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CHARM - Challenges of Reservoir Management - Meeting environmental and social requirements

Hydrolink

CHARM – CHALLENGES OF RESERVOIR MANAGEMENT – MEETING ENVIRONMENTAL AND SOCIAL REQUIREMENTS

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The project CHARM aims at contributing to a better understanding between reservoir management and its impact on the surrounding environment and the reservoir itself. CHARM is a multidisciplinary research project addressing five fundamental issues of reservoir management: sedimentation, biostabilization, harmful cyanobacterial blooms, greenhouse gas emissions, and societal implications. These issues are tackled through analytical approaches, field monitoring, laboratory experiments and numerical models, thus gaining insights into the involved processes at different scales. The project outcomes will support the development of reservoir management strategies to meet challenges related to increasing anthropogenic impacts on water bodies and to climate and demographic changes resulting in altered energy and water demands.

Reservoirs serve a multitude of purposes: hydropower production, drinking and irrigation water supply, flood retention, and recreation. The significance of reservoirs is highly increasing due to anthropogenic influences exacerbated by climate and demographic changes[1]. The ongoing debate about sedimentation in dam reservoirs often ignores accompanying side effects, which have been insufficiently investigated. Apart from a loss in reservoir storage space due to sedimentation, further processes are involved such as the production of greenhouse gases and, in many cases, the development of harmful cyanobacterial blooms[2]. One of the reasons is that reservoirs affect the development of benthic and pelagic bacterial communities that may in turn change the biochemical processes. Furthermore, the effect of biofilm growth in reservoirs is hardly studied although it has considerable implications for sediment transport processes[3]. All these effects can alter reservoir use and perception, leading to possible conflicts between stakeholders, revealing that not only the construction but also reservoir operation and management have societal implications.

The need for sustainable, economically, socially and environmentally acceptable reservoir management strategies is now recognized. Selecting optimal strategies is a challenging task due to the complexity and interconnection of the processes involved (*e.g.* hydraulics, sediment transport, biochemistry), requiring collaborative research work from complementary disciplines.

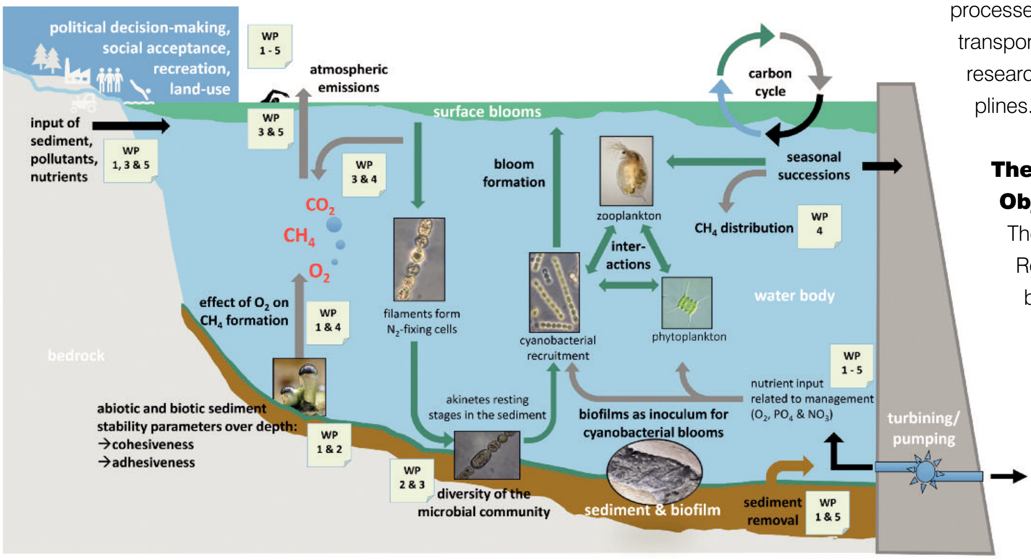

Figure 1. Interconnections between major physicochemical and biological processes in reservoirs. These processes and their relations are addressed within CHARM in a holistic approach by five cross-linked workpackages: Sedimentation (WP1), Biostabilization (WP2), Harmful cyanobacterial blooms (WP3), Greenhouse gas emissions (WP4), and Societal implications (WP5).

The project "CHARM"

Objectives and work packages

The project CHARM (CHAllenges of Reservoir Management, www.charm-bw.de) brings together scientists, with expertise in engineering, natural and social sciences, from three German universities (Stuttgart, Konstanz and Freiburg) to address, in cross-linked work packages, five of the main issues related to reservoir management: sedimentation, biostabilization, harmful cyanobacterial blooms, greenhouse gas emissions, and societal implications. The CHARM project seeks to address complex interconnections (Figure 1). For instance, the sediment deposit stability depends on several abiotic and biotic parameters that include both cohesiveness and adhesiveness. Gas produced in sediments impacts the atmospheric emissions and depends on the oxygen concentration in the deep water that is affected by reservoir operation[4]. The nutrient inputs impact the close interactions between zooplankton, phytoplankton, and cyanobacterial recruitment and initiate or boost the development of algae blooms. Algae blooms are important for socioeconomic weighting, evaluation, and development of a balanced and sustainable reservoir management. Thus, the project requires considerable inter- and transdisciplinary research to reveal these interconnections, which is accomplished by close collaboration between scientists working across different fields.


