated GHG emissions from young (less than 10 years) reservoirs are commonly observed

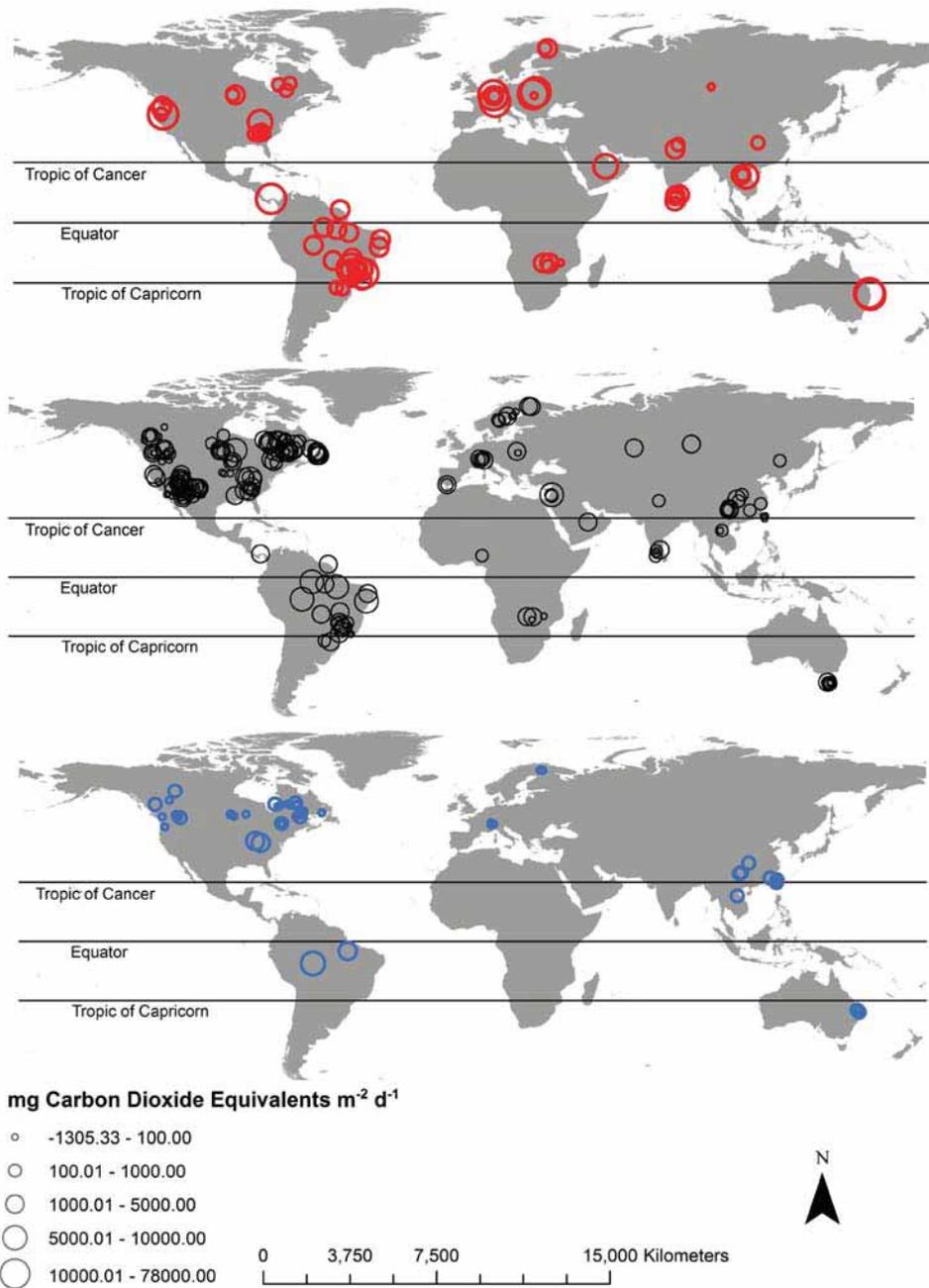


Figure 2. Diffusive + ebullitive methane (top), carbon dioxide (middle), and nitrous oxide (bottom) emissions from reservoirs on a CO<sub>2</sub>-equivalent basis (100-year horizon). Few reservoirs had measurements for all three gases.

**Table 2. The number of reservoirs with surface water GHG emission estimates by continent, as well as a break down of the number of CO<sub>2</sub>, ebullitive + diffusive (E+D) CH<sub>4</sub>, diffusive only (D) CH<sub>4</sub>, and N<sub>2</sub>O emission estimates by continent.**

Continent	CO <sub>2</sub>	CH <sub>4</sub> (E + D)	CH <sub>4</sub> (D)	N <sub>2</sub> O	Total number of reservoirs with any GHG emission estimates
North America	144	23	56	37	158
South America	22	21	1	2	23
Africa	5	4	0	0	5
Europe	18	11	10	7	31
Asia	30	14	6	8	36
Australia	10	2	12	4	14
<b>World</b>	<b>229</b>	<b>75</b>	<b>85</b>	<b>58</b>	<b>267</b>

(Abril et al. 2005, Bastien et al. 2011, Teodoru et al. 2012) and are thought to be due to rapid decomposition of the most labile terrestrial organic matter, although some reservoirs may continue to have elevated GHG emissions at least 20 years after flooding (Kemenes et al. 2011). Measurements in an oligotrophic system in Canada's boreal zone have shown that heterogeneity in pre-flood carbon stocks can affect young reservoir CO<sub>2</sub> fluxes, with greater rates of sediment CO<sub>2</sub> production in higher carbon sediments (Brothers et al. 2012). However, the experimental flooding of high, medium, and low carbon boreal forests yielded no discernible relationship between the soil or sediment carbon stock and GHG production over a 3-year time span (Hendzel et al. 2005, Matthews et al. 2005). Reservoir GHG emissions can also be positively correlated with temperature (DelSontro et al. 2010, UNESCO-IHA 2012). Consequently, the negative correlation between latitude and hydroelectric GHG emissions reported in previous work could reflect higher average water temperatures at low latitudes. In addition, lower latitude regions typically experience higher rates of terrestrial net primary production (NPP), a factor that has been positively correlated with GHG emissions from hydroelectric reservoirs (Hertwich 2013). High rates of NPP may promote enhanced leaching of dissolved organic matter (DOM), fueling additional decomposition of terrestrial organic matter within tropical reservoirs.

A growing body of work highlights the role that nutrient status and associated primary productivity may play in determining overall reservoir GHG dynamics. For example, Li and colleagues (2015) reported a negative correlation between both nutrient enrichment and primary production and CO<sub>2</sub> fluxes, and at least one study has argued that increasing primary production can shift lentic ecosystems from CO<sub>2</sub> sources to sinks (Pacheco et al. 2013). This occurs when additional nutrients promote atmospheric carbon sequestration via enhanced photosynthesis leading to accelerated rates of organic carbon sedimentation and burial. At the same time, eutrophication may promote larger CH<sub>4</sub> emissions, both by reducing O<sub>2</sub> concentrations in reservoir bottom waters and by increasing organic matter quantity (as

described below). In wetland ecosystems, NPP has been posited as a "master variable" that integrates several important environmental factors influencing CH<sub>4</sub> emission (Whiting and Chanton 1993). Some of these factors are likely to be more important in wetlands than in reservoirs (i.e., rooted plants as conduits for CH<sub>4</sub> exchange), whereas others are applicable across systems (i.e., increased substrate availability associated with elevated rates of carbon fixation). Regionally, positive correlations between chlorophyll *a* concentrations and both dissolved CH<sub>4</sub> concentrations (Indian reservoirs; Narvenkar et al. 2013) and CH<sub>4</sub> fluxes (north temperate lakes; West et al. 2015a) have been found in lakes and reservoirs. Although less is known about the controls on reservoir N<sub>2</sub>O flux, strong positive correlations between NO<sub>3</sub><sup>-</sup> concentrations and both N<sub>2</sub>O concentration and flux have been observed across aquatic ecosystems (Baulch et al. 2011, McCrackin and Elser 2011).

Overall, better predictive tools are needed for identifying environmental controls on reservoir GHGs. Some progress has been made toward accomplishing these tasks through the modeling of hydroelectric CO<sub>2</sub> and CH<sub>4</sub> emissions (Barros et al. 2011, IEA Hydropower 2012, UNESCO-IHA 2012, Hertwich 2013). Still, we are not aware of any modeling efforts that have explicitly incorporated ebullition; instead, existing efforts have used either diffusive-only emissions or a combination of diffusive-only and ebullitive + diffusive emissions. In the section that follows, we explicitly consider ebullition by categorizing CH<sub>4</sub> fluxes on the basis of collection methods and considering the extent to which environmental controls differed on the basis of CH<sub>4</sub> flux pathway (ebullitive versus diffusive). In particular, we explore the hypothesis that nutrient loading and the resulting increase in primary production stimulates GHG emissions from reservoir water surfaces, primarily via enhanced CH<sub>4</sub> production.

