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Aspects of Water Quality and Transport Modelling in the Oder Estuary (Southern Baltic Sea): Background, Strategy and Example

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Abstract

Various types of utilization, conflicting interests and environmental problems call for coastal water management as part of an integrated coastal zone management. This is especially necessary for the Oder (Odra) estuary at the German/Polish border. The river Oder causes severe, ongoing and large scale eutrophication, which limits the ecological and economic value of its adjacent coastal ecosystems. Simulation models are an important tool with which to tackle these practical problems and support management. We present a general concept of a decision support system with an integration of sub-models. Two types of models for long-term water quality forecasts and scenario simulations, as well as short-term prediction of water pollution are available at present. Spatial human-pathogenic virus transport and decay simulations are used as an example to demonstrate their practical use.

1. Background and Future Challenge

Coastal zones adjacent to large river systems play an outstanding role in trade, transport, agriculture, fisheries, energy production and tourism. They are under intensive human use and a preferred location for harbours, industries and settlements. At the same time coastal zones are of outstanding ecological value and a transformer and sink for terrestrial nutrients and pollutants.

The water quality of coastal waters of rivers draining into these systems is a key factor for sustainable development and management. This awareness and increasing public demand for higher environmental standards are the reasons why the HELCOM Convention on the Protection of the Marine Environment of the Baltic Sea Area was ratified by the European Community in 1994. It declares that

'... the protection and enhancement of the marine environment of the Baltic Sea Area are tasks that cannot effectively be accomplished by national efforts alone, but by close regional co-operation and other appropriate international measures.' The fundamental principles are that '... the Contracting Parties shall individually or jointly take all appropriate legislative, administrative or relevant measures to prevent and eliminate pollution in order to promote ecological restoration of the Baltic Sea Area...'.

During recent years the European Commission has also made water protection one of the priorities of its work. The new European water policy resulted in the Water Framework Directive (WFD), which will be implemented in the member states of the European Community during the coming years. New in this Water Framework Directive is, besides the intensive participation of the public, the spatial integrative aspect. Water management will then cover entire river basins including their coastal zones and will be independent of existing administrative units. For each river basin district a 'river basin management plan' will be established. In several cases, like the Oder (Odra), this has to traverse national frontiers.

The Baltic Sea is defined as a separate Ecoregion. The WFD requires an adaptation of national environmental laws, the definition of recent water quality states, as well as the definition of good states for all lakes, rivers, transitional and coastal waters. The goal is, that all aquatic systems attain a good state during the next 20 years.

The convention on the protection of the marine environment of the Baltic Sea Area and the WFD have similar implications for modelling. Models are needed to understand and simulate the behaviour of aquatic ecosystems and they will be applied as forecast tools for future developments. Not only have spatial integrative aspects to be taken into account in modelling, but different types of models are also needed. These different types (socio-economic, natural scientific etc.) are tools in 'Decision Support Systems (DSS)' to assist integrated catchment areas and coastal zone management. An example of a possible structure of a decision support system for the Oder basin is presented in Fig. 1. In decision support systems models play an important role in scenario analysis and evaluation of management strategies aiming at an improvement of environmental and water quality.

2. The Oder Estuary: Status and Problems

The basin of the river Oder covers an area of about 120.000 km^2 with a population above 10 million people and drains into the central part of the Baltic, the Baltic Proper. With high nutrient load the Oder is one of the most important sources of eutrophication in the central Baltic and its respective coastal zones suffer from severe water quality problems.

