URBAN WATER INTERFACES (UWI)
RESEARCH ALIGNED IN COMMON TOPICS

Urban Water Interfaces (UWI)

UWI – RESEARCH ALIGNED IN COMMON TOPICS

Water quality and quantity in urban water systems of metropolitan areas face numerous threats. Climate and demographic change exacerbate the occurrence of extreme hydrological events and of new and persistent substances in the water cycle, thus further increasing pressure on urban water systems. This suggests that management based on a solid system understanding is necessary to ensure sustained functioning of urban water systems under both current and future conditions.

Interfaces will play key roles in the urban water cycle. The processes and fluxes of water, matter and heat across interfaces are characterised by steep hydrodynamic and biogeochemical gradients, non-linear interactions between biotic and abiotic system components, and heterogeneous and dynamic structures. Because of this complexity, the current understanding of the processes at urban water interfaces (UWI) is notably incomplete. Understanding the functioning of natural interfaces and technical interfaces requires a broader integrative framework than has commonly been used calling for interdisciplinary approaches and the initiation of UWI.

UWI is an interdisciplinary research training group (RTG) of engineers and natural scientists located at the Technische Universität Berlin (TUB) and the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), funded by the Deutsche Forschungsgemeinschaft (DFG). Within the RTG, 13 doctoral students and several kollegiates have to pass a strongly interdisciplinary and internationally-oriented structured scientific education programme and investigate interfaces in urban water systems within a common framework by involving both natural and technical systems in an interdisciplinary environment. The UWI doctoral students are working on their own respective doctoral thesis project but are at the same time joined together through common activities and interactions between projects, which are merged in seven common topics. Based on this collaboration between engineers and natural scientists, we aim at a new quality of general process understanding and, thus, significant progress in fundamental research. In this brochure, we present current research carried out in the framework of these common topics and show how the individual doctoral projects are interlinked.

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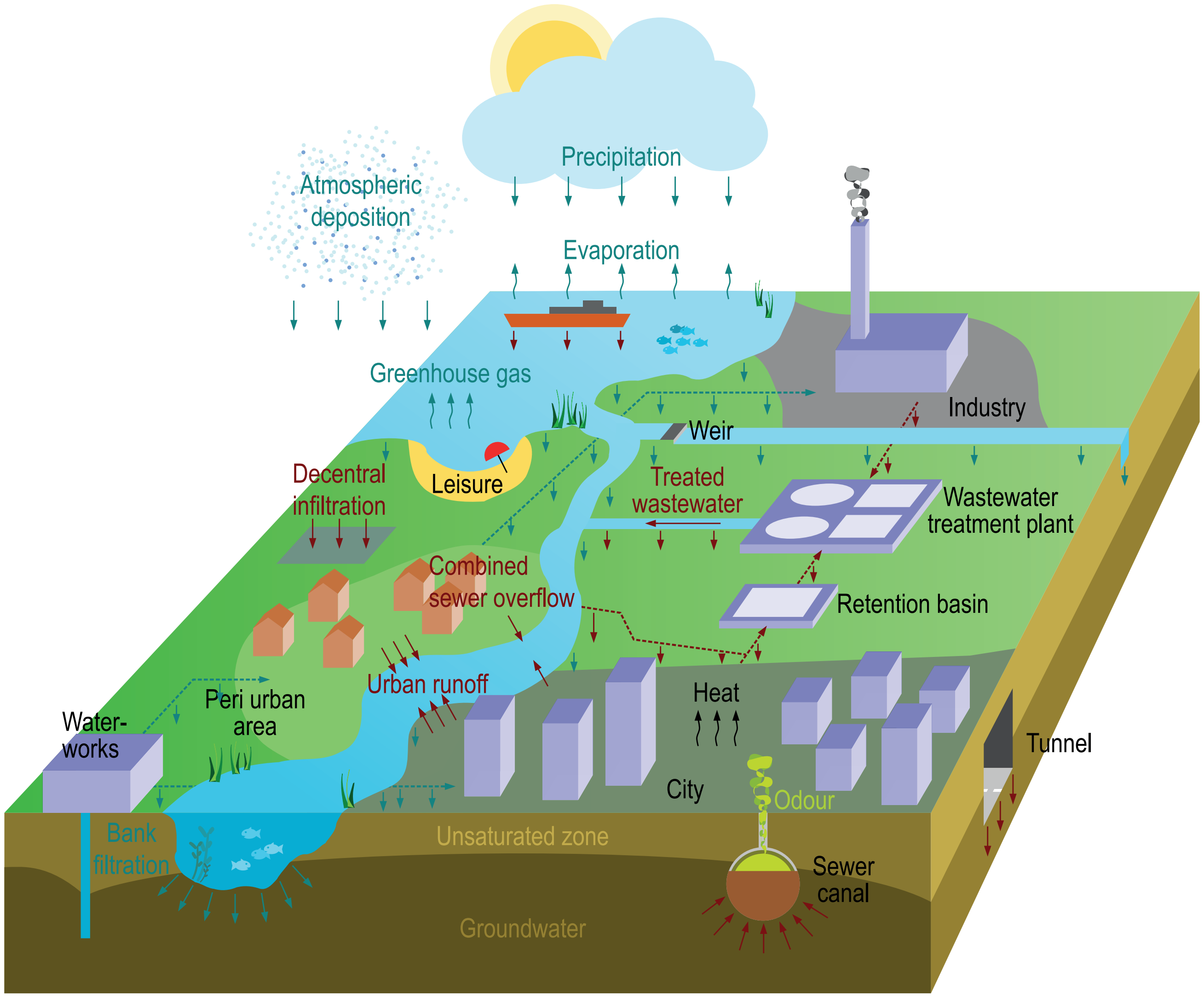

URBAN SOIL – ATMOSPHERE INTERFACE

DOCTORAL STUDENTS: Kyle Pipkins, Anne Timm*
KOLLEGIATES: Ilhan Özgen (TU Berlin), Lauranne Pille (TU Berlin)

The unique challenge of research at the soil – atmosphere interface in urban areas is related to the high heterogeneity in urban surfaces. These surfaces are composed of varying mixes of permeable and impermeable materials, and therefore require a flexible research approach. These different surfaces have different effects on the transport of heat and water above and below the respective surface types. From above, these effects can be measured through the consideration of the surface energy balance, which takes into account the fluxes of energy between the surface and the atmosphere. From below, these effects can be described in terms of the coupled movement of heat and water between the respective surface and the soil medium. The following two research projects focused on this common topic incorporate methods from both approaches: **Project N2** – Heat and vapour transport at the soil – atmosphere interface; and **Project T1** – Water and heat transport at the soil-atmosphere interface.

> Collecting hyperspectral sample points for image calibration.

