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LAND USE AND CLIMATE IMPACTS ON FLUVIAL SYSTEMS DURING THE PERIOD OF AGRICULTURE IN THE RIVER RHINE CATCHMENT (RHINELUCIFS) – AN INTRODUCTION

With 1 figure

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This special issue of the journal ERDKUNDE is related to the research project RhineLUCIFS, which is part of the IGBP (International Geosphere – Biosphere Programme) PAGES Focus 5 project LUCIFS (Land Use and Climate Impacts on Fluvial Systems during the period of agriculture). Recommendations for a LUCIFS research project and its implementation were published as PAGES Workshop Report in 1996 (WASSON 1996). LUCIFS aims to understand for the period of agriculture the variations in water and particulate fluxes through fluvial systems. These variations are to be understood at global, regional and local scales, and both long and short time scales since agriculture began. Five research questions have been developed in LUCIFS:

1. How have fluvial systems respond to past changes in climate and/or land use?
2. What are the key factors that have controlled water and particulate fluxes in different regions?
3. In each region, does the sensitivity of the system to these key factors vary spatially and temporally?
4. In each region, how do long-term processes affect the present day responses of fluvial systems?
5. What feedback exists between variations in water/particulate fluxes and global environmental change?

Different LUCIFS research projects and catchments were presented in a PAGES Newsletter (OLDFIELD a. ALVERSON 2000; WASSON a. SIDORCHUK 2000) and in a special issue of Hydrological Processes (WALLING 2003). RhineLUCIFS case studies were published by LANG et al. (2000) and LANG et al. (2003a). A specific focus on long term and large scale modelling of fluvial systems with respect to the challenge to link sediment archive data with numerical models was given at a RhineLUCIFS workshop in 2001 (LANG et al. 2003b).

Sediment budget approaches are central analytical frameworks to understand the complex forcing/response relationships in fluvial systems between land use and climate change, sediment transport, sediment sinks and sediment yields. Several results of sediment budget approaches have been published in the last decades from different parts of the world (SIDORCHUK 1996; TRIMBLE 1999; TRUSTRUM et al. 1999; WASSON a. SIDORCHUK 2000; WALLING 2003; WALLING a. FANG 2003). REID and DUNNE (1996) introduced methods to reconstruct mean sediment budgets related to years or decades using sediment accumulation data, tracers and simple models to model soil losses from slopes. In general sediment budget approaches include several system components and processes:

- Soil erosion on slopes
- Temporal storage of sediment in colluvial sediments
- Sediment transport in rivers
- Temporal storage of sediments in flooding plains
- Remobilization of sediments of different storage types
- Sediment output from the system

The reason to prepare the contributions of this special issue was to summaries research results of the River Rhine catchments (Fig. 1) in a more systematic way covering broader topics of the fluvial River Rhine system. The results are related to different components of the sediment flux system in different time scales. Therefore, we included research results of fluvial sediment sinks, water and biogeochemical fluxes of the last decades and paleoclimate and human impact research results. In chapter 2 sediment source areas on slopes and sinks in lakes are considered. Sediment sink and source areas in channels and floodplains are introduced in chapter 3. The discussion of water and biogeochemical fluxes of chapter 4 are related to shorter time scales of the last decades. Palaeoclimate reconstructions of chapter 5 are related to the Late Glacial and Holocene time scale and to the last 500 years. In chapter 6 human impact and vegetation change during the Holocene are presented, in chapter 7 engineering impacts in the channels are discussed.

The contribution of THIEMEYER et al. (2005, this issue) is concerned with pedological and sedimentological results and methodologies in small-scale system components. They build the basis to understand spatial sediment source variations on slopes. Pedological analyses of Holocene soil development and soil degradation are of high significance to reconstruct spatial and temporal variations of sediment source and sink areas of the fluvial system. Results of the River Rhine catchment show highly variable soil losses from slopes since the beginning of the deforestation in the Early Neolithic. Increase of soil loss from the slope storages of the systems can be allocated to the end of the Neolithic time about 6,000 years ago. Pollen records show a significant decrease of woodland pollen indicating the beginning of agricultural land use and the development of a open landscape. Historical soil erosion resulted in the development of storages of colluvial and alluvial sediments indicating significant changes of the internal configuration of the River Rhine system. Further Holocene periods of high sediment movement from slope storages to sinks are the Iron Age (4th to 1st centuries BC) and the Roman times (1st to 4th centuries AD). In difference to open source – sink systems of slopes lake sediment constitute closed systems, which build a powerful basis for reconstructing past ecosystems. The results of the Lake Holzmaar sediment analysis (catchment size of the lake: 2,058 km^2) indicates stable environmental conditions between 9,860 and 2,750 a cal BP. Here, during the last 800 years the human impacts increased significantly resulting in average denudation rates of 11.3 mm/1,000 years. However, considerable temporal variability of the erosion/deposition processes could be observed during the Holocene, which is a general conclusion of historical soil erosion research in the River Rhine catchment.

