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Sediment Transport Caused by Ice Processes: A Quantitative Approach

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A field study was conducted on two different reaches of a gravel-bed river (Stoke River) located in the Eastern Townships, Québec, Canada. The study was performed to quantitatively assess the mobility of the bed sediments due to ice and ice-free processes. At both sites, PIT tags were placed in the river bed and were tracked via a dual antenna system. Fixed antennas were placed in the river bed and were connected to a data logger in order to follow the tagged particles for a period of 1 year. To complement this system, surveys were made with a mobile antenna in order to measure the exact movement of the particles. Bathymetric surveys were also done to record profile changes and the overall transport balance of each reach. In order to identify the nature of the movement, water level data and meteorological data were collected. Surface photos were also taken for most of the duration of the study in order to correlate surface activity (ice cover) with the sediment transport. The dual antenna system enabled us to quantify the movement of the tagged particles, but the complexity of ice processes at the time of the ice jam/release led to difficulty in identifying the quantity of movement coming from a specific process.

1. **Intro**

Ice regimes in gravel-bed rivers are a well-documented subject (Turcotte et al. 2011) but sediment transport during this period is difficult to quantify. A field study was conducted on two different reaches of a gravel-bed river (Stoke River 45.568325 N, -71.764070 E) located in the Eastern Townships, Québec, Canada in order to quantitatively assess the mobility of the bed sediments due to ice and ice-free processes throughout the winter and spring-time period.

2. Study Sites

The data collected in this paper comes from two different study sites. The first site, Rang 11 (Site 1), is a mildly steep channel (0.95%). The freeze-up is mainly driven by anchor-ice formation and subsequently anchor-ice damming (Tremblay et al. 2014). Hydraulic and bed characteristics of Site 1 are presented in Table 1. The second site, Rang 12 (Site 2) in contrast, has a milder slope (0.24%). The freeze-up is characterized by bankfast ice merging into a stable ice cover. Hydraulic and bed characteristics of Site 2 are presented in Table 2.

TABLE 1. HYDRAULIC AND BED CHARACTERISTICS – SITE 1.

Rang 11	
Length	145 m
Bankfull width	6 m – 10 m
Bankfull depth	1.2 m
Slope	0.95%
Bankfull flow	3.6 m^3/s
Bed size distribution	
D_{16}	40 mm
D_{50}	65 mm
D_{84}	104 mm

TABLE 2. HYDRAULIC AND BED CHARACTERISTICS – SITE 2.

Rang 12	
Length	110 m
Bankfull width	10 m
Bankfull depth	1.6 m
Slope	0.24%
Bankfull flow	2.9 m^3/s
Bed size distribution	
D_{16}	20 mm
D_{50}	45 mm
D_{84}	70 mm

3. Methodology and Materials

At both sites, PIT tagged rocks were placed in the river bed and were tracked via a dual fixed and mobile antenna system. For Site 1, 104 tagged rocks were inserted prior to this study (Tremblay et al. 2014) and 45 were added for this one. For site 2, 61 tagged rocks were inserted for the purpose of this study. At both sites the newly placed rocks were laid out in a straight line perpendicular to flow in order to prevent marker clustering which may lead to signal jamming on the fixed antennas if too many markers are read at the same moment.

4. Fixed antennas and mobile antennas

Fixed antennas were placed in the river bed and were connected to a control module acting as a data logger (RFID Quatro by Aquartis, Quebec) in order to follow the tagged particles for a period of 2 years. This period enabled us to account for water working in the recorded movements. The antennas were made out of two loops of copper wire embedded in a polyethylene pipe shell for protection. The antenna was connected to a tuning module which in turn is connected to the Quatro control module. Four antennas were placed at both sites spanning across the site lengths.

To complement this system, surveys were made with a mobile antenna (Léonie by Aquartis, Québec) in order to measure the exact movement of the particles. Bathymetric surveys were also performed using a robotic Leica Total Station (TS 15) to record profile changes and the overall transport balance of each reach. In order to identify the nature of the movement, water level data and meteorological data were collected. Surface photos were also taken with a time lapse camera in order to correlate surface activity (ice cover) with the sediment transport.

5. Results and discussion

<u>Site 1</u>

The first year minimal bed elevation changes were measured on the overall site length at Site 1 (Figure 1). More sediment movement was observed for new markers (mean distance = 29.3 m/median = 17.5 m) in comparison with the waterworked markers (mean distance = 13.1 m/median = 2.1 m) already in place in the river. Terminal position was noticed to be more prevalent in aggradation zones, especially at the junction of the end of a riffle and the start of a pool. The small run between antenna 2 and 3 (Figure 1) was the geomorphological unit that presented the most prevalent sediment movement.

