Surface Water-Ground Water Interactions Along the Lower Dungeness River and Vertical Hydraulic Conductivity of Streambed Sediments, Clallam County, Washington, September 1999-July 2001

By F. William Simonds (U.S. Geological Survey) and Kirk Sinclair (Washington State Department of Ecology)

USGS science for a changing world

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Oblique aerial photograph of the lower Dungeness River as it crosses the Sequim-Dungeness peninsula, Clallam County, Washington. Photo courtesy of Jennifer Bountry, U.S. Bureau of Reclamation.

Introduction

In the Sequim-Dungeness peninsula, to enhance endangered salmon and trout populations, increasing competition for ground-water resources, changing water-use patterns, and recent requirements to maintain minimum in-stream flows, have severely strained the peninsula's water resources and necessitated a better understanding of surface-water and ground-water interactions.

Three methods were used to characterize surface-water and ground-water interactions along the lower 11.8 miles of the Dungeness River corridor between September 1999 and July 2001.

1) In-stream piezometers were used to estimate vertical hydraulic gradients between the river and ground water at 27 points along the river to help define the distribution of gaining and losing stream reaches.
2) Seepage runs were used to quantify the net volume of water exchanged between the river and ground water within each of five seepage reaches.
3) Continuous water level and temperature monitoring at two, off-stream well transects provided data on near-river horizontal-hydraulic gradients and temporal patterns of water interaction for a representative gaining and losing stream reach.

Vertical hydraulic conductivity values were estimated for the riverbed sediments using the in-stream piezometer gradients and estimated seepage fluxes. The resulting conductivity values will be used to help calibrate a transient three-dimensional ground-water flow model of the Sequim-Dungeness peninsula.

Background

In recent years, increased use of surface-water and ground-water resources in watersheds of Washington State has created concern that insufficient in-stream flows remain for fish and other uses. In response, the Washington State legislature passed the Watershed Management Act of 1998 (ESHB 2514), which encourages and provides some funding for watershed planning and delegates the planning to a local level. As part of this planning, stakeholders within a watershed designated as a Water Resources Inventory Area (WRIA) can assess the status of water resources in the WRIA and prepare a plan for managing the water available for allocation and use within the WRIA.

Surficial geology of the study area

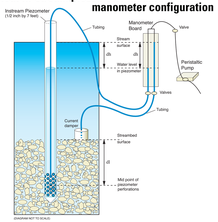
Study area location

In-stream Piezometers

Twenty-seven in-stream piezometers were installed in the streambed of the Dungeness River to define the vertical hydraulic gradient and direction of flow between the river and the water-table aquifer. The piezometers for this study were constructed from 7-foot lengths of 1/2-inch diameter galvanized pipe. One end of the pipe was crimped shut to form a drive point and was then perforated within the bottom 6 inches with several 1/8-inch diameter holes to allow water entry. The piezometers were hand driven into the streambed 3 to 5 feet from the streambank using a fence post driver. Each piezometer was installed to a depth of approximately 5 feet.

A manometer board was used throughout the study to measure differences between water levels in the piezometers and water levels in the river. The difference in water level between the piezometer and the river provides an indication of the vertical direction of water flow. When the piezometer water level (ground-water head) is higher than the river stage (surface-water head), ground water discharges into the river in the immediate vicinity of the piezometer. Conversely, when the water level in the piezometer is lower than the river stage, water seeps from the river and recharges groundwater in the immediate vicinity of the piezometer.

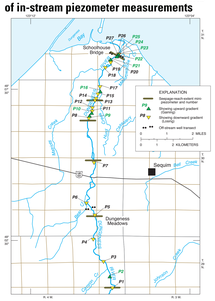
Typical in-stream piezometer installation and manometer configuration



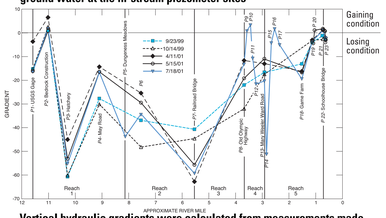
How a manometer board is used for measuring hydraulic head difference between surface water and ground water.

The hydraulic head representing the river, on the left side of the board, is higher than the hydraulic head representing ground water, on the right side of the board. This condition indicates a downward gradient of water at this point in the streambed.

Locations of the river reaches and results of in-stream piezometer measurements



Comparison of vertical hydraulic gradient (*dh/dl*) between the river and ground water at the in-stream piezometer sites



Vertical hydraulic gradients were calculated from measurements made between September 1999 and July 2001.

Seepage runs

A seepage run consists of making measurements of discharge at selected sites along the main stem of the Dungeness River, at tributary inputs to the river, at irrigation ditch outtakes and at returns of fish-bypass water. An estimate of the net volume of water exchanged between the river and ground water is estimated from the increase or decrease in discharge between two measurement stations that cannot be attributed to tributary input or out-of-stream diversions. Seepage runs were conducted over one- or two-day periods during stable streamflow conditions in April 2000, October 2000, and April 2001.

How discharge measurements are made

Discharge is calculated from velocity and depth measurements at 25 to 30 sections across the width of the river. A seepage run consists of making multiple discharge measurements at different cross sections along the river, at all tributaries and at diversion out flows.