Pedological evidences and methods are highly important for reconstructing sediment fluxes in catchments. In the River Rhine region we find mainly deposit types of aeolian, alluvial or periglacial origin. In THIEMEYER's et al. paper (2005, this issue) the pedogenesis in different parent material and the change of soil type pattern due to soil loss processes are described. In this way the eroded soil profiles can serve to estimate sediment losses of the slope storages of the system. Pedological methodologies have also been applied to the reconstruction and dating of Holocene fluvial terrace sequences and palaeo meanders of the catchment. The field studies show, that e.g. the younger meander generation of the Rhine system (Subboreal – Subatlantic period) carry Fluvisol and Gleysols which are influenced by the relation of the hydrology of the river with the floodplain deposits. Historical soil erosion research has to be linked with fluvial sediment flux analysis. Here, the quantification of colluvial storage components, as first order storage types, can be based on numerous research results of colluvial sediments in the River Rhine catchment. A further aspect of sediment delivery is related to landslides. If landslides are contributors to the Holocene fluvial sediment flux depends on the morphometric structure of the system in terms of their coupling with the river channels.

Holocene river terraces constitute higher order sediment storage types of the fluvial system. The system components show a complex pattern in relation to climatic and human control and to the location within the catchment. Increasing catchment areas result in more complex sedimentary records indicating that the processes and the process couplings within the catchment change significantly with changing spatial scales. The paper of SCHIRMER et al. (2005, this issue) is related to the Holocene floodplain deposits of different parts of the River Rhine system. Field studies of these storage types especially in relation to the number of Holocene terraces, their distribution and age has a long tradition in Central Europe. Based on morphological, lithological and pedogenetical evidences seven Holocene river terrace systems and three meander generations are proposed. A significant shift of the "younger meander generation" occurred during the transition from the Subboreal to the Subatlantic period. It is stated that this shift was influenced by both the human impacts and the climatically induced changes of the sedimentation pattern of the river flood plains. In large parts of the northern River Rhine clay accumulation was replaced by overbank depositions of silt and sand. Further results of the complex river terrace system analyses indicate that the deposit thickness increased in the Atlantic significantly especially in the loess areas.

The meaning of scale effects in sub catchments has been addressed by case studies in the Rhine-Main region. Here, the sediment propagation system shows in smaller scales a patchy distribution pattern which is related to topography and human-induced land use factors, whereas the higher order components of the lowland areas exhibit more complex sediment structures additionally influenced by the internal behaviour of the flux processes. A special case study is related to the alpine Rhine and its delta sediments in the Lake Constance. Sedimentologically, this system is closed and delivers an excellent opportunity for Late Pleistocene and Holocene sediment budget analyses. Here, a high variability of sediment supply to the delta has been found indicating that 4,100, 3,500 and 2,600 years ago major periods of increased sediment deposition occurred.

The contribution of KEMPE and KRAHE (2005, this issue) is related to the youngest time scale of the River

