The Oder Estuary as a Filter and Transformation Area - Summary of the Project Final Report

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Lagoons and estuaries act as specific links between rivers and the sea. They are characterized by intensive matter turnover and possess a high self purification potential. Due to the rapid change of environmental conditions from limnic to marine, the substances delivered from the land into the estuaries are altered in their chemical, physical and biological properties and in their kinds of transport.

The changes taking place in lagoons and estuaries can be divided into

- an alteration of transport velocity (which is mostly a retardation) and
- an alteration of the (geo/bio-) chemical relationship between chemical elements or compounds (transformation).

In many cases transformation is the prerequisite for substances to be stored either in the water body (dissolved or particle bound), in sediments or in organisms for a specific time or forever. The behavior of nutrients provides an example: when they reach the estuary in inorganic form, they are introduced into the food web via phytoplankton, zooplankton etc., become part of the sediments after the planktons die, are subject to mineralization and finally some of them will be flushed out. In this way transformation is an important process for slowing down the movement of substances. We call this slowing "retardation". However, some of the substances will remain in the sediments or in organisms. The fixation of a substance for a very long time is called "retention". Due to this retention function, lagoons and estuaries have often been described as filters or sinks, admittedly of varying efficiency depending on the specific geographical conditions such as hydrography, climate or topography.

The filter effect is based, firstly, on the sedimentation of particulate matter and attached substances with declining current velocity and, secondly, on the incorporation of essential nutrients into the food web. Output is only possible via

episodic water exchange with the sea (horizontal exchange) or

accumulation in the permanent sediments or the transition of gaseous compounds into the atmosphere (both vertical exchange).

In shallow coastal waters, which are already well mixed, sediments, water body and atmosphere exchange matter steadily and intensively. They act continously or alternately as sources or sinks of specific substances - depending on a lot of external conditions. However, considering a long lasting positive net sedimentation, the waters basically possess a filter function for all substances which can accumulate in sediments.

The Oder estuary and the adjacent Greifswalder Bodden are typical lagoonal estuaries of the southern Baltic coast: They are tideless, polymictic, and strongly affected by nutrient inputs. To quantify the matter transported through the different water bodies the Joint Project GOAP was conducted by 14 scientific teams of the universities of Greifswald, Rostock, Szczecin, the GKSS Research Center and their staff.

The investigation area amounts to around 1400 km² and includes the Oderhaff (or Szczecin Bay) with its three outlets Peenestrom, Swina and Dziwna as well as the Greifswalder Bodden. Most investigations were conducted on German territory, so this article will mainly focus on them.

According to the HELCOM hot spot list of 1993 the Oder estuary is one of the most polluted waters in the Baltic. On average, 80.000-100.00 t nitrogen and 5.000-6.000 t phosphorus are introduced per year from the catchment area. The additional input from Szczecin and the Ina river and from the German tributaries are not included in these data. This input causes heavy eutrophication in the estuary and influences not only the Pomeranian Bight but also the

Arkona and Bornholm Basins too.

Depending on the fluvial input into the inner estuary the waters are characterized by a salinity gradient ranging from around 0,5 PSU in the Großes Haff to around 7-8 PSU in the Greifswalder Bodden. The gradient is steep and well developed especially in the northern Peenestrom, but similar conditions can be found in the Swina and the Dziwna. The concentrations of nutrients, biovolume, metals or other pollutants take the contrary course due to the heavy pollution in the inner part of the estuary and the increasing mixing and dilution with Baltic Sea water in the outer part.

The goal of the project was to get a better understanding of how the estuary works, of its matter budget and its function as a filter and transformation area. To solve this problem at least three approaches are possible with different methodologies, results, difficulties and uncertainties. We have tried to use all of them.

The first is a black box approach where the inputs and outputs are observed. The differences lead us to a calculation of the filter capability and efficiency. It is a very rough method and little can be learned about the causes of the results.

Using a 2D hydrodynamical model, the water exchange through the estuary was calculated for the two years 1994 and 1995. Two examples of model run results are depicted in the figures: they show the salinity distribution or the distribution of residual currents for one week in April 1995. The spreading of the Oder water through the Großes Haff and the plumes in front of the Swina and Peenestrom mouths can be seen very clearly.

To improve the approach the estuary was divided into some **subsystems**. Using the hydrodynamical model the daily water exchange was calculated across the boundaries of all subsystems. An example of this daily water exchange is depicted for the subsystem Kleines Haff. The red line shows the amount of water crossing the boundary to the Großes Haff and the green line shows the water crossing the boundary to the Peenestrom. Positive values mean outputs, negative values represent inputs.

Additional biweekly to monthly measurements of dissolved and particle bound nutrient concentrations in all subsystems were carried out and the nutrient inventories of the subsystems were measured for these particular moments. As a third step spline functions for the nutrient inventories were determined from which daily data were calculated. Lastly the daily nutrient budgets were determined by considering the daily nutrient inventories and the amounts and directions of water exchange (review of all steps).

Summing up the daily results for all subsystems a net nutrient budget for different parts of the estuary was obtained. It shows the inputs and outputs for the subsystems and reveals the sinks and sources, where less nutrients come out than were introduced or vice versa. A comparison leads to the conclusion that the nutrient reduction on the way through the waters differs greatly between different parts of the estuary. During the investigation period and related to the respective input it can reach around 15% for nitrogen or around 25% for phosphorus for the Kleines Haff, but for the Peenestrom 20-40% for nitrogen or 12-20% for phosphorus. The Achterwasser acts as a source of phosphorus and sometimes of nitrogen too. However, these are short term budgets, which are closely related to particular boundary conditions. Probably each year would show another budget (1994, 1995 or both) depending on the hydrographic circumstances and there is no clear evidence what processes are responsible for the particular behaviour. It also remains open, whether the reduction observed is retention in the sense described above or if processes not yet considered such as the nearbottom particle transport, subsequently limit the reduction.

