Estimating Groundwater Discharge and Nutrient Loading to Lynch Cove, Hood Canal, Washington

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Abstract

Low dissolved-oxygen concentrations in the waters of Hood Canal, WA (fig. 1) threaten marine life in late summer and early autumn. Eutrophication and subsequent oxygen depletion in the landward reaches of the Canal (Lynch Cove) has been linked to phytoplankton growth, which is controlled by nutrients (primarily nitrogen) that enter the Canal from various sources. Previous work has shown that seawater entering the Canal is the largest source of nitrogen; however, groundwater discharge also may contribute significant quantities, particularly during summer months (fig. 2), when increased nutrient availability in the Canal directly effects eutrophication.

The amount of nitrogen entering Hood Canal from groundwater was estimated using direct and indirect measurements of groundwater discharge, analysis of nutrient concentrations, and estimates of denitrification in near-shore sediment. In areas with confirmed groundwater discharge, shore-perpendicular electrical resistivity profiles, manual and automatic seepage-meter measurements, fiber optic distributed temperature sensors, and continuous radon measurements were used to characterize temporal variations in groundwater discharge over several tidal cycles. Although nitrogen concentrations in groundwater are generally low (average 0.5 mg N/L), the flux of groundwater discharge associated nitrogen may be large in some areas of the Hood Canal coastline.

Groundwater discharge was estimated using all methods and ranged from 2.5 to 40 cm/d in the study area. Groundwater discharge carries nitrogen loads to the marine environment ranging from 14 to 749 MT/yr. However, some of this nitrogen is attenuated by sediment denitrification. A recent pilot study of denitrification potential in the nearshore sediments indicated that sediments can remove much of this groundwater-derived nitrogen as it flows into the surface water system under ideal conditions. These data demonstrate that groundwater discharge to Hood Canal is highly variable in space and time because of the heterogeneous local geology, the variable hydraulic gradients in the groundwater system adjacent to the shoreline, and a large tidal range of 3 to 5 meters. Therefore, a more refined understanding of the nutrient loads entering Hood Canal from submarine groundwater discharge, particularly in summer, is an important component of the overall nutrient budget in this system.