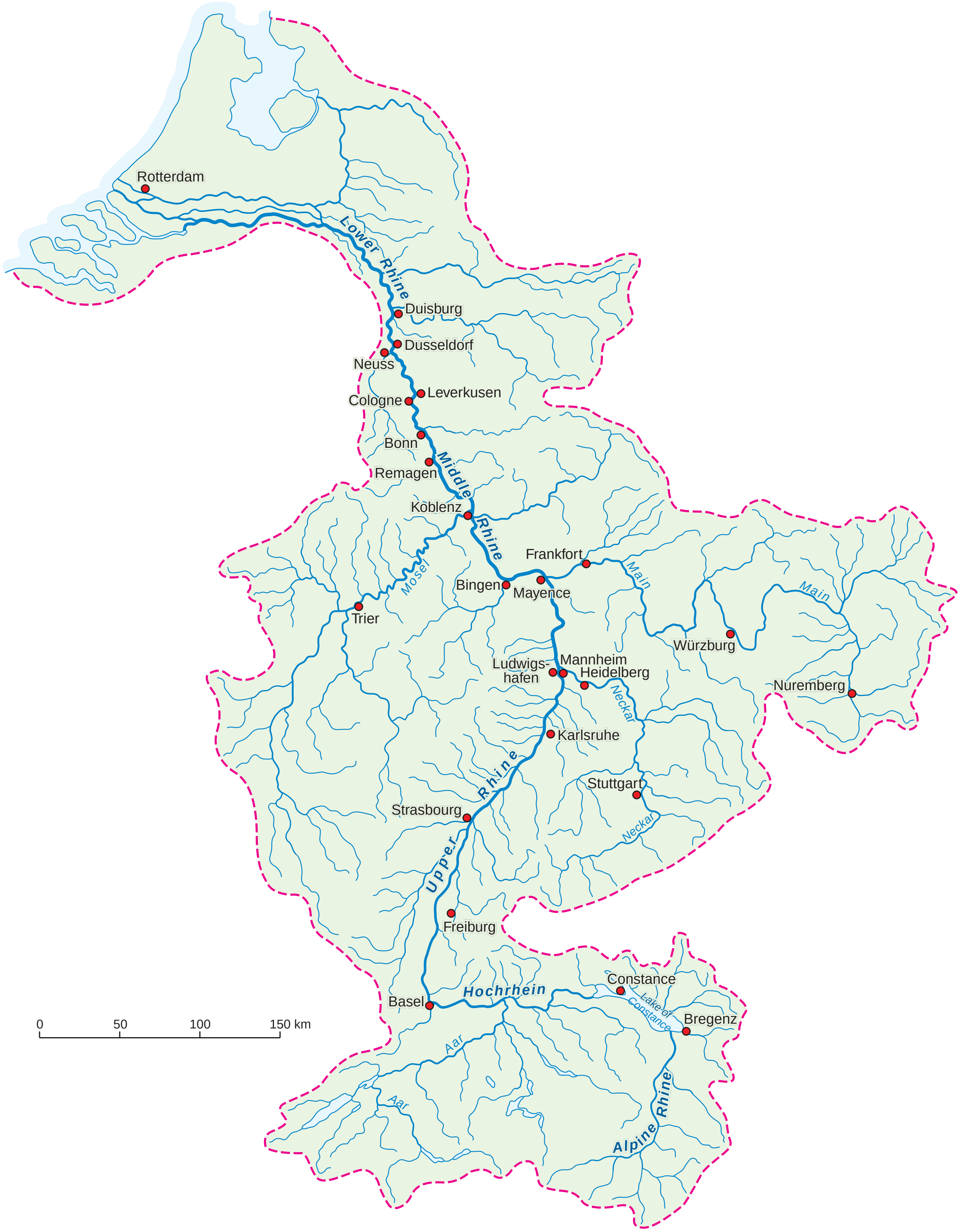

Fig. 1: River Rhine catchment with main tributaries (Bundesanstalt für Gewässerkunde)

Einzugsgebiet mit den wichtigsten Teileinzugsgebieten des Rheins (Bundesanstalt für Gewässerkunde)

Rhine research. The hydrological and biogeochemical measurements comprise the last four decades. Discharge time series for the gauge station Cologne are used from 1891 to 2002. The understanding of recent fluxes through the system delivers important information as a prerequisite to reconstruct system behaviour in Holocene time scales. Analysis of meteorological and hydrological time series show clear evidences of increased discharge variabilities. It is stressed, that for water resources planning the assumption of stationary time series is not longer valid and that natural and human-induced climate changes have to be considered. Estimations for water balance and river basin modelling related to climate change scenarios has been accomplished. Here, hydrological extreme events and the sensitivity of the modern civilization requires higher emphasize and improved protection and adaptation strategies. The biogeochemical analysis of fluxes in the River Rhine is based on data from 1980 to 1990. Here, the first attempt was made to quantify carbon fluxes through the system and to evaluate seasonal behaviour and downstream changes. Total fluxes of dissolved and suspended solids were calculated. An important result is that the River Rhine ranks by the transport of nutrients among the top ten while by discharge it is the 40th largest river worldwide. This indicates the substantial human impacts in this system. The detailed discussion of the biogeochemical load of the River Rhine concludes that these investigations are of high importance for a better understanding of the global carbon cycle.