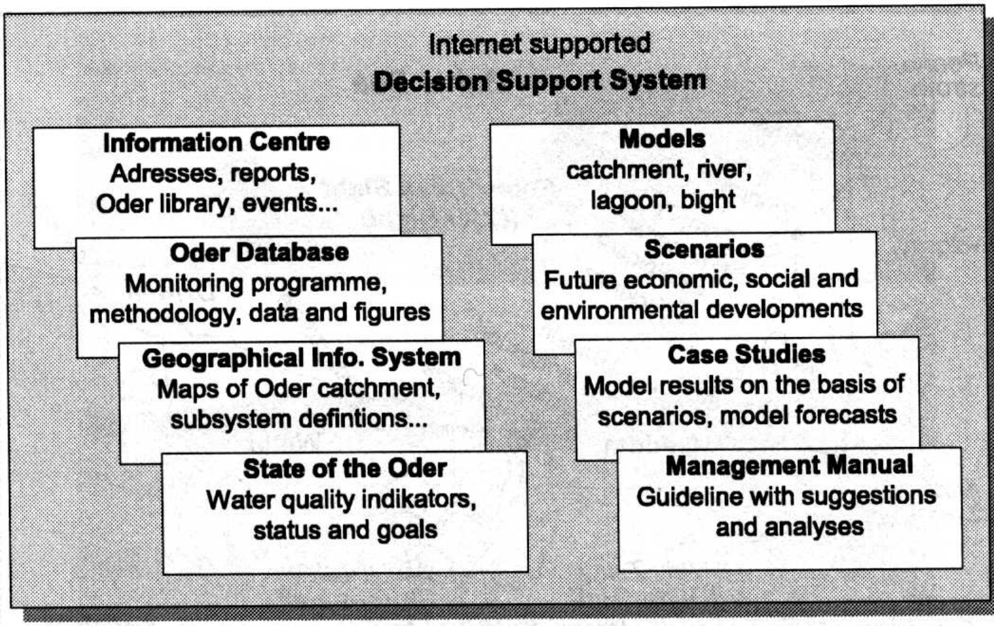

Fig. 1. Exemplary structure of an internet supported decision support system for integrated water quality management of the Oder basin

The coastal zone, which is directly affected by the River Oder, can be divided into the inner coast, with the Oder Lagoon (Oder or Stettiner Haff) and the outer coast covering the Oder Bight (Pomeranian Bight), a part of the Baltic Sea. The islands of Usedom and Wolin separate the two parts.

The Oder Lagoon: The lagoon covers an area of about 680 km^2. In the regional development plan the islands of Usedom (Germany) and Wolin (Poland) with their attractive landscapes (Fig. 2, 3), sandy beaches and reed zones are foreseen for sustainable environmental protection and tourist development. The lagoon is dominated by the water inflow of the Oder and has a water exchange time of only 2–3 months. It is characterized by heavy eutrophication with intensive algal blooms in summer (Fig. 4). The poor surface water quality along the inner shore oriented towards the lagoon is one main obstacle for future tourist development. Due to ongoing pollution the lagoon has lost its function as a sink for nutrients. Neither fixation of nutrients in sediments nor denitrification take place to a high degree (e.g. Meyer & Lampe 1999). On the basis of recently discussed water quality indicators and standards linked to the Water Framework Directive it is very likely that the state of the lagoon will be classified as poor with urgent need for restoration.

The Oder (Pomeranian) Bight: Open boundaries towards the Baltic Sea cause intensive water exchange in the bay. Despite this, it has an important function as a purification unit for the Baltic Sea. The sandy sediments show high denitrifica-