#### **Synthesis findings: Productivity predicts the radiative forcing capacity of reservoir GHG emissions**

We collated system characteristics likely to covary with, or control, GHG fluxes. These characteristics included

**Table 3. The least squared regression statistics for a subset of the best models relating reservoir CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O fluxes to potential predictor variables. All the significant linear regressions ( $p < .05$ ) with  $R^2 > 0.1$  are shown. Sign indicates whether the slope of the regression line was positive (+) or negative (-). Note that reservoir CO<sub>2</sub> fluxes are inverse transformed such that a negative regression correlation indicates a positive relationship between the predictor variable and the CO<sub>2</sub> flux. \* Indicates modeled predictor. Complete regression statistics can be found in supplemental tables S4 and S5.**

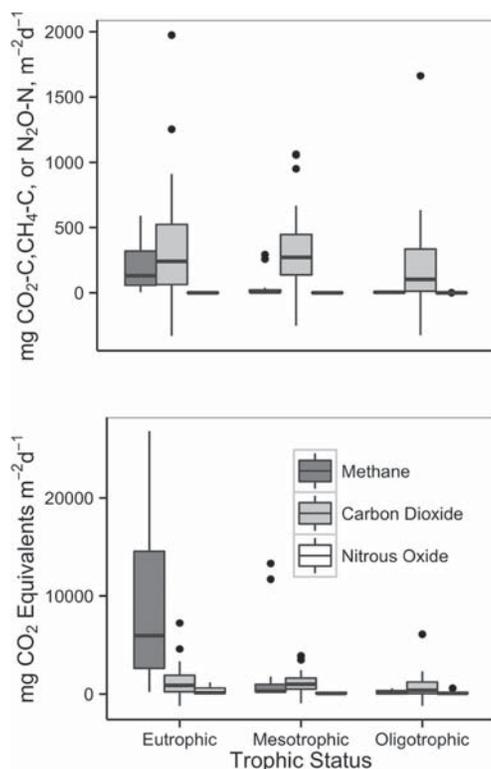
Gas	Predictor	Transformation	df	p value	R <sup>2</sup>	Sign
Ln (CH <sub>4</sub> + 1) Bubble + Diffusion n = 75	[Chlorophyll a]	Ln	29	<.001	0.50	+
	[DIP]*	Ln	31	0.02	0.18	+
1/(CO <sub>2</sub> + 1000) n = 229	Mean Annual Precipitation	none	31	0.04	0.11	-
Ln (N <sub>2</sub> O + 1) n = 58	[NO <sub>3</sub> <sup>-</sup> ]	Ln	16	<.001	0.49	+
	Latitude	none	56	<.001	0.46	-
	Mean Annual Air Temperature*	Sqrt	55	<.001	0.33	+
	Mean Annual Precipitation*	Sqrt	54	<.001	0.30	+

morphometric, geographic, and historical properties of study reservoirs (i.e., depth, residence time, volume, surface area, age, and latitude), biologically significant water column solute concentrations (i.e., NO<sub>3</sub><sup>-</sup>, total phosphorus, and dissolved organic carbon), and metrics of ecosystem primary productivity (i.e., trophic status and mean or modeled surface water chlorophyll *a* concentrations; see the supplemental materials for a complete list of the tested variables).

Of the factors examined, CH<sub>4</sub> emissions were best predicted by chlorophyll *a* concentrations (positive correlation,  $p < 0.001$ ,  $R^2 = 0.50$ ,  $n = 31$ ); CO<sub>2</sub> emissions were best predicted by reported mean annual precipitation (positive correlation,  $p = 0.04$ ,  $R^2 = 0.11$ ,  $n = 33$ ); and N<sub>2</sub>O emissions were most strongly related to reservoir NO<sub>3</sub><sup>-</sup> concentrations (positive correlation,  $p < 0.001$ ,  $R^2 = 0.49$ ,  $n = 18$ , table 3, supplemental figure S6). Although latitude was also a strong predictor of N<sub>2</sub>O flux ( $p < 0.001$ ,  $R^2 = 0.47$ ,  $n = 55$ ), latitude and NO<sub>3</sub><sup>-</sup> were weak covariates ( $-0.29$  Pearson correlation), and latitude was not a significant predictor of N<sub>2</sub>O ( $p = 0.10$ ) in a multiple linear regression model with NO<sub>3</sub> ( $p = 0.01$ ). CH<sub>4</sub> emissions were only weakly related to latitude ( $p = 0.05$ ,  $R^2 = 0.04$ ), and CO<sub>2</sub> emissions were not significantly related to latitude. Whereas CO<sub>2</sub> emissions were weakly related to reservoir age ( $p = 0.003$ ,  $R^2 = 0.04$ ), CH<sub>4</sub> and N<sub>2</sub>O fluxes were not (supplemental table S4). The positive, albeit weak, relationship between CO<sub>2</sub> fluxes and mean annual precipitation is consistent with observations in boreal lakes where precipitation has been observed to flush terrestrial carbon into surface waters and enhance CO<sub>2</sub> concentrations and emissions via organic matter degradation (Rantakari and Kortelainen 2005). The relationship between N<sub>2</sub>O fluxes and NO<sub>3</sub><sup>-</sup> concentrations is consistent with observations

from small streams (Baulch et al. 2011) as well as observed positive relationships between concentrations of N<sub>2</sub>O and NO<sub>3</sub><sup>-</sup> in reservoirs (Beaulieu et al. 2015) and in lakes receiving atmospheric nitrogen deposition (McCrackin and Elser 2011).

The controls on reservoir CH<sub>4</sub> flux deserve particular attention because our analysis suggests that CH<sub>4</sub> emissions are responsible for 79% of the radiative forcing from reservoirs over the 100 year timespan. Chlorophyll *a* and air temperature were significant predictors of CH<sub>4</sub> emissions from reservoir water surfaces regardless of flux type (i.e., diffusive only, ebullitive only, diffusive + ebullitive; supplemental tables S4 and S5). Mean reservoir depth and chlorophyll *a*, both of which have been reported to control lake and reservoir CH<sub>4</sub> emissions, were weakly correlated in this analysis (Pearson correlation 0.46). Depth was not a significant predictor of CH<sub>4</sub> flux for the whole data set ( $p = 0.14$ ,  $R^2 = 0.02$ ) or for the subset of the data for which chlorophyll *a* concentrations were available ( $p = 0.19$ ,  $R^2 = 0.02$ ), indicating that chlorophyll *a* is a better predictor of system-wide CH<sub>4</sub> emissions than mean depth. Depth has been found to exert an important control on the spatial variability of CH<sub>4</sub> fluxes from lakes, particularly with respect to ebullition (Bastviken et al. 2004, West et al. 2015a). In the marine environment, ebullition-based emissions to the atmosphere are thought to be negligible in waters deeper than 100 meters because of the dissolution of bubbles en route from sediments to the atmosphere (McGinnis et al. 2006), and a recent study of north temperate lakes reported that ebullition rarely occurred at sites deeper than 6 meters (West et al. 2015a). Although both depth and age (discussed above) may be important predictors of carbon emissions in individual reservoir systems,



**Figure 3. Average reservoir GHG fluxes by trophic status.** The top panel shows areal flux rates; the bottom panel shows fluxes converted to CO<sub>2</sub> equivalents. The legend is for both panels. The lines within the boxes indicate median fluxes. The boxes demarcate the twenty-fifth and seventy-fifth percentiles, the whiskers demarcate the 95% confidence intervals, and the dots plot data outside this range. One methane flux from a eutrophic reservoir is removed from the bottom panel (78,000 milligrams CO<sub>2</sub> equivalents per m<sup>2</sup> per day from the Rzeszów Reservoir) to improve readability.

these relationships do not appear to scale up in the global model, which only considers mean values for individual reservoirs (e.g., mean reservoir depth or the mean age of the reservoir when carbon emissions were measured).

The strong positive correlation between reservoir CH<sub>4</sub> flux and chlorophyll *a* is also reflected in the significantly different CH<sub>4</sub> emissions found in systems of different trophic statuses (Kruskal Wallis test,  $\chi^2 = 16.8$ ,  $p < .001$ ). Specifically, eutrophic systems emitted approximately an order of magnitude more CH<sub>4</sub> than oligotrophic ones (figure 3). This pattern has been observed regionally in North American,

Swedish, and Canadian lakes (Bastviken et al. 2004, Rasilo et al. 2015, West et al. 2015a) as well as Finnish lakes and reservoirs (Huttunen et al. 2003), and is consistent with recent findings from shallow lake mesocosms where CH<sub>4</sub> emissions were best predicted by factors related to primary production (i.e., nutrient concentrations and primary producer abundance; Davidson et al. 2015). This suggests that the low oxygen and high dissolved organic carbon conditions that often develop in eutrophic systems promote elevated CH<sub>4</sub> production relative to lower nutrient systems. In addition to increasing the quantity of organic carbon and reducing the availability of oxygen, eutrophication may also affect the overall quality of organic matter for fueling CH<sub>4</sub>-producing archaea. Algae-derived organic matter has been found to fuel higher rates of CH<sub>4</sub> production than land-based “terrestrial” carbon (West et al. 2012), and may even stimulate the enhanced incorporation of recalcitrant terrestrial carbon into bacterial biomass (i.e., priming effect; Guillemette et al. 2015). Thus, increasingly high fractions of algae-derived organic matter will likely support more methane production.

