Canadian-US Project towards an International Nitrogen Management System

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Abstract
Bellingham Bay and the Nooksack River Basin will provide the test case for an international nitrogen (N) management system for North America. Spanning a portion of the western interface of the U.S. and Canada, the region supports intensive agriculture, freshwater and estuarine fisheries, diverse wildlife, cities and towns, and to the east, North Cascades National Park that is protected by the US Wilderness Acts. Using abundant data and model activities from a well-established scientific community, our project seeks to create knowledge, build regional capacity, and forge collaborations toward creation of regional N management solutions that protect or restore ecosystems and human health affected by excess reactive N while maintaining a vibrant agricultural community.

Key Words
Agriculture, groundwater, estuaries, water quality, air quality

Introduction
An International Nitrogen Management System has been proposed by the International Nitrogen Initiative to bring scientific evidence together to inform policies of the benefits and threats of reactive nitrogen. This four-year program will build on existing networks and develop new collaborations to improve N management and cooperation between science and policy across nations. As part of this, the US and Canada will collaborate on a demonstration project centered on the Nooksack River basin near the border of the State of Washington (WA) and the Province of British Columbia (BC) (Figure 1). This location presents a good opportunity for international collaborative effort because of abundant scientific data and connections between scientists and stakeholders, including Canada, U.S., and native Nooksack and Lummi nations residing in Whatcom County, WA. There are other well-studied areas in the US but this presents an opportunity to develop new international collaboration in an area with nitrogen-sensitive terrestrial, groundwater, rivers and coastal systems. The project can serve as an example of science-based international policy development. Our work will include knowledge synthesis, capacity building among stakeholders, economic analysis, and collaboration across international boundaries, inclusive of scientists, practitioners, and managers of different sectors in the region.

The focus of the Nooksack-Nitrogen Assessment and Management Program (Nooksack-NAMP) is the Nooksack River basin in Whatcom County WA. Intensive agriculture including dairy, poultry, field grass, field corn, berries, potatoes, and other diverse horticultural and amenity crops in British Columbia and the US are sources of high N concentrations in the river and groundwater (Schindler et al. 2006, Wise and Johnson 2011). High N is a cause for concern among residents concerned with subsistence fisheries, environmental and human health. Nitrogen induced harmful algal blooms are an emerging concern. They impact human health through direct (impaired water uses) and indirect (shellfish poisoning) pathways. Tribal interest in this topic is growing rapidly due to the potential lethal effect of toxins on migrating salmon. The Nooksack River originates within the Cascade Mountains and drains approximately 2,050 km^2. Below the confluence of three tributaries, the river drains the Puget Sound Lowlands province. Population density in the basin is low, with 0–50 people per square mile and some population centers of 51–250 people per square mile. The basin has a maritime climate with cool winters with abundant precipitation between October and May. The headwaters receive most precipitation as snow. Summers are mild with reduced precipitation. Land cover is dominated by high-altitude mountains with glaciers, snowfields, and forests (75%) and contains a portion of the North Cascades National Park. Agriculture covers 22%; remaining land cover is urban/suburban, dominated by the city of Bellingham, WA. While overland flow from the intensive

agriculture in the lower watershed accounts for much of the instream N load, groundwater also adds N to lowland streams. In the Abbotsford-Sumas aquifer, 29% of groundwater wells sampled exceeded the maximum drinking water standard level of 10 mg L^{-1} NO_3^- -N (Carey and Cummings 2013). The aquifer is used for irrigation as well as domestic purposes in both BC and WA.