Figure 2. Schwarzenbach Reservoir at maximum operation level (left) and during water level lowering (right)


Figure 3. Kleine Kinzig Reservoir used for drinking water supply (left) and reservoir Großer Brombachsee initially constructed for low water regulation but also used for local recreation (right).

Study areas and reservoirs

Research is conducted in three reservoirs (Figures 2-3): Schwarzenbach Reservoir (hydropower and recreation), Kleine Kinzig Reservoir (drinking water supply) and reservoir Großer Brombachsee (low water regulation and recreation). Joint field measurements provide data which are used (i) to correlate sediment stability with sediment parameters and greenhouse gas emissions, (ii) as background information for biofilm cultivation, (iii) for the assessment of temporal development of the phyto- and zooplankton community considering toxin production and release, and finally (iv) as a basis for hydrodynamic, sediment transport, and water quality modelling. Some aspects are investigated under controlled conditions in the laboratory, such as the vertical sediment stability over depth using novel erosion detection methods[5], the stabilizing capacity of biofilms by conducting manipulative experiments and adhesion measurements with a magnetic device[6], and the formation and toxicology of cyanobacterial blooms using mesocosm experiments[7]. To evaluate the social environment of the reservoir systems and the associated conflict potential, methodical approaches (*e.g.* constellation analyses, surveys, interviews, composite programming[8]) are used. In addition, a Collaborative Research Environment (CRE) will be prepared.

The Schwarzenbach Reservoir case

In 2016 and 2017, the focus of the project was on the Schwarzenbach Reservoir (SBT), used for hydropower production since 1926 (pumped-storage operation). The reservoir is also an attractive recreation destination ("Nationalpark Schwarzwald"), with a surface area of approximately 60 ha, a maximum depth of 65 m (average depth of 21.8 m), and a volume of about 14.4 Mm³ at maximum operation level. An intensive data acquisition, involving stationary, continuous, and spatiotemporal resolved measurements, was conducted to record a comprehensive abiotic and biotic dataset. A mooring station equipped with an Acoustic Current Doppler Profiler (ADCP), thermistors (T), optodes (O_2, CO_2) and pH sensors was installed to obtain long-term, vertically resolved datasets. Autonomously measuring funnels were installed along the thalweg and at the river mouth of the reservoir to measure the ebullition of CH_4. During regularly conducted field campaigns, the spatial distribution of CH_4 and CO_2 flux above the air-water interface was measured by floating chambers in combination with automatic CO_2 sensors, or with a portable gas sensor. In addition, local profiles of temperature, conductivity, O_2, pH, CO_2, turbidity, and Chl-a pigments were measured with different probes. The field campaigns were complemented by measurements of nutrient concentration (P, N), alkalinity, phyto- and zooplankton composition, collection of water for experiments, sediment sampling (grab and core sampling) at selected locations, and the collection of resting stages of cyanobacteria and *Daphnia* in the pelagial, profundal, and benthic sediments of the reservoir.

Sediments in the SBT consist of mainly silty material with a decreasing grain size along the thalweg towards the dam (Figure 4). The extracted sediment cores are characterized by a low bulk density (0.9 to 1.3 g/cm³) that can be due to large water and gas contents as well as a high organic content (7 to 14%). The laboratory experiments of sediment deposit stability suggest that erosion should be initiated at low shear stresses. Moreover, they emphasize that the erosion behavior can only be described by taking into account both cohesive and adhesive forces.

In 2016, water samples from the SBT (oligotrophic, slightly acidic) were collected to cultivate biofilm in the laboratory. The reservoir water was circulated in six independent, identical flumes. While the biofilm growth was studied in relation to varying flow conditions, the effects on species composition, metabolic activity, and functionality, here the ***biostabilization*** potential, were studied over a period of several weeks. The results illustrated the high potential of biofilm to stabilize fine sediments (up to 15 times as compared to the control) and revealed a strong link of this biofilm function to the nutrient and flow condition. Altogether, these first investigations indicate the impact of microorganisms on sediment deposit stability and dynamics in reservoirs.