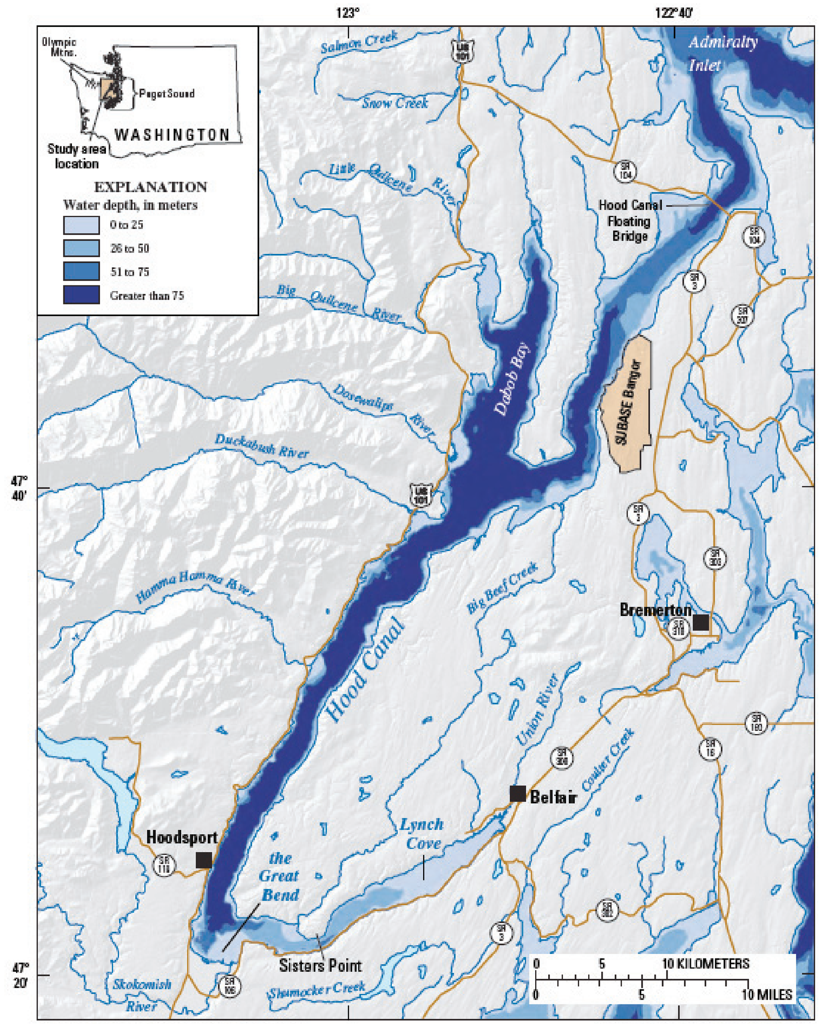

Figure 1. Location of Hood Canal on the west side of the Puget Sound lowland adjacent to the Olympic Mountains in western Washington.

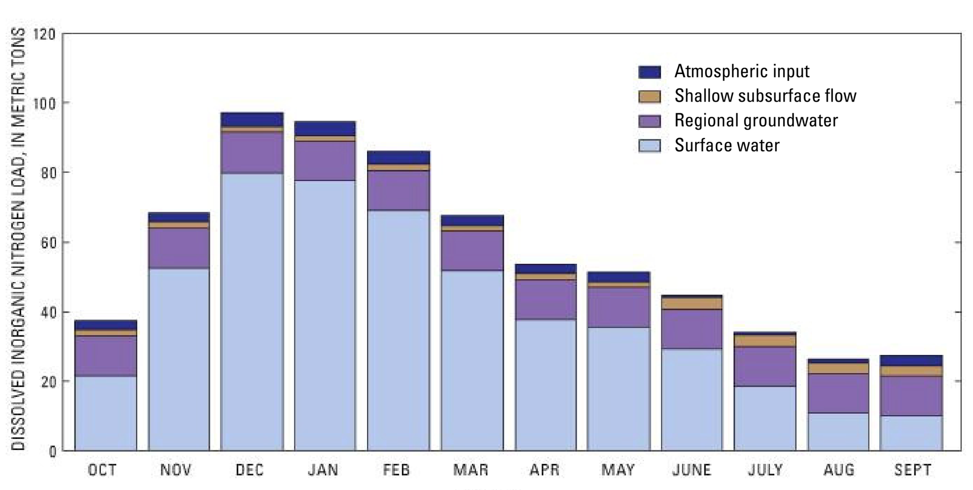

Figure 2. Breakdown by source of monthly loads to Hood Canal estimated from historical data and a regional water balance (Paulson and others, 2006).

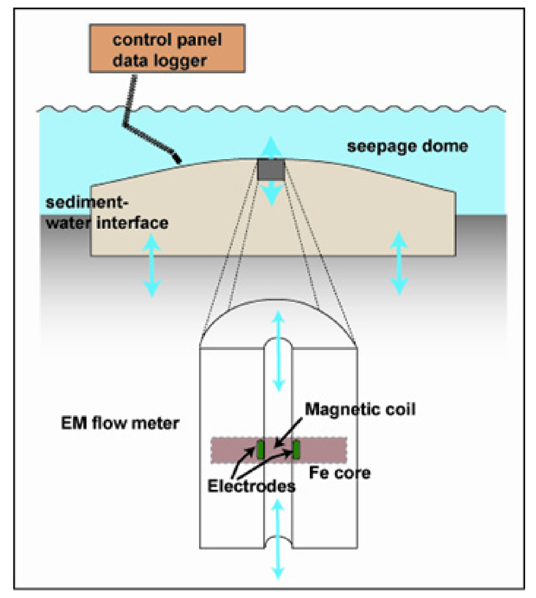

Figure 3A. Diagram of electromagnetic seepage meter. This meter allows continuous flow measurements during several tidal cycles.