#### Global surface area of reservoirs

Global-scale estimates of reservoir GHG emissions are dependent on estimates of both areal fluxes (discussed above) and global reservoir surface area. There have been a number of recent efforts to improve global reservoir (and lake) surface-area estimates (Downing and Duarte 2009, Lehner et al. 2011, Verpoorter et al. 2014). Although St. Louis and colleagues (2000) estimated global reservoir surface area by multiplying the surface area of reservoirs in the *World Register of Dams* by a factor of four, more recent reservoir surface-area estimates were made assuming that reservoir surface areas follow a pareto distribution (Downing et al. 2006, Lehner et al. 2011). Downing and colleagues (2006) used data from the International Commission on Large Dams together with pareto-based extrapolations to estimate that reservoirs more than 0.01 square kilometers (km<sup>2</sup>) cover 258,570 km<sup>2</sup> of the earth's surface. Following this, Lehner and colleagues (2011) used the Global Reservoir and Dam Database (GRAND) together with pareto-based extrapolations to estimate that reservoirs more than 0.00001 km<sup>2</sup> cover 507,102 km<sup>2</sup> of earth's surface. These reservoir surface-area estimates are one-sixth to one-third the value used by St. Louis and colleagues (2000). For our best estimate of global reservoir GHG fluxes, we use 305,723 km<sup>2</sup> of reservoir surface area (table 1). This estimate is based on GRAND and excludes the original surface area of natural lakes that have been modified with water regulation structures (this includes Lakes Victoria, Baikal, and Ontario; Lehner et al. 2011). The 267 reservoirs whose CO<sub>2</sub>, CH<sub>4</sub>, and/or N<sub>2</sub>O emission estimates we synthesize here cover a collective surface area of over 77,287 km<sup>2</sup> (28 reservoirs with unknown surface area), and therefore represent 25% of global reservoir coverage.

In addition, reservoir surface area is likely to increase substantially in coming decades given the 847 large hydropower

projects (more than 100 MW) and 2853 smaller projects (more than 1 MW) that are currently planned or under construction (Zarfl et al. 2015). In this synthesis, reservoirs with more than 1MW installed capacity had a median surface area of 226 km<sup>2</sup>. Assuming each of the 847 large hydropower projects that are planned or under construction has an equivalent surface area, this would constitute 225,691 km<sup>2</sup> of additional reservoir surface area, nearly doubling current reservoir surface-area estimates. Although there is a net trend toward dam decommissioning in the United States, most of these removals have been small dams, and the global number of removals is more than offset by recent increases in dam construction (O'Connor et al. 2015).

#### Global magnitude of reservoir GHG emissions

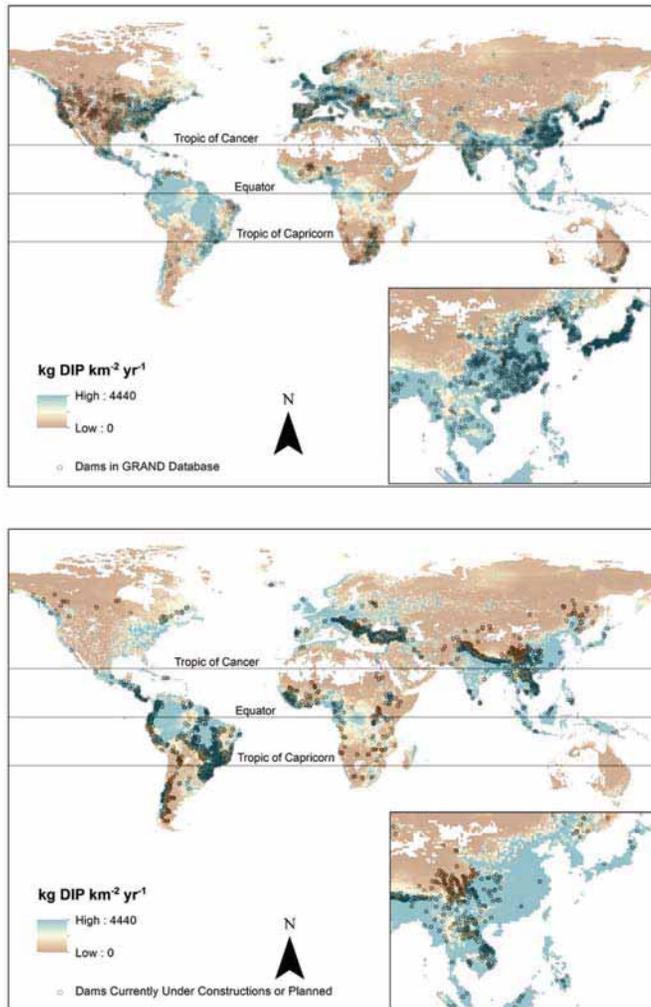
We report global GHG emissions from reservoir water surfaces on the low end of previously published values (table 1), but stress that these emissions still contribute significantly to global budgets of anthropogenic CO<sub>2</sub> equivalent emissions. CH<sub>4</sub> constituted the majority of CO<sub>2</sub> equivalent emissions from reservoirs, and the per area reservoir CH<sub>4</sub> fluxes reported in this synthesis are higher than per area fluxes for any other aquatic ecosystem (table 1). We estimate that reservoirs emit 13.4 Tg CH<sub>4</sub>-C per year (5<sup>th</sup> and 95<sup>th</sup> confidence interval: 8.9–22.2 Tg CH<sub>4</sub>-C per year), 36.8 Tg CO<sub>2</sub>-C per year (5<sup>th</sup> and 95<sup>th</sup> confidence interval: 31.8–42.8 Tg CO<sub>2</sub>-C per year), and 0.03 Tg N<sub>2</sub>O-N per year (5<sup>th</sup> and 95<sup>th</sup> confidence interval: 0.02–0.07 Tg N<sub>2</sub>O-N per year; table 1). The estimate of global reservoir GHG emissions presented here is calculated on the basis of the product of bootstrapped estimates of mean areal GHG fluxes and best estimates of global reservoir surface area (as was done in a recent estimate of global methane emissions from streams and rivers, Stanley et al. 2016). See the supplemental materials for information about the bootstrapping technique used. Given the dominant controls on GHG emissions from reservoir water surfaces identified in this study and given the current availability of relevant predictor variables at the global scale, we do not see an advantage to segmenting our upscaling efforts at this point in time. Still, identifying regional differences in reservoir GHG emissions remains a needed area of future research (see below section on Uncertainties and Future Research Directions).

Although the global mapping of reservoir trophic status (and associated upscaling of CH<sub>4</sub> emissions) is beyond the scope of this article, recent progress in the mapping of chlorophyll *a* in medium and large-sized lakes and reservoirs shows that about 60% of systems have more than 10 micrograms per liter chlorophyll *a* (Sayers et al. 2015), and would therefore be considered eutrophic by most classification schemes (Cunha et al. 2013). Similarly, a comparison of large reservoir locations (Lehner et al. 2011) with model-predicted dissolved inorganic phosphorus (DIP) yields (Harrison et al. 2010) indicates that most large reservoirs occur in phosphorus enriched regions (figure 4a) that may promote eutrophication of reservoirs. To illustrate, the average DIP yield (per 0.5 degree grid cell) in grid cells with dams is over threefold

higher than the global average DIP yield (45 versus 13 kilograms P per km<sup>2</sup> per year). Given this pattern and the high fraction of nutrient enriched, productive reservoirs in our GHG database (of systems where trophic status data were available, 38% and 24% were eutrophic and mesotrophic respectively), it is likely that a large fraction of reservoirs are highly productive and therefore support high CH<sub>4</sub> emission rates. However, overlaying a map of the hydroelectric projects that are currently planned or under construction (Zarfl et al. 2015) on a map of average DIP yield (Harrison et al. 2010) suggests that newer hydroelectric projects will be more evenly distributed between phosphorus enriched and relatively phosphorus poor regions (Figure 4b). Further research is needed to better understand how much P will be routed through current and future reservoirs to support large-scale models of reservoir trophic status and associated CH<sub>4</sub> emissions. Specifically, models of riverine DIP yield would need to be downscaled to quantify how much DIP individual reservoirs are intercepting.

#### Emissions from alternative flux pathways

There are several emission pathways that are either nonexistent or of marginal importance in natural lakes, but that may contribute significantly to reservoir GHG budgets. These include: drawdown emissions, downstream emissions, emissions from decomposing wood, and emissions from dam spillways and turbines (e.g., “degassing” emissions). Drawdown emissions occur when fluctuating water levels cause large changes in hydrostatic pressure and create sediments that are periodically inundated with water and then exposed to the atmosphere. Although all aquatic systems experience natural fluctuations in water level, the amplitude and/or frequency of these fluctuations is likely more pronounced in reservoir ecosystems (Zohary and Ostrovsky 2011). Drawdown zones (that are periodically dry and then inundated) may contribute disproportionately to systemwide GHG emissions because of the shifting redox conditions they experience (Lu et al. 2011, Yang M et al. 2014). Drawdown may also be a hot moment for systemwide CH<sub>4</sub> release because reductions in hydrostatic pressure can stimulate ebullition events (Maeck et al. 2014). These events may constitute significant components of annual reservoir-wide CH<sub>4</sub> emission budgets and are the subject of ongoing work, but are not included in the analyses presented here. Degassing emissions from turbines and spillways occur when reservoir water undergoes rapid depressurization and/or aeration resulting in rapid emission of dissolved gases. GHGs that remain in solution after water passes through a dam either diffuse into the atmosphere or are consumed by microbes (e.g., methane oxidation) downstream of the dam. Downstream emissions refer to GHGs that are produced within the reservoir and emitted from the river channel below a dam. The spatial footprint of these emissions is generally defined as the river reach for which GHG emissions are elevated above background (Kemenes et al. 2007). Finally, the decomposition of standing woody material was found to constitute a large fraction



**Figure 4.** Global NEWS half-degree dissolved inorganic phosphorus (DIP) yield (Harrison et al. 2010) overlaid on existing reservoirs from the GRAND database (Lehner et al. 2011) and hydropower reservoirs currently either under construction or planned (bottom panel; Zarfl et al. 2015). The inset maps show Southeast Asia, a region of rapid dam construction. China is projected to remain the global leader in hydropower dam construction, producing approximately one-fourth of global hydropower (Zarfl et al. 2015).

of total GHG emissions in a tropical reservoir (26%–45% of CO<sub>2</sub> equivalents over a 100-year time frame; Abril et al. 2013), but this GHG source remains to be studied in reservoirs from other regions.

age of GHG flux measurements has improved in recent years, there are still few measurements from many regions, including Africa, Australia, and Russia (table 2, figure 2). With respect to the forms of GHGs measured, there are currently threefold and fourfold more reservoirs with CO<sub>2</sub>

Both downstream and degassing emissions are likely highly dependent on reservoir GHG concentrations, dam engineering, spill practices and downstream biogeochemistry. Larger degassing and downstream emissions are expected when the spilled reservoir water is high in GHGs (Guérin et al. 2006). This generally occurs in systems in which the water is withdrawn from the lower portion of the reservoir (hypolimnetic release), because this water is typically highly pressurized and is also enriched in GHGs relative to surface waters (Kemenes et al. 2007). These emissions may also depend on dam-specific engineering. For example, an aerating weir at Petit Saut reservoir was installed to optimize CH<sub>4</sub> degassing immediately below the dam to avoid problems associated with methane-oxidation-induced hypoxia (Abril et al. 2005). Finally, the environmental controls on methane consumption (e.g., methane oxidation; Abril et al. 2005, Kemenes et al. 2007) and air–water gas exchange rates downstream of a dam may also play an important role in determining the magnitude of downstream emissions.

