Nitrogen balance and use efficiency in the Calapooia River Watershed, Oregon, United States

Jiajia Lin[1], Susanna Pearlstein[2], Jana Compton[3], William Matthews[4], Scott Leibowitz[5]

[1] National Research Council, based at US Environmental Protection Agency, Western Ecology Division, 200 SW 35th St, Corvallis, OR 97333, Lin.jiajia@epa.gov
[2] Oak Ridge Institute for Science and Education, based at US Environmental Protection Agency, Western Ecology Division, 200 SW 35th St, Corvallis, OR 97333, Pearlstein.susanna@epa.gov
[3] US Environmental Protection Agency, Western Ecology Division, 200 SW 35th St, Corvallis, OR 97333, Compton.Jana@epa.gov
[4] Oregon Department of Agriculture, Natural Resources Division, 635 Capitol St NE, Salem, OR 97301, Wmatthews@oda.state.or.us
[5] US Environmental Protection Agency, Western Ecology Division, 200 SW 35th St, Corvallis, OR 97333, Leibowitz.Scott@epa.gov

Abstract
Reducing nitrogen (N) release into the environment through greater N use efficiencies (NUE) is a current challenge in watershed management. Examining N sources and sinks at local scales allows for better watershed-scale N use, for example when considering the tradeoffs between the uses of animal waste from Concentrated Animal Feeding Operations (CAFOs) as a resource compared with the use of synthetic fertilizers. We use data on land-use, CAFOs, N deposition, stream chemistry, and crop-level and county-level fertilizer use to assess the N inputs, exports and retention in the Calapooia River Watershed (CRW). The CRW is influenced by intensive agricultural activities, mostly in grass seed crops. We determined that at the CRW scale, annual TN export is 25% of the inputs. Nearly 48% of the total area has a net TN input of 100-200 kg N ha^{-1} yr^{-1}, dominated by agricultural land. About 41% has an input of <100 kg/ha/yr and 2.4% >200 kg N ha^{-1} yr^{-1}. Almost 50% of the annual hydrologic N yield occurs during wet winter and reaches 50 kg ha^{-1}. The minimum TN yield as low as <1 kg ha^{-1} happens in dry summer. The effect of crop type on NUE is estimated based on N retention calculation and land use data. A manure-distribution model will be built to help improve manure NUE and prevent excess fertilizer application. Information on N balances will also be combined with local groundwater and drinking water nitrate level to assess the implications of N release for water quality and human health.

Key Words
Nitrogen budget, N use efficiency, N retention, N fertilizer, CAFOs, watershed N export

Introduction
Humans have substantially altered biogeochemical cycles by introducing excess nitrogen (N) to the environment via the processes of food production, fossil fuel combustion, and point source discharge. Excess N contributes to numerous negative impacts on human health and the environment, such as eutrophication and hypoxia (Seitzinger et al., 2010; Rabalais, 2001). Significant social/economic damage is also caused by excess N and the cost of mitigation (Secchi et al., 2007). For example, it is estimated that the annual damage costs of anthropogenic N leaked to the environment for 2000 totaled $289 billion (Sobota et al., 2015). It is urgent to study the sources and inventory of environmental N in watersheds, and to develop approaches to improve the N use efficiency, particularly in agricultural regions.

As a major tributary to the Willamette River in Oregon, the Calapooia River is a major influence on water quality and stability in downstream ecosystems. It is a perennial stream originating on the western flanks of the Cascade Mountains and covers a watershed area of 963 km^2 (Figure 1). The watershed is characterized by a mountainous forested uplands and flat agricultural lowlands (Leibowitz, 2015). Agricultural land accounts for 53% of the watershed area, and forest 43%.

The purpose of this study is to better understand the impacts of natural processes and land uses on the N use efficiency of this watershed. Calculation results of total nitrogen (TN) input and export are used to quantify the amount of N transported and retained within the watershed under different land uses. Seasonal and temporal variations in TN export and proportional contribution of major N sources are also studied. We also propose to build a mathematical model to help improve the manure N use efficiency within the watershed.

Methods
N balance estimate
The inputs and outputs of TN were calculated to determine the net retention of N within the watershed over

the year. We also examined the seasonal and spatial variations in the N balance.

