The Interaction of Ground Water and Surface Water within Fall Chinook Salmon Spawning Areas in the Hanford Reach of the Columbia River

By David R. Geist

INTRODUCTION

The Hanford Reach is the last unimpounded section of the mainstem Columbia River in the United States and supports a large run of fall chinook salmon (*Oncorhynchus tshawytscha*) that returns there annually to spawn (Dauble and Watson 1997). Previous studies have shown that adult salmon repeatedly spawn in definite locations within the Reach (Geist 1999; Geist and Dauble 1998; Dauble and Watson 1997), but the physical characteristics associated with these areas are variable and poorly understood. More information on the spawning habitat characteristics of fall chinook salmon that utilize large rivers is needed to recover stocks listed on the Endangered Species Act.

The association between fall chinook salmon spawning and physical habitat characteristics was previously examined in the Hanford Reach at Locke Island and Wooded Island (Geist 1999). Although the physical habitat characteristics, e.g., depth, substrate, and water velocity, at the two sites were similar, only the Locke Island site had extensive salmon spawning. Additional measurements were taken to determine if the interaction of ground water and surface water within the hyporheic zone could explain this discrepancy in habitat use between the two sites. Hyporheic discharge was assumed to affect spawning site selection by providing cues (chemical, temperature, and physical) for pre-spawning adults to locate spawning reaches (usually 2 to 5 km in length). Once these reaches were "discovered," hyporheic discharge was assumed to correlate with the distribution of redd clusters (500 to 800 m in length, 120 m in width; Geist 1999) within these river reaches

METHODS

During the fall chinook salmon spawning seasons (October and November; Dauble and Watson 1997) from 1995 to 1997, mini-piezometers (Lee and Cherry 1979) and internal-drive-rod piezometers (Geist, et al. 1998) were installed within the two sites. Piezometers were installed within the river channel in groups of three or four, and hyporheic water within the piezometers was sampled 2 to 7 times each year for specific conductance (µS/cm at 25°C), water temperature (T, °C), dissolved oxygen (DO, mg/ℓ), and hydraulic head (h, cm). These same parameters were also measured on a contiguous river sample.

It was assumed that water discharging from the hyporheic zone into the river was a combination of ground water and surface water. Specific conductance was the primary measure used to differentiate undiluted ground water from surface water; specific conductance of undiluted ground water adjacent to the Hanford Reach averages 300-400 µS/cm while the river water averages ~150 µS/cm. The differences in temperature (T) and hydraulic head (h) were based on the piezometer reading (hyporheic water) minus the reading from its paired river sample. Differences in hydraulic head between the river and hyporheic waters were used to calculate a vertical hydraulic gradient (VHG) between the two

(VHG = h/depth of piezometer). Slug tests were used to estimate the volume of hyporheic discharge from the sediments into the river channel.

RESULTS AND DISCUSSION

The results showed that fall chinook salmon spawning locations were highly correlated with hyporheic discharge that was composed of mostly river water and not undiluted ground water. Hyporheic water that discharged into fall chinook salmon spawning locations was consistently greater in magnitude, and had higher dissolved oxygen and lower specific conductance than discharge into non-spawning locations. However, there was no significant difference in temperature between hyporheic and river water. These results were true when comparisons were performed between Locke Island (spawning site) and Wooded Island (non-spawning site) (Figure 1), and also true when spawning and non-spawning clusters within the Locke Island site were evaluated (Figure 2).

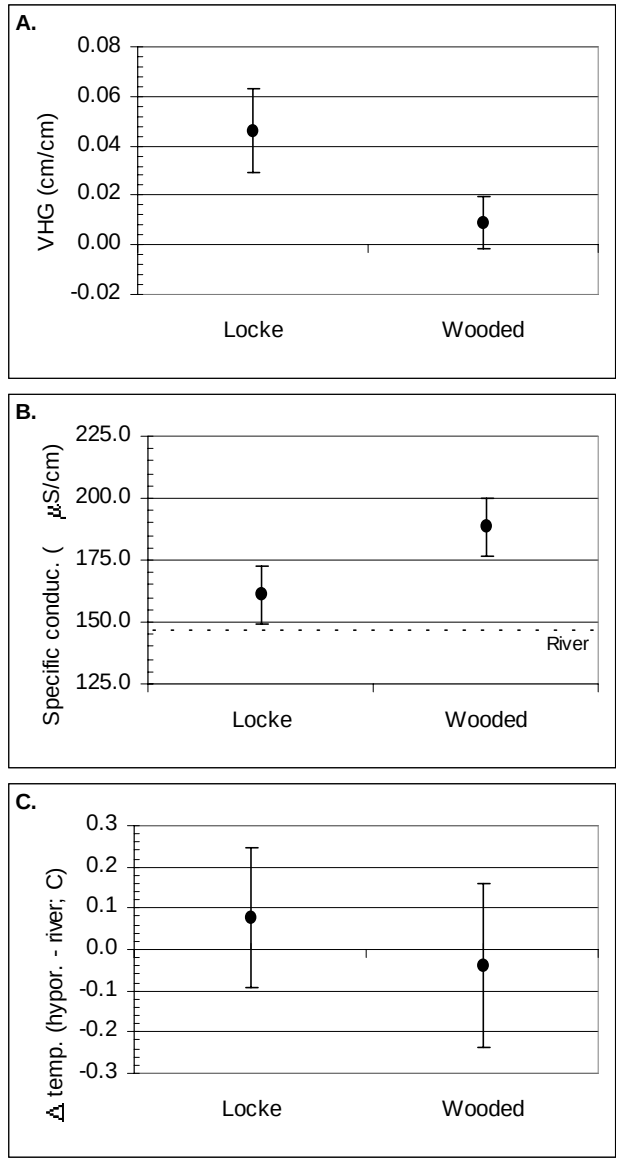

Figure 1. Physiochemical data collected from piezometers installed and monitored at the Locke Island and Wooded Island study sites during October and November, 1995. Bars above and below the points represent the 95% confidence interval of the mean. (A) Vertical hydraulic gradient (VHG) between hyporheic and surface waters where positive values indicated potential upwelling and negative values downwelling, (B) specific conductance of hyporheic and surface waters, and (C) differences in water temperatures of hyporheic and surface waters.