Measurements of GHG emissions from drawdown zones, downstream river reaches, wood decomposition, as well as spillways and turbines are currently too limited and/or too poorly constrained to meaningfully include in analyses of the controls and magnitude of reservoir GHGs. Still, these pathways may contribute significantly to overall ecosystem fluxes, particularly in the case of CH<sub>4</sub> (figure 1). For a more detailed summary of reservoir GHG fluxes via alternative flux pathways, see the supplemental discussion and table S1.

#### Uncertainties and future research directions

In developing this synthesis, we identified a number of areas that are beyond the scope of our analysis but that certainly deserve additional attention and research. Although the spatial cover-

emission estimates than for CH<sub>4</sub> (ebullitive + diffusive) and N<sub>2</sub>O emissions, respectively (table 2). In addition, there is a crucial need to better constrain GHG emissions from boreal reservoirs, especially the relative role of diffusive versus ebullitive CH<sub>4</sub> emission pathways. The roles of reservoir typology, spatiotemporal variability, and ecosystem productivity in determining GHG emissions all deserve further analysis. In the sections that follow, we highlight some significant research needs that will improve our ability to model and potentially manage reservoir GHG emissions.

**Reservoir typology.** Currently, there are relatively few GHG flux estimates from nonhydroelectric systems. Although hydroelectric dams are estimated to constitute 30%–62% of global impoundments (Lehner et al. 2011, Varis et al. 2012), 82% of reservoirs with known uses in our GHG database had the capacity to generate hydroelectricity (supplemental figure S7). Although we did not detect any significant difference between the areal emission of CH<sub>4</sub>, CO<sub>2</sub>, or N<sub>2</sub>O from hydroelectric versus nonhydroelectric systems (Mann Whitney test,  $p = .83, .27, \text{ and } .87$  respectively; figure S3), we also did not consider degassing, downstream, or drawdown zone emissions, all of which are likely to vary on the basis of reservoir typology. Better characterization of reservoir outlet structure (e.g., proportion of surface versus bottom water withdrawals by reservoir type) and associated turbine and downstream GHG emissions would aid our understanding of how different types of reservoirs (hydroelectric, flood control, irrigation etc.) contribute to overall GHG emissions. In addition, small farm impoundments were not included in this data set because of lack of data, but these systems clearly deserve more attention because they are often located in eutrophied areas and are disproportionately active with respect to carbon cycling (Downing et al. 2008). In fact, natural ponds less than 0.001 km<sup>2</sup> are estimated to make up less than 10% of global lake and pond surface area but constitute more than 15% of CO<sub>2</sub> emissions and more than 40% of diffusive CH<sub>4</sub> emissions (Holgerson and Raymond 2016).

**Hot spots and hot moments.** Lake and reservoir GHG emissions are often highly variable in both space and time. The flux estimates presented in previous sections use available estimates from every reservoir where GHG emissions have been reported (and mean estimates from reservoirs where multiple studies or years of data have been collected), but it is important to note that the spatial and temporal coverage of these emission estimates are highly variable. Reservoir GHG emission estimates are often made at temporal scales ranging from minutes to hours even though lake and reservoir GHG emissions can vary over single day–night cycles (Morales-Pineda et al. 2014, Podgrajsek et al. 2014, 2015), seasonally with changes in productivity and/or river inflow (Knoll et al. 2013, Morales-Pineda et al. 2014, Pacheco et al. 2015), and episodically because of water-level fluctuations (Maeck et al. 2014) or water-column mixing dynamics (Jammet et al. 2015). The spatial coverage of reservoir GHG

emission measurements is also often limited; many studies measure emissions at fewer than 5 sites and very few studies have more than 10 sites. Recent spatial analyses of reservoir CH<sub>4</sub> dynamics highlight the disproportionate importance of inlets and other depositional zones toward overall flux (DelSontro et al. 2011, Maeck et al. 2013) as well as from seasonally flooded and downstream zones (see the Emissions From Alternative Flux Pathways section).

Despite the considerable uncertainty associated with the reservoir-specific GHG emission estimates synthesized here, we argue that these data provide a low-end estimate of global emissions. A recent study quantified the effects of spatial and temporal sampling resolution on diffusive and ebullitive CH<sub>4</sub> emission estimates from 3 shallow boreal lakes and found that low sampling coverage is more likely to lead to underestimates of flux than overestimates (72% chance of flux underestimation when bubble trap sampling is limited to 1–3 days; Wik et al. 2016). The authors estimate that diffusive and ebullitive CH<sub>4</sub> fluxes should be measured from a minimum of 3 and 11 depth stratified sites on at least 11 and 39 days (respectively) to achieve  $\pm 20\%$  of the emissions estimated from sampling more intensively (Wik et al. 2016). More work is needed to characterize sampling bias in other types of systems, and to understand how sampling bias scales up. In this analysis, we treated system-specific estimates of GHG flux equally despite a large range in the degree of sampling effort represented by each study.

The development of methods and protocols that effectively capture spatial and temporal variation in GHG fluxes is crucial for improving our ability to compare “apples to apples” between different reservoir systems. Efforts are already being made in this direction (UNESCO–IHA 2010, Bastviken 2015).

**Seasonality and ice cover.** The seasonality of reservoir GHGs is a major frontier. Future research should aim to quantify both seasonal patterns in emission and the extent to which water-column mixing and other short-term events contribute to annual-scale GHG emissions. Although warmer temperatures have been correlated with higher rates of CH<sub>4</sub> production across a range of ecosystems (Yvon-Durocher et al. 2014), annual-scale reservoir GHG data are currently too limited to make inferences on how seasonal biases may either under or overestimate annual-scale fluxes. Spring (ice melt) and fall (destratification) turnover events can result in pulse emissions wherein gasses that have accumulated under the ice or thermocline are suddenly mixed upward and vented to the atmosphere as a lake circulates. Although turnover data from reservoir systems is extremely sparse (but see Bastien et al. 2011, Demarty et al. 2011, Beaulieu et al. 2014), in lakes, turnover flux may account for an average of 35% (and a range of less than 1% to 70%) of annual CH<sub>4</sub> emissions, with the highest contribution from small systems (Michmerhuizen et al. 1996, Bastviken et al. 2004, Jammet et al. 2015).

Currently, the role of CH<sub>4</sub> oxidation (a microbial process that consumes methane) in mediating atmospheric CH<sub>4</sub>

fluxes during lake turnover events is also not well understood. Commonly employed methods for estimating turnover flux use hypolimnion storage (i.e., the gasses that have accumulated under the ice or thermocline) to estimate emissions and assume that there is no significant CH<sub>4</sub> oxidation during turnover (Michmerhuizen et al. 1996). Research in boreal and temperate lakes has found that anywhere between 60 and 94% of the CH<sub>4</sub> stored in the water column can be oxidized during turnover (Rudd and Hamilton 1978, Utsumi et al. 1998) but the environmental controls on turnover-related methane oxidation rates are not well known. Given current uncertainties, our global-scale estimate of reservoir GHG flux does not account for ice cover, but see the supplemental materials for an estimate of the extent to which ice cover could reduce annual-scale emissions (assuming no turnover emissions).

**The role of boreal systems.** Results from this synthesis suggest that biases in the application of different measurement techniques have led to spurious assignment of age as a significant control on reservoir CH<sub>4</sub> fluxes. In addition, this sampling bias may have overemphasized the significance of latitude as a predictor of CH<sub>4</sub> fluxes. The majority of measurements from old systems and high latitude systems have been diffusive only (supplemental figures S4 and S5), which may underestimate true CH<sub>4</sub> fluxes. It is possible, however, that ebullition is limited in boreal systems. Large-scale monitoring efforts in Canadian hydroelectric reservoirs suggests that CH<sub>4</sub> bubbling constitutes less than 5% of total emissions in many boreal systems (Tremblay pers. comm.). Still, we are aware of only a handful of published studies that report both diffusive and ebullitive emissions from boreal systems, and the fraction of bubbling in these systems covers a broad range (0%–20% in Eastmain reservoir, 18% in Porttapahta reservoir, 61% to 75% in Canadian experimental reservoirs, and 87% in Lokka reservoir [Huttunen et al. 2002, Matthews et al. 2005, Teodoru et al. 2012]). Unfortunately, CH<sub>4</sub> flux measurements from permafrost reservoirs and nonhydroelectric boreal reservoirs are currently lacking. Future study of boreal reservoir GHG fluxes should target these underrepresented systems and incorporate more comprehensive ebullition rate measurements.

