Ground-Water Sources and Impacts in Lynch Cove, Hood Canal, Washington

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Abstract

Low dissolved-oxygen concentrations in the waters of Hood Canal threaten marine life in late summer and early autumn. Eutrophication in the landward reaches of the canal has been linked to phytoplankton growth, which is controlled by nutrients (primarily nitrogen) that enter the canal from various sources. Although seawater entering the canal is the largest source of nitrogen (Paulson and others, 2006), ground-water discharge also contributes significant quantities, particularly during summer months (fig. 1), when increased nutrient availability in the canal directly effects eutrophication.

The amount of nutrients entering Hood Canal from ground water was estimated using direct and indirect measurements of ground-water discharge and analysis of nutrient concentrations. Ground-water discharge to Hood Canal is variable in space and time because of local geology, the hydraulic gradient in the ground-water system adjacent to the shoreline, and a large tidal range of 3 to 5 meters. In areas with confirmed ground-water discharge, shore-perpendicular resistivity profiles, seepage-meter measurements, and continuous radon measurements were used to characterize temporal variations in ground-water discharge over several tidal cycles. Although nutrient concentrations in ground water are small (average 0.6 mg N/L), the flux of ground-water discharge may be large in some areas of the Hood Canal coastline as confirmed in some recent thermal imaging conducted in September 2008. Therefore, understanding the relative load of nutrients entering the canal from the ground-water pathway, is potentially important. Ground-water fluxes into Lynch Cove determined from these various field methods will provide needed information for modeling the circulation of Lynch Cove as well as providing estimates of nutrient loading to this sensitive area.

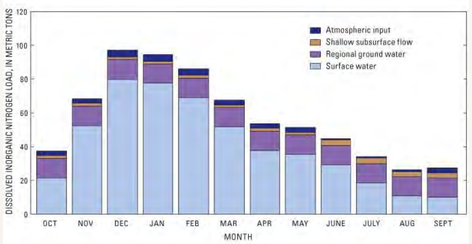

Figure 1. Breakdown by source of monthly loads to Hood Canal estimated from historical data and a regional water balance (Paulson and others, 2006.)

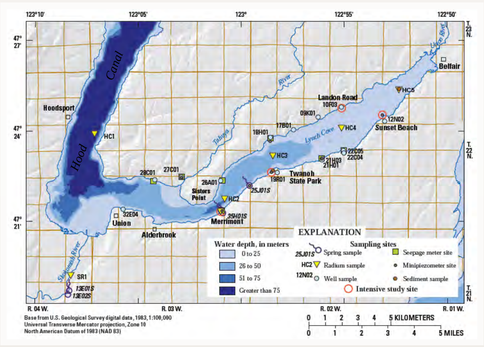

Figure 2. Location of intensive sites (red circles) where ground-water flux was estimated. Spring and well samples were used to estimate nitrogen concentration in ground water in order to calculate loads into Lynch Cove.

Figure 3. Lee-type seepage meter with capture bag attached. A known volume of water is put into the capture bag, and the change in volume over time is used to estimate ground-water flux.

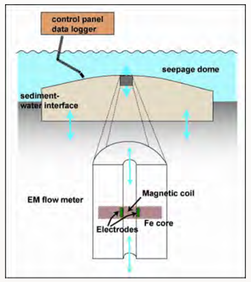

Figure 4A. Diagram of electromagnetic seepage meter. This meter allows continuous flow measurements during several tidal cycles.

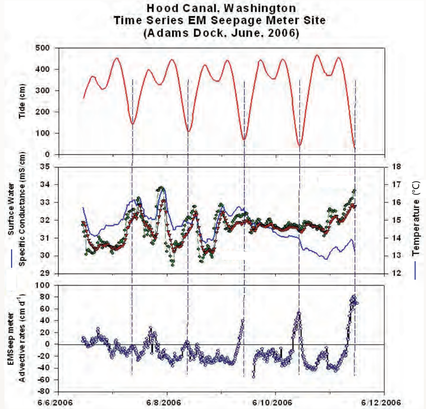

Figure 4B. Continuous flow measurements collected in 2-minute intervals during several tidal cycles.

Field Methods

Ground water discharge into Lynch Cove was estimated at four intensive field sites in 2005 and 2006 (fig. 2, red circles). At these intensive sites, several methods were used to estimate ground-water flux and nutrient loads, including direct measurements of ground water discharge using seepage meters and indirect geophysical and geochemical methods.

