Objective
Simulating the Holocene discharge and sediment flux of the Rhine catchment with the hydrological model HYDROTREND v.3.0 in order to understand fluvial response to changing external forcing factors (climate, human impact, sea level and tectonics) and thus past, present and future changes of sediment flux.

Study Area
The 1325km long Rhine River is situated in central western Europe and drains in total 158,000 km² hinterland, including large parts of the Alps with reliefs over 4.0 km, the French and German Low Mountain Ranges and the northern German and Dutch Lowlands (Figure 1). The Rhine River is chosen as study area because 1) its wealth of geoscientific case studies and thus extensive data availability; 2) its morphologically diverse basin encompassing glacial, nival and pluvial discharge regimes; and 3) its long story of intense human-water interactions resulting in largely man-induced sediment fluxes from the Mid-Holocene onwards.

Model Description
HYDROTREND v.3.0 simulates (i) discharge and (ii) sediment load at a river outlet. (i) Daily water discharge values are calculated based on the classic water balance model (Eq. 1a) considering five runoff processes (Eq. 1b). The subcomponents’ boundaries are determined with each time step by using the time varying freeze line and glacier equilibrium line (Eq. 1c) considering five runoff processes (Eq. 1b). The subcomponents’ boundaries are determined with each time step by using the time varying freeze line and glacier equilibrium line (Eq. 1c) considering five runoff processes (Eq. 1b). The subcomponents’ boundaries are determined with each time step by using the time varying freeze line and glacier equilibrium line (Eq. 1c). The subcomponents’ boundaries are determined with each time step by using the time varying freeze line and glacier equilibrium line (Eq. 1c).

\[ Q = Q_r + Q_n + Q_{ice} - Q_{Ev} + Q_g \]

\[ Q = A \sum P_i - E_i \pm S_i \]

\[ Q = \frac{Q_s (T - T_a)}{h} + Q_{w(0.5)} + Q_{melt} + Q_{g} + Q_{water(0.31)} \]

\[ Q_s = \frac{I}{w} \]

\[ Q = \frac{Q_s (T - T_a)}{h} + Q_{w(0.5)} + Q_{melt} + Q_{g} + Q_{water(0.31)} \]

Daily water discharge:

\[ \Delta Q = A \sum P_i - E_i \pm S_i \]  
Eq. 1a

\[ Q_s = \frac{I}{w} \]  
Eq. 1b

\[ Q = \frac{Q_s (T - T_a)}{h} + Q_{w(0.5)} + Q_{melt} + Q_{g} + Q_{water(0.31)} \]  
Eq. 1c

(i) Long-term sediment load is derived from the empirical BQAR equation which relates the long-term sediment load to basin area, discharge, relief, temperature, average basin lithology, glacier extention, human activity and sediment trapping efficiency of lakes or reservoirs (Eq. 2a, 2b) (Kettner & Syvitski 2006). The stochastische PSQ estimation (Morehead et al. 2003) is used to study the inter-annual variability of sediment flux variability.

\[ Q_s = \frac{A}{w} \]  
Eq. 2a

\[ Q_s = \frac{A}{w} \]  
Eq. 2b

(ii) Long-term suspended sediment load:

\[ Q_{ss} = \frac{Q_s}{w} \]  
Eq. 3

\[ Q_s = \frac{A}{w} \]  
Eq. 3

Data
Climate Precipitation data from 26 weather stations and over a period of 20 years was analyzed. Monthly, annual totals and standard deviations have been spatially averaged for the present day climate statistics of the Rhine catchment (Figure 2). To assess Holocene climate conditions, climate values for 10,000 BP have been extracted from the CCM3 climate model (Otto-Bliesner, yet unpublished). These were combined with the present day data and interpolated over time using the normalized temperature curve of Davis et al. (2003) as forcing factor (Figure 3).

Lithology and Reservoirs A representative basin with an average volume of 16 km³ catchment of a total upstream area of 18,855 km² (Figure 4). Smaller dams in the main stem have not been incorporated in the simulation, as they will not influence the sediment flux at the outlet.

Anthropogenic impact The Rhine has a long history of human intervention leading to largely man-induced sediment fluxes from the Mid-Holocene onwards (Houben et al. 2007, Hoffmann et al. 2010). Quantifications of forest/cultivation land ratios during the Holocene in Central Europe are made by Kaplan et al. (2009). This values still need to be assigned to an anthropogenic factor.

Future Work
After validating the model against sediment load and discharge observations of the present day Rhine, a simulation run over the entire Holocene period will be done. Changes in sediment flux and discharge are analyzed with regard to the dominant external drivers, climate and human impact, on the Rhine fluvial system. The second project will be a spatial resolution of the model. This will be done by considering several sections of the Rhine River as outlets. The sediment load and discharge output will be compared in regard to the allocation of sediment sources and sinks. This is relevant because the Rhine discharge regime gets strongly influenced by its tributaries, changing from a summer peak glacial regime to a winter peak pluvial regime (Figure 6) (Kempe et al. 2005).

References