Measures for structural improvement with regard to the good status of water bodies – estimation of expenditure for a river basin in Germany

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Abstract To achieve the objective of "good chemical and ecological status" in water bodies as stipulated by the European Water Framework Directive (WFD) in particular, a package of measures geared to improving the water bodies' hydromorphology will be required. These upgrading measures can, to some extent, also be seen as an alternative to still more advanced measures in the field of wastewater treatment and stormwater treatment in the context of status improvement in water bodies. On account of the very high level of wastewater and stormwater treatment already achieved, additional efforts in this specific area would, as experience has shown, not only be extremely costly, but produce just moderate if not minor results. In an estimate of the funding required to achieve "good status" by hydromorphological change, undertaken for the Ruhr River Basin (German state of North Rhine-Westphalia), it was found that costs would be in the range of €200 million to €1 billion. This translates into inhabitant-specific costs of €100 to €500 per capita. All measures are to be put into practice within the scope of an integrated water body development concept, optimised with regard to space and time.

Keywords Costs; hydromorphology; water body

Water Science and Technology **Vol 48 No 10 pp 39–46** © IWA Publishing 2003

Introduction

By the end of 2015, all surface waters in Europe have to be able to fulfil the criteria for "good ecological status" required by the WFD. This requirement alters the way in which rivers and lakes are to be assessed, not just by parameters related to water uses, but instead by characteristics of aquatic ecosystems. So the focus is on anthropogenically only slightly modified water bodies. The directive not only stipulates chemical and physico-chemical parameters and concentrations of water constituents, but in particular also biological features. Given the fact that in Germany, treatment of wastewater of municipal and industrial origin has indeed made good progress, there is little room left for further reduction of pollutant input from point sources – not least for economic reasons. Therefore input of pollutants from diffuse sources and their impact on water quality is gaining in importance. And to suit the needs of an integrated approach under this more ecological perspective, it will be necessary to develop alternative measures improving the hydromorphology instead of promoting further reduction of pollutant input. Compared to the latter, efforts aiming at structural improvement have the advantage of a significantly better cost/effect ratio (cost efficiency). In spite of the still prevailing uncertainties with regard to quantification and prognosis of achievable status change by specific measures, some alternatives are described below as examples.

- Reduction of eutrophication by increased shading (light limitation) with bushes and woods instead of further measures for nutrient elimination in wastewater treatment plants.
- Improvement of flow dynamics and enlargement of water surface to enhance oxygen uptake instead of further measures for elimination of organic substances (BOD_5, COD) in wastewater treatment plants.

- Creation of fish refuges/habitats instead of further measures for minimising concentration peaks in ammonium nitrogen in the effluent of combined sewer overflows and wastewater treatment plants.
- Increase of run-off into the diversion canals of hydropower stations instead of further measures for wastewater and stormwater treatment facilities.

The key for good ecological status can primarily be seen – for densely populated and industrially highly developed regions and intensively cultivated areas alike – in the improvement of hydromorphology, helping to initiate and establish functioning aquatic and adjacent terrestrial ecosystems of high diversity and stability. Though the condition of good ecological status formulated by the WFD does implicate *per se* a homogeneously and continuously good hydromorphology, it can be assumed in general that measures taken in the river bed, on river banks and flood plains (water body environment with foreland and border strips), and the positive effect of the water body's natural self-development will contribute towards achieving the stipulated good water body status. And this in spite of still existing uncertainties with regard to interpretation and the complex interactions to be considered. In a survey, recently conducted among experts at two workshops on the subject of river basin management, the trend towards measures aimed at enhancing hydromorphology was confirmed.

In Germany, assessment of hydromorphology is carried out by a standardised methodology, which is now also being integrated in the European standardisation. With this method, river bottom, river banks and flood plains are divided by a seven-stage scale into 100 m-sections (Landesumweltamt, 1998). Aggregation then takes place via the river's longitudinal profile as well as via the parameters concerned (river bottom, river bank, flood plains). Thus it is possible to assess the hydromorphology of the Ruhr by different classes over its entire length of 219 km (Figure 1).