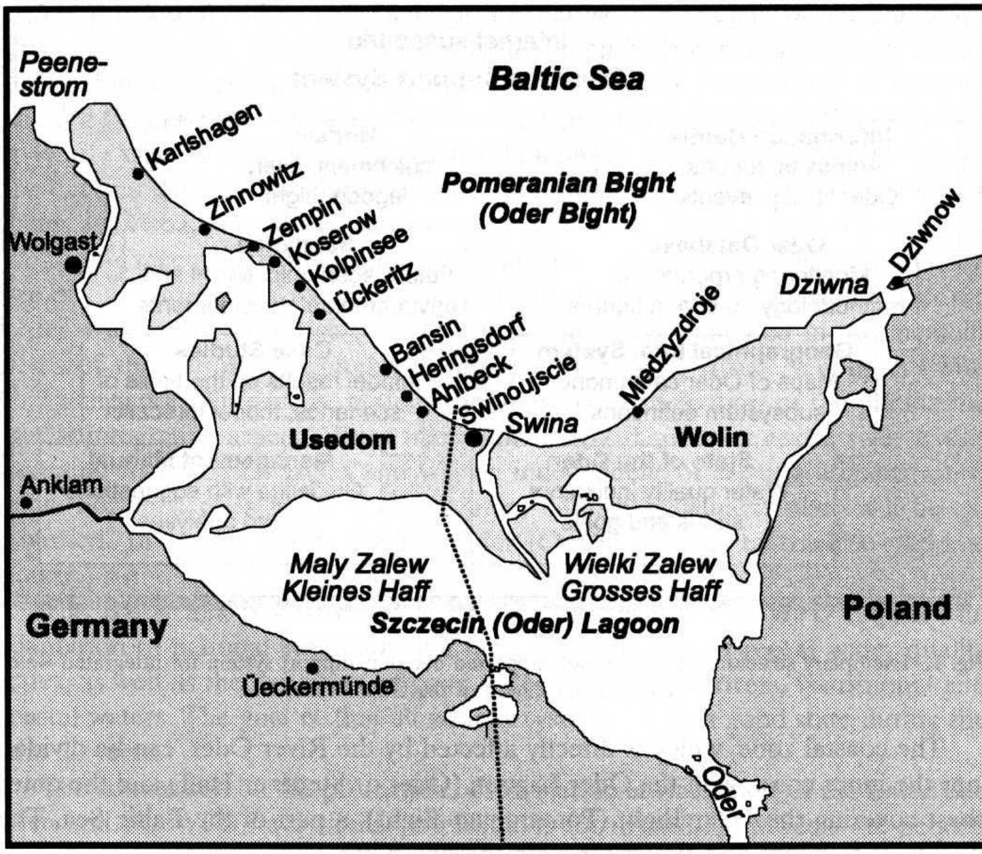

Fig. 2. The Oder estuary

tion rates and reduce the nitrogen input with the River Oder by 85% (Neumann in press). Only 15% of the nitrogen input is transferred towards the open sea. Nitrogen is the main restricting element for the primary production of the Baltic Sea and is therefore of superior importance. Purification processes in the Pomeranian Bight increase water quality and diminish long distance effects by the River Oder plume. This is an important fact for the already intensively used swimming beaches along the outer shorelines of the islands and an essential economic factor for them.

The water quality of the Pomeranian Bight and to a much higher degree the water quality of the Oder Lagoon cannot be restored by internal measures inside these systems or local management. The systems are too closely linked with the River Oder and its large basin. The large population in the Oder catchment area and the poor state of sewage treatment, as well as the large and intensively used agricultural area in the hinterland, are the main reasons for the quality problems in ground, surface and coastal waters. The water quality in the lagoon is an indicator and mirror of this pollution in the river basin. Due to its size, economical and