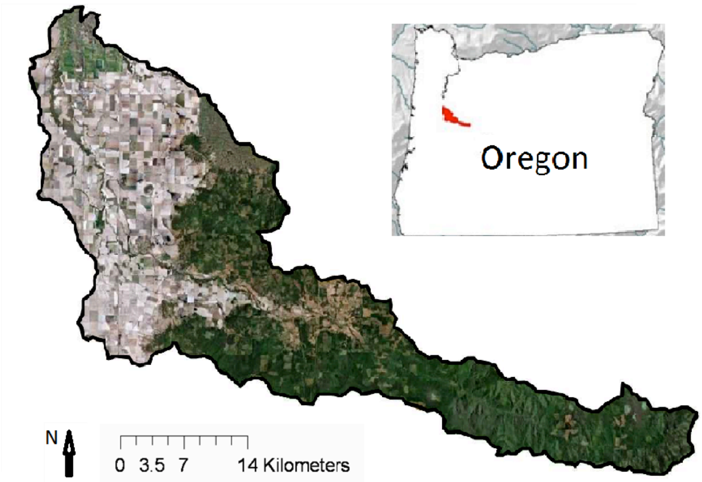

Figure 1. The Calapooia River Watershed in western Oregon, US (modified from Leibowitz, 2015). The majority of green area is mountainous forest land, and the grey area is dominated by agricultural land.

The dominant sources of N to the watershed are respectively agricultural fertilizer, non-farm fertilizer, CAFOs (Concentrated Animal Feeding Operations), agricultural Biological Nitrogen Fixation (BNF), alder BNF, point source (urban sewage), non-sewered point source, and atmospheric deposition. Data at the state level of dominant N sources from 2008 were obtained under collaborative efforts from Oregon State University and multiple US government agencies. GIS (Geographic Information System) layers were clipped to the watershed boundary of the Calapooia River, and utilized to quantify contributions of various N sources.

Stream output of total nitrogen (TN) load was calculated using LOADEST (Load Estimator) (Runkel, 2004) combining data of simulated discharge by a hybrid hydrologic model of the watershed (Leibowitz, 2015) and stream measurement of TN concentration. Water chemistry data including TN and nitrate concentration were measured at 15 mainstem and 58 tributary stations in the Calapooia River Watershed between 2003 and 2011. The hybrid hydrologic model was developed for Calapooia subbasins (Leibowitz, 2015). It uses local meteorological data with the EXP-HYDRO model (Patil and Stieglitz, 2014) plus a regression model to simulate daily stream discharge at each sampling site. The model calibration and validation generated satisfactory values of KGE (Kling-Gupta Efficiency). The TN load estimated by LOADEST were inspected and calibrated before being utilized to calculate seasonal and annual sub-watershed N export. We model the entire CRW as well as 73 sub-basins.

Nitrogen exported via plant harvest will be estimated based on land use, annual crop yield and plant N content of the harvested tissue. The belowground biomass of crops is assumed to remain in the soil. Data are acquired from US Department of Agriculture (USDA) websites.

We assume the N retention in the watershed is driven by inputs, plant uptake, soil type, and climate (precipitation), and will be calculated using the equation below:

$$N_{r,i}\% = \frac{TN_{in,i} - TN_{exp,i} - N_{harvest,i}}{TN_{in,i}} \times 100\% \qquad (1)$$

where $N_{r,i}$ is the percent of nitrogen retention in subwatershed i; $TN_{in,\,i}$ represents the total TN input at that subwatershed; $TN_{exp,i}$ is the TN exported by stream flux, and $N_{harvest,i}$ is the amount of N removed via plant harvest. The correlation between N retention and inputs, crop type, soil, and climate will be studied.

N use efficiency

Nitrogen Use Efficiency (NUE) at the watershed scale is determined by comparison between land use and N retention and the percent TN exported by streams. The percent of TN exported (Figure 2) is calculated as the ratio of stream TN output and total TN input. We will conduct statistical analyses to examine the crop N use efficiency of different crops within the sub-watersheds and the impacts on N retention and export. Currently, we are finalizing the calculation of watershed TN retention and its correlation with land use.