The relevant water body status cannot be derived directly from the assignment of river segments to structure classes. However, it becomes evident that there is a great potential for measures in this field, which promise a more favourable cost/efficiency ratio than those in the field of wastewater treatment, at least at the present state of assessment.

In connection with the costs incurred for achieving good status, it should be mentioned that besides targeted measures in the water body in accordance with the WFD, some spending will be required for administrative tasks (licensing and monitoring procedures, mandatory documentation and reporting, participation of the public, etc.). However, these expenses appear to be tolerable as the required structures are already available. It should also be mentioned that in the cost estimates herein represented, no reference has been made to groundwater, possibly tightening regulation for wastewater and combined water disposal as well as to terrestrial ecosystems depending on water. Furthermore, there are some fixed expenses for planning (concept design and planning of measures) and for operation

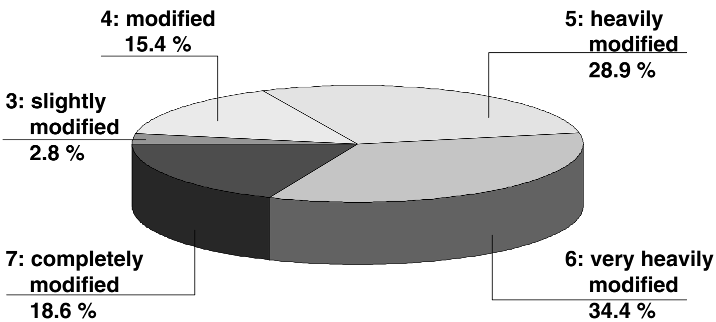

Figure 1 Classification of the hydromorphology of the Ruhr River aggregated to 1-scale and 1 km segments

and maintenance (in particular water body maintenance and monitoring) which are to be considered, but have not been specified separately in this context (Beckereit, 2002; Butler, 2001; Kolisch and von Seidlitz, 2002). In conclusion it can be said that implementation of the WFD will give rise to significant changes in both cost level and cost structure of infrastructure-related measures and with that eventually in the charges to be levied.

Measures required in the field of hydromorphology

To achieve good ecological status in rivers in a cost-effective way – i.e. in an effort that reconciles ecology and economy – it will be advisable to base the required measures for improving the hydromorphology on a target-performance comparison. Whereby the reference status, which serves as assessment basis, will be taken as the model for the water body under review. This model represents the ideal from a scientific point of view (adjusted to real reference water bodies explicitly assigned to the different water body sections); there are no cost-benefit considerations at this point. Whereas the development target (target condition) is defined as the best achievable natural-like status that is still viable under consideration of the given socio-economic conditions (Landesumweltamt, NRW 1999). Consequently, not only a variety of conflicting interests have to be considered such as for example supply and disposal pipelines on the water edge, streets, paths and residential areas, but also the efficiency of the measures to be implemented.

The model applicable for an approximately 60 km long segment in the upper Ruhr (upstream of the confluence of the Möhne River and the Ruhr River) is the following: "River with several side courses, moderately bent, with gravel bed originating from primary formation of rocks". It is characteristic for this type of river that it regularly changes its stream bed and therefore needs a lot of space to develop naturally in the valley (WAGU, 2001). In the development concept for the upper Ruhr (WAGU, 2001), four primary targets have been identified under consideration of the prevailing local conditions: "*wild river landscape*", "*open river plain*", "*river near residential areas*", and "*urban river*". And in exactly this order, the ecological value of the development targets will diminish. This becomes evident in the measures formulated for the different development targets under consideration of the actual status, for example when comparing "wild river landscape" to "urban river" (see Table 1).