This research is being carried out at a field site where two weighing lysimeters have been prepared with different sealing materials. In addition, two grass lysimeters are being used for reference evapotranspiration measurements. Moisture and temperature probes have been installed in the two partially sealed lysimeters in order to construct moisture and temperature profiles. Additionally, thermal and multispectral cameras collect surface temperature data and imagery from different heights. A further stage of research will involve the application of information gathered at the lysimeters to a larger field-scale site.

While both research projects are focusing on heat and water transport, research Project T1 aims at understanding the hydrological processes within urban soils and partially sealed surfaces using the lysimeters with the aim to predict evaporation using only meteorological data and surface properties. In comparison, research Project N2 will focus on energy fluxes with the help of remote sensing and meteorology-based methods. It will also consider the relation between scale of measurement and model performance, through the use of different measurement platforms (3 – 9 meter tripod and an unmanned aerial vehicle – UAV) and potentially through satellite data. The first results will serve to assess the surface temperature dynamics of partially sealed surfaces, and future efforts will focus on the application of surface energy balance models for the estimation of evapotranspiration from such surfaces.

> Weighing lysimeters with different paving materials.

INTERFACES
- soil – atmosphere (N2 – Kyle Pipkins, T1 – Anne Timm, Ilhan Özgen, Lauranne Pille)

COLLABORATIONS
- Umweltbundesamt (UBA)

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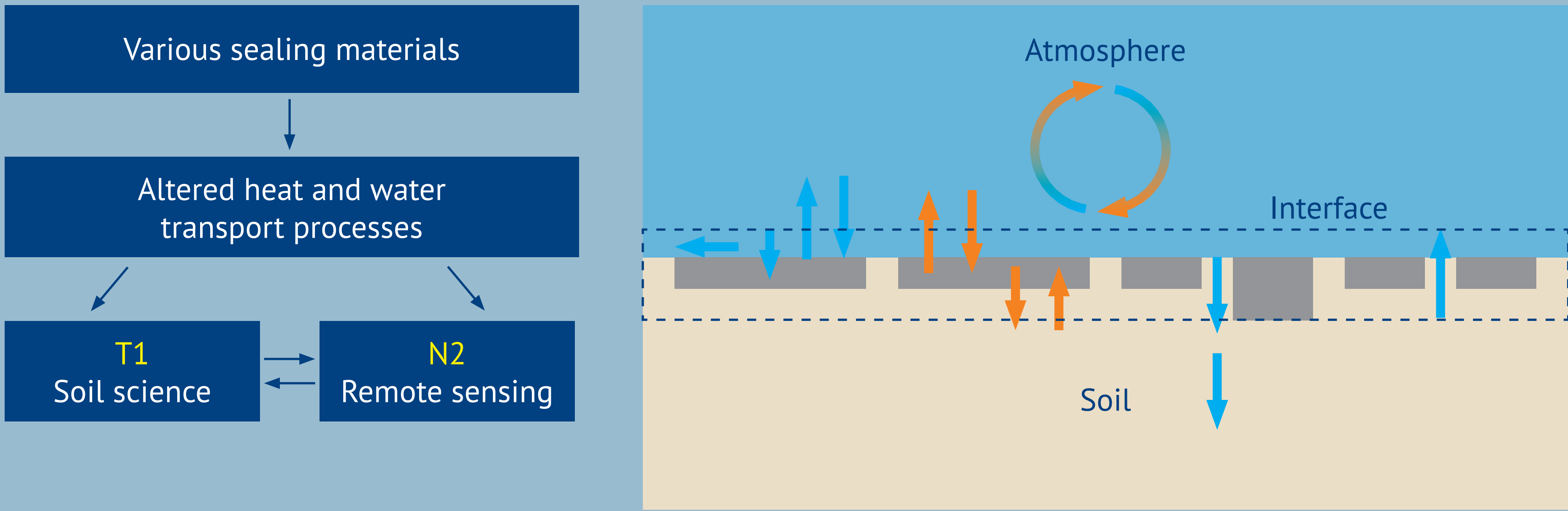
URBAN SOIL – ATMOSPHERE INTERFACE



INTERFACES IN URBAN SURFACE WATERS

DOCTORAL STUDENTS: Tabea Broecker, Fatima El-Athman, Mikael Gillefalk, Sonia Herrero, Robert Ladwig*, Clara Romero, Jonas Schaper

Urban surface waters are heavily modified systems that face various challenges caused by interactions between technical and natural compartments. The morphological degradation of surface waters due to water management can cause a disruption between water systems and their riparian area, floodplains, the hyporheic zone and aquifers. Further, high loads of pollutants, nutrients and organic carbon are discharged into the recipients from various sources like wastewater treatment plants (WWTP), industry, road runoffs, paved surfaces and atmospheric deposition. Eventually, this can result in the eutrophication of urban surface waters. In comparison to low affected surface waters, the water quality and quantity of urban ones are altered on microscale to macroscale spatial and temporal levels when flows across different interfaces appear. These deep gradients occur between (1) aquifers and surface waters, (2) atmosphere and surface waters, and (3) sediments and surface waters. In addition, all these interfaces are also affected by urban technical systems. The main focus of the research in this common topic group is the semi-closed water cycle and management in the city of Berlin, Germany. The urban water management aims at managing a secure water supply for domestic and industrial consumption, an adequate sanitation, the protection of humans and infrastructure as well as urban ecosystems and the conservation of biodiversity. Such a system is vulnerable to changing meteorological conditions as well as pollutant loads. We aim to increase the understanding of urban flow dynamics, interactions between surface waters and their surrounding interfaces, as well as the metabolism of surface waters to improve urban water management.

To assess water management measures, paleolimnological methods are used to investigate sediments of urban surface waters in Berlin. These natural archives give information about past pollutant loadings and can act as possible internal sources. Further, with the help of coupled numerical models for hydrodynamics, water chemistry and diagenesis it is possible to optimise current and future lake water management as well as to find weaknesses and potential threats. This will be done by formulating different management scenarios using 1D as well as 2D lake models incorporating modelling systems like General Lake Model and TELEMAC-MASCARET **(Project T4).**

> Field work on Berlin's surface waters.