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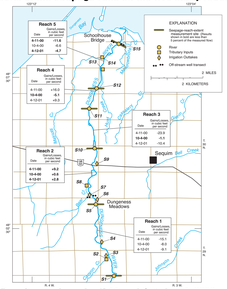
Results of the seepage runs on the five study reaches



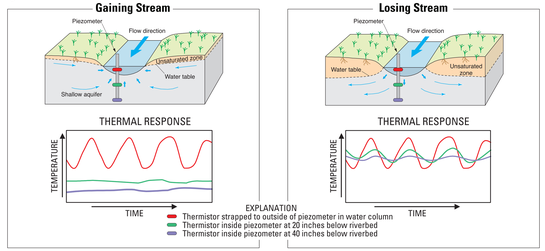
Results are from April 11 and October 4, 2000, and April 12, 2001

Off-stream Well Transects

Off-stream well transects were installed at two locations to verify the in-stream piezometer results, and to assess horizontal hydraulic gradients between the river and ground water within a typical losing reach (Dungeness Meadows transect) and gaining reach (Schoolhouse Bridge transect). A total of 6 wells were installed at each site using a Stratoprobe™ truck mounted, direct-push drilling system. Three wells were installed on each side of the river to depths of 15 to 30 feet and consisted of 1.25-inch diameter PVC casing with a standard 5-foot length of PVC well screen.

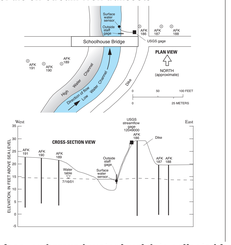
Continuous river stage and river temperature data were collected at both sites between June 16, 2000 and July 20, 2001. Water-level sensors (pressure transducers) and temperature sensors (thermistors) were inserted into the three off-stream wells closest to the river stage sensor. At each site, all sensors were hard-wired to a data logger and set to record hourly water levels and temperatures.

Surface- and ground-water relations and thermal response in streams during summer and early fall with gaining reaches and losing reaches

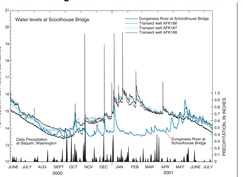


Schoolhouse Bridge

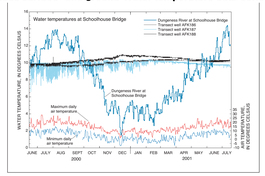
Configuration of the off-stream well transects



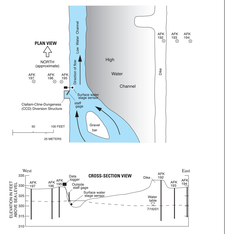
Continuous surface- and ground-water level data collected from June 2000 to July 2001



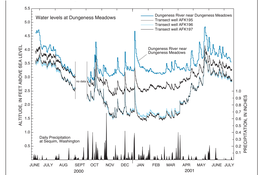
Continuous surface- and ground-water temperature data collected from June 2000 to July 2001



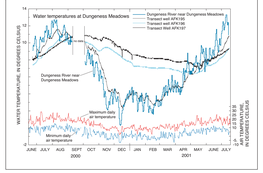
Dungeness Meadows



Continuous surface- and ground-water level data collected from June 2000 to July 2001



Continuous surface- and ground-water temperature data collected from June 2000 to July 2001



Vertical Hydraulic Conductivity of Streambed Sediments

Darcy's Law was applied to the in-stream piezometer and stream seepage data from April 10-11, 2001, to estimate average vertical hydraulic conductivity values for the streambed sediments within each of the reaches. Darcy (1856) demonstrated empirically that the volume rate of discharge (Q) through a porous medium is equal to the product of the hydraulic gradient (I) and the cross sectional area (A) through which water moves, times a constant of proportionality (K), which describes the hydraulic properties of the porous material.

$$Q = -KIA$$

When rearranged to solve for vertical hydraulic conductivity Darcy's Law becomes:

$$K_v = -(Q / I_v A)$$

Where,

K_v is the average vertical hydraulic conductivity of the streambed material contained within a reach (feet per day);
Q is the total volume of water gained or lost by the river between the two transects that define a reach (cubic feet per second);
I_v is the average vertical hydraulic gradient between the river and ground water, as determined from in-stream piezometer measurements (dimensionless); and
A is the estimated streambed area across which water exchange occurs (square feet).

For this study, the streambed area (A) in a reach was calculated by averaging the widths of the upper and lower river transects that defined the reach and then multiplying the average width by the reach length. The gain or loss of flow from the stream (Q) for each reach was determined during the seepage run of April 10-11, 2001. The average vertical hydraulic gradient (I_v) for a reach was determined by averaging the individual gradients for all piezometers in the reach. The results of these calculations yield an approximation of the average vertical hydraulic conductivity (K_v) for the streambed within the reach as represented by the April 2001 data.