A manure distribution model will be developed as an approach to maximize manure NUE within the watershed before bringing in outside synthetic fertilizer. The Calapooia River Watershed is characterized by intensive grass seed planting and CAFOs: more than 40% of the watershed is covered by grass seed crops, which require a fertilizer application rate ranging between 125 kg N ha^{-1} yr^{-1} to 180 kg N ha^{-1} yr^{-1}. There are ten CAFO sites of varying size and animal type within the watershed. Based on existing CAFO records and crop data, we will build a mathematical model that will provide approaches to effectively distribute and utilize CAFO manure in order to meet local grass seed N demands. This model will provide constructive insights on how to reduce commercial fertilizer usage through enhancing manure N use efficiency, which can be achieved by a better cooperation between CAFO owners and grass seed farmers. Manure management and transport data are being gathered in collaboration with the Oregon Department of Agriculture for model construction.

Drinking water assessment
While there is no direct drinking water withdrawals from the Calapooia River, stream nitrate can have a direct impact on human health from drinking water withdrawal from groundwater. The US Environmental Protection Agency (EPA) Maximum Contaminant Level for nitrate in drinking water is 10 mg NO_3-N L^{-1}, and the action level for the state of Oregon is 7 mg NO_3-N L^{-1}. Stream NO_3-N concentrations of the Calapooia River and its tributaries often exceed this value and sometimes reach above 30 mg NO_3-N L^{-1}. With impaired stream water quality, there can be potential contamination of drinking water and damage to human health in the watershed. We will compare the stream chemistry measurement with drinking water and groundwater nitrate data collected as part of the Real Estate Transaction databased by the Oregon Public Health Department. We will assess the impact of watershed N balances on drinking water quality within the 73 study sub-watersheds.