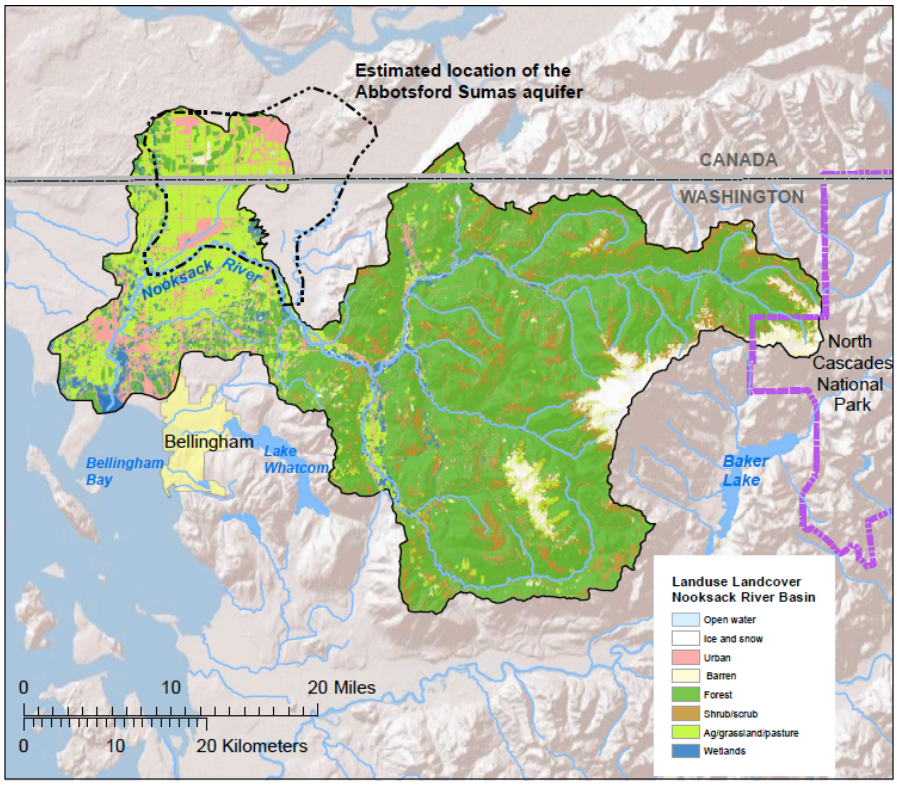

Figure 1. The Nooksack River flows east to west toward Bellingham Bay in northern Washington and southern British Columbia. The Abbotsford-Sumas aquifer (dashed lines) is linked. Agriculture dominates the lower elevations of the basin (map source: Washington Water Science Center, USGS)

Methods

Anticipated to take place over a four-year period, the demonstration project will assemble an up-to-date regional nitrogen budget, a temporally and spatially resolved ammonia emission inventory and atmospheric model, an evaluation of the benefits and threats of nitrogen in the region to the economy, environment, and human health, and a description of potential future nitrogen loads under possible management scenarios framed with stakeholders. These are described in more detail below. The immediate product of this project is a document that can be used to support multi-national policy development aimed toward reducing N loss to the region in forms that affect environmental and human health. However, it is hoped the project will enable research to test and quantify the effects of specific management actions, provide support for additional environmental effects monitoring and research, offer and build support for best management practices within the agricultural community, and generate educational opportunities for students and scientific publications.

Nitrogen budget. Sources, transport mechanisms, and fate of nitrogen in the Nooksack Basin will be compiled from existing data sources and analyzed with the use of models such as SPARROW (Spatially-Referenced Regressions on Watershed Attributes; Wise et al. 2011), SWAT (Soil and Water Assessment Tool; http://swat.tamu.edu/), DayCent (Parton et al. 1998), and CMAQ (Community Modeling of Air Quality; https://www.cmascenter.org/cmaq/). A partial list of available data shows the abundance of existing information (Table 1). Gaps in the N budget that might need to be estimated include N imports and exports, discharge from municipal and industrial wastewater treatment plants, estimates of organic N emissions and deposition (Sobota et al. 2013). Cross-border transfers of N will be calculated. Community involvement will drive decisions on cost effective and socially acceptable solutions by addressing contributions and management options from agriculture, urban wastewater and stormwater.

