IMPACT OF LONGSHORE SEDIMENT TRANSPORT ON THE DESIGN AND MAINTENANCE OF LOW-ENERGY, NON-TIDAL SANDY BEACHES

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INTRODUCTION

When low-energy, non-tidal lake beaches have a flood safety function, such as at the Houtribdijk, the Netherlands, sediment losses can directly affect the functioning of the beach (fig. 1). Detailed understanding of morphodynamic processes is needed to enable reliable predictions of the morphological development and the design of efficient maintenance strategies. Ton et al. (2021) showed that the development of these beaches is driven by both cross-shore and longshore processes. Wave action causes a distinct cross-shore profile shape to develop, with a steep beach face and a gently sloped platform around the depth of closure. However, on top of that, the combined effect of large-scale horizontal flow circulations (caused by gradients in storm surge level across the lake, Ton et al., submitted) and wave-induced sediment stirring was found to be an important driver of sediment losses along the beaches. In this work, we research how longshore transport (LST) can best be determined for low-energy lake beaches and classify and quantify the uncertainties related to this method.

Figure 1 – Houtribdijk, the Netherlands. From Bureau Start the Future commissioned by Rijkswaterstaat.

METHOD

Normally, non-tidal beaches are designed for wave-driven longshore currents only. We calibrate the commonly used transport formula by Van Rijn (2014), to represent our system in which large-scale lake currents affect longshore transport heavily. The longshore transport formula by Van Rijn (2014):

$$Q_{t,mass} = K_{cal} K_{swell} \rho_s d_{50} tan\beta^{-0.6} H_{s,br}^{2.6} * V_{eff,L}, \tag{1}$$

where $Q_{t,mass}$ is longshore sand transport, K_{cal} and K_{swell} are calibration factors in general and for swell occurrence, ρ_s is sediment density, d_{50} is median grain size, $\tan\beta$ is the slope of the surf zone, $H_{s,br}$ is significant wave height at the breaker line and $V_{eff,L}$ is the effective longshore flow velocity, calculated as:

$$V_{eff,L} = 0.3\left(gH_{s,br}\right)^{0.5} \sin(2\theta_{br}) + V_{flow}, \tag{2}$$

where θ_{br} is the wave angle to shore normal at breaker line. For this method, the LST direction is heavily dependent on the incoming wave angle, while the residual flow direction from wave-driven and large-scale circulation currents combined can have a different direction. We calibrate the equation for $Q_{t,mass}$ by using the measured longshore flow velocity as $V_{eff,L}$ and altering the calibration factor K_{cal} (0.0006 in Van Rijn (2014)), to match predicted longshore transports to measured longshore transports at our study sites at the Houtribdijk and Marker Wadden in lake Markermeer, the Netherlands. With the calibrated equation, longshore transport for (wind) conditions that did not occur during the measurement period can be predicted. Wave and flow input for those conditions are obtained from a calibrated numerical Delft3D model of lake Markermeer.

Using this new method, yearly transported volumes can be predicted. With a 70-year long wind time series, mean yearly LST and its deviation are calculated, quantifying the uncertainty in sediment transport, related to the wind climate. The uncertainty in K_{cal} is determined from the calibration using curve fitting. Uncertainties of the profile shape (platform width), that influence nearshore flow velocities and wave height, are evaluated with the numerical model and field measurements. Based on these new insights, we explore possible design optimizations to the benefit of future project developments in low-energy lake environments.

RESULTS AND DISCUSSION

Out of the different sediment transport formulae, longshore transport is best represented by Van Rijn (2014) with a K_{cal} of 0.005 and the measured longshore flow velocity as $V_{eff,L}$, as this trend line best approaches x=y (fig. 2). The results from the original equation by Van Rijn (2014) give an error in the LST direction, showing the importance of taking into account the total current velocity and direction, including the large-scale lake circulations. Moreover, this original equation gives a substantial underestimate of the LST for the site under investigation.

Taking into account the uncertainties of K_{cal}, the wind climate and profile shape leads to higher standard deviation of the predicted yearly LST, but a steady average.

With this knowledge, the design of the beach location and orientation can be optimized, minimizing LST. Initial results reveal that the location of the beach relative to the large-scale circulation affects sediment losses from the beaches greatly.

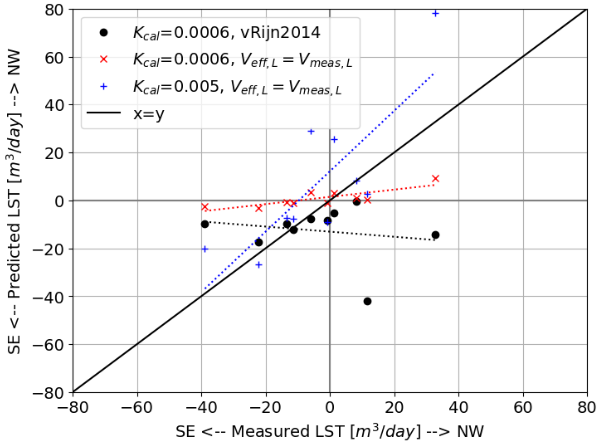

Figure 2 – Measured longshore transport from bathymetrical surveys and predicted longshore transport per morphological period for the original Van Rijn (2014) equation (black), the Van Rijn (2014) equation with measured longshore velocities (red) and the Van Rijn (2014) equation with measured longshore velocities and a higher K_{cal}.

CONCLUSION

Various beaches around lake Markermeer are affected in different ways by the large-scale lake currents because of their location and orientation. Research into the optimal location of a natural intervention in lake Markermeer, based on minimized longshore transports, provides valuable insight into their impact on the large-scale lake currents and into the design of possible new beaches. This study offers key insights into the prediction of LST in lake environments and the design and maintenance of lake beaches. It thus forms a stepping stone towards future design and implementation of nature-based flood-protection measures in lake environments.

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