Techniques for Measuring Ground-Water Discharge

Direct Ground Water Flux Measurements - Seepage Meters.
Several Lee-Type seepage meters were installed at each intensive site. These meters employed a capture bag to determine the change in volume over time to estimate ground-water 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. 4A and B).

Indirect Ground-Water Flux Measurements – Electrical Resistivity and Geochemical Methods.
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. 5).

Geochemical Methods.
Near-continuous Rn^{222} data were collected during both streaming (fig. 6A) and stationary (fig. 6B) deployments of a commercial radon in air detector. The amount of Rn^{222} in a water sample is proportional to the quantity of ground-water discharge.

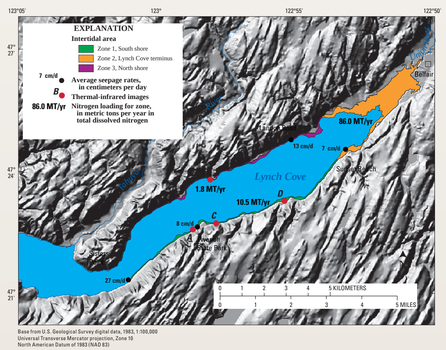

Figure 7. Intertidal areas of Lynch Cove, based on a 5-meter tidal range, subdivided into zones representing the south shore, the terminus of Lynch Cove, and the north shore areas of Hood Canal, Washington. Location of nutrient loading to Lynch Cove using a Zone approach and average lee-type seepage fluxes.

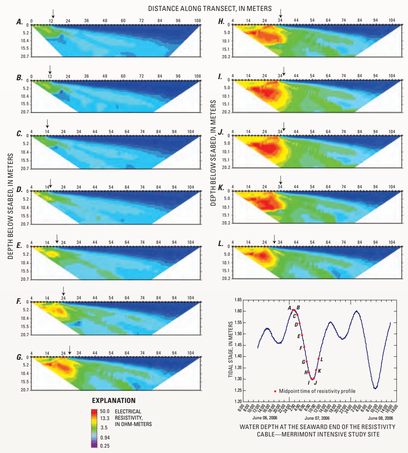

Figure 5. Electrical-resistivity profiles perpendicular to the shoreline at the Merrimont intensive study site, Lynch Cove area of Hood Canal, Washington. Each profile represents a snapshot of electrical resistivity along a cross-section of the intertidal area. Colors represent resistance in ohm-meters. 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.

Geochemical methods
Near-continuous Rn^{222} data were collected during both streaming (fig. 6A) and stationary (fig. 6B) deployments of a commercial radon-in-air detector. The amount of Rn^{222} in a water sample is proportional to the quantity of ground-water discharge.

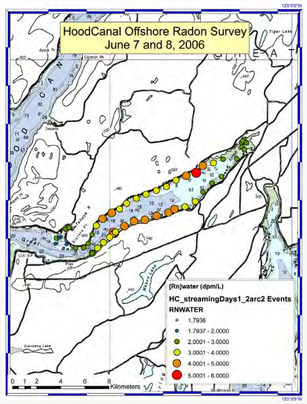

Figure 6A. Radon data from a boat survey along Lynch Cove indicating hot-spots of ground-water discharge (red).

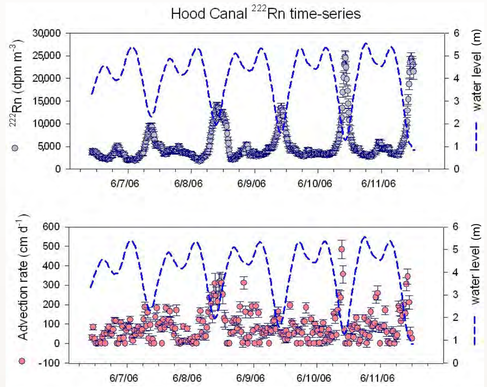

Figure 6B. Continuous radon data at a stationary site in Lynch Cove showing changes due to tides and the respective advection rates calculated from this data.

Full Color Image **Thermal-infrared Image**

Figure 8A. This figure shows a stream flowing across the beach, bifurcating and then mixing into the waters of Lynch Cove, at Twanoh State Park.