In order to use this approach, it was necessary to make several simplifying assumptions:

1) Flow between the Dungeness River and water table aquifer occurs only in the vertical dimension (no horizontal flow component).
2) The net seepage volume (Q) is equal to the total volume of water exchanged between the river and water table aquifer.
3) The average gradient derived from the in-stream piezometer data accurately represents the average vertical hydraulic gradient for the reach.
4) Averaging the upper and lower transect widths provides a good approximation of the average stream width.

Characteristics of and calculated average vertical hydraulic gradient and vertical hydraulic conductivity for the lower Dungeness River, April 12, 2001

Reach designation	Reach designation (by river miles)	Stream reach length (miles)	Stream reach length (feet)	Stream reach width Upper (feet)	Stream reach width Lower (feet)	Average stream width (feet)	Total area of reach (A) (ft^2)	Measured gain or loss for reach (Q) (ft^3/s)	Average vertical hydraulic gradient (I_v) (dimensionless)	Average vertical hydraulic conductivity (K_v) (feet/day)
1	11.80 to 8.13	3.67	19,377.6	75	45.2	60.1	1,164,594	-9.1	-0.28	2
2	8.13 to 5.54	2.59	13,675.2	45.2	49.5	47.35	647,521	2.8	-0.51	4
3	5.54 to 3.68	1.86	9,820.8	49.5	59	54.25	532,778	-10.4	-0.43	1
4	3.68 to 2.92	0.76	4,012.8	59	92	75.5	302,966	9.3	-0.09	29
5	2.92 to 0.71	2.21	11,668.8	92	44	68	793,478	-4.7	-0.06	8

Reach Designations (upper to lower transect)

Reach 1: USGS streamgaging station to Dungeness Meadows
Reach 2: Dungeness Meadows to Dungeness at Railroad Bridge
Reach 3: Dungeness at Railroad Bridge to Dungeness at Old Olympic Highway
Reach 4: Dungeness at Old Olympic Highway to Dungeness below Woodcock Road
Reach 5: Dungeness below Woodcock Road to Dungeness at Schoolhouse Bridge

Conclusions

Results of flow measurements in reaches 1 and 3 reveal that the river consistently lost water with the exception of a short segment near river mile 11.0. The river is narrowly confined by a bedrock constriction near river mile 11.0 that locally forces ground water into the river. Vertical hydraulic gradients in the in-stream piezometers within these reaches were negative, but became less negative in the downstream direction. Repeat measurements of the in-stream piezometers at different times and flow conditions yielded some variability in the magnitude of gradient, but produced consistent results with regard to gradient direction. Net seepage losses through reach 1 confirmed the in-stream piezometer results.

Results for reach 2 indicate that there is a net gain within the reach. These results contradict the vertical gradients observed in the in-stream piezometers within reach 2. The reason(s) for this discrepancy are not well understood. It is possible that a short gaining segment may exist between consecutive piezometer locations. However, ground-water levels at the off-stream well transect within this reach (near Dungeness Meadows) were consistently below the river stage and support the in-stream piezometer results.

The results for reach 4 suggest the presence of small gaining and losing stream segments within the broader context of each reach. In-stream piezometers within the reach exhibited both positive and negative vertical hydraulic gradients. Net seepage results suggests that gaining segments may dominate in the spring while losing segments may dominate in the fall.

The results for reach 5 showed a continuation of the interspersed gains and losses measured within reach 4. Most of the in-stream piezometers exhibited negative vertical hydraulic gradients consistent with the seepage results for reach 5, which exhibited consistent net losses. In the vicinity of Schoolhouse Bridge, vertical hydraulic gradients were positive suggesting the presence of a localized gaining segment. This localized zone of ground-water discharge to the river was confirmed by data collected at the off-stream well transect near Schoolhouse Bridge where ground-water levels were consistently higher than the river stage.

Discussion and Evaluation of Uncertainty

Each of the field techniques and analysis methods used during this study has respective strengths and weaknesses. No single technique or analysis method can uniquely quantify the distribution, timing, volume, and rate of water exchange between a river and ground water. The use of multiple techniques, as was done here, helps to increase confidence in the collected data. Knowledge of the inherent uncertainty in each of the techniques becomes especially important when assigning confidence to data or combining the data and results from two or more techniques.

In-stream Piezometers

+ Inexpensive and easy to deploy
+ Useful for initial reconnaissance and verifying seepage-run results
+ Manometer board can measure head differences in the 0.03- to 3-foot range
– In-stream piezometers provide information for only one point within the streambed
– The manometer board is not good at measuring small head differences less than 0.03 foot
– Head differences do not distinguish hyporheic flow from ground-water flow

Seepage Runs

+ Provide quantitative estimate of the net gain or loss across larger reaches of the river
– Expensive and labor intensive
– Provide only net estimates and reveal nothing about local gains and losses
– Discharge measurement error may be larger than the actual amount of gain or loss
– Discharge measurements may not be possible for higher flows

Off-stream Well Transects

- Expensive to install
- Requires site access by truck mounted drilling rig
+ Can be instrumented to collect a variety of continuous data (water level, temperature)

For Additional Information

This report is available on the USGS web site at http://water.usgs.gov/pubs/wri/wrir24161/ and on the Ecology web site at http://www.ecy.wa.gov/biblio/020327.html