**The role of reservoir productivity.** Recent work has suggested that eutrophication might “reverse” the carbon budget of lakes and reservoirs (i.e., shifting the ecosystem from net heterotrophy to net autotrophy) by converting large amounts of CO<sub>2</sub> to organic matter via elevated primary production (Pacheco et al. 2013). Our analysis does not support this idea. A comparison of CO<sub>2</sub> and CH<sub>4</sub> fluxes from eutrophic reservoirs suggests that eutrophication does little to change the net carbon balance of reservoirs, but greatly increases the atmospheric radiative forcing caused by these systems through the stimulation of CH<sub>4</sub> production (figure 3). This suggests a potential positive feedback loop wherein a warming climate supports larger algal populations, larger algal populations

provide more organic matter to support more methane production, and a portion of the methane produced escapes to the atmosphere, where it functions to further warm climate. The relationship between organic matter quality and methane production is an active area of research that may reduce the strength, or possibly even negate, the feedback loop proposed above. A recent laboratory study revealed that algal biomass quality, in terms of lipid content, enhanced rates of methane production (West et al. 2015b). Because algae grown under nutrient rich conditions tend to be relatively lipid poor, the authors posit that this resource quality feedback reduces the strength of the positive feedback between eutrophication and methane production (West et al. 2015b). Developing our understanding of these feedbacks should help inform quantitative modeling efforts.

**The larger context.** In this study, we have discussed only gross carbon emissions from existing reservoirs, ignoring other stages or factors of a reservoir’s carbon cycle that are important to consider. For example, it will be necessary to eventually place gross fluxes in context by comparing them with (a) the GHG balance of the land prior to flooding, (b) the rates of reservoir carbon fixation and storage, (c) the GHGs associated with reservoir creation and decommissioning (e.g., life-cycle-analysis perspective), and (d) the long-term fate of carbon buried in reservoirs that are decommissioned. Few studies have placed reservoir GHG emissions into such a context, but those that have find that reservoirs result in a net carbon footprint that exceeds that of the preflooded landscape and that they are net emitters of CO<sub>2</sub> equivalents (Jacinthe et al. 2012, Teodoru et al. 2012, Faria et al. 2015). A recent analysis of CH<sub>4</sub> fluxes from hydroelectric reservoirs showed that 10% of reservoirs have emission factors (gCO<sub>2</sub>e per kilowatt hour) larger than the CO<sub>2</sub> emissions from natural gas combined cycle plants (Hertwich 2013), although the authors did not consider carbon burial offsets. Although dams are responsible for high rates of carbon burial (Clow et al. 2015), it has been argued that at least a portion of this burial would still be occurring farther downstream, perhaps even in coastal waters, in the absence of dams (Mendonça et al. 2012). The role of dams in re-locating sediment carbon pools may be significant in determining total carbon burial (Mendonça et al. 2012) as well as the fraction of carbon that is emitted as CH<sub>4</sub>. For example, faster-moving, more oxygenated “lotic” waters typically support more rapid decomposition and CO<sub>2</sub> production but less CH<sub>4</sub> production. Similarly, at the coast, high concentrations of SO<sub>4</sub><sup>2-</sup> generally prohibit high CH<sub>4</sub> emissions. Accounting for the short and long-term fate of carbon in reservoir sediments is an important next step in global carbon budgeting exercises.

#### Policy implications

When CH<sub>4</sub>, CO<sub>2</sub>, and N<sub>2</sub>O emissions are combined, our synthesis suggests that reservoir water surfaces contribute 0.8 Pg CO<sub>2</sub> equivalents per year over a 100-year time span (fifth and ninety-fifth confidence interval: 0.5–1.2 Pg CO<sub>2</sub> equivalents

per year), or approximately 1.5% of the global anthropogenic CO<sub>2</sub>-equivalent emissions from CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O reported by the IPCC (table 1; Ciais et al. 2013) and 1.3% of global anthropogenic CO<sub>2</sub>-equivalent emissions from well mixed GHGs overall (Myhre et al. 2013). Therefore, we argue for inclusion of GHG fluxes from reservoir surfaces in future IPCC budgets and other inventories of anthropogenic GHG emissions. The reservoir-based CH<sub>4</sub> emissions reported here (8.9–22.2 Tg CH<sub>4</sub>-C per year) are similar in magnitude to estimates of CH<sub>4</sub> emissions from rice paddies and to those from biomass burning (which includes biofuel emissions) by the IPCC (21–30 and 18–29 Tg CH<sub>4</sub>-C per year respectively; Ciais et al. 2013). Reservoir CO<sub>2</sub> and N<sub>2</sub>O fluxes, however, are lower than other anthropogenic or natural sources as reported by the IPCC (Ciais et al. 2013).

Although global-warming potentials for CO<sub>2</sub>-equivalent calculations are often reported for a 100-year time span, the selection of time span is somewhat arbitrary (Myhre et al. 2013). CH<sub>4</sub> is relatively short-lived in the atmosphere (atmospheric lifetime on the order of a decade) relative to CO<sub>2</sub> (atmospheric lifetime on the order of centuries) and therefore has a higher global warming potential over the shorter 20-year time horizon (86 versus 34; Myhre et al. 2013). Policymakers should carefully consider the timescales that are relevant to GHG mitigation efforts, especially given the recent international push to maintain average global temperatures within 1.5–2°C of the pre-industrial mean (Fearnside 2015). Over shorter timescales (decades), and given the exclusion of several important alternative emission pathways (i.e., degassing, downstream and drawdown zone emissions; see section above), reservoirs are almost certainly contributing more than the 0.8 Pg CO<sub>2</sub> equivalents per year calculated here. In fact, when looking over the 20-year time horizon, CO<sub>2</sub> equivalent emissions from reservoir surface waters are estimated at double the flux presented here (1.7 Pg CO<sub>2</sub> equivalents per year, 5<sup>th</sup> and 95<sup>th</sup> confidence interval: 1.1 to 2.7 Pg CO<sub>2</sub> equivalents per year). With the current boom in global dam construction (Zarfl et al. 2015), reservoirs will represent an even larger fraction of anthropogenic CO<sub>2</sub> equivalent emissions in the coming years. Therefore, policymakers and water managers that are siting new dams or decommissioning old ones should weigh the multiple services that reservoirs provide against their GHG-related costs in planning to either construct or decommission a dam. A number of papers compare reservoir GHG emissions to those of the natural gas combined cycle (see the Larger Context section above), but many reservoirs do not produce energy at all.

### Conclusions

Sixteen years ago, the first global review of reservoir GHG emissions highlighted the potential significance of reservoir surfaces as GHG sources and postulated that factors such as age, water temperature, and organic carbon inputs could regulate fluxes (St. Louis et al. 2000). At that time, there were GHG flux estimates from only 22 reservoir systems

and potential controlling factors could not be quantitatively assessed. Here, we discuss a more comprehensive set of reservoir GHG flux estimates than has previously been analyzed, and use that data set to develop new insight into the rates and controls of reservoir GHG fluxes. Specifically, this work highlights the dominant contribution of CH<sub>4</sub> emissions to total reservoir carbon emissions, and the importance of including ebullitive CH<sub>4</sub> emissions in modeling efforts. Furthermore, it appears that reservoir nutrient loading and associated eutrophication leads to increased radiative forcing by reservoirs because of increased CH<sub>4</sub> emissions. The relationship between reservoir eutrophication and GHG emissions presented here provides a crucial first step in identifying potential management opportunities for the reduction of reservoir GHGs. Specifically, watershed nutrient reduction strategies aimed at preventing reservoir eutrophication may also mitigate both CH<sub>4</sub> and N<sub>2</sub>O emissions (specifically via reduction of P and NO<sub>3</sub><sup>-</sup> loading). In addition, when possible new reservoirs could be strategically sited upstream from anthropogenic nutrient sources. With the need for better global water management and the push for expanded global hydropower capacity, careful siting of new reservoirs, and revising management of existing ones may help balance the positive ecosystem services that reservoirs provide against the GHG emission costs.

### Acknowledgments

This synthesis benefitted from supplemental data graciously provided by Huai Chen, Pierre-Andre Jacinthe, Yang Meng, Yu-Hsuan Wang, and Christiane Zarfl. We also appreciate the helpful input provided by David Bastviken, M. Keith Birchfield, Amy Burgin, Will Forney, Frédéric Guérin, Lesley Knoll, Andreas Maeck, Rebecca Martin, John Melack, Geneviève Metson, Cody Miller, Reed Norton, Dan Reed, Katrin Sturm, Alain Tremblay, and Yan Zhao. Funding was provided by the Hundred Talent Program of the Chinese Academy of Sciences and the National Natural Science Foundation of China (NSFC 31670473) to Li, the European Research Council under the European Union's Seventh Framework Programme (no. FP7/2007-2013) and ERC agreement no. 336642 to Barros, the CNPq/Brazil fellowship 202937/2014-3 to Bezerra-Neto, US Army Corps of Engineers Climate Preparedness and Resilience Programs and National Science Foundation (NSF) DEB Grant no. 135211 to Harrison, and US Environmental Protection Agency STAR Fellowship no. FP917450 and NSF IGERT Fellowship no. 0903714 to Deemer.

### Supplemental material

The supplemental material is available online at <http://bioscience.oxfordjournals.org/lookup/suppl/doi:10.1093/biosci/biw117/-/DC1>.

