INSTREAM WOOD AS A DRIVER OF NUTRIENT ATTENUATION IN A LOWLAND SANDY STREAM

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This paper outlines the initial results of research to assess the potential of instream wood to enhance nutrient (nitrogen and carbon) attenuating potential in UK lowland rivers. Temperature data were collected at nine locations surrounding instream wood, at four depths within the stream bed over a week long period. Cross correlation functions were used to assess how wood placement alters surface water- hyporheic exchange, and vertical head gradients collected from 40 in-bed piezometers identified areas of upwelling and downwelling. Results suggest instream wood alters hyporheic flow, increasing surface water- streambed hyporheic exchange as evidenced by the cross correlation functions showed increased surface water penetration into the streambed at locations influenced by instream wood. This enhanced hyporheic exchange in tangent with increased hyporheic residence times and altered thermal regimes provide the potential for denitrification processes to take place which can attenuate high nitrate levels in surface and groundwaters.

1 INTRODUCTION

One of the most critical water quality problems in UK river basins is the increase in nitrate concentrations in lowland rivers, causing adverse impacts on the environment as well as the economy, due to the cost of nutrient removal. Previous research on upland rivers with large sediments and low nutrient loadings indicated that instream wood can substantially increase the structural heterogeneity [1, 2] of the streambed and directly affect streambed thermal patterns, dissolved oxygen (DO) concentrations and biogeochemical cycling [3, 4]. These wood-induced changes result in enhanced hydrodynamic forcing of surface water into the streambed, and an increased hyporheic zone (HZ) area in addition to increased residence times [5, 6], all of which indicate the potential for instream wood to increase biogeochemical cycling and denitrification activity within the HZ.

Residence time is a prime control of biogeochemical turnover of carbon (C) and nitrogen (N) with effective N removal being associated with long HZ residence times and respiratory DO consumption [7]. Microbial-mediated reactions, such as denitrification are also temperature dependent [8], and hence wood-induced increases in hyporheic exchange have the potential to cause a warming of the streambed in summer due to the infiltration of warmer surface water, resulting in enhanced microbial metabolic activity and biogeochemical processing.

Here, we outline initial results of an investigation of streambed thermal patterns resulting from wood-induced hydrodynamic forcing over a 7 day period in April (3-9 April, 2015) to illustrate how instream wood enhances exchanges between surface water and hyporheic zone, creating conditions which favor the turnover of nitrate into nitrogen gas, and attenuation of elevated nitrate levels.

2 METHODS

2.1 Study site

The Hammer Stream is a lowland, sandy stream located in West Sussex, U.K. (Figure 1). It is a 4th order stream approximately 31 km² in area, dominated by agricultural land interspersed with areas of deciduous woodland. The geology is predominantly sedimentary mudstone and clay deposits in the upper catchment and sandstone formations further downstream. Baseflow is ~0.16m^3s^{-1} and the stream has been observed to be very flashy in nature. Hammer Stream has been recorded as being above the Water Framework Directive (WFD) threshold for phosphate levels, and is located within a Nitrate Vulnerable Zone. Poor farming practice in the area has resulted in a large amount of fine sand to be deposited in the stream over time, resulting in sand depths of up to 1m in some locations.

A study reach, approximately 60m in length was chosen for study due to its ease of access and the presence of two naturally occurring instream wood structures. The study reach averages 2.5m in width and 0.2m in depth during baseflow. Data was collected for a seven day period from 3-9 April, 2015.

2.2 Streambed and surface water temperature monitoring

Custom made thermal lances were installed into the streambed at nine locations to monitor temperature at 5, 10, 20 and 30cm depth. Data was collected every 15 minutes and stored on 4 channel Hobo loggers. Surface water temperatures were collected at a stilling well at the top of the study site using a Solinst Levelogger which recorded water temperature and stage every 15 minutes. Air and atmospheric pressure measurements were collected using a Solinst Barologger and recorded every 15 minutes.

2.3 Vertical head gradients

Hydraulic head measurements were calculated using data collected from 40 streambed piezometers located throughout the study reach (Figure 2). Piezometers were made using plastic tubing 2.4m in length, with a series of holes drilled in to the bottom 5 cm and covered in nylon mesh. A stainless steel nut and bolt was affixed to the end of the piezometer to act as an anchor following the insertion of the piezometer into the streambed to a depth of 1m, leaving 1.4m of tubing above the sediment to allow a dip meter to be used to assess inside water height.