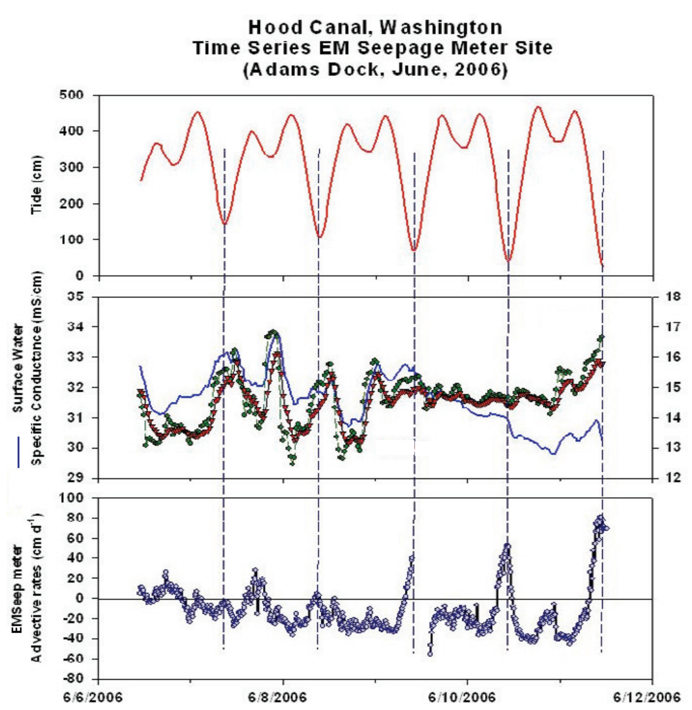

Figure 3B. Continuous flow measurements collected in 2-minute intervals during several tidal cycles.

Methods for Measuring Groundwater Discharge

Direct Groundwater Flux Measurements – Seepage Meters
Several Lee-type seepage meters were installed at each intensive site. A capture bag was used to determine the change in volume over time and to estimate groundwater flux (fig. 3). Electromagnetic (EM) seepage meters were placed in the intertidal zone at each intensive site and collected continuous data at 2-minute intervals over several tidal cycles (fig. 3A and 3B).

Indirect Groundwater Flux Measurements – Electrical Resistivity
A stationary electrical resistivity (ER) cable, 112 meters long containing 56 electrodes spaced 2 meters apart, was placed perpendicular to the shore to see how fresh water and salt water interact in the intertidal zone of Lynch Cove. A complete resistivity profile is collected about once per hour during the tidal cycle (fig. 4).

Geochemical Methods
Near-continuous radon (^{222}Rn) data were collected during both streaming (fig. 5A) and stationary (fig. 5B) deployments of a commercial radon in air detector. The amount of ^{222}Rn in a water sample is proportional to the quantity of groundwater discharge.

Denitrification Rates

A series of laboratory flask studies were conducted to assess the potential for nearshore sediments to process nitrate. Sediment was collected from approximately 30 sites along Lynch Cove and denitrification rates were estimated using the acetylene block technique. Results from these studies are pending.

