South Puget Sound Nitrogen Loading: Magnitudes and Sources

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INTRODUCTION

Nutrient loads, particularly nitrogen, have been identified as a potential stressor to the Puget Sound ecosystem. One consequence of excessive nutrient loads is low dissolved oxygen (DO) concentrations. Field data have shown that portions of South Puget Sound violate Washington State water quality standards for DO. The Washington State Department of Ecology has initiated the South Puget Sound Dissolved Oxygen Study to study the dynamics that result in low DO concentrations and to identify nutrient loads into South Puget Sound. This study involves the development of a hydrodynamic and water quality model to assess alternative management scenarios. This in turn requires data to characterize daily nutrient loads into South and Central Puget Sound from rivers, streams, wastewater treatment plants (WWTPs), on-site septic systems, and the atmosphere.

Figure 1 shows the study area for the South Puget Sound Dissolved Oxygen Study; the model boundary extends to Central Puget Sound since nutrient loading from Central Puget Sound might affect DO concentrations in South Puget Sound.

OBJECTIVES

- Apply a statistical technique to develop daily nutrient loads from river, streams, and WWTPs from monthly field data.
- Describe the seasonal nature of nutrient loading.
- Compare nitrogen loading from South Puget Sound to loading from Central Puget Sound.
- Compare the relative contribution of nitrogen from rivers/streams, WWTPs, and atmospheric deposition.
- Communicate results to the public through creative and visual means.

Figure 1. Study area for the South Puget Sound Dissolved Oxygen Study.

METHODS

Monthly field monitoring for various water quality parameters was conducted for 15 months from July 2006 – October 2007 from a number of rivers, streams, and WWTPs within the study area. In addition, 3 or 4 months of data were collected at smaller streams and WWTPs. A statistical method called multiple linear regression was applied to the 15 months of field data to predict daily nutrient concentrations for the years 2006 and 2007. This statistical approach relates concentrations to flow , time of year, and season using a best-fit to monitoring data. The multiple linear regression equation used in this analysis is given by:

Equation 1

$$\log(C) = b_0 + b_1\log(Q) + b_2[\log(Q)]^2 + b_3\sin(2\pi f_y) + b_4\cos(2\pi f_y) + b_5\sin(4\pi f_y) + b_6\cos(4\pi f_y)$$

where: C is the observed parameter concentration (mg/L); Q is streamflow (m^3/s); f_y is the year fraction (dimensionless, varies from 0 to 1); b_i are the best-fit regression coefficients

The multiple linear regression model solves Equation 1 to determine the optimum combination of b_i coefficients that will yield the best fit between predicted and observed concentrations for each parameter of interest. In the case of rivers, the flows (Q) in Equation 1 were normalized by watershed area, and, given the order of magnitude variability in the source data between different watersheds, logarithms of concentration and flow were used. Model fit was evaluated based on the significance of the regression relationship, R^2 values, and an evaluation of residual plots.

Regression relationships developed for monitored watersheds (82% of the study area) were then extrapolated to under/unmonitored target watersheds (18% of the study area) that were in close proximity. Flows for ungaged watersheds were developed by scaling USGS flow from nearby gaged locations by the target watershed area and the average annual precipitation. Monitored WWTPs were grouped according to their size, and average nutrient concentrations in each group were applied to under/unmonitored WWTPs that fell into the same size group. In the end, we had daily flows and nutrient concentrations for every watershed and WWTP that drains or discharges into South and Central Puget Sound.

Dissolved Inorganic Nitrogen (DIN = nitrate + nitrite + ammonium) is the form of nitrogen that is of most interest. Daily DIN loads were developed by simply multiplying the daily flow by the daily concentration. DIN loading from rivers, streams, and WWTPs were compared to each other across all locations between 2006 and 2007. DIN load estimates from on-site septic systems were developed by Whiley (2010), but we found that extrapolated watershed loads were sufficient to account for on-site septic system loads.

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RESULTS

The resulting daily loads provide a better fit to monitoring data than simply using monthly averages. Overall, the multiple linear regression method performed well in providing continuous daily data throughout the study area for most parameters.

The main results show that:

- Median WWTP effluent DIN concentrations are generally an order of magnitude higher than median DIN concentrations in rivers and streams (Figures 2 and 3).
- Watersheds which contribute the largest DIN loads (> 1000 kg/d) include Lake Washington, Green River, Puyallup River, and Nisqually River (Figure 4).
- WWTPs which discharge the largest DIN loads include West Point and South King, (> 5000 kg/d), and Tacoma Central and Chambers Creek (> 1000 kg/d).
- WWTPs contribute the largest share of DIN loads during the summer (July, August, and September) and on an annual average basis (Figure 5 and 7).
- Watersheds draining into Henderson and Budd Inlets have higher DIN load contributions for their size, relative to other watersheds in the study area (Figure 6).
- During the winter months, DIN loads from rivers and WWTPs are comparable, but summer DIN loads from rivers are much less than those from WWTPs (Figure 7).
- Overall, rivers and WWTPs in Central Puget Sound contribute a much greater fraction of DIN loads than rivers and WWTPs in South Puget Sound (Figure 8).
- DIN loads from atmospheric deposition are much smaller (~1%) than those from rivers and WWTPs (Figure 9).