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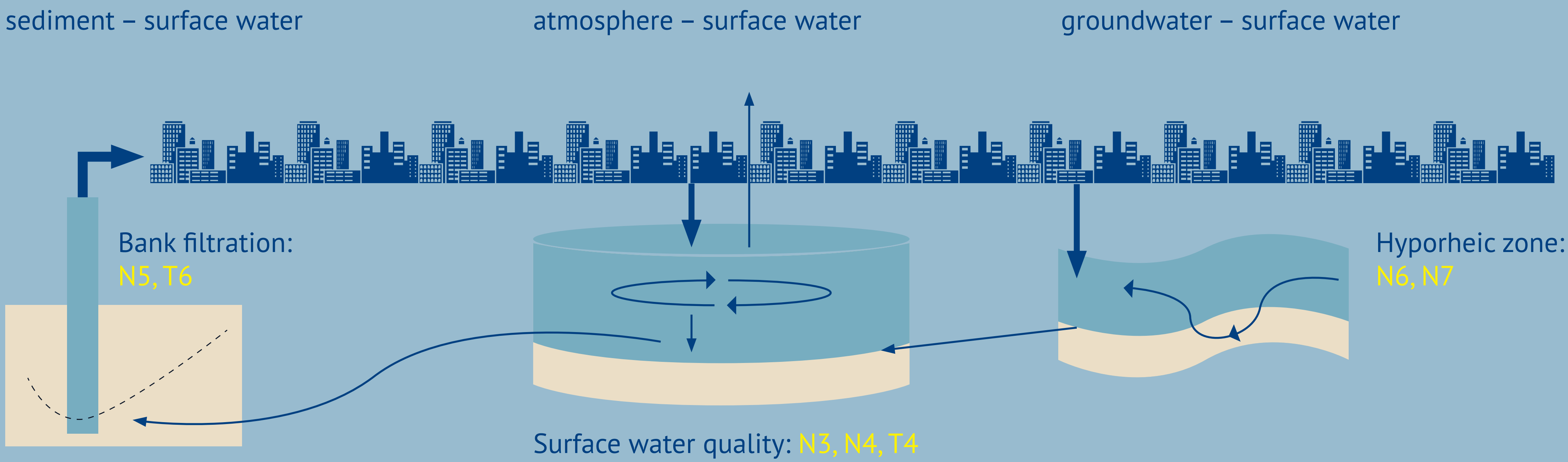
INTERFACES IN URBAN SURFACE WATERS

∑ gradients in a "semi-closed" water cycle



Processes of interest:

1. Flow dynamics
2. Transformation processes
3. Gas emissions

Research topics:

1. Hyporheic zone
2. Surface water quality
3. Bank filtration

Further research activities include the investigation of the groundwater – surface water interface by extensive monitoring of a river field site **(Project N6)** and formulating a flow and transport model **(Project N7).** Here, a three-dimensional, integral single-domain model is applied and extended using the Navier-Stokes equations for surface water and groundwater. The simulations comprise flow, transport and reaction processes in the transitional area of surface water and groundwater. For the calculations, the computational fluid dynamics software OpenFOAM is used.

Laboratory and modelling studies are used to explore the effects of bank filtration on lake ecosystems **(Project N5)**, as well as drinking water purification regarding micropollutants. A particular emphasis is put on the degradation processes of iodinated contrast media during bank filtration **(Project T6).** These diagnostic agents show decreasing concentrations during bank filtration although they are known to be very stable and persistent to conventional wastewater treatment. Further, the investigation of the effects of bank filtration on lake water ecosystems will result in a new research field which is approached in a number of different ways: (i) with field work, (ii) with experiments, both in a laboratory as well as a field setting and also (iii) by computer simulation using the ecosystem model PCLake.

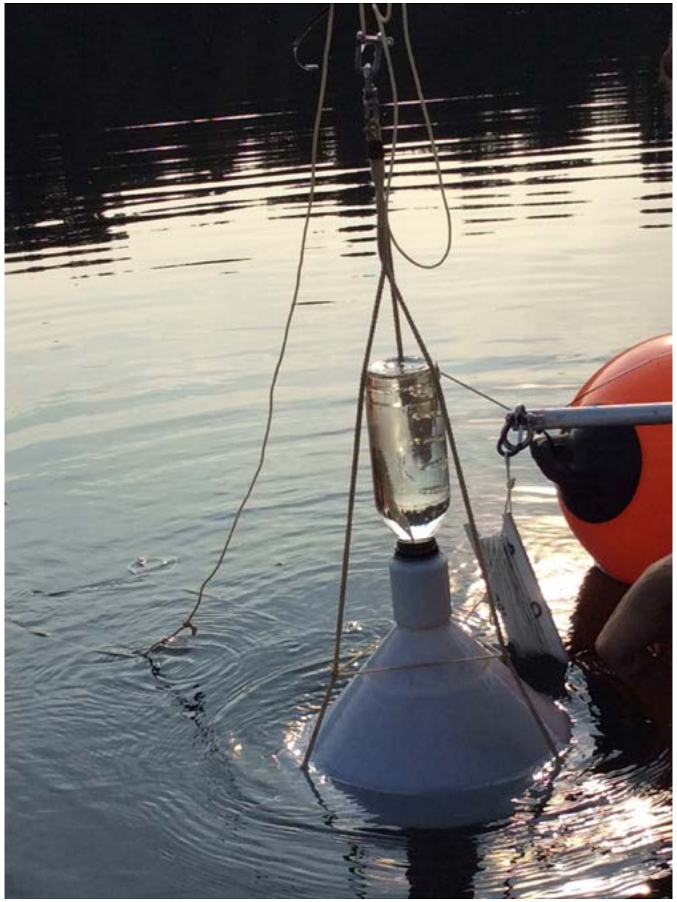
A major field campaign intends to monitor the ecosystem metabolism **(Project N4).** This is motivated by two equally important aspects: (i) the need to estimate the total CO_2 emissions from metropolitan areas to improve knowledge on the role of inland waters in the global carbon cycle and (ii) the need to obtain a better mechanistic understanding of urban water networks as meta-ecosystems with ecosystem metabolism as a central integrative element of ecosystem functioning. Further, the project aims at quantifying greenhouse gas emissions in order to understand the specific drivers in aquatic urban ecosystems. Different processes will be studied from production in the sediments to different flux pathways **(Project N3).**

INTERFACES

- surface water – sediment (T4 – Robert Ladwig)
- surface water – groundwater (N5 – Mikael Gillefalk, N6 – Jonas Schaper, N7 – Tabea Broecker, T6 – Fatima El-Athman)
- surface water – atmosphere (N3 – Sonia Herrero, N4 – Clara Romero)

COLLABORATIONS

- Berliner Wasserbetriebe (BWB)
- Senatsverwaltung für Stadtentwicklung und Umwelt, Berlin
- Netherlands Institute of Ecology (NIOO), Wageningen
- Helmholtz Centre for Environmental Research (UFZ), Leipzig



> Measurement of methane ebullition from sediments.

> Growth experiment with water plants *(Potamogeton pectinatus)*.