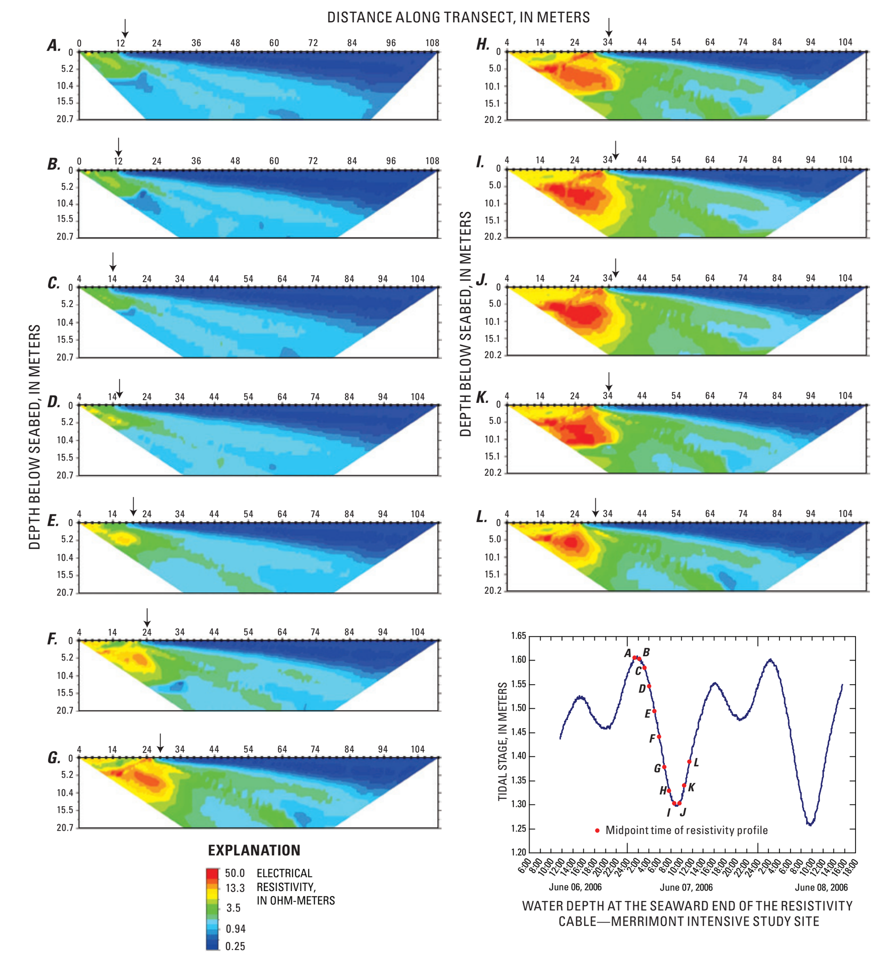

Figure 4. Electrical-resistivity profiles perpendicular to the shoreline at the Merrimont intensive study site near Sisters Point, Lynch Cove area of Hood Canal, Washington. Each profile represents a snapshot of electrical resistivity along a cross-section of the intertidal area. Colors represent electrical resistance in ohm-meters. Red colors indicate more electrically resistant freshwater, and blue colors indicate more electrically conductive saline water. Approximate position of the waterline on the beach is indicated by the arrow above the profile. The plot shows the midpoint time of the data acquisition interval relative to the tidal cycle.

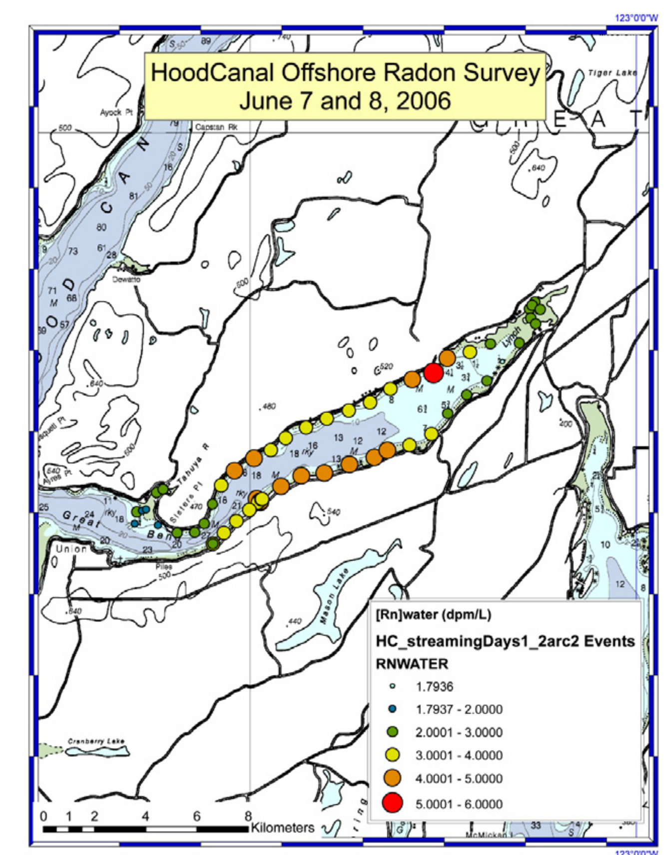

Figure 5A. Radon data from a boat survey along Lynch Cove indicating hot-spots of ground-water discharge (red).