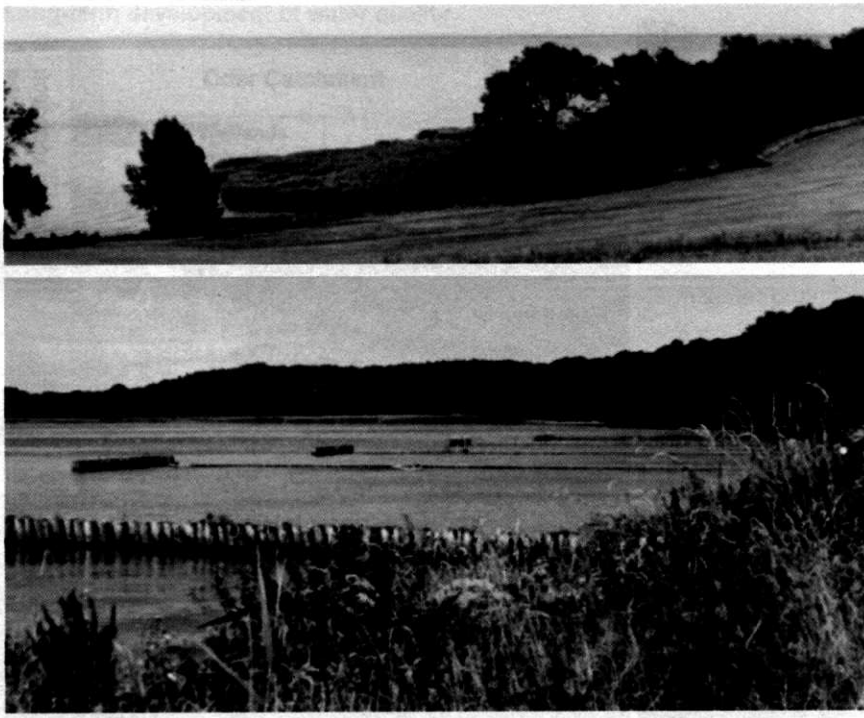

Fig. 3. Usedom and the Oder lagoon in August 1999 near Neverow (top) and Kamminke (bottom)

ecological importance on the one side and heavy pollution on the other, the Oder System becomes an outstanding case and indicates the urgent need for integrated management.

3. Water Quality and Pollution Modelling the Oder Estuary

Water quality models are needed to understand the ecosystem and simulate its behaviour under varying management scenarios, with, for example, reduced nitrogen and phosphorus input. One single model can hardly cover all relevant water quality aspects. The goal is, to develop complementary models that can be spatially and topically linked.

This means that several modelling groups and various approaches are needed. The models should be kept simple to become widespread and generally used as tools in Decision Support Systems. A conceptual example of variously linked models in the water quality system covering the entire catchment is shown for the Oder and its coastal zone (Fig. 5).

In future, it will be important that model results can be prepared in such a manner as to serve public information, too. In the Oder estuary in particular is

Fig. 4. Algae bloom in the Oder lagoon during August 1999 at a beach near Kamminke (Usedom) and in the harbour of Dargen (Usedom)

international cooperation between Poland and Germany imperative for successful management and modelling. Only intensive cooperative ensures acceptance of models, results and increases the impact of management measures.

4. Approach of the Baltic Sea Research Institute

With respect to surface water quality of the Oder Lagoon two types of models are currently available and under further development at the Baltic Sea Research Institute (Fig. 6).

A **eutrophication box model** of the Oder Lagoon that describes the chemistry and basic hydrobiology of the system. The model is based on a box model by Humborg et al. (in press), which was used to simulate the nutrient state and development of the lagoon over the last 30 years on a yearly basis. The advanced new water quality model, developed in cooperation with the Marine Fisheries Institute in Gdynia, Poland, will have a better temporal and spatial resolution and will be able to simulate and quantify the seasonal dynamics of nutrients and main phytoplankton groups. The model was developed and will be improved in the following steps:

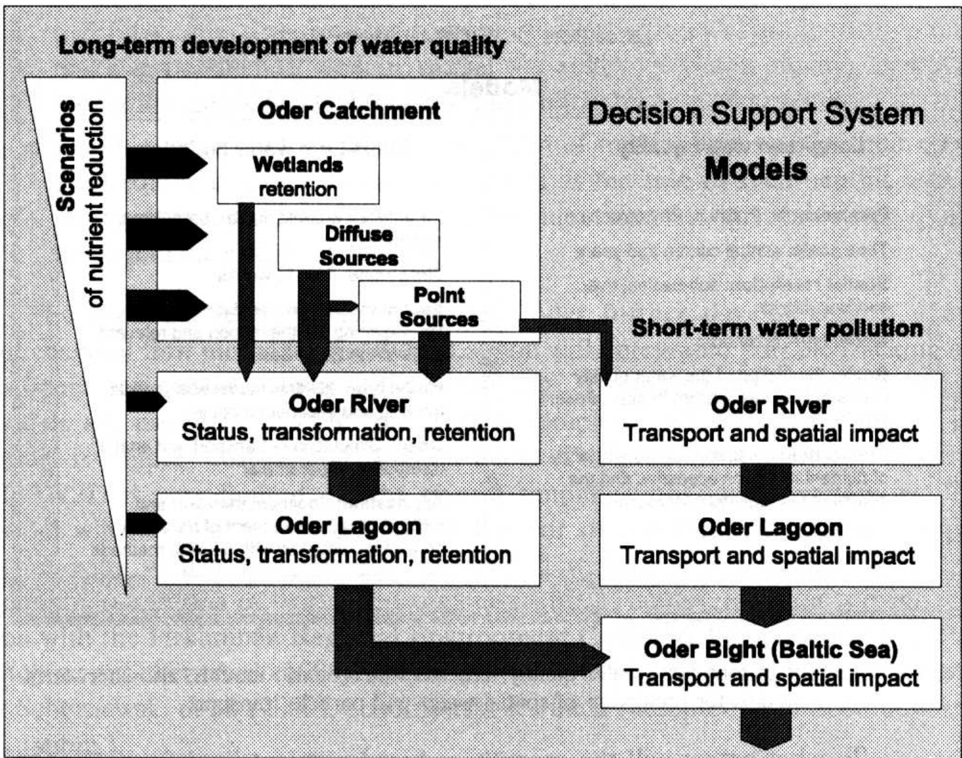

Fig. 5. Spatial integration of subsystem models for a) long-term water quality forecasts and scenario simulations and b) short-term prediction of water pollution. The independent models serve as tools in the decision support system for integrated management

- Identification and quantification of the annual course and inter-annual variability of nutrient transformations, cycling and trophic state. The result was a basic conceptual model of the Oder Lagoon.
- Based on this conceptual model a dynamic 1 layer box-model was developed to simulate the annual course of nitrogen and phosphorus and 2–3 phytoplankton groups. This allows first applications, such as the comparison of different years with respect to changes in River Oder discharge, nutrient load, as well as seasonal weather conditions.
- The model will later be applied to long term past and future trophic situations. At this stage it will become a useful tool for water quality prediction and management of the Oder Lagoon and helps to answer the following questions:
  - What is the relative influence of the River Oder on the lagoon ecosystem comparing with the point sources located around the lagoon in the long term?

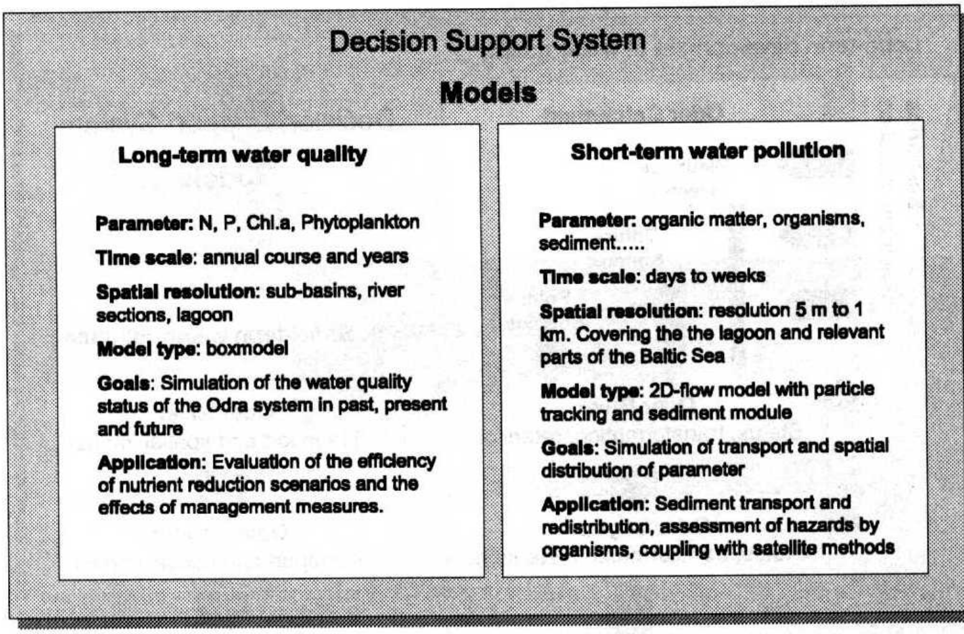

Fig. 6. Properties of long-term water quality forecasts and scenario models, also short-term models for prediction of spatial water and particle transport