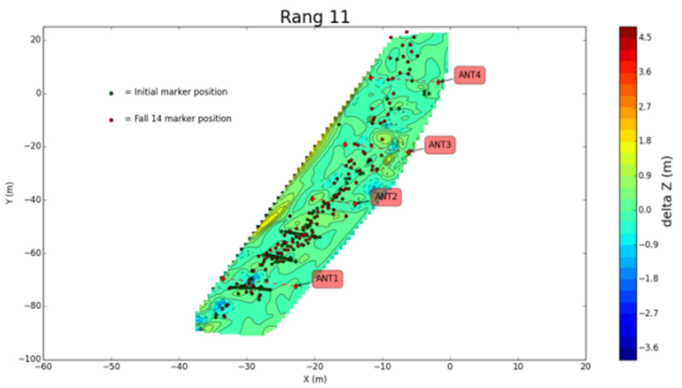

FIGURE 1. DIFFERENTIAL DEM AND MARKER LOCATION – SITE 1/YEAR 1.

The second year, marker movement decreased significantly throughout all the markers (mean = 5.4 m/median=0). The main movement occurred in the same run between antenna 2 and 3 that was active the previous year. Degradation was noticed at the upstream end of the run (Figure 2).

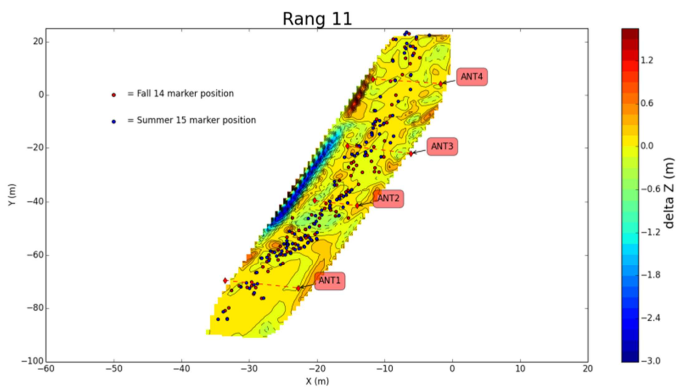

FIGURE 2. DIFFERENTIAL DEM AND MARKER LOCATION – SITE 1/YEAR 2.

The fall 2014-spring 2015 period was also less intense hydraulically. The break-up was much less intense and no mid-winter breakups were recorded. Other than less important hydraulic activity, bed armoring and marker cluster formation seem to be noticeable factor on sediment movement. These variables still need to be investigated.

Site 2

The fall 2013-spring 2014 saw little movement at Site 2 (mean =8.7 m/med= 1.0 m). The markers with the smallest mass and diameter were the ones that moved the most distance downstream. 48% of the tagged rocks stayed in place (Figure 3).

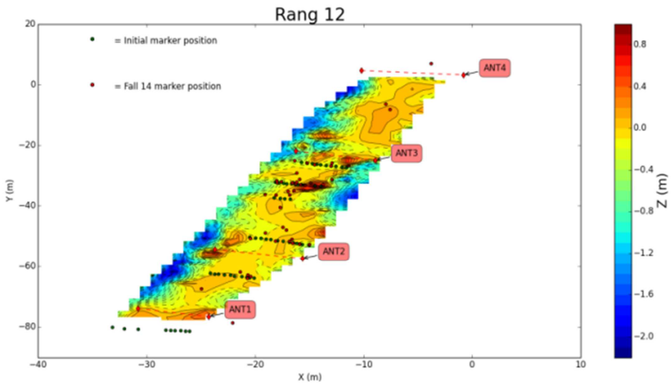

FIGURE 3. DIFFERENTIAL DEM AND MARKER LOCATION – SITE 2/YEAR 1.

All of these displacements occurred at the rising limb of the spring thaw. Transit times at the antennas varied between 1 second and 3 months. Transit time is difficult to translate into sediment velocity since it is possible that the marker was blocked in place either by bed formation or even the antenna itself. The second year movement was similar to Site 1 (mean = 5.7 m/median=1.3 m) and lower than the previous year. Only 2 tagged rocks out of 7 that crossed an antenna threshold were recorded and their transit times were similar (± 25 minutes).

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