Vertical head gradients (VHGs), which indicate the strength and direction of groundwater- surface water fluxes were determined from the hydraulic head measurements by calculating $\Delta h/\ \Delta l$ where Δh= elevation difference of water heights inside and outside of the piezometer tubes and Δl= distance between the mid screen depth of the piezometers (0.925m) and the sediment- water interface.

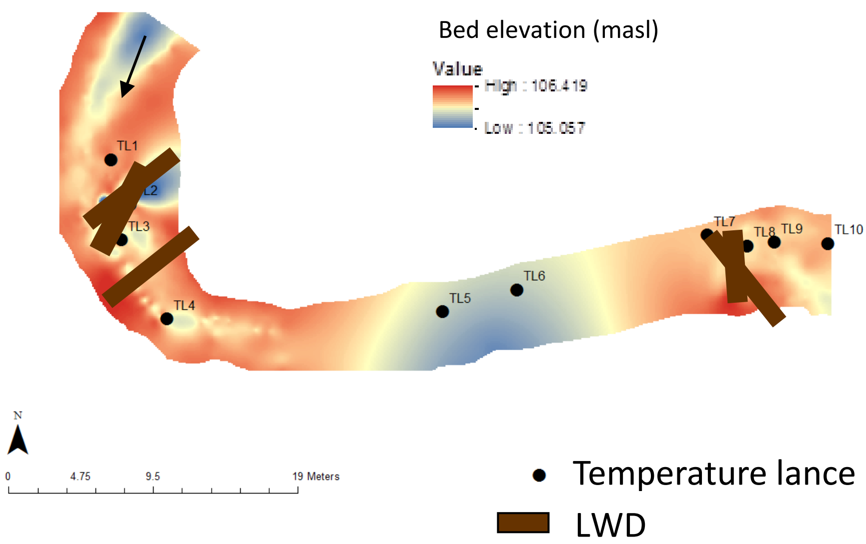

Figure 1. Location of the Hammer Stream, UK (inset) and temperature lance positioning relative to instream wood in the Hammer Stream, West

2.4 Statistical analysis

The location of thermal lances and piezometers were separated into two groups for initial analysis of temperature data over the week long period, based on their position relative to instream wood. Lances near to or affected by wood-induced features, such as sediment accumulation or wood- induced scour were classified as 'wood influenced' while lances located in areas with no nearby (>1.5m) wood or wood- induced features were classified as 'no wood'. Daily averaged thermal patterns were calculated for each lance to ascertain spatial differences between lances.

Using measurements of diurnal fluctuations in temperature over the seven day study period, cross correlation functions (CCF) were calculated to assess the lag times (T lag) in the maximum correlations between surface water and streambed temperatures at different depths and locations. CCF was calculated in R[9] using the standard ccf function.

3 RESULTS

Vertical head gradients indicate some downwelling of surface water immediately surrounding instream wood, and a much more pronounced (indicated by the size of the symbol in Figure 2) upwelling of water downstream of the wood. Average VHG for piezometers associated with wood features (scour or deposition resulting from instream wood, n= 19) was 0.12, while that for piezometers without wood influence (n= 21) was 0.043.

Results from the CCF analysis (summarized in Table 1) show a varied response in the time it takes for the transfer of warmer surface water to reach different depths in the streambed, which also vary between temperature lances. In some cases (Lances 2 & 9), it only takes 15 minutes for the heat signal from surface water to be picked up at 5cm depth, while Lance 1 takes up to 165 minutes. Those locations which showed a quick response at 5cm continued to respond quickly at 10cm, however the time lag between 5 and 10cm depths increased for all locations, and continued to do so at 20cm. In all cases, the peak diurnal heat signal was not detected at 30cm over the seven day study period.

4 DISCUSSION

Initial analysis using temperature lances and piezometer measurements suggest that instream wood is altering VHG and increasing hyporheic exchange flows (upwelling and downwelling). There was also evidence of spatial and temporal variation in temperature dynamics resulting from wood placement. Additional metabolic tracer, nutrient and modelling data, not presented here, have shown a correlation between locations of hyporheic exchange flow reported here and increased denitrification hotspots.