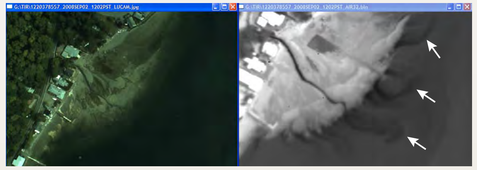

Figure 8B. A small stream flowing across an alluvial fan and multiple ground-water sources.

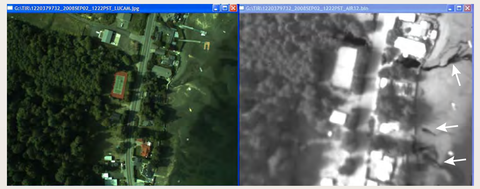

Figure 8C. The upper right quadrant shows a small stream flowing across the beach, the lower right-hand quadrant shows several ground-water seeps high on the beach.

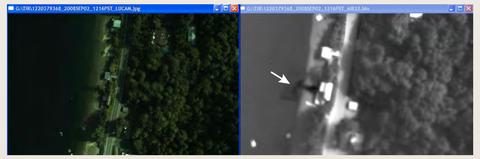

Figure 8D. Water flowing out from under a bulkhead in front of a private residence.

Thermal Infrared Imaging

To determine the spatial distribution of ground water seeps along the shores of Lynch Cove, we imaged the shoreline of Lynch Cove with an airborne thermal infrared camera (7-12 micrometers) and a true-color camera, at the beginning of a flood tide in September 2008. Approximately 3,500 thermal infrared and true-color images were collected, although only one-half covered the beach. Figures 8A-8D are examples of the imagery and the corresponding visual image. The thermal-infrared camera could resolve 0.1° C temperature differences and had a spatial resolution of approximately 2 meters, which easily allowed for the detection of cooler ground water. The individual images were referenced to an open-water scene towards the west end of Lynch Cove. In the images, cooler ground water 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 ground water discharge from alluvial fans, and cooler water flowing from beneath bulkheads in front of homes.

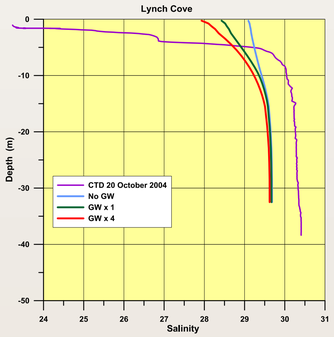

Figure 9. Salinity stratification in Lynch Cove from three model simulations and measurements from October 2004. The simulations are for: no ground water, ground-water estimates from the field observations, and four times the field estimates.

Impact on Lynch Cove

Ground-water 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 (fig. 9). To evaluate the importance of these sources on the oceanography of Lynch Cove, we used a numerical hydrodynamic model of Hood Canal that simulated ground-water 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 the 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. For all cases, the model included the climatological average flow from the Tahuya and Union Rivers. Preliminary results show that ground-water and small streamflow increases the stratification in the surface layers and restrict the vertical mixing. When these freshwater sources are included in the model, the salinity of the surface water is reduced, when compared to simulations without the freshwater sources. However, the model simulation results still do not replicate field observations.

Summary of nitrogen loading into Lynch Cove via ground water

Method	Ground water flux (cm/day)	Nitrogen load* (MT/yr)	Reference
Regional water balance	2.5	14-47	Paulson and others, 2006
Lee-type seepage meters	6.1	34-113	Simonds and others, 2008
Electromagnetic seepage meters	30.4	169-563	Simonds and others, 2008
Radon-radium mass balance	40.4	231-749	Simonds and others, 2008

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

References

Paulson, A.J., Konrad, C.P., Frans, L.M., Noble, M., Kendall, C., Josberger, E.G., Huffman, R.L., and Olsen, T.D., 2006, Freshwater and saline loads of dissolved inorganic nitrogen to Hood Canal and Lynch Cove, western Washington: U.S. Geological Survey Scientific Investigations Report 2006-5106, 92 p.

Simonds, F.W., Swarzenski, P.W., Rosenberry, D.O., Reich, C.D., and Paulson, A.J., 2008, Estimates of nutrient loading by ground-water discharge into the Lynch Cove area of Hood Canal, Washington: U.S. Geological Survey Scientific Investigations Report 2008–5078, 54 p.

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