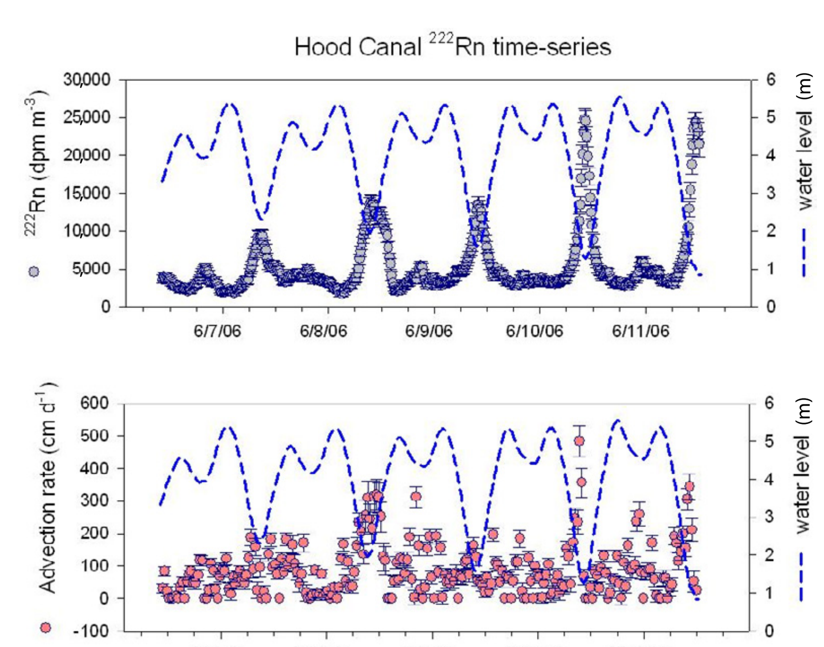

Figure 5B. Continuous radon (^{222}Rn) data and the calculated advection rates with changing tidal levels at a stationary site in Lynch Cove.

Thermal Infrared Imaging

To determine the spatial distribution of groundwater seeps along the shores of Lynch Cove, we imaged the shoreline of Lynch Cove with an airborne thermal infrared camera (7-12 micrometers wavelength) and a true-color camera at the beginning of a flood tide in September 2008. Approximately 3,500 thermal infrared (TIR) and true-color images were collected, although only one-half of the images covered the beach. Figures 6A and 6B are examples of the imagery and the corresponding visual image. The thermal-infrared camera resolved 0.1°C temperature differences and had a spatial resolution of approximately 2 meters, which easily allowed for the detection of cooler groundwater. The individual images were referenced to an open-water scene toward the west end of Lynch Cove. In the images, cooler groundwater appears dark as it flows over the exposed beach and into the warmer surface water. The side-by-side comparison of the two types of images clearly shows both the sporadic location and relative strengths of cooler water flowing into Lynch Cove. Visible in the imagery are many small ungaged streams flowing across the exposed beach, springs and groundwater discharge from alluvial fans, and cooler water flowing from beneath bulkheads in front of homes. The complete set of images available online at: http://wa.water.usgs.gov/projects/hoodcanal/seepage.htm.

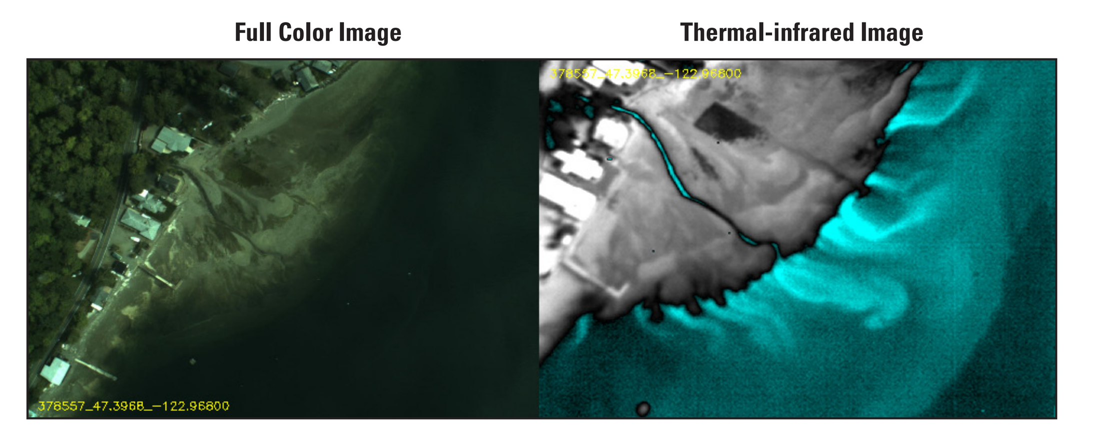

Figure 6A. A small stream flowing across an alluvial fan and multiple groundwater sources. The thermal-infrared image has been colorized to show the coldest temperatures in cyan.