Therefore we open the black box now to investigate the sediments. As explained earlier an estuary must work as a filter, if a net deposition occurs. The accumulation rate of a substance is the material amount per square meter and year which is deposited for a very long time, the sedimentation rate is the growth of the sediment column in mm/yr. Unfortunately it is very difficult to obtain true recent sedimentation rates because wind induced resuspension and intensive bioturbation prevent undisturbed sedimentation and the identification of time marks. Particular indicators, such as the Tchernobyl fallout or the nuclear weapon fallout of the sixties, are strongly dispersed by sediment mixing processes.

For most parts of the estuary, a mixing horizon is evident. In the Oder Haff for example it has a thickness of around 15 cm and shows a noticeable enrichment with both trace metals and nutrients. We assume that this horizon originated in the last 100 to 150 years when industrialization took place in the catchment area. For the Oder Haff this assumption leads to an estimated sedimentation rate of 1 mm/a, also suppported by ^{210}Pb measurements.

If we now calculate the accumulation rate, we find that, on a long-term average, only 510 t/yr nitrogen or 76 t/yr phosphorus were accumulated in the Oderhaff. Summing up the results for the entire estuary, we must assume that not more than 2 - 5% of nutrients are buried in the sediments in relation to the present total input. For some trace metals like zinc, lead and copper, the buried part of the total input reaches approximately 10 - 15%. These are surprisingly low amounts, and lead to the conclusion, that the estuary is not acting as a filter but more as a bypass.

In a third approach, we open the black box again but now investigate the biological compartments and the processes responsible for the internal turnover of the nutrients introduced . This is the most sophisticated approach but also contains the most uncertainties, due to the complexity of the ecosystem.

Assuming that all nutrients are incorporated in biomass in a proportion corresponding to the Redfield ratio, we can express their circulation in terms of organic carbon. It is also important to differentiate between carbon pools (shown as rectangels) and process rates (depicted as hexagons). Because we have only investigated two years, we assume that the pools were constant on average, i.e. the total amount of carbon incorporated in the biomass of all species has not changed and the system has revealed a steady state.

Further simplifying, let us consider only the processes of the primary production and the respiration of consumers and microorganisms. The net primary production of the phytoplankton is the main process of transformation of inorganic nutrients into biomass. In the Greifswalder Bodden alone a small contribution of macrophytobenthos must be taken into account too. The secondary production of macrozoobenthos and the microbial release of carbon as CO_2 and CH_4 are the main processes of carbon rebound. Comparing the primary production of carbon and the respiration in different parts of the estuary, it can be shown that in the Greifswalder Bodden the relationship is more or less well-adjusted, while in the northern Peenestrom respiration processes predominate and an import of organic carbon seems to be necessary to feed the macrozoobenthos. In all other waters a predomination of primary production processes was found. That means that the surplus of carbon could be accumulated in the sediments. However, transports of suspended particles are not considered in this approach, and we are not able to say where the carbon surplus is really accumulated in the estuary or where the filter function takes place.

Putting together all the evidence, it seems that the whole estuary can not retain more than 2-5% of the nutrients and 10-15% of the trace metals, if we determine the retention by the sediment accumulation approach which especially considers the long term aspect. This coincides with the results from calculating the nutrient transport caused by water exchange. We found that a large proportion of the input is flushed directly through the Großes Haff into the Pomeranian Bight via the Swina. The retention in the Großes Haff is lower than that in the adjacent waters due to the high load and the short residence time of the river water. Measurements have shown that up to 70% of the annual nitrogen load can pass through the Oderhaff especially in the case of early spring floods and reach the Baltic more or less untransformed and in a short time.

A much smaller amount of the input arrives from the western part (Peenestrom and Greifswalder Bodden) and undergoes many transformations there. Because of the slower transport velocity through the waters and their high biological activity, a reduction of 10-20% P and 20-40% N of the total input into the western part of the Oder estuary can be observed. But for the Achterwasser it can be proved that at present the output of phosphorus is greater than the input. So some parts of the estuary act as sinks and others as sources of nutrients.

The analysis of pools and process rates has shown that the transformation of nutrients into particles occurs mainly in the inner estuary. Only some of this particulate matter is accumulated in the sediments. A larger amount is flushed out into the adjacent waters due to the main direction of water movement and wind induced resuspension, and in that way determines the filter efficiency. Because both the water exchange and the wind induced resuspension are most intensive in late winter and early spring, the particle transport occurs mainly at that time. Transformation of dissolved nutrients into particles and temporal sedimentation predominate in the remaining seasons.

Summarizing all the evidence we can conclude

- The Oder load reaching the estuary amounts to around 90.000 t N and 5.000 t P per year.
- The main proportion is flushed through the Großes Haff into the Pomeranian Bay via the Swina. The long term retention is very low and reaches around 2-5% of the total annual input.
- A small part of the Oder input is introduced into the western area. Here intensive transformation takes place with considerable particle building and temporal sedimentation. Especially in the first third of the year these particles are flushed in the downstream waters and the Baltic.
- In general the estuary acts more as a transformation area than as a filter.

We do not know if the filter capability was greater in the past than today, because our knowledge about the load in the past is very limited. But we can do something to increase the recent filter efficiency and save the Baltic. Therefore it is necessary

- **to limit inputs from the catchment area**
- **to revitalize, diversify and enlarge the biological pools in the ecosystem and**
- **to create free access again for particle loaded waters to external nutrient sinks such as naturally flood-prone areas like reeds, bogs, and salt meadows which were diked in recent centuries.**

This would lead to a higher filter efficiency and a better water quality. However, probably the restoration will take several decades.