There is also an accompanying supplementary spreadsheet available via Dryad (doi:10.5061/dryad.d2kv0) that contains the complete data set used in this synthesis and accompanying references.

## References cited

- Abril G, Guérin F, Richard S, Delmas R, Galy-Lacaux C, Gosse P, Tremblay A, Varfalvy L, Dos Santos MA, Matvienko B. 2005. Carbon dioxide and methane emissions and the carbon budget of a 10-year old tropical reservoir (Petit Saut, French Guiana). *Global Biogeochemical Cycles* 19 (art. GB4007).
- Abril G, Parize M, Pérez MAP, Filizola N. 2013. Wood decomposition in Amazonian hydropower reservoirs: An additional source of greenhouse gases. *Journal of South American Earth Sciences* 44: 104–107.
- Baron JS, Hall EK, Nolan BT, Finlay JC, Bernhardt ES, Harrison JA, Chan F, Boyer EW. 2013. The interactive effects of excess reactive nitrogen and climate change on aquatic ecosystems and water resources of the United States. *Biogeochemistry* 114: 71–92.
- Barros N, Cole JJ, Tranvik LJ, Prairie YT, Bastviken D, del Giorgio PA, Roland F, Huszar VLM. 2011. Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. *Nature Geoscience* 4: 593–596.
- Bastien J, Demarty M, Tremblay A. 2011. CO<sub>2</sub> and CH<sub>4</sub> diffusive and degassing fluxes from 2003 to 2009 at Eastmain 1 reservoir, Québec, Canada. *Inland Waters* 1: 113–123.
- Bastviken D. 2015. Inland Water Greenhouse Gas FLUX Forum. Linköping University Tema Environmental Challenge. (23 August 2016; [www.tema.liu.se/tema-m/twflux?l=en](http://www.tema.liu.se/tema-m/twflux?l=en))
- Bastviken D, Cole J, Pace M, Tranvik L. 2004. Methane emissions from lakes: Dependence of lake characteristics, two regional assessments, and a global estimate. *Global Biogeochemical Cycles* 18 (art. GB4009).
- Bastviken D, Tranvik LJ, Downing JA, Crill PM, Enrich-Prast A. 2011. Freshwater methane emissions offset the continental carbon sink. *Science* 331: 50.
- Baulch HM, Schiff SL, Maranger R, Dillon PJ. 2011. Nitrogen enrichment and the emission of nitrous oxide from streams. *Global Biogeochemical Cycles* 25 (art. GB4013).
- Beaulieu JJ, Smolenski RL, Nietch CT, Townsend-Small A, Elovitz MS. 2014. High methane emissions from a midlatitude reservoir draining an agricultural watershed. *Environmental Science and Technology* 48: 11100–11108.
- Beaulieu JJ, Nietch CT, Young JL. 2015. Controls on nitrous oxide production and consumption in reservoirs of the Ohio River Basin: N<sub>2</sub>O in reservoirs. *Journal of Geophysical Research: Biogeosciences* 120: 1–16.
- Brothers SM, del Giorgio PA, Teodoru CR, Prairie YT, Smith R. 2012. Landscape heterogeneity influences carbon dioxide production in a young boreal reservoir. *Canadian Journal of Fisheries and Aquatic Sciences* 69: 447–456.
- Ciais P, Sabine G, et al. 2013. Carbon and other biogeochemical cycles. Pages 465–570 in TF Stocker, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, eds. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Clow DW, Stackpoole SM, Verdin KL, Butman DE, Zhu Z, Krabbenhoft DP, Striegl RG. 2015. Organic carbon burial in lakes and reservoirs of the conterminous United States. *Environmental Science and Technology* 49: 7614–7622.
- Cunha DGE, Calijuri M do C, Lamparelli MC. 2013. A trophic state index for tropical/subtropical reservoirs (TSI<sub>tr</sub>). *Ecological Engineering* 60: 126–134.
- Davidson TA, Audet J, Svenning J-C, Lauridsen TL, Søndergaard M, Landkildehus F, Larsen SE, Jeppesen E. 2015. Eutrophication effects on greenhouse gas fluxes from shallow-lake mesocosms override those of climate warming. *Global Change Biology* 21: 4449–4463.
- DelSontro T, McGinnis DF, Sobek S, Ostrovsky I, Wehrli B. 2010. Extreme methane emissions from a Swiss hydropower reservoir: Contribution from bubbling sediments. *Environmental Science and Technology* 44: 2419–2425.
- DelSontro T, Kunz MJ, Kemper T, Wüest A, Wehrli B, Senn DB. 2011. Spatial heterogeneity of methane ebullition in a large tropical reservoir. *Environmental Science and Technology* 45: 9866–9873.
- DelSontro T, McGinnis DF, Wehrli B, Ostrovsky I. 2015. Size does matter: Importance of large bubbles and small-scale hot spots for methane transport. *Environmental Science and Technology* 49: 1268–1276.
- Delwiche K, Senft-Grupp S, Hemond H. 2015. A novel optical sensor designed to measure methane bubble sizes in situ: Sensor to measure CH<sub>4</sub> bubble sizes. *Limnology and Oceanography: Methods* 13: 712–721.
- Demarty M, Bastien J. 2011. GHG emissions from hydroelectric reservoirs in tropical and equatorial regions: Review of 20 years of CH<sub>4</sub> emission measurements. *Energy Policy* 39: 4197–4206.
- Demarty M, Bastien J, Tremblay A. 2011. Annual follow-up of gross diffusive carbon dioxide and methane emissions from a boreal reservoir and two nearby lakes in Québec, Canada. *Biogeosciences* 8: 41–53.
- Deshmukh C, et al. 2014. Physical controls on CH<sub>4</sub> emissions from a newly flooded subtropical freshwater hydroelectric reservoir: Nam Theun 2. *Biogeosciences* 11: 4251–4269.
- Downing J, Duarte C. 2009. Abundance and size distribution of lakes, ponds, and impoundments. Pages 469–478 in GE Likens, ed. *Encyclopedia of Inland Waters*, vol. 1. Elsevier.
- Downing JA, Cole JJ, Middelburg JJ, Striegl RG, Duarte CM, Kortelainen P, Prairie YT, Laube KA. 2008. Sediment organic carbon burial in agriculturally eutrophic impoundments over the last century. *Global Biogeochemical Cycles* 22 (art. GB1018).
- Downing JA, et al. 2006. The global abundance and size distribution of lakes, ponds, and impoundments. *Limnology and Oceanography* 51: 2388–2397.
- Eugster W, DelSontro T, Sobek S. 2011. Eddy covariance flux measurements confirm extreme CH<sub>4</sub> emissions from a Swiss hydropower reservoir and resolve their short-term variability. *Biogeosciences* 8: 2815–2831.
- Faria FAM, Jaramillo P, Sawakuchi HO, Richey JE, Barros N. 2015. Estimating greenhouse gas emissions from future Amazonian hydroelectric reservoirs. *Environmental Research Letters* 10: e124019.
- Fassbinder JJ, Schultz NM, Baker JM, Griffis TJ. 2013. Automated, low-power chamber system for measuring nitrous oxide emissions. *Journal of Environmental Quality* 42: 606–614.
- Fearnside PM. 2015. Emissions from tropical hydropower and the IPCC. *Environmental Science Policy* 50: 225–239.
- Giles J. 2006. Methane quashes green credentials of hydropower. *Nature* 444: 524–525.
- Grinham A, Dunbabin M, Gale D, Udy J. 2011. Quantification of ebullitive and diffusive methane release to atmosphere from a water storage. *Atmospheric Environment* 45: 7166–7173.
- Guérin F, Abril G, Richard S, Burban B, Reynouard C, Seyler P, Delmas R. 2006. Methane and carbon dioxide emissions from tropical reservoirs: Significance of downstream rivers. *Geophysical Research Letters* 33: 1–6.
- Guillemette F, Leigh McCallister S, del Giorgio PA. 2015. Selective consumption and metabolic allocation of terrestrial and algal carbon determine allochthony in lake bacteria. *ISME Journal* 10: 1373–1382.
- Harrison JA, Bouwman AF, Mayorga E, Seitzinger S. 2010. Magnitudes and sources of dissolved inorganic phosphorus inputs to surface fresh waters and the coastal zone: A new global model: Global DIP loading to surface waters. *Global Biogeochemical Cycles* 24: 1–16.
- Hendzel LL, Matthews CJD, Venkiteswaran JJ, St. Louis VL, Burton D, Joyce Em, Bodaly RA. 2005. Nitrous oxide fluxes in three experimental boreal forest reservoirs. *Environmental Science and Technology* 39: 4353–4360.
- Hertwich EG. 2013. Addressing biogenic greenhouse gas emissions from hydropower in LCA. *Environmental Science and Technology* 47: 9604–9611.
- Holgerson MA, Raymond PA. 2016. Large contribution to inland water CO<sub>2</sub> and CH<sub>4</sub> emissions from very small ponds. *Nature Geoscience* 9: 222–226.
- Huttunen JT, et al. 2002. Fluxes of CH<sub>4</sub>, CO<sub>2</sub>, and N<sub>2</sub>O in hydroelectric reservoirs Lokka and Porttipahta in the northern boreal zone in Finland. *Global Biogeochemical Cycles* 16: 1–17.