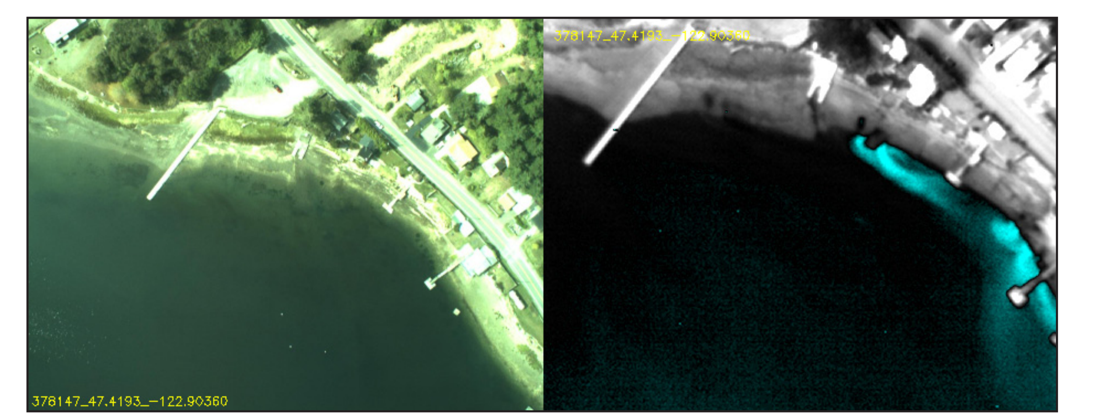

Figure 6B. The small bay where the fiber optic Distributed Temperature Sensing (DTS) was deployed (below), showing freshwater inputs along the waterfront.

Pilot Study on the use of Fiber-Optic Distributed Temperature Sensing

To determine a reliable and efficient method for identifying areas of substantial groundwater and nutrient discharge to Lynch Cove, we tested fiber-optic (DTS) technology along a stretch of the Lynch Cove shoreline that also had TIR imagery available (fig. 6B). In September 2009, we deployed about 300 meters of fiber-optic cable on the seabed parallel to the shoreline at a depth just below low-tide elevation. Using DTS technology, we measured the marine-water temperature at about 1 meter increments along the cable every 10 minutes for 3 days. The results (fig. 7) show where relatively cold (about 11° C) groundwater was discharging to Lynch Cove. These discharge locations were consistent with areas of cold water discharge indicated in the TIR imagery as well as conductivity, depth, and temperature (CTD) profiles immediately offshore of the study site (CTD data not shown here). The DTS unit is capable of monitoring temperatures along 4 kilometers of shoreline at a given time, so the technology is appropriate for identifying groundwater discharge zones over large areas.

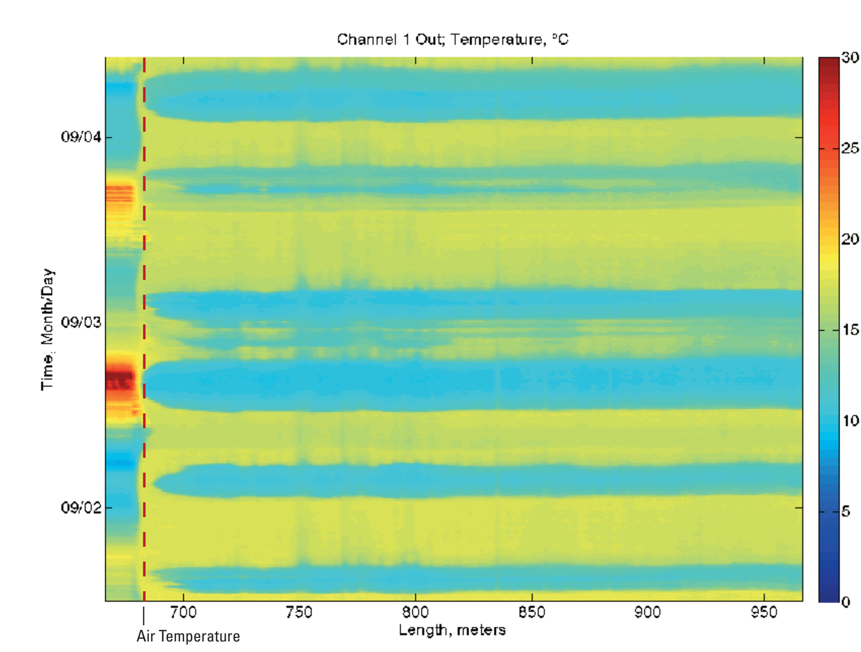

Figure 7. Temperatures measured using DTS near the Port of Allyn boat launch on Lynch Cove, Washington. The temperatures on the left (length 670 – 680 meters) are air temperature at the dock where day and night cycles predominate. The thick horizontal blue bands indicate periods of cooler water temperature that coincide with incoming tides. The blue vertical "streaks" such as those near the label 750-meter label, indicate areas where a consistent cool water source is present, likely from groundwater discharge that is keeping marine water relatively cool.