This data in conjunction with ongoing experimentation suggests that instream wood could be used in river basin management and river restoration efforts to improve water quality and hydromorphic integrity within lowland sandy streams. Ongoing work seeks to quantify the efficiency of alternative (stationary and transient) wood designs for controlled alteration and management of hyporheic exchange fluxes and residence times and nutrient turnover in the streambed.

Table 1. Cross correlation function (CCF) and calculated time lags (T lag) of surface water to interstitial porewater temperature timeseries at depths 5, 10, 20 and 30cm at 9 temperature lance locations. NW= no wood influence, W= wood influenced

Lance #	**5cm**		**10cm**		**20cm**		**30cm**	
	T lag	CCF	T lag	CCF	T lag	CCF	T lag	CCF
1 (NW)	165	0.931	225	0.835	360	0.654	375	0.433
2 (W)	15	0.939	60	0.952	270	0.843	375	0.586
3 (W)	135	0.942	225	0.863	375	0.629	375	0.427
4 (NW)	135	0.947	195	0.872	345	0.731	375	0.463
6 (NW)	120	0.973	195	0.911	375	0.546	375	0.363
7 (NW)	45	0.990	135	0.953	300	0.762	375	0.479
8 (W)	45	0.989	135	0.944	315	0.682	375	0.436
9 (W)	15	0.931	60	0.927	240	0.857	375	0.677
10 (W)	120	0.971	240	0.917	375	0.809	375	0.456

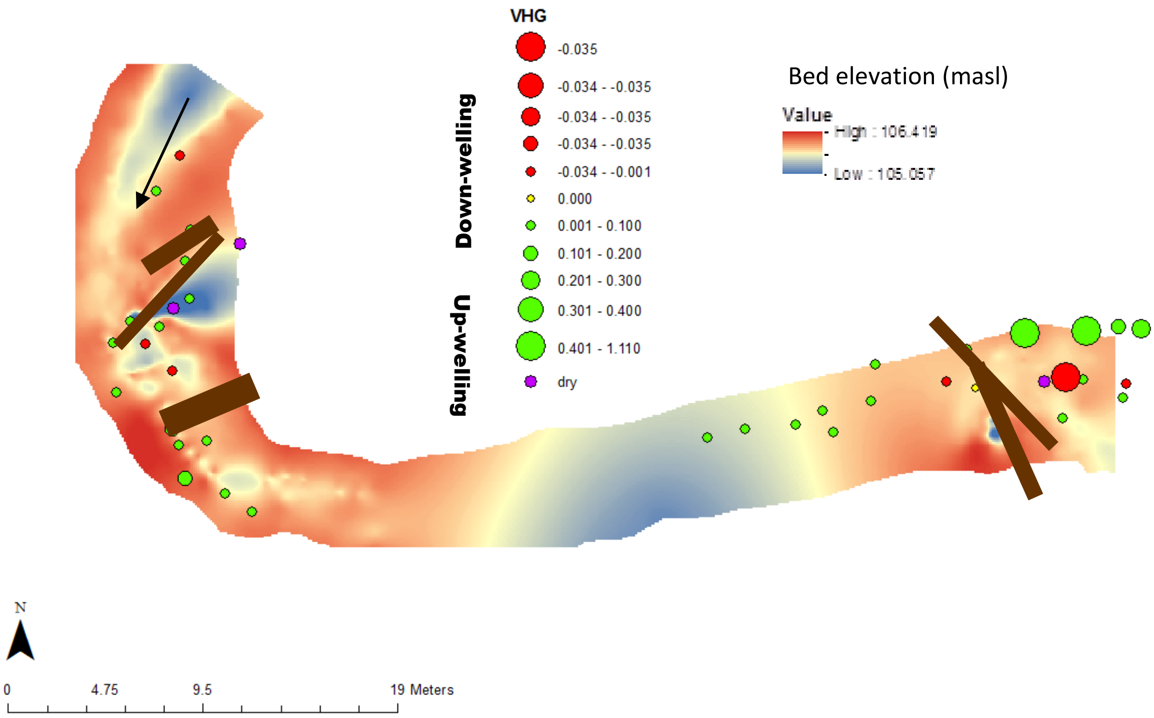

Figure 2. Vertical head gradients at piezometers within the study reach. Green symbols indicate upwelling, red symbols downwelling. The size of the symbol indicates the strength of the VHG.

5 ACKNOWLEDGMENTS

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