- Huttunen JT, Alm J, Liikanen A, Juutinen S, Larmola T, Hammar T, Silvola J, Martikainen PJ. 2003. Fluxes of methane, carbon dioxide and nitrous oxide in boreal lakes and potential anthropogenic effects on the aquatic greenhouse gas emissions. *Chemosphere* 52: 609–621.
- [IEA Hydropower] International Energy Agency Technology Collaboration Programme on Hydropower. 2012. Annex XII: Hydropower and the Environment Task 1: Managing the Carbon Balance of Freshwater Reservoirs (2007–Present). IEA Hydropower. (23 August 2016; [www.ieahydro.org/annex-xii-hydropower-and-the-environment](http://www.ieahydro.org/annex-xii-hydropower-and-the-environment))
- Jacinthe PA, Filippelli GM, Tedesco LP, Raftis R. 2012. Carbon storage and greenhouse gases emission from a fluvial reservoir in an agricultural landscape. *Catena* 94: 53–63.
- Jammet M, Crill P, Dengel S, Friborg T. 2015. Large methane emissions from a subarctic lake during spring thaw: Mechanisms and landscape significance. *Journal of Geophysical Research: Biogeosciences* 120: 1–17.
- Kemenes A, Forsberg BR, Melack JM. 2007. Methane release below a tropical hydroelectric dam. *Geophysical Research Letters* 34 (art. L12809).
- Kemenes A, Forsberg BR, Melack JM. 2011. CO<sub>2</sub> emissions from a tropical hydroelectric reservoir (Balbina, Brazil). *Journal of Geophysical Research: Biogeosciences* 116 (art. G03004).
- Kiene RP. 1991. Production and consumption of methane in aquatic systems. Pages 111–146 in Rogers JE, Whitman WB, eds. *Microbial Production and of Greenhouse Gases: Methane, Nitrogen Oxides, and Halomethanes*. American Society for Microbiology.
- Knoll LB, Vanni MJ, Renwick WH, Dittman EK, Gephart JA. 2013. Temperate reservoirs are large carbon sinks and small CO<sub>2</sub> sources: Results from high-resolution carbon budgets. *Global Biogeochemical Cycles* 27: 52–64.
- Lehner B, et al. 2011. High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment* 9: 494–502.
- Li S, Zhang Q. 2014. Carbon emission from global hydroelectric reservoirs revisited. *Environmental Science and Pollution Research* 21: 13636–13641.
- Li S, Zhang Q, Bush RT, Sullivan LA. 2015. Methane and CO<sub>2</sub> emissions from China's hydroelectric reservoirs: a new quantitative synthesis. *Environmental Science and Pollution Research* 22: 5325–5339.
- Lu F, et al. 2011. Preliminary report on methane emissions from the Three Gorges Reservoir in the summer drainage period. *Journal of Environmental Sciences* 23: 2029–2033.
- Maeck A, DelSontro T, McGinnis DF, Fischer H, Flury S, Schmidt M, Fietzek P, Lorkel A. 2013. Sediment trapping by dams creates methane emission hot spots. *Environmental Science and Technology* 47: 8130–8137.
- Maeck A, Hofmann H, Lorke A. 2014. Pumping methane out of aquatic sediments: Ebullition forcing mechanisms in an impounded river. *Biogeosciences* 11: 2925–2938.
- Matthews CJ, Joyce EM, Louis VLS, Schiff SL, Venkiteswaran JJ, Hall BD, Bodaly RA, Beaty KG. 2005. Carbon dioxide and methane production in small reservoirs flooding upland boreal forest. *Ecosystems* 8: 267–285.
- McCrackin ML, Elser JJ. 2011. Greenhouse gas dynamics in lakes receiving atmospheric nitrogen deposition. *Global Biogeochemical Cycles* 25: 1–12.
- McGinnis DF, Greinert J, Artemov Y, Beaubien SE, Wüest A. 2006. Fate of rising methane bubbles in stratified waters: How much methane reaches the atmosphere? *Journal of Geophysical Research: Biogeosciences* 111: 1–15.
- Melton JR, et al. 2013. Present state of global wetland extent and wetland methane modelling: Conclusions from a model inter-comparison project (WETCHIMP). *Biogeosciences* 10: 753–788.
- Mendonça RF, Kosten S, Sobek S, Barros N, Cole JJ, Tranvik L, Roland F. 2012. Hydroelectric carbon sequestration. *Nature Geoscience* 5: 838–840.
- Michmerhuizen CM, Striegl RG, McDonald ME. 1996. Potential methane emission from north-temperate lakes following ice melt. *Limnology and Oceanography* 41: 985–991.
- Morales-Pineda M, Cózar A, Laiz I, Úbeda B, Gálvez JÁ. 2014. Daily, biweekly, and seasonal temporal scales of CO<sub>2</sub> variability in two stratified Mediterranean reservoirs. *Journal of Geophysical Research: Biogeosciences* 119: 509–520.
- Myhre G, et al. 2013. Anthropogenic and natural radiative forcing. Pages 659–708 in TF Stocker, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, eds. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Narvenkar G, Naqvi SWA, Kurian S, Shenoy DM, Pratihary AK, Naik H, Patil S, Sarkar A, Gauns M. 2013. Dissolved methane in Indian freshwater reservoirs. *Environmental Monitoring and Assessment* 185: 6989–6999.
- O'Connor JE, Duda JJ, Grant GE. 2015. 1000 dams and counting. *Science* 348: 496–497.
- Ostrovsky I, McGinnis DF, Lapidus L, Eckert W. 2008. Quantifying gas ebullition with echosounder: The role of methane transport by bubbles in a medium-sized lake. *Limnology and Oceanography: Methods* 6: 105–118.
- Pacheco F, Roland F, Downing J. 2013. Eutrophication reverses whole-lake carbon budgets. *Inland Waters* 4: 41–48.
- Pacheco FS, Soares MCS, Assireu AT, Curtarelli MP, Abril G, Stech JL, Alvalá PC, Ometto JP. 2015. The effects of river inflow and retention time on the spatial heterogeneity of chlorophyll and water–air CO<sub>2</sub> fluxes in a tropical hydropower reservoir. *Biogeosciences* 12: 147–162.
- Peltola O, Mammarella I, Haapanala S, Burba G, Vesala T. 2013. Field inter-comparison of four methane gas analyzers suitable for eddy covariance flux measurements. *Biogeosciences* 10: 3749–3765.
- Podgrajsek E, Sahlée E, Rutgersson A. 2014. Diurnal cycle of lake methane flux: Diurnal cycle of lake methane flux. *Journal of Geophysical Research: Biogeosciences* 119: 236–248.
- . 2015. Diel cycle of lake–air CO<sub>2</sub> flux from a shallow lake and the impact of waterside convection on the transfer velocity. *Journal of Geophysical Research: Biogeosciences* 120: 29–38.
- Rantakari M, Kortelainen P. 2005. Interannual variation and climatic regulation of the CO<sub>2</sub> emission from large boreal lakes. *Global Change Biology* 11: 1368–1380.
- Rasilo T, Prairie YT, del Giorgio PA. 2015. Large-scale patterns in summer diffusive CH<sub>4</sub> fluxes across boreal lakes, and contribution to diffusive C emissions. *Global Change Biology* 21: 1124–1139.
- Raymond PA, et al. 2013. Global carbon dioxide emissions from inland waters. *Nature* 503: 355–359.
- Rudd JWM, Hamilton RD. 1978. Methane cycling in a eutrophic shield lake and its effects on whole lake metabolism. *Limnology and Oceanography* 23: 337–348.
- Sayers MJ, et al. 2015. A new method to generate a high-resolution global distribution map of lake chlorophyll. *International Journal of Remote Sensing* 36: 1942–1964.
- Stanley EH, Casson NJ, Christel ST, Crawford JT, Loken LC, Oliver SK. 2016. The ecology of methane in streams and rivers: Patterns, controls, and global significance. *Ecological Monographs* 86: 146–171.
- St. Louis VL, Kelly CA, Duchemin É, Rudd JW, Rosenberg DM. 2000. Reservoir surfaces as sources of greenhouse gases to the atmosphere: A global estimate. *BioScience* 50: 766–775.
- Sturm K, Yuan Z, Gibbes B, Werner U, Grinham A. 2014. Methane and nitrous oxide sources and emissions in a subtropical freshwater reservoir, South East Queensland, Australia. *Biogeosciences* 11: 5245–5258.
- Teodoru CR, et al. 2012. The net carbon footprint of a newly created boreal hydroelectric reservoir. *Global Biogeochemical Cycles* 26 (art. GB2016).
- Thornton KW, Kimmel BL, Payne FE, eds. 1990. *Reservoir Limnology: Ecological Perspectives*. Wiley.
- Tian H, et al. 2015. Global methane and nitrous oxide emissions from terrestrial ecosystems due to multiple environmental changes. *Ecosystem Health and Sustainability* 1: 1–20.