SURFACE WATER – GROUNDWATER INTERACTIONS

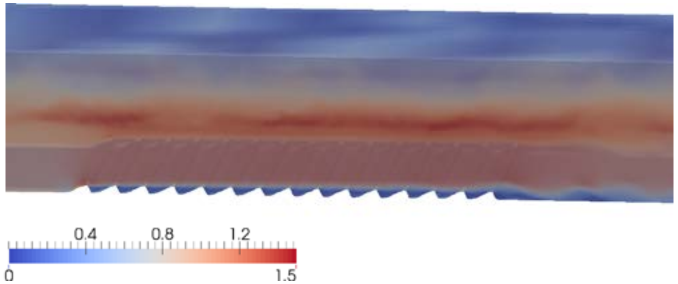
DOCTORAL STUDENTS: Tabea Broecker, Fatima El-Athman, Mikael Gillefalk, Jonas Schaper*
KOLLEGIATES: Anna Jäger (IGB Berlin), Liwen Wu (IGB Berlin)

This thematic group focuses on the hydrological and biogeochemical processes occurring in saturated sediment interfaces between groundwater and surface water bodies in urban areas. While some projects target lake – groundwater interactions (i.e., bank filtration), others focus on the hyporheic zone, the sediment interface between groundwater bodies and lotic systems. Both interfaces are characterised by steep hydrological and biogeochemical gradients, diverse microbial communities and a distinct distribution of hydrological residence times and thus constitute important sinks for urban water contaminants. Therefore, they do not only play a pivotal role with regard to ecosystem functioning and health, but they also constitute reactive barriers, which help protect drinking water resources. Combining expertise from civil engineers and natural scientists, our overall aim is to understand both the ecosystem services provided by groundwater – surface water interfaces and their role in urban water cycles.

Field, laboratory and modelling studies are used to explore the effects of bank filtration on lake ecosystems **(Project N5).** A particular interest lies in the degradation processes of iodinated contrast media during bank filtration **(Project T6).** These diagnostic agents show decreasing concentrations during bank filtration although they are known to be very stable and persistent to conventional wastewater treatment.

Detailed field investigations across a number of different sites in Berlin, Germany, as well as Adelaide, Australia, are combined with transport and reaction models to elucidate the hydrological and biogeochemical processes that control pollution dynamics of polar organic trace contaminants in hyporheic bioreactors of urban rivers **(Project N6).** An integral solver for groundwater – surface water interactions is being extended for transport

> Field work at river Erpe.



> Velocity distribution at a rippled streambed.

processes in OpenFOAM **(Project N7).** For the first time, the Navier-Stokes equations are being applied to model hyporheic exchange and solute transport across the sediment – water interface.

INTERFACES

- surface water – groundwater (N5 – Mikael Gillefalk, N6 – Jonas Schaper, N7 – Tabea Broecker, T6 – Fatima El-Athman, Anna Jäger, Liwen Wu)

COLLABORATIONS

- Berliner Wasserbetriebe (BWB)
- Netherlands Institute of Ecology (NIOO), Wageningen
- Flinders University, Adelaide, South Australia
- Department of Environmental Science and Analytical Chemistry (ACES), Stockholm University
- Marie Curie ITN HypoTrain

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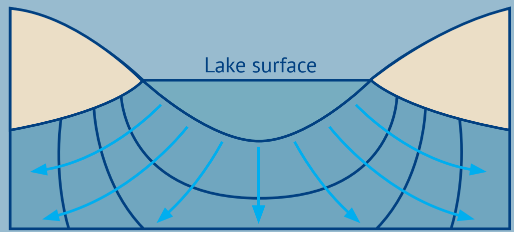
SURFACE WATER – GROUNDWATER INTERACTIONS

Biogeochemical gradients at SW – GW interfaces promote high chemical turnover rates

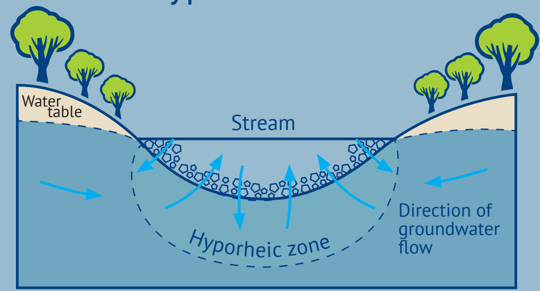
N5: Effects of bank filtration on lake ecosystems

T6: Deiodination of iodinated contrast media



Winter et al. 1998 USGS, circ1139

N6: Fate of organic micropollutants in hyporheic reactors



N7: Modelling of flow and reactive transport in hyporheic zones

Biogeochemistry and flow patterns impact ecosystem functioning and local biota

Pressure gradients cause exchange flows which in turn impact chemical turnover

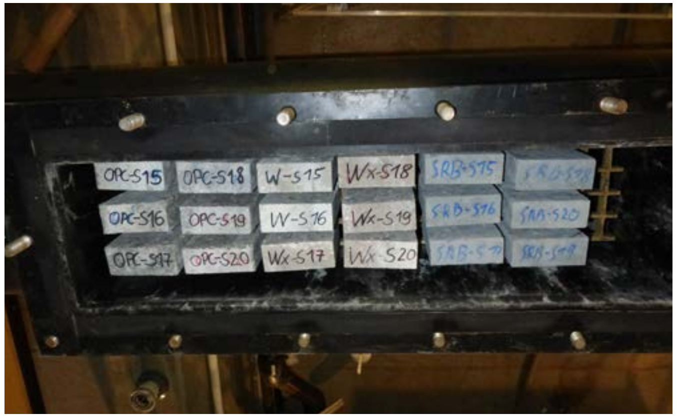
INTERFACES IN SEWER SYSTEMS

DOCTORAL STUDENTS: Maria Grüneberger*, Katharina Teuber
KOLLEGIATE: Daneish Despot (TU Berlin)

During its transportation, wastewater in sewer systems undergoes a number of physical, biological and chemical processes and transformations. Under certain conditions, such as high detention times formation of hydrogen sulphide (H_2S) in sewer systems leads to odour in the sewer atmosphere and corrosion at sewer walls. High concentrations of odorous substances in the atmosphere can even lead to the death of sewer workers with annual costs for rehabilitation and replacement of damaged sewers reaching several billion euros in Germany. Two driving aspects are focused on in three projects in this context: the enhanced understanding of odour and corrosion mechanisms and the development of a simulation model.

An enhanced understanding of the conversion of sulphurous compounds in sewers is gained by operating and maintaining a research pilot plant of the Berliner Wasserbetriebe (BWB) **(Project T2).** In addition, the effectiveness and efficiency of different countermeasures are evaluated. A conceptual model for transformation processes at the biofilm – wastewater interface is being developed to identify key parameters contributing to transformations within the sewer sulphur cycle. Biogenic sulphuric acid corrosion (BSC) is investigated on the interface between sewer atmosphere and building material. Concrete samples of different compositions are being exposed to acid under field and laboratory conditions. New information is being gained on the comparability between BSC of concrete in real sewer systems and laboratory acid resistance tests. Also, different laboratory acid resistance tests are being compared. These investigations will lead to detailed insights on corrosion mechanisms caused by BSC.