Palaeoclimate reconstruction and modelling within the River Rhine catchment are summarized in the paper of GLASER et al. (2005, this issue). Central Europe is an area with one of the highest densities of palaeoclimatic data worldwide. The paper reviews and evaluates different natural archives and methods of palaeoclimatic time series development in relation to the reconstructed climate parameters. For the time scale of the Late Glacial and the Holocene it is stated, that the most complete data sets are available from the alpine regions, for which at least six periods of reduced summer temperature has been suggested. Other evidences indicate an approximate 1,000-years cyclicity of the Holocene climate oscillation. In Central and northwestern Europe lake sediment data deliver varved records and precise chronologies to reconstruct past climatic oscillations. As one of the strongest climatic fluctuation during the Holocene the event of 2,650 varve years BP has been identified. This Iron Age event of high sedimentation rates is the beginning of significant responses of lake sedimentations due to human activities. For the Holocene time scale the authors draw the conclusion, that in the future research projects should put more attention on issues of temporal and spatial scales, the multi-proxy approach and a careful site selection.

A second part of the paper of GLASER et al. (2005, this issue) is concerned with climate reconstructions of the last 500 years. For this period historical documents deliver climate observations with almost complete time series of monthly and partly daily weather (1500–1800), individual instrumental measurements (1680–1860) and instrumental measurements of national and international networks (since 1860). For the last 500 years historical climatology reconstructed major periods of temperature decrease during the "Little Ice Age" from 1571–1591, 1690–1700 and 1710–1730. These periods correspond with more humid phases. Historical data have also been used to reconstruct flood frequencies in Central Europe, which is of high importance for a better understanding of the fluvial response of the River Rhine system. The frequency analyses give evidences for a clear inter decadal variability and that during the middle of the 19th century higher flood frequencies are correlated with advective westerly weather types. High magnitude flood events at the Middle Rhine and the Main Rivers are dated for the years 1595, 1682, 1784 and 1845.

In chapter 6 DIX et al. (2005, this issue) describes methods and research results related to the reconstruction of human impacts and vegetation change of the River Rhine system during the Holocene. Historic geographical, archaeological, palynological and sedimentological methods have been applied. The human impact can be divided into the direct hydraulic engineering of the river channels and floodplains and the change of land use on slopes and other components of the fluvial system including different vegetation types and the ratio of open land and woodlands. These impact parameters have to be connected with responses of soil losses on slopes and changes of the fluvial deposition and sediment flux behaviour. The paper introduces and evaluated different archive types. The geomorphological approach relates changes of the sedimentation pattern in the floodplains and reconstruction of the river history with human impact periods. Forest clearances and the extension of arable land are correlated with the development of river terraces and fine grained sediments covering the floodplain surface. There exist clear linkages between our current palynologic knowledge and the land use history in the River Rhine catchment from early medieval times. Archaeological data indicate population development and density in the early stages of agriculture and its impact on water and sediment fluxes. It is obvious, that the human impact increased in historic times due to increasing population and changes in agricultural techniques. After 1000 AD archival sources like maps and other written documents produced for administrative purposes, become more and more important. In the Lower Rhine area historic maps for selected regions give spatial information of land use change and the change of natural structures since medieval times. For the last 300 years these methods have been applied to reconstruct spatially the change of human impact in more detail. For understanding changes in the fluvial system these are very promising results because they deliver spatial data independently from the fluvial sediment archive.