- [UNESCO-IHA] International Hydropower Association, United Nations Educational, Scientific, and Cultural Organization. 2010. GHG Measurement Guidelines for Freshwater Reservoirs. IHA. (23 August 2016; [www.hydropower.org/ghg-measurement-guidelines](http://www.hydropower.org/ghg-measurement-guidelines)).
- . 2012. GHG Risk Assessment Tool (Beta Version) User Manual. IHA. (23 August 2016; [www.ceeg.uqam.ca/Prairie/Publications\\_files/USER%20MANUAL-Risk%20Assessment%20Tool%20-%20BetaVersion.pdf](http://www.ceeg.uqam.ca/Prairie/Publications_files/USER%20MANUAL-Risk%20Assessment%20Tool%20-%20BetaVersion.pdf)).
- Utsumi M, Nojiri Y, Nakamura T, Nozawa T, Otsuki A, Takamura N, Watanabe M, Seki H. 1998. Dynamics of dissolved methane and methane oxidation in dimictic Lake Nojiri during winter. *Limnology and Oceanography* 43: 10–17.
- Varadharajan C, Hermosillo R, Hemond HF. 2010. A low-cost automated trap to measure bubbling gas fluxes. *Limnology and Oceanography Methods* 8: 363–375.
- Varis O, Kumm M, Härkönen S, Huttunen JT. 2012. Greenhouse gas emissions from reservoirs. Pages 69–94 in Tortajada C, Altinbilek D, Biswas AK, eds. *Impacts of Large Dams: A Global Assessment*. Springer.
- Verpoorter C, Kutser T, Seekell DA, Tranvik LJ. 2014. A global inventory of lakes based on high-resolution satellite imagery. *Geophysical Research Letters* 41: 6396–6402.
- West WE, Coloso JJ, Jones SE. 2012. Effects of algal and terrestrial carbon on methane production rates and methanogen community structure in a temperate lake sediment: Methanogen response to trophic change. *Freshwater Biology* 57: 949–955.
- West WE, Creamer KP, Jones SE. 2015a. Productivity and depth regulate lake contributions to atmospheric methane: Lake productivity fuels methane emissions. *Limnology and Oceanography* 54: 2298–2314.
- West WE, McCarthy SM, Jones SE. 2015b. Phytoplankton lipid content influences freshwater lake methanogenesis. *Freshwater Biology* 60: 2261–2269.
- Whiting GJ, Chanton JP. 1993. Primary production control of methane emission from wetlands. *Nature* 364: 794–795.
- Wik M, Thornton BF, Bastviken D, Uhlbäck J, Crill PM. 2016. Biased sampling of methane release from northern lakes: A problem for extrapolation. *Geophysical Research Letters* 43: 1256–1262.
- Yang L, Lu F, Zhou X, Wang X, Duan X, Sun B. 2014. Progress in the studies on the greenhouse gas emissions from reservoirs. *Acta Ecologica Sinica* 34: 204–212.
- Yang M, Geng X, Grace J, Lu C, Zhu Y, Zhou Y, Lei G. 2014. Spatial and seasonal CH<sub>4</sub> flux in the littoral zone of Miyun Reservoir near Beijing: The effects of water level and its fluctuation. *PLOS ONE* 9 (art. e94275).
- Yvon-Durocher G, Allen AP, Bastviken D, Conrad R, Gudasz C, et al. 2014. Methane fluxes show consistent temperature dependence across microbial to ecosystem scales. *Nature* 507: 488–491.
- Zarfl C, Lumsdon AE, Berlekamp J, Tydecks L, Tockner K. 2015. A global boom in hydropower dam construction. *Aquatic Sciences* 77: 161–170.
- Zohary T, Ostrovsky I. 2011. Ecological impacts of excessive water level fluctuations in stratified freshwater lakes. *Inland Waters* 1: 47–59.

---

*Bridget R. Deemer (bdeemer@wsu.edu) and John A. Harrison are affiliated with the School of the Environment at Washington State University, in Vancouver. Siyue Li is with the Chongqing Institute of Green and Intelligent Technology at the Chinese Academy of Sciences, in Chongqing, China. Jake J. Beaulieu is affiliated with the US Environmental Protection Agency's Office of Research and Development and National Risk Management Research Laboratory, in Cincinnati, Ohio. Tonya DelSontro is with the Department of Biological Sciences at the University of Québec at Montréal, in Canada, and was formerly at the Swiss Federal Institute of Aquatic Science and Technology (Eawag), Kastanienbaum, Switzerland. Nathan Barros is affiliated with the Institute of Biological Sciences at the Federal University of Juiz de Fora, in Minas Gerais, Brazil. José F. Bezerra-Neto is with the Institute of Biological Sciences at the Federal University of Minas Gerais, in Belo Horizonte, Minas Gerais, Brazil. Stephen M. Powers is with the School of the Environment and the Center for Environmental Research, Education, and Outreach at Washington State University, in Pullman. Marco A. dos Santos is with the Energy Planning Program, COPPE, and Centro de Tecnologia at the Federal University of Rio de Janeiro, in Brazil. J. Arie Vonk is affiliated with the Department of Aquatic Environmental Ecology of the Institute for Biodiversity and Ecosystem Dynamics at the University of Amsterdam, in The Netherlands.*

*Mr. Chairman*

My name is Melissa Birchard and I represent Conservation Law Foundation. Thank you for the opportunity to speak tonight.

Conservation Law Foundation is a regional membership-based organization that uses the law, science, and the markets to develop innovative, pragmatic solutions to some of New England's greatest challenges.

Consistent with its mission to promote thriving, resilient communities, CLF is dedicated to advancing solutions that strengthen New England's – and New Hampshire's – environmental and economic vitality.

CLF and its members are concerned that the Northern Pass transmission line as currently proposed has far too many negative impacts on the state of New Hampshire – its landscapes, its communities, and an energy future built on efficiency and clean local renewables.

At the DOE, CLF has advocated for a comprehensive environmental impact statement that would assess regional need and the various projects proposed or under development that could serve the same or similar goals that this project purports to serve. CLF continues to believe that there are sound alternatives to the ~~proposed project~~ <sup>project as proposed</sup>, and that the ~~mandates of the National Environmental Policy Act and the Site Evaluation Committee~~ <sup>do not necessitate the</sup> review ~~require those alternatives to be~~ <sup>necessitate the</sup> rigorously and objectively considered ~~at all~~ <sup>of those alternatives</sup>.

CLF is particularly concerned that New Hampshire needs to focus its energy and resources on the development of local, renewable technologies. We ~~are~~ <sup>are</sup> disappointed that the draft EIS ~~gives~~ <sup>gave</sup> energy efficiency and renewable power such short shrift. ~~has given~~ <sup>has given</sup>

We are also ~~disappointed~~ <sup>dismayed</sup> that utilities like Eversource ~~seek~~ <sup>will</sup> to undermine lesser-impacting energy alternatives like rooftop solar while

1726-1

Thank you for your comment. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. Additionally, seventeen alternatives were considered but eliminated from detailed analysis. Section 2.4 of the final EIS has been updated with additional information on alternatives considered but eliminated from detailed analysis. A power generation alternative was considered but was eliminated from detailed analysis in the EIS because it is not a reasonable alternative. Section 2.4.8 of the final EIS has been updated with additional information about this alternative. Section 1.4 of the final EIS has been updated to include new information on market trends and energy use, including demand-side management and energy efficiency, since the draft EIS was published in 2015.

1726-1

claiming that big, cross-border high-voltage transmission lines are an inevitability.

*As for the draft EIS*

Although it is excessively narrow in its consideration of alternatives to the project, <sup>the draft EIS</sup> does consider a range of feasible burial options. <sup>CLP is concerned that</sup> Absent burial, <sup>such</sup> the proposed project remains fatally flawed by the inequity that it imposes on the state of New Hampshire.

While the project Applicants suggest that climate change, unit retirements, and <sup>overreliance on natural gas</sup> fluctuating energy prices necessitate the project as proposed, that is not the case. There are alternatives <sup>to the proposed project,</sup> with lesser impacts on the state of New Hampshire and the region. <sup>Importantly, there are alternatives</sup>

*Thank you very much.*

1726-2

Thank you for your comment. Socioeconomic impacts are addressed in the EIS within Section 4.1.2. The EIS also includes an analysis of potential disproportionate impacts on minority and low-income residents of New Hampshire (see Section 4.1.9 of the EIS). The range of alternatives evaluated does include the No Action Alternative under which the Project would not be approved which is responsive to the commenter's concern that the Project is inequitable to NH. DOE determined that other transmission projects, power generation alternatives, and energy conservation do not meet the purpose and need for DOE's action. The EIS analyzes in detail the potential environmental impacts of a No Action Alternative and eleven action alternatives. Under the No Action Alternative, it is assumed that existing energy sources, including distributed generation and alternative energy generation, would continue to supply the ISO-NE region and that energy efficiency measures would continue.

1726-2

1726-3

1726-3

Thank you for your comment. Executive Order (EO) 10485, as amended by EO 12038, "requires that executive permission be obtained for the construction and maintenance at the borders of the United States of facilities for the exportation or importation of electric energy." DOE is authorized to "receive applications for the construction, operation, maintenance, or connection, at the borders of the United States, of facilities for the transmission of electric energy between the United States and a foreign country[,]" and "[u]pon finding the issuance of the permit to be consistent with the public interest, and, after obtaining the favorable recommendations of the Secretary of State and the Secretary of Defense thereon, to issue to the applicant, as appropriate, a permit for [the] construction, operation, maintenance, or connection." (EO 10485). DOE's purpose and need reflects this limited authority. As discussed in Section 1.4 of the EIS, Northern Pass set forth a range of project objectives and benefits in its permit application. DOE and the cooperating agencies reviewed this documentation and determined that the project objectives include addressing three primary needs concerning New England's electricity supply: diverse, low-carbon, non-intermittent electricity. While DOE's authority is limited to the approval or denial of the amended Presidential permit application (August 2015) as requested by the Applicant, DOE's policy is to analyze not only the proposed border crossing, but also the alignment of new infrastructure required between the proposed border crossing and connection to the existing U.S. electricity system as a connected action. In keeping with this policy, DOE

analyzed the potential environmental impacts of the alignment proposed by the Applicant. In addition, in response to input from Cooperating Agencies, other agencies, and extensive public comment, DOE analyzed a range of other alignments and underground and overhead configurations between the proposed border crossing and connection with the existing U.S. electricity system. The EIS analyzes in detail the No Action Alternative and eleven action alternatives. Additionally, seventeen alternatives were considered but eliminated from further detailed analysis.