The investigation of ***cyanobacterial blooms*** revealed that the blooms in the SBT primarily consist of *Anabaena* species and that the composition of the zooplankton community changes during the formation of a cyanobacterial bloom, *i.e.* the abundance of large zooplankton species decreases (*Daphnia longispina*) while smaller species increase (*Ceriodaphnia* sp. and *Bosmina* sp.). Reasons for this shift in the zooplankton species community, caused by the formation of cyanobacteria, are currently investigated in laboratory and mesocosm experiments. Based on the obtained dataset from the field campaigns, ***greenhouse gas emission*** and storage can be linked to hydrodynamic conditions, sediments, and phytoplankton development. In the SBT, the diffusive CH_4-fluxes from sediments are comparatively low (Figure 4). However, a significant correlation between ebullition and daily water level fluctuations can be seen[9]. In general, the release of methane bubbles through pumped storage operations contributes considerably to the total emission of CH_4. The O_2 concentration in the deep water decreases less with pumping compared to no pumping operation. As a result of the high O_2 concentration, the CH_4 accumulation in the deep water is reduced. Hence, the pumped storage operation indirectly contributes to the fact that CH_4 emissions of stored methane are comparatively low in the SBT during the autumn overturn.

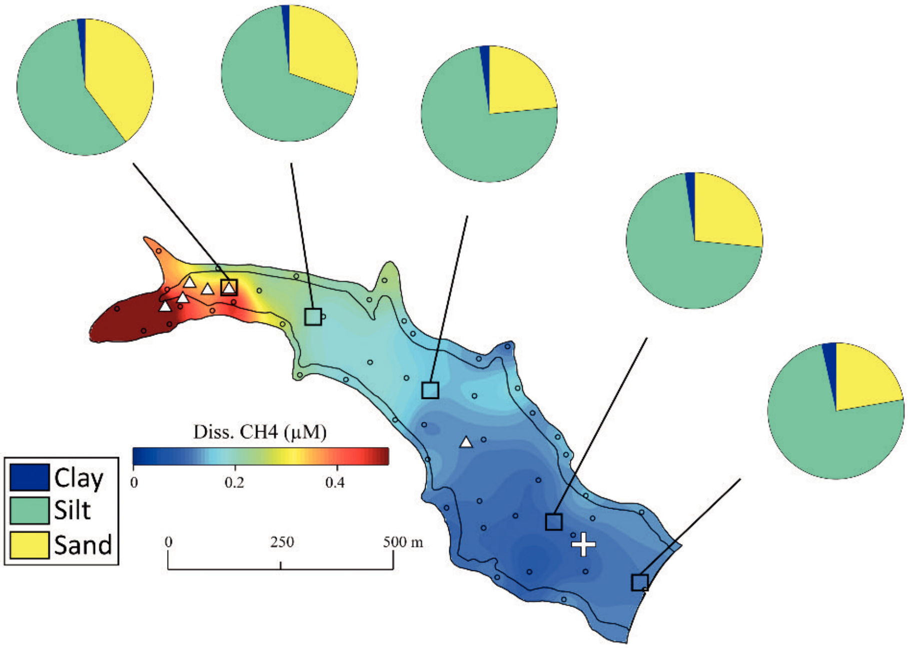

Figure 4. Spatial distribution of the dissolved CH4 concentration in the Schwarzenbach Reservoir and surface sediment composition along the thalweg (data recorded in 2016). Black circles: CH4 sampling stations; White triangles: ebullition funnels; Black squares: sediment sampling locations; White cross: mooring station. The map shows the reservoir at maximum operation water level, whereas the black contour line indicates the minimum operation level.

The combination of the gained insights on biological, chemical and geological processes and the management procedures help to understand the reservoir as a system embedded in its immediate social surrounding. This knowledge can be used to mitigate ***societal implications***. For example, the formation of cyanobacterial blooms has notably increased since 2002 and is likely connected to a change in the reservoir operation. The combined relationships between major effects and the potential impairment of reservoir functionality are considered by all involved experts, to jointly derive sustainable management strategies that are designed to attenuate or avoid conflicting interests.

First lessons

The first results gained within the CHARM project reveal that there are complex interdependencies between the processes of sedimentation, biostabilization, harmful cyanobacterial blooms, greenhouse gas emissions, and their societal implications. These interdependencies can only be addressed by transdisciplinary research among the involved disciplines. It is recommended to take into consideration biochemical parameters (*e.g.* biostabilization) in investigating sediment stability in reservoirs. The reservoir management also impacts greenhouse gas emissions, showing a clear correlation between ebullition and water level fluctuations. This knowledge is of significant importance for drawdown periods or pumping operations, which further affect the nutrient influx and the distribution of dissolved substances and algae in the reservoir that may support the formation of cyanobacterial blooms. The latter may lead to conflicts between stakeholders, especially when the reservoir is used for other purposes (*e.g.* recreation).

After the completion and evaluation of the integrated data collection, it is intended to implement the obtained information in a numerical model that takes into account physical and biological processes, thereby contributing to a better understanding of sediment dynamics, distribution and release of greenhouse gases, and water quality in reservoirs. The model can be used to simulate and predict the effects of reservoir management scenarios to derive sustainable strategies, meet multiple interests, and increase societal acceptance of reservoirs. Conclusively, reservoirs with different purposes and management (Kleine Kinzig, Großer Brombachsee) will be considered within the next two years in order to ensure the transferability of the results. ■

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The CHARM-Team i
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For further information about CHARM:
www.charm-bw.de