A tool is being developed by simulating the three-phase water-air-solid system of a sewer by using the three-dimensional Computational Fluid Dynamics (CFD) tool OpenFOAM **(Project T3).** The focus of the CFD model lies on the correct description of in-sewer water-air flow and transformation processes, reaeration and H_2S emission which highly depend on the three-dimensionality of the hydraulic behaviour. After a thorough validation of the hydraulic behaviour, transport processes including reaction mechanisms and transfer processes across the water – air interface including their dependencies on factors such as pH and temperature are implemented. Data is obtained from the research pilot plant. First results concerning the hydraulic behaviour show a good agreement of the model results with measured water velocities and water levels.



> Concrete samples in chamber at research pilot plant.

INTERFACES

- wastewater – biofilm (T3 – Katharina Teuber, Daneish Despot)
- wastewater – sewer atmosphere (T3 – Katharina Teuber, Daneish Despot)
- sewer atmosphere – biofilm – construction material (T2 – Maria Grüneberger, T3 – Katharina Teuber, Daneish Despot)

COLLABORATIONS

- Berliner Wasserbetriebe (BWB)
- Universiteit Gent, Belgium
- KIWA, Berlin

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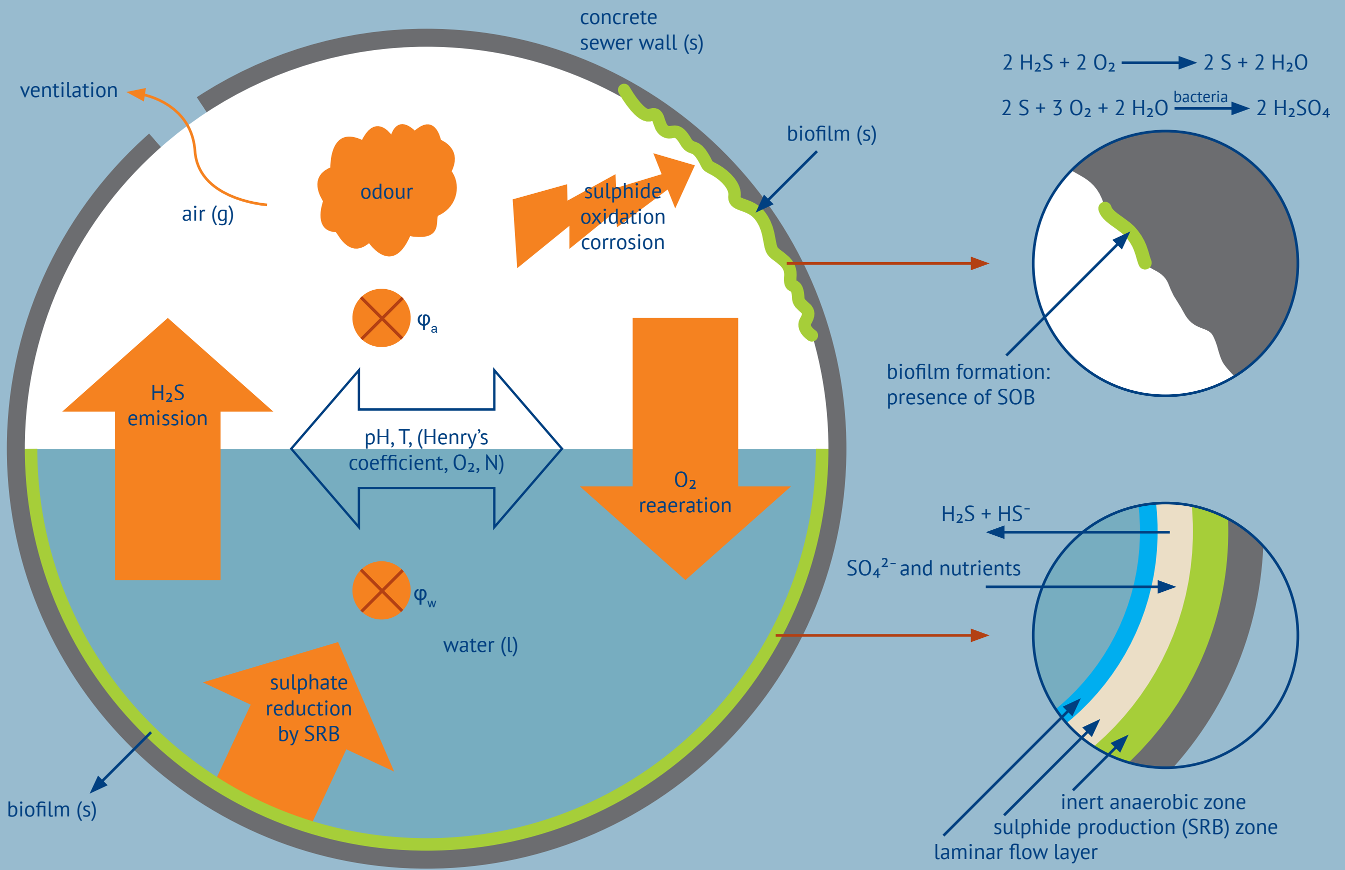
INTERFACES IN SEWER SYSTEMS



Reaction pathways for sulphur conversions in sewers (following Hvitved-Jacobsen 2013).
SRB – Sulphate Reducing Bacteria
SOB – Sulphide Oxidising Bacteria

Research topics

Enhanced understanding of odour and corrosion mechanisms in sewers (T2, T3)

Development of simulation model (T3)

> Research pilot plant of Berliner Wasserbetriebe in Berlin-Neukölln.

Berliner Wasserbetriebe

MICROPOLLUTANTS

DOCTORAL STUDENTS: Geert Aschermann*, Fatima El-Athman, Sonia Herrero, Robert Ladwig, Marcella Nega, Clara Romero, Jonas Schaper
KOLLEGIATE: Anna Jäger (IGB)

Over the last decade, more and more organic contaminants in trace-level concentrations (µg/L to ng/L) have been detected ubiquitously in the aquatic environment and especially in urban water cycles. These so-called organic micropollutants are introduced into the environment by anthropogenic activities. They include pharmaceuticals, radiocontrast agents, household chemicals, food additives etc. These persistent compounds are discharged as part of municipal wastewater and cannot or only partly be retained in wastewater treatment plants. Thus, they end up in the receiving surface waters and spread in the aquatic environment. Furthermore, in closed or partially closed water cycles, which can often be found in urban areas, they can potentially end up in drinking water sources.

There is a lack of knowledge about the effects of the discharge of organic micropollutants. The processes that they undergo as well as the processes that they affect within the urban water cycle are only poorly investigated to date. These processes are studied in a multidisciplinary approach, with several projects focusing on different interfaces of the urban water cycle.