- To what extent will the recently reduced nutrient load from the Oder catchment affect the lagoon, how fast is the reaction of the lagoon, in what timescale can recreation theoretically be achieved and how does it affect the nutrient input into the Baltic Sea?
- What are the internal effects of altered nutrient load: Does the course of annual phytoplankton succession, the intensity of blooms, their seasonal maximum change? To what extent are water visibility and light conditions affected?
- What will be the consequences of altered N:P ratio in nutrient load? If an alteration of a limiting nutrient takes place, to what extent is phytoplankton biomass, the abundance of different groups and their temporal succession affected? What are the possible consequences for management?
- What is the efficiency of different management measures and how can they be supported by measures inside the lagoon (e.g. artificial reefs, extended macrophyte stands) and the adjacent coastal drainage area?
- To what level has the nutrient input to be reduced to meet the water quality requirements of the Water Framework Directive in the lagoon?

- Splitting the one box model into three spatial defined boxes (Grosses Haff, Kleines Haff and shipping channel) enables the consideration of different hydrodynamic situations and water residence times. This in turn, should make it possible to explain spatial variability of water quality, as well as local differences in algal blooms and their temporal occurrences.

- Possible extensions are the introduction of makrophyte stands, their ecological role and spatial behaviour as well as the role of such benthic aspects as the zebra mussel. Both might be important for internal water quality management efforts in the lagoon.

The second already available model under further development is a **two-dimensional flow model** for the Oder Lagoon with integrated particle tracking and sediment transport modules (FEMFLOW2D). Two-dimensional depth-averaged models are useful in shallow lakes with a completely mixed water column. The model is simple, flexible and runs on a PC. The predictive capability of FEMFLOW2D is very limited due to several simplifications and uncertainties. The model will be able to simulate the behaviour of particles with flexible properties moving with a spatially high resolved flow field. The particles can be, for example, organisms or suspended organic matter. The development is a cooperation with the Pirkanmaa Regional Environment Centre in Tampere, Finland (Podsetchine & Schernewski 1999, Schernewski et al. 2000). Applications are presented in Schernewski et al. (2000), Schernewski & Jülich (accepted) and Schernewski et al. (subm.).

Its main application in future, will be the analysis and simulation of sedimentation, resuspension and sediment transport in the lagoon. Sediment input data like median grain size, 90% grain size, settling velocity, critical deposition shear stress and critical erosion shear stress will be measured or derived from existing data. The goal is the evaluation, to what extent internal measures in the lagoon are able to increase net sedimentation, the storage capacity for nutrients, water quality and especially turbidity. Possible measures that effect the flow field as well as the transport and sedimentation conditions in the lagoon are artificial reefs, mussel banks, macrophyte stands or wooden piles.

For simulation of nutrient transport and cycling in the Pomeranian Bight, the **Baltic Sea Model** (ERGOM) is available. ERGOM is a powerful three-dimensional flow model with integrated water quality and basic eutrophication module on the basis of MOM3 and further developed at the Baltic Sea Research Institute, Warnemünde (Fennel & Neumann 1996, Neumann in press). The model will be used to calculate the water exchange between the Baltic Sea and the Oder Lagoon. This output serves as input for FEMFLOW2D. It already allows the simulation of three-dimensional flow fields as well as the transport of neutral particles. ERGOM has some limitations concerning coastal zone applications. The maximum rectangular grid density is only about 600 m, the rectangular grid is not suitable to follow the coastline in detail and requires enormous computational power and is therefore less flexible. By combining FEMFLOW2D and ERGOM it is possible to simulate the particle transport from the river Oder mouth, through the Oder Lagoon and the Pomeranian Bight into the open Baltic Sea. For simulation of the transport of flexible particles the tracking module developed in the Oder Lagoon will be used with both flow models.

On the basis of average synoptic years, long-term runs with ERGOM are possible and give some information concerning future nutrient concentrations and primary productivity of the Baltic Sea. Linking results of the eutrophication model of the lagoon with ERGOM hopefully will yield valuable information about effects of nutrient reduction measures in the Oder catchment area on the lagoon, the Pomeranian Bight, as well as the Baltic Sea.