Slug tests showed that substrate permeability decreased with increasing distance below the river bed at Wooded Island but did not change over the depths monitored at Locke Island (Figure 3). This suggested the mixing zone where river water penetrated into the river bed was greater within the spawning site than within the non-spawning site. Specific discharge calculations gave an average flux out of the sediments on the order of 9.0 x 10^{-4} cm/s at Locke Island and 3.0 x 10^{-4} cm/s at Wooded Island. Thus, specific discharge of hyporheic waters was approximately 3 times larger at Locke Island than Wooded Island.

River water was presumed to have entered highly permeable riverbed substrate at locations upstream of spawning areas. Geomorphic bed features (i.e., islands, gravel bars, riffles) of alluvial rivers are able to create hydraulic gradients sufficient to direct surface water into the bed (Stanford, et al. 1996; Brunke and Gonser 1997). River water is able to penetrate deeper into hyporheic habitats if the riverbed is composed of alluvium that is highly permeable (Vaux 1962, 1968; White 1993). The more permeable the alluvium, the more that the physiochemical characteristics of the hyporheic waters will resemble surface water rather than ground water. In contrast, the relative proportion of phreatic ground water in hyporheic waters will be greater if the riverbed sediments are of low hydraulic permeability because

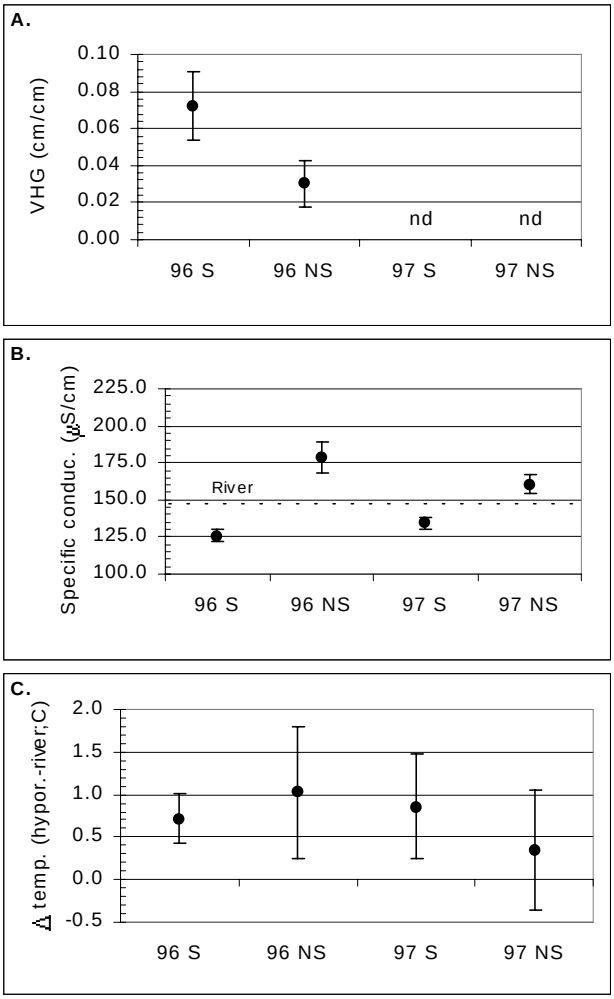

Figure 2. Physiochemical data collected from piezometers installed and monitored within the Locke Island site at spawning (S) and non-spawning (NS) sites during October and November, 1996 and 1997. Bars above and below the points represent the 95% confidence interval of the mean. ND = no data.

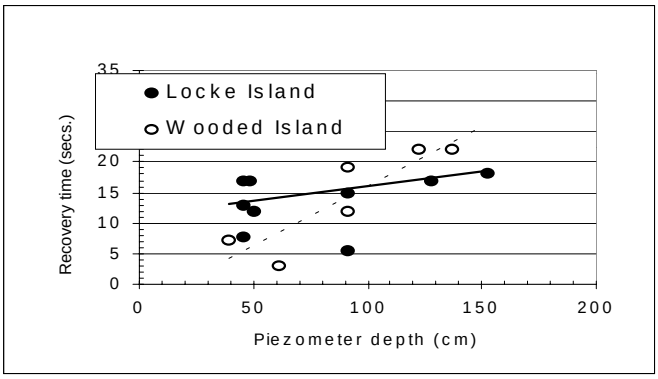

Figure 3. Recovery time to 37% of the initial hydraulic head following a slug-test within piezometers installed at Locke Island and Wooded Island. The trend line at the Wooded Island site (dashed line) was significant (P = 0.02, r^2=0.78) but not significant at Locke Island (P = 0.42, r^2= 0.08).

river water will not be able to readily enter the substrate and dilute the ground water (White 1993; Brunke and Gonser 1997). I concluded river water that became entrained into the "hyporheic corridor" had a strong influence on vertical hydraulic gradients and influenced the use of salmon spawning habitat. Knowledge of the three-dimensional connectivity between rivers and ground water within the hyporheic zone can be used to improve the definition of fall chinook salmon spawning habitat.

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