One aspect of research is the effect of organic micropollutants on the microbial metabolism with focus on the interface urban surface water – atmosphere. Hereby, extensive data are collected to understand the consequences of an organic micropollutant exposition on the emissions of CO_2 **(Project N4)** and CH_4 **(Project N3).** Further, investigating the sediment – surface water interface the impact of treated wastewaters (including micropollutants) on the hydraulics and water quality of urban lakes will be evaluated using numerical models **(Project T4).** The behaviour of organic micropollutants at the interface of surface water and groundwater is also of special interest, from a natural as well as from a technical point of view. On the one hand, field as well as lab scale experiments are conducted to study the transport and retention of micropollutants in the hyporheic zone **(Project N6).** On the other hand, new information about the biotic and abiotic removal during bank filtration is gained, with a special focus on the behaviour of radio contrast agents **(Project T6).**

Moreover, the processes at solid – water interfaces are an important aspect which is studied in the research training group to understand micropollutant dynamics in urban water cycles. The degradation potential of microbial communities in biofilms is investigated in the lab as well as in the field **(Project N1).** Besides, the behaviour in technical treatment systems is of interest. So far, there is only little knowledge about potential desorption effects of organic micropollutants in activated carbon processes. New findings will help to get a better understanding of this established technical application **(Project T5).**

All projects cover a wide range of research approaches and techniques, different zones and interfaces, as well as different scales of interest. Combined with modern, state-of-the-art analytical advices and methods improved knowledge about the effects and behaviour of organic micropollutants in urban water cycles will be gained.

INTERFACES

- solid – water (N1 – Marcella Nega, T5 – Geert Aschermann)
- surface water – atmosphere (N3 – Sonia Herrero, N4 – Clara Romero)
- surface water – groundwater (N6 – Jonas Schaper, T6 – Fatima El-Athman)
- sediment – surface water (T4 – Robert Ladwig)

COLLABORATIONS

- Berliner Wasserbetriebe (BWB)
- Helmholtz Centre for Environmental Research (UFZ), Leipzig
- Senatsverwaltung für Stadtentwicklung und Umwelt, Berlin
- Bundesanstalt für Materialforschung und -prüfung (BAM)

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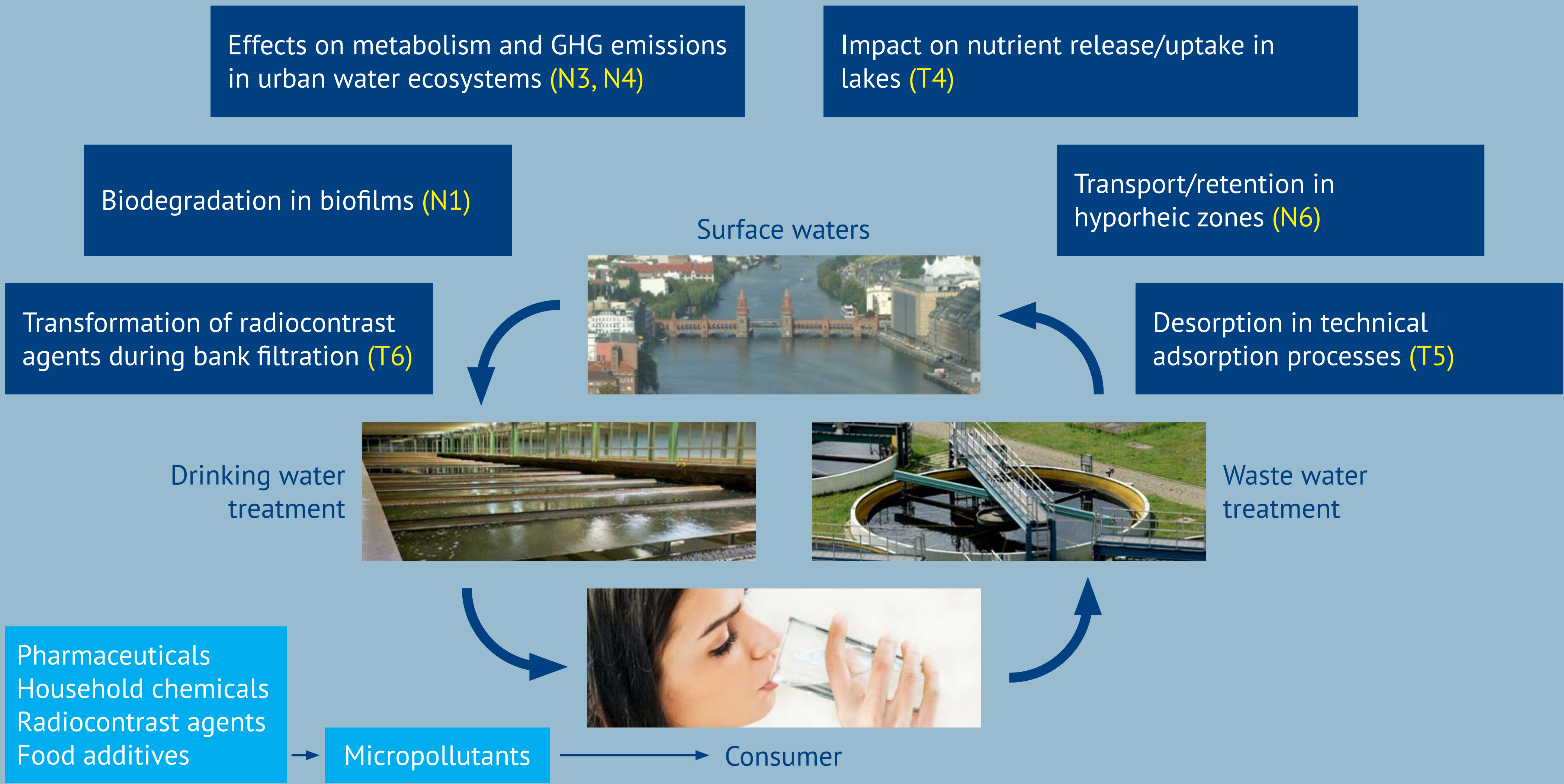
MICROPOLLUTANTS



BIOGEOCHEMICAL PROCESSES

DOCTORAL STUDENTS: Fatima El-Athman, Marcella Nega, Sonia Herrero, Clara Romero*
KOLLEGIATES: Daneish Despot (TU Berlin), Liwen Wu (IGB Berlin)

Urban water bodies are strongly modified ecosystems. They typically receive large loads of nutrients, organic carbon, suspended solids and a wide variety of other macro- and micropollutants such as heavy metals, pharmaceuticals and personal care products. Furthermore, the morphology of urban water bodies has usually been changed and habitat heterogeneity has been reduced, which limits the ability to support aquatic biodiversity. In this common topic we aim to enhance the understanding of interface processes in natural and technical urban water systems. Several doctoral students work here on different biogeochemical processes associated with urban water interfaces.