5. Example: Virus Transport and Decay Simulations

Human pathogenic viruses can generally be expected in all surface waters that are affected by municipal sewage. There is an increasing awareness that predisposed persons can be infected by a few infective units or even one active virus. Another new aspect is, that at least Polio-viruses attached to suspended particles can be active over weeks and therefore transported over long distances. Therefore, the highest risk of virus inputs in the Szczecin Lagoon arise from the large amounts of untreated sewage of the city of Szczecin (Poland), which are released into the river Oder and transported to the lagoon and the Baltic Sea.

Summer tourism is the most important economic factor in this coastal region and further growth is expected. Human pathogenic viruses therefore might be a serious problem for bathing water quality and sustainable summer tourism. On the basis of model simulations and laboratory results the potential hazard of virus infections along beaches and shores of the Oder lagoon and adjacent parts of the Baltic Sea was re-evaluated. We used two scenarios for the Oder Lagoon considering free viruses and viruses attached to suspended particle matter. The spatial impact of the average virus release in the city of Szczecin during summer (bathing period) was simulated with a hydrodynamic and particle tracking model (Schernewski & Jülich, accepted).

Simulations suggest (Fig. 7) that, due to fast inactivation, free viruses in the water are a risk only in the river and near the river mouth. On the other hand, viruses attached to suspended matter can affect large areas of the eastern, Polish part of the lagoon (Grosses Haff). At the same time the accumulation of viruses on suspended particulate matter increases the likelihood of an infection after incorporation of a particle. There is no evidence of there been a risk of virus infections in the western part of the lagoon (Kleines Haff) or along the outer Baltic Sea coast (Schernewski & Jülich, accepted).

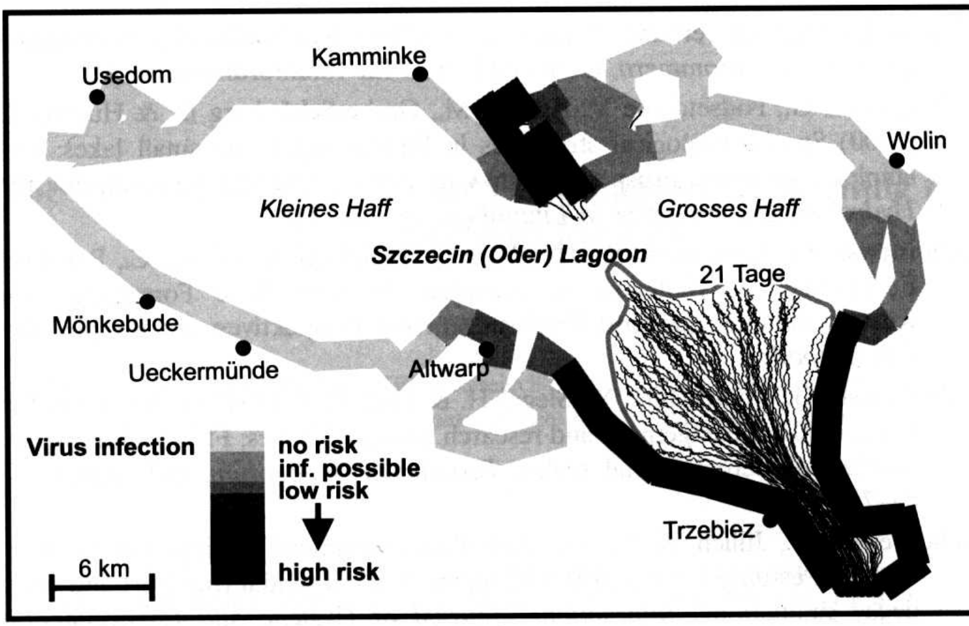

Fig. 7. Trajectories of particles indicating transport and decay of active viruses attached to natural suspended particle matter in the Oder Lagoon under typical summer conditions. The starting concentration was 10^4 viruses/m^3 at the river mouth. In the simulation 10^3 particles with ten attached viruses each were assumed. After 14 days a concentration of 10^2 particles (10^3 viruses/m^3) remained and after 42 days the number decreased to 1 particle (10 active virus/m^3). The areas where an infection is regarded as possible, take into account that, under certain meteorological conditions, extreme river discharges or an increased release of viruses due to epidemic situations, a realistic risk of infection can occur. Modified after Schernewski & Jülich (accepted)

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