Engineering impacts on channels and floodplains in the River Rhine catchment is the focus of the paper presented by HERGET et al. (2005, this issue). The catchment of the River Rhine has been influenced by engineering projects since centuries. Flood protection and drainage of the floodplains, improvements of navigation and the construction of hydroelectric power stations are major reasons for these impacts. Industrialisation and the growing population, water supply and sewage disposal became relevant in the middle of the 19th century. Today rehabilitation and re-cultivation of previous channels and floodplain modifications are important activities to handle increased peak discharges of floods after melioration of the floodplains. In the lowland areas of northwestern Central Europe, flood protection is a very important task, especially in the delta areas of the Netherlands. Already in Roman times measures to improve navigation on the River Rhine and its tributaries were carried out. First meander cuttings are known from medieval times. The meander cutting at the beginning of the 19th century in combination with the building of dikes at the upper Rhine valley by *Tulla* belongs to the period of systematic changing the morphometry of the channels and the stabilisation of the valley bottom. This caused significant incision of the river channel already in the middle of the 19th century with problems for navigation especially during periods of low water levels. The building of several hydroelectric power stations after the World War II caused significant lowering of the groundwater level in the floodplains and the necessity for bedload supply to stabilized the river bed. Further discussions of the paper are related to the "Delta-Plan" in the estuaries of the River Rhine delta. Here, barriers along the coastline protect the lowland areas from catastrophic flooding from the North Sea. In summary the authors stated, that the quantification of engineering impacts on sediment budgets and fluxes are not fully understood and difficult to regionalize from local case studies.

The history of the RhineLUCIFS project goes back to the 2nd International LUCIFS Workshop in Bonn in 2000. In 2002 the project started with 5 partners from geomorphology, archaeology and historical geography including the following studies:

Geomorphology:

Establishing mass balances for Holocene sediments from the Upper Rhine and Black Forest (MÄCKEL, Freiburg)

Quantification and dynamics of Holocene sediment and matter fluxes of the northern Upper Rhine (THIEMEYER, MOLDENHAUER, WUNDERLICH, Frankfurt)

Modelling Holocene sediment fluxes in fluvial systems (DIKAU, Bonn)

Archaeology:

The development of population density and agricultural land use between the 6th millennium BC and the 3rd century AD extracted from archaeological and palynological data (ZIMMERMANN, Köln)

Historical Geography:

Regionalisation of historical land use and settlement data as a methodological contribution to RhineLUCIFS (DIX, Bonn)

The geomorphological projects aim to reconstruct sediment budgets in selected regions based on available data. The archaeological and historic geographical projects aim to develop methods for the regionalisation of prehistoric and historic land use and settlement data. Palaeoclimatic and human land use impacts are the main drivers of fluvial sediment fluxes. However, the internal controls of the system can result in the interaction of a high number of system components creating variable temporal sediment yields caused by self-organisation processes within the catchments. Sediment yields as an emergent property of a fluvial system means therefore, that we cannot directly correlate system response with forcing variables. In that case the analysis has to be extended to the internal system components and their temporal dynamics.

There are numerous palaeoclimatic research results available in the River Rhine catchment covering different Holocene time scales. Future challenges to link these data with fluvial system development necessitates comparable standards to handle the high variability of the archive records and a better differentiation of the human and climatic impacts creating the archive used for reconstruction.

Direct and indirect human impacts in the River Rhine catchment are related to land use change by deforestation, land use practices, settlement development and river engineering activities. There are numerous human impact studies available in the River Rhine catchment covering different Holocene time scales, which demonstrate significant changes of the impact magnitude. Therefore, a key challenge for future research is related to the regionalisation of local impact studies to develop models for land use and human impact history for higher order scales of the entire catchment. Significant direct impacts on the channels of the River Rhine catchment goes back to the beginning of the 19th century, which has changed the sediment fluxes. However, we do not fully understand which consequences this engineering work had on the quantification of the sink and source relationship of the sediment system. This problem can only be resolved if we extend the time series of the study into a longer time scale. OLDFIELD (2003) summarised this key area of research by the statement that "it is essential that we place our concerns for the future of the environment in the context of the changes that have occurred during the Holocene as a whole".

RhineLUCIFS has a long term Holocene research perspective. This time scale is of high importance because instrumental records of sediment fluxes cover only a very limited time scale in relation to earth system variability. Sediment budget approaches are the central analytical frameworks to understand the complex forcing/response relationships in fluvial systems and to link the proxy parameter (sediment record) with the target parameter (sediment flux). The conclusion to be drawn from Holocene fluvial system research includes new challenges and research objectives of non-linearity, spatial scale effects, landform structure and the delineation of human impact transformation types. In summary, studies of the past are essential components of global change research, which are otherwise limited by the short period of direct measurement and monitoring.

The scientific results presented in the articles of this special issue cover Holocene research results of several decades. This demonstrates that the River Rhine catchment has probably one of the highest palaeo data densities worldwide. To use and apply these data for the LUCIFS research objectives will be a challenge for the future.

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