Impact on Lynch Cove

Although the estimation methods vary, groundwater input can be an important component in the nitrogen budget in Lynch Cove. This and other ungaged sources become increasingly important through the summer, combining with solar heating to produce a highly stratified surface layer. To evaluate the importance of these sources on the oceanography of Lynch Cove, we used a numerical hydrodynamic model of Hood Canal that simulated groundwater input by a series of small point sources distributed along the shoreline of Lynch Cove. The amount of flow was set by the results of our field studies. The sensitivity of Lynch Cove to this previously ignored freshwater source was evaluated by running the model with different levels of freshwater input (table 1). For all cases, the model included the climatological average flow from the Tahuya and Union Rivers (fig. 8). Preliminary results show that groundwater and small streamflows increase the stratification in the surface layers and restrict the vertical mixing in Hood Canal. When these freshwater sources are included in the model, the salinity of the surface water in Hood Canal is reduced, when compared to simulations without the freshwater sources.

Nutrient Loading to Lynch Cove

Groundwater discharge measurements across all methods were scaled up in order to estimate an annual nitrogen (N) load from groundwater (table 1). Discharge rates from each method were applied across an intertidal area representing the 5 m tidal range at the site (shaded areas in fig. 8) and multiplied by total dissolved nitrogen concentrations from numerous wells, seeps, and piezometers sampled during the study. The N loading estimates were highly variable across methods ranging from 14 to 749 MT/yr. Using a zonal approach (fig. 8), estimates of N loading from the terminus of Lynch Cove are much greater than those from the north and south shores. However, denitrification rates of the nearshore sediment can process on average 1,480 MT/yr (range 0 to 4800 MT/yr) of nitrate, implying that groundwater nitrate may not be as important as originally suspected.

Table 1. Summary of nitrogen loading into Lynch Cove from groundwater

Method	Groundwater flux (cm/day)	Nitrogen load* (MT/yr)	Reference
Regional water balance	2.5	14-47	Paulson and others, 2006
Lee-type seepage meters	5.0	28-93	Simonds and others, 2008 and unpublished data
Electromagnetic seepage meters	21.2	118-393	Simonds and others, 2008 and unpublished data
Radon-radium mass balance	40.4	231-749	Simonds and others, 2008

* Range in N loads based on range in total dissolved nitrogen (TDN) concentrations from field surveys. TDN ranged from 0.33 to 1.1 mg N/L.

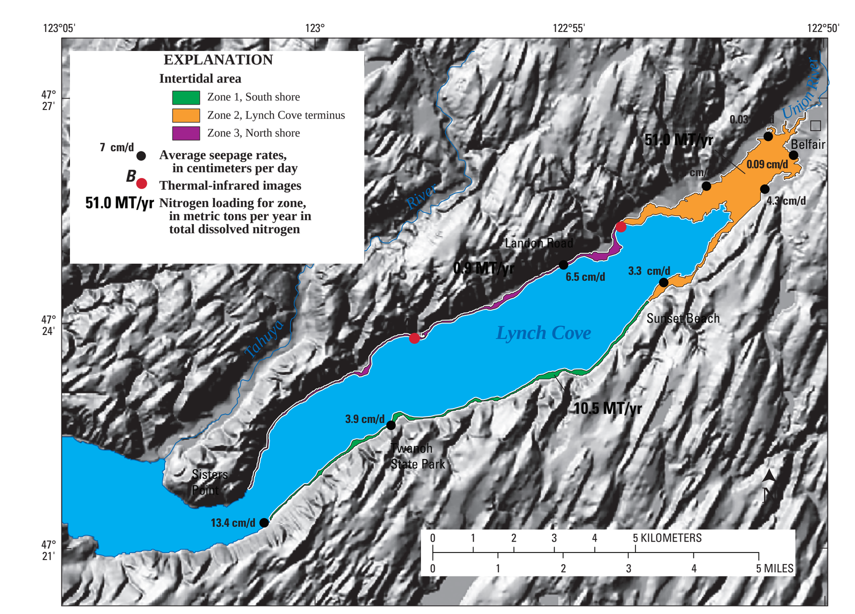

Figure 8. Estimates of nutrient loading to Lynch Cove using a Zone approach and average lee-type seepage fluxes. Intertidal areas of Lynch Cove, based on a 5-meter tidal range, are subdivided into zones representing the south shore, the terminus of Lynch Cove, and the north shore areas of Hood Canal, Washington.

References

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