The first project addresses the degradation of organic trace pollutants in biofilms at solid – water interfaces **(Project N1).** It specifically tackles the potential of both defined and natural biofilm communities to degrade pollutants such as diclofenac, carbamazepine and iodinated contrast media in urban water systems. The second project aims at understanding the patterns and controls of greenhouse gas (GHG) fluxes in urban waters **(Project N3)**, with special emphasis on methane emissions. Closely interlinked with this is the third project also dealing with GHG fluxes, focusing specifically on ecosystem metabolism in urban aquatic environments **(Project N4).** The objectives are to: (i) estimate whole-ecosystem metabolism based on diel O_2-dynamics in a variety of urban water bodies, (ii) estimate CO_2 concentrations, their dynamics and resulting fluxes across the water – atmosphere interface, (iii) scale up aquatic ecosystem metabolism and CO_2 fluxes to the metropolitan area of Berlin, and (iv) identify the key drivers and gradients of metabolism and CO_2 fluxes. A further project is dealing with sulphur cycles in sewers **(Project T2)**, specifically at the interface defined by wastewater – atmosphere – biofilm – construction material. Finally, one project aims to improve our understanding of the deiodination of iodinated contrast media during bank filtration of urban waters **(Project T6).** Mass balances of iodine will be established that consider both abiotically and biologically mediated transformations.

> Oxygen and CO_2 measurements in the field.

> Inoculation of iron/manganese depositing bacteria.

INTERFACES
- solid – water (N1 – Marcella Nega)
- surface water – atmosphere (N3 – Sonia Herrero, N4 – Clara Romero)
- surface water – groundwater (T6 – Fatima El-Athman, Liwen Wu)
- wastewater – sewer atmosphere (T2 – Daneish Despot)
- sediment – surface water (T6 – Fatima El-Athman)

COLLABORATIONS
- Berliner Wasserbetriebe (BWB)
- Senatsverwaltung für Stadtentwicklung und Umwelt, Berlin
- Helmholtz Centre for Environmental Research (UFZ), Leipzig

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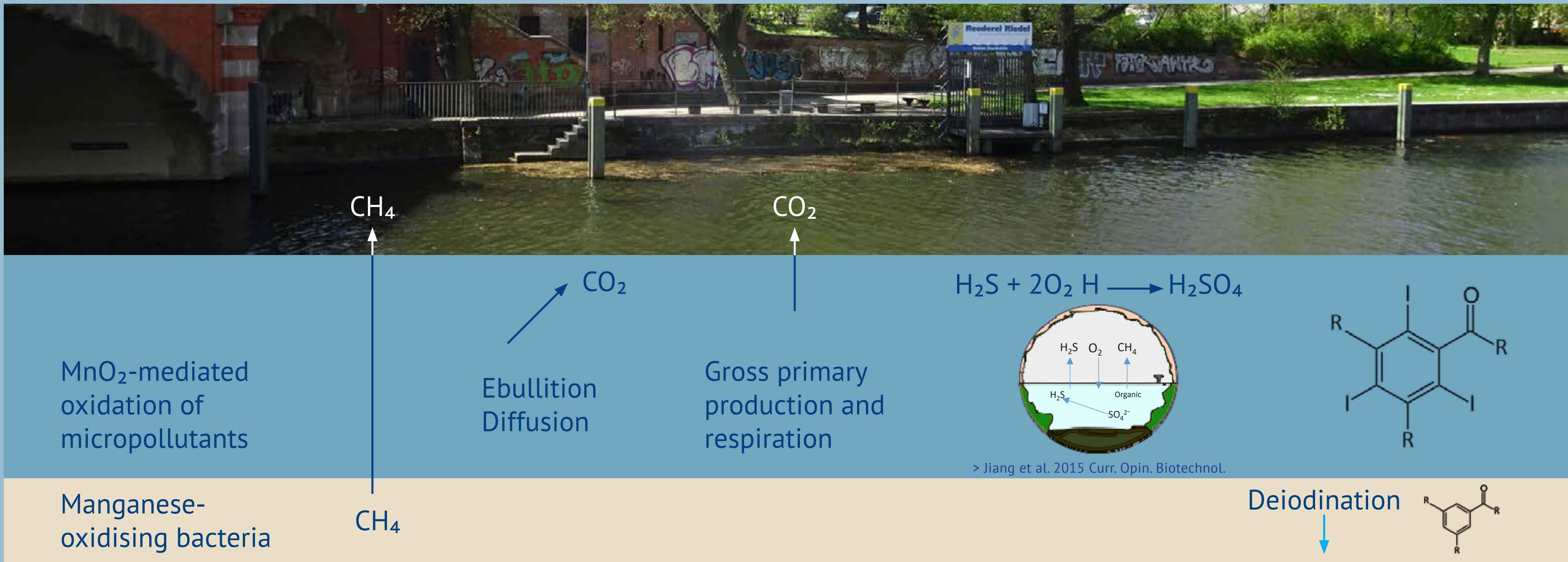
BIOGEOCHEMICAL PROCESSES



N1 Degradation of organic trace pollutants (Laboratory)

N3 Greenhouse gas formation and fluxes (Field)

N4 Ecosystem metabolism (Field)

T2 Corrosion, sulphur transport and conversion in sewers (Experimental treatment plant)

T6 Deiodination of iodinated contrast media (Laboratory)

MODELLING

DOCTORAL STUDENTS: Tabea Broecker, Mikael Gillefalk, Sonia Herrero, Robert Ladwig, Kyle Pipkins, Clara Romero, Jonas Schaper, Katharina Teuber*, Anne Timm
KOLLEGIATES: Daneish Despot (TU Berlin), Ilhan Özgen (TU Berlin), Liwen Wu (IGB Berlin), Tayebeh Zinati (TU Berlin)

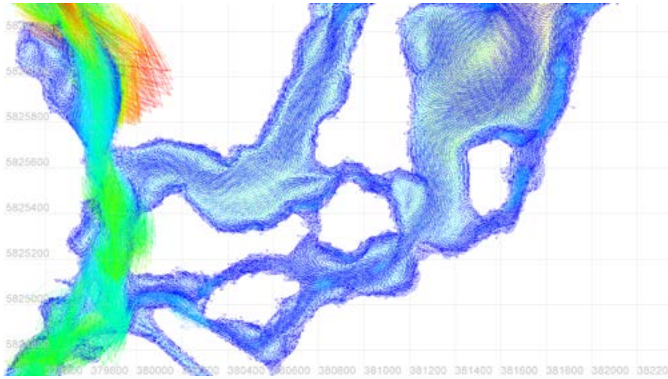
The biggest thematic group covers the area of modelling. Hydrodynamic-numerical, water quality, ecosystem and data-driven models are being developed, extended and coupled in order to describe processes in interface systems within the urban water cycle. If possible, open source software tools are used. In the following, some examples are given. However, for comprehensive information on all modelling activities please visit the project websites.

For some research areas, coupled model approaches are used. In order to evaluate the impact of remaining wastewater constituents on the sediment – water interface in urban lakes **(Project T4)** two coupled hydrodynamic-biogeochemical models are developed to either simulate lakes as one- or two-dimensional systems. The hydrodynamics of the model are described by using the 1D-General Lake Model or TELEMAC-MASCARET, respectively, whereas biogeochemical processes are modelled using either the Aquatic Ecodynamics Model Library or the Delft Water Quality module.