Results

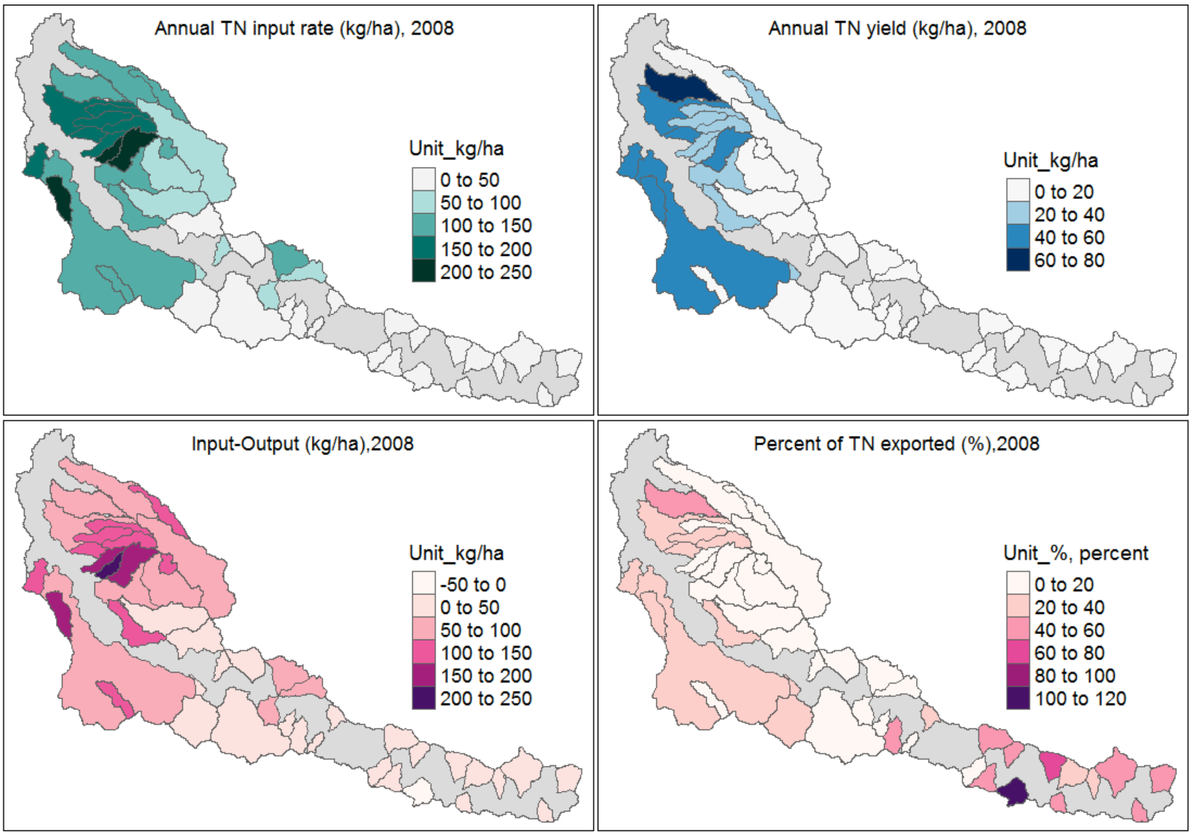

Figure 2. Calculation results of TN input and output of the subwatersheds of the Calapooia River, based on 2008 data: (upper left) the annual TN input rate (kg/ha); (upper right) the annual stream export rate of TN (kg/ha); (lower left) the difference between annual TN input and stream export; (lower right) the percent of TN exported via stream flux. The grey area represents no data.

Preliminary results of TN input and export are shown in Figure 2. Nearly 48% of the total area has a net TN input of 100-200 kg N ha^{-1} yr^{-1}, which is dominated by agricultural land. About 41% has an input of <100 kg N ha^{-1} yr^{-1}, while 2.4% receives more than 200 kg N ha^{-1} yr^{-1}. The forested mountains receive a TN input of <30 kg N ha^{-1}, with red alder (*Alnus rubra*) N fixation inputs driving the variation in forest land.

Seasonal and spatial variations in TN export are observed. Precipitation within the watershed occurs mostly from October to May as a result of the Mediterranean climate of Oregon (Leibowitz, 2015). Based on our 2008 data, dry summer TN yield is as low as <1 kg N ha^{-1}, while nearly 50% of the annual yield occurs during the wet winter, and reaches 50 kg N ha^{-1} over the season. The fraction exported ranges from 2 to >60% at the subbasin level with the highest values found at the mountainous areas. Subbasins with the greatest TN input do not correspond with areas with the highest yield. Differences in crops, riparian buffers or soil could explain the discrepancies. At the watershed scale, annual TN export is 25% of the inputs, which is considered relative high for western US watersheds (Schaefer et al., 2009).

Conclusion

Nitrogen balances within the Calapooia River Watershed can be used to understand the net fate of N as influenced by crop cultivation, harvest, export and use of N in manures from CAFOs. This assessment will provide important information for managers on N use efficiency of various crops and land use practices. The manure distribution model will provide assistance to managers for reducing the cost and application of synthetic fertilizer and for improving manure N usage.

References

Leibowitz SG. Subtask 7 of SSWR 1.1B QATP (Revision 0). Research to development methods and indicators for predicting watershed condition nationally. EPA internal Quality Assurance Project Plan, Jun. 17, 2015.

Patil S, and Stieglitz Jr. M (2014). Modelling daily streamflow at ungauged catchments: what information is necessary? Hydrological Process. 28 (3), 1159–1169.

Rabalais N (2001). Hypoxia in the Northern Gulf of Mexico: Description, causes and change. In: Coastal hypoxia: Consequences for living resources and ecosystems, EPA Science Advisory Board, pp. 1-36.

Runkel R, Crawford C, and Cohn T (2004). Load Estimator (LOADEST): A FORTRAN program for estimating constituent loads in streams and rivers. In: USGS Techniques and Methods Book 4, Chapter A5, 2004.

Schaefer S, Hollibaugh JT and Alber M (2009). Watershed nitrogen input and riverine export on the west coast of the US. Biogeochemistry93:219-233.

Secchi S, Gassman P, Jha M, Kurkalova L, Feng H, Campbell T and Kling C (2007). The cost of cleaner water: Assessing agricultural pollution reduction at the watershed scale. Journal of Soil and Water Conservation 62: 10-21.

Seitzinger S, Mayorga E, Bouwman AF, Kroeze C, Beusen AHW, Billen G, et al (2010). Global river nutrient export: A scenario analysis of past and future trends. Global Biogeochem Cycles 24, GB0A08, doi:10.1029/2009GB003587.

Sobota DJ, Compton JE, McCrackin ML, and Singh S (2015). Cost of reactive nitrogen release from human activities to the environment in the United States. Environmental Research Letters 10: doi:10.1088/1748-9362/10/2/025006.