Table 1. Some data and model results available for the demonstration project for the Nooksack-NAMP. EPA: Environmental Protection Agency; USGS: U.S. Geological Survey; WSDA: Washington State Department of Agriculture; USDA: U.S. Department of Agriculture; NRCS: Natural Resource Conservation Service

Data or simulations	Location	Years	Source	Notes
Groundwater NO_3 concentrations	Abbotsford Aquifer, Canada and US	2000-2012	Env. Canada; Simon Fraser Univ; Univ Calgary; Agriculture and Agri-Food Canada;	Water supply for Sumas WA, Abbotsford BC, private wells, hatcheries, agriculture, industry
Groundwater well N, fertilizer and manure N inputs	Washington State		EPA; USGS; WSDA	
Groundwater chemistry	Whatcom County	Since 1992	USGS,	Part of Puget Sound Basin National Water Quality Assessment
U.S. county level N use and crops, N balance and ag. census data	Nooksack watershed	2012	Internat'l Plant Nutrition Institute,	
Water quality	Whatcom County edge of field	2015	Whatcom Countty Conservation District, USDA NRCS;	
Water quality	Puget Sound	2004-2013; 2015	USGS	Nutrient process work, Bertrand Cr. with continuous NO_3 and DO sensors
SPARROW watershed model	Pacific NW	2013	USGS	Atmospheric deposition, fertilizer, manure, point source discharge, N fixation in forests
N budget, 4X4 km grid (calculated)	Lower Fraser Valley	2005	Agriculture and Agri-Food Canada	Fertilizer use, crop removal, manure production and application, NH_3 emissions
Ag census data	Puget Sound	2007	USDA	
Ag nutrient use, BMP information	Whatcom County	Ongoing	WSDA	
Air quality, NH_3 emission inventory	Lower Fraser Valley	2002 and ongoing	Env. Canada, Agriculture and Agri-Food Canada	
Modeled wet+dry Atmospheric N deposition	Puget Sound	2006, 2012	CMAQ, EPA	
Weekly wet deposition	North Cascades National Park	1984-present	NADP/NTN	
N inventory for US assessment	Nooksack and Fraser watersheds	1990-2000s	Sobota et al. 2013	

Discussion

Benefits and threats of N to economy, environment, human health. We will address ecosystem services affected by N (Compton et al. 2011, Blett et al. 2016, Wahl et al. 2013), including water quality for fisheries, biodiversity, and recreation, potable groundwater, shellfish productivity, air quality and air quality related values in North Cascades National Park. Economic analysis of different management approaches, including on farm, municipal, in-stream or riparian, and estuarine, will be augmented with sociological assessments of acceptable practices to develop feasible management strategies. By accounting for effects of reactive N on multiple ecosystem services we hope to provide a full picture of value, damages, and abatement costs for this region.

Current N management. All future N management plans will be inclusive of stakeholders. Community meetings will include stakeholders from conservation districts, municipalities, Western Washington

University, federal, state, provincial, and tribal leaders, all participating groups will learn of current nitrogen management practices and concerns.

Future N management scenarios. The consequences of different management strategies on air and water quality can be estimated with models. An integrated system linking water quality goals with climate and water quality data and water quality models including SWAT, SPARROW, and the DayCent (Parton et al. 1998) models has recently been developed as part of the CLEAN Center at Colorado State University (https://erams.com/clean/) to analyze the effects of multiple agricultural conservation practices in order to determine which ones provide the most water quality protection or restoration. Our project may adopt a similar approach for projections to 2050.

Conclusion

N management efforts will take place at the international policy level, with opportunities through the Convention on Long-Range Trans boundary Air Pollution, Convention on Biodiversity, International Joint Commission, for example. Through a coordinated science support system, we also will build N literacy in the region. We recognize change takes time, but through knowledge sharing, common goals, evaluation of best management practices, and a community-driven effort to reduce impacts, and realistic N reduction goals, we anticipate changes in N management and improvements in water and air quality.

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