In other areas, models are being extended. Within the Computational Fluid Dynamics (CFD) model OpenFOAM, a multiphase solver is being extended by transport and mass transfer processes in order to describe fluxes of hydrogen sulphide across the water – air interface in sewer systems **(Project T3).** In another project, an integral solver for groundwater – surface water interactions is being extended for transport processes in OpenFOAM **(Project N7).** For the first time, this integral solver is being applied to the hyporheic zone which can be described as the groundwater – surface water interaction space.

> CFD model of a complex sewer system.

Data-driven models are being developed in order to describe the complex processes at the surface water – atmosphere as well as the urban soil – atmosphere interface. At the urban soil – atmosphere interface relationships and feedbacks between evapotranspiration processes and surface sealing are modelled **(Project N2).** The carbon and nitrogen cycle across the surface



> Velocity profiles at Lake Tegel under west wind conditions.

water – atmosphere interface are being modelled in order to quantify greenhouse gas formations and fluxes **(Project N3)**, as well as ecosystem metabolism **(Project N4).**

INTERFACES
- sediment – surface water (T4 – Robert Ladwig)
- surface water – groundwater (N6 – Jonas Schaper, N7 – Tabea Broecker N5 – Mikael Gillefalk , Liwen Wu)
- surface water – atmosphere (N3 – Sonia Herrero, N4 – Clara Romero)
- urban soil – atmosphere (N2 – Kyle Pipkins, T1 – Anne Timm, Ilhan Özgen)
- wastewater – sewer atmosphere (T3 – Katharina Teuber, Daneish Despot)

COLLABORATIONS
- Berliner Wasserbetriebe (BWB)
- Netherlands Institute of Ecology (NIOO), Wageningen

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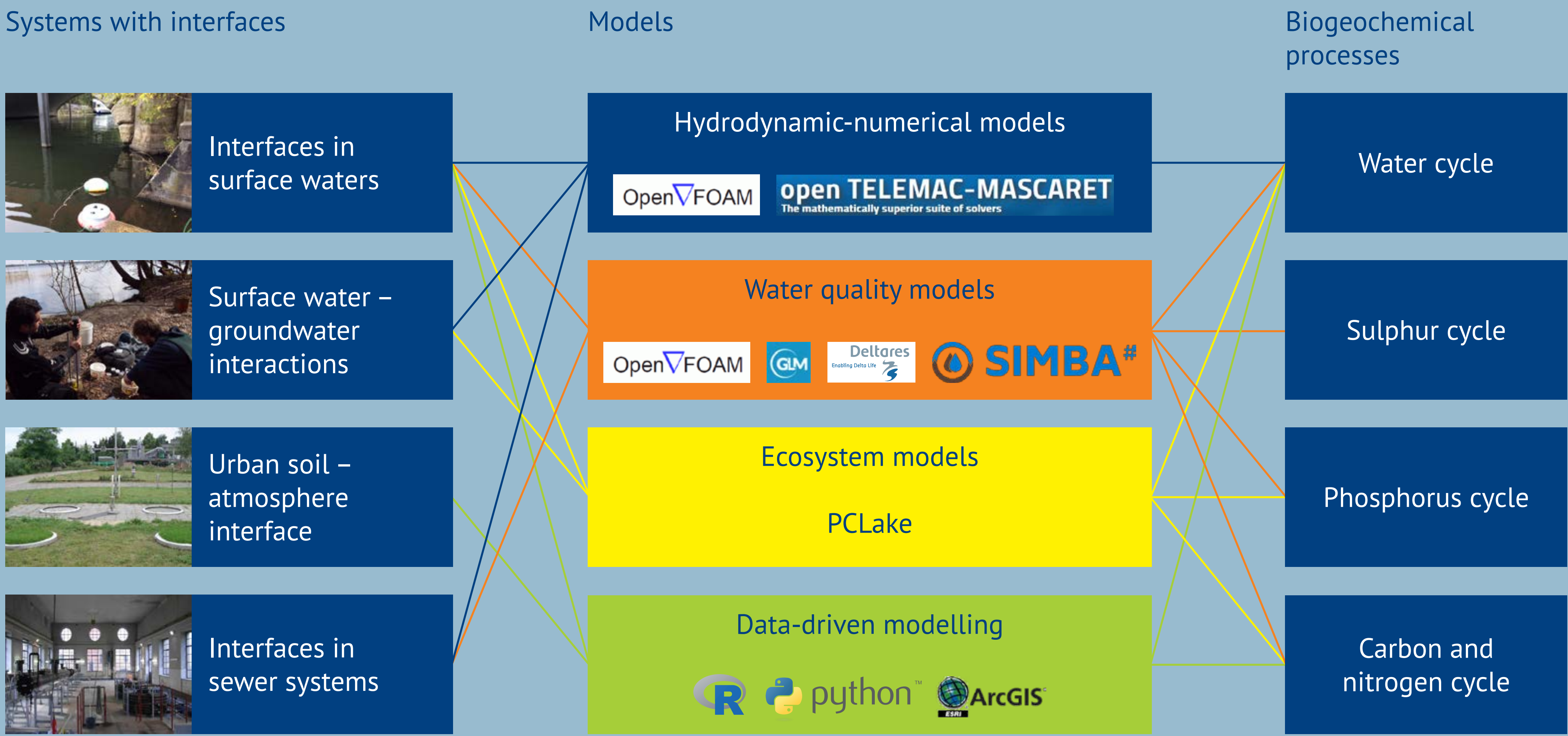
MODELLING



Systems with interfaces
Models
Biogeochemical processes
Interfaces in surface waters
Surface water – groundwater interactions
Urban soil – atmosphere interface
Interfaces in sewer systems
Hydrodynamic-numerical models
OpenFOAM
open TELEMAC-MASCARET
The mathematically superior suite of solvers
Water quality models
OpenFOAM
GLM
Deltares
SIMBA#
Ecosystem models
PCLake
Data-driven modelling
R
python
ArcGIS
Water cycle
Sulphur cycle
Phosphorus cycle
Carbon and nitrogen cycle

FOR FURTHER INFORMATION PLEASE CONTACT US

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P. 15 bottom:	skynesher/istockphoto.com
P. 16 left:	Clara Romero
P. 16 right:	Marcella Nega
P. 17:	Clara Romero
P. 18 left:	Katharina Teuber
P. 18 right:	Robert Ladwig
P. 19 left:	Interfaces in surface waters: Sonia Herrero
P. 19 left:	Surface water – groundwater interactions: Anna Stelmecke
P. 19 left:	Urban soil – atmosphere interface: Anne Timm
P. 19 left:	Interfaces in sewer systems: Stefan Rettig