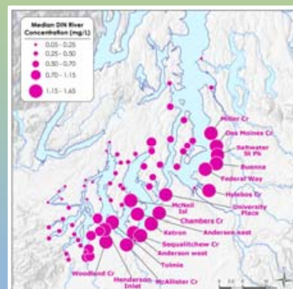

Figure 2. Median freshwater DIN concentrations for 2006-2007.

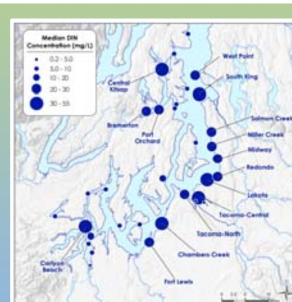

Figure 3. Median WWTP DIN concentrations for 2006-2007.

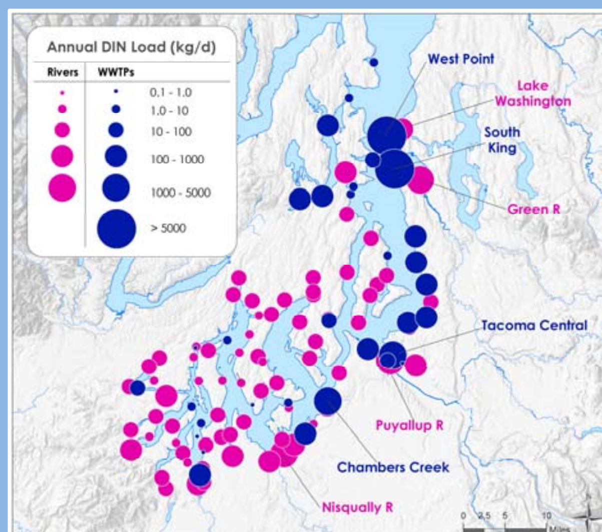

Figure 4. Comparison of annual average DIN loads during 2006-2007 from rivers and WWTPs discharging into South and Central Puget Sound

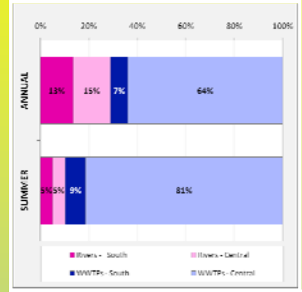

Figure 5. Mean summer and annual DIN loads from rivers & WWTPs into South & Central PS during 2006-2007.

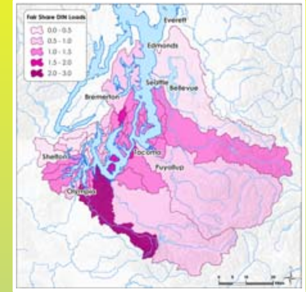

Figure 6. Annual relative DIN loads (ratio of fractional load to fractional area) from watersheds in the study area.

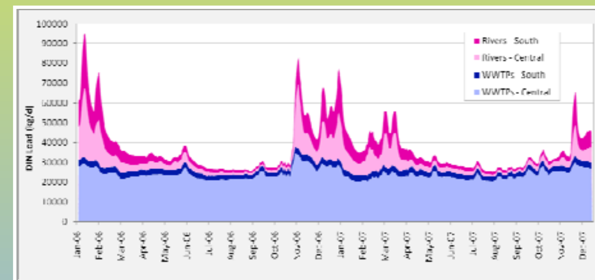

Figure 7. 7-day average of daily DIN loads from rivers and WWTPs draining/discharging into South and Central Puget Sound during 2006-2007.

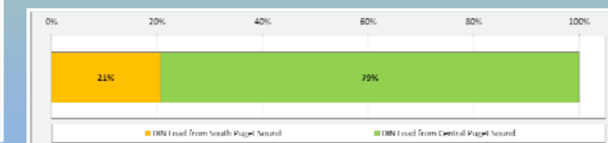

Figure 8. Comparison of annual 2006-2007 DIN loads into South and Central Puget Sound.

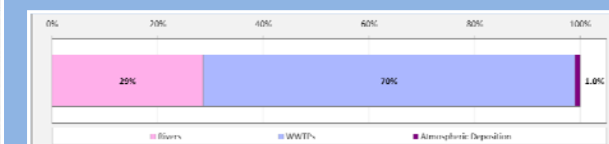

Figure 9. Comparison of annual 2006-2007 DIN Loads from rivers, WWTPs, and atmospheric deposition.

CONCLUSIONS

The continuous daily data generated for this study will be an important part of the modeling effort, and the data have enabled us to better understand the relative magnitudes and sources of nitrogen loading into South and Central Puget Sound. Relative contributions of DIN loads from rivers and WWTPs vary by season, though WWTPs are the largest source of DIN overall and during the summer, which is a critical time for DO conditions in South Puget Sound. As these data are used for the modeling effort , we will be able to better understand what happens to the nitrogen once it enters Puget Sound, how sensitive the ecosystem is to reductions in nitrogen loading, and which areas should be targeted for management actions.

REFERENCES

Roberts, Mindy, Julia Bos, Skip Albertson, 2008. South Puget Sound Dissolved Oxygen Study: Interim Data Report. Washington State Department of Ecology, Olympia, WA. Publication No. 08-03-037. www.ecy.wa.gov/biblio/0803037.html

Whiley, Tony, 2010. Technical Memorandum: Estimate of DIN loading associated with on-site wastewater systems within the South Puget Sound study area. Washington State Department of Ecology, Olympia, WA

This poster is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/1103007.html.