While in the wild river landscape, on account of sufficient land availability, the measures are geared to furthering e.g. the river's self-dynamics with regard to erosion, deposition, and bed dislocation as well as to an early overflowing of the banks, those necessary in the urban river are restricted to developing gallery-like belts of small wood or even shrubs on the riversides, instead of e.g. lowland forests. So measures in such urban river segments will rather have to cope with lack of land supply, high land prices, and flood protection. Though a continuum for fish and other aquatic organisms remains high on the agenda also for rivers in municipal areas.

In Table 2, examples are given for construction and modification measures aimed at the improvement of hydromorphology. For the choice of the best suited measures, the "natural" solution should always prevail over the "technical" one, in consideration of the given local conditions and restrictions; that means measures which support the self-dynamics of the river, such as removal of bottom and bank reinforcements or placement of stone obstacles or dead wood should be preferred.

Specific costs

Specific costs have been assigned to the different tasks for water body improvement listed in Table 1. However, these figures are only meant to give an idea of the magnitude of capital expenditure involved.

Table 1 Exemplary development targets and respective measures geared to improve the hydromorphology in the upper Ruhr (according to WAGU 2001)

Development target	Measures
Wild river landscape	• procurement of land (riparian area and plains) by public bodies • renaturation measures such as removal of river bottom and bank reinforcements, aimed at furthering self-dynamics in bed formation • excavation of landfills in flood plains (stream widening) • promotion of an early flooding of riparian plains to increase retention capacity, connection of side-courses, stoppage of deepening and if necessary reversal of deepening processes • abstention from maintenance measures for water bodies as far as possible • removal of all stands of broad-leafed trees non-compatible to location and coniferous trees • abstention from land use by agriculture and forestry in the flood plains, aimed at natural post-succession of plain forest, possibly supported by planting of woods (under consideration of the issue of neophytes)
Urban river	• rebuilding of barrages hindering migration to make them passable for migratory fish and aquatic invertebrates • development of side-strips of woods alongside the Ruhr River, wherever possible (to ensure flood runoff). However, the river should not be completely "shut off", but gaps should be left to allow the visitors to have a look at the water body and to enjoy the scenic view • promotion of development of margins of tall herbaceous plants or reeds compatible to location alongside the river

The capital expenditure needed for the measures aimed at improving the structure quality and to achieve the water body's good ecological status is very difficult to determine. For such an estimate, covering an entire river basin system, it is not really helpful to know the specific costs relating to square or cubic metres, as long as the relevant concepts do not include the corresponding quantitative data.

Furthermore, it can be assumed that the costs for the renaturation measures will vary significantly as a function of the different local conditions. Given the fact that both the clearing (opening) of a piped water course in an industrial area (possibly with the heritage of a residual pollution risk) and a simple riverside fencing belong to this package of measures, categorisation appears to be advisable (Zumbroich, 2000):

- Category "*no modification*":
  Acquisition or lease of riverside strips; removal of waste:
  Cost frame: €0 /m to €50/m
- Category "*developmen*t" (measures that can be undertaken within the scope of regular water body maintenance):
  removal or modification of bank reinforcement, installation of fences or drinking bowls to protect the cattle, planting measures and wood maintenance, removal of stream bottom reinforcement, local stormwater management
  Cost frame: €50/m to €250/m
- Category "*remodelling*" (measures that require a plan approval procedure):
  Modification of barrages, opening of piped stream systems, relocation of water courses:
  Cost frame: €250/m to €500/m and more.

The following costs for water body renaturation have been determined by the environmental agency of the state of North Rhine-Westphalia relying on data that have been compiled from a cluster of 278 studies made into the subject of ecological change between 1986 and 1996 (Landesumweltamt Nordrhein-Westfalen, 1996, quoted herein according to Zumbroich, 2000):

- ecological modifications without change of the linear course, without acquisition of land: €25/m to €115/m.

Table 2 Examples of construction and modification measures for improving hydromorphology including the specific costs

Measures	Notes	Costs (€)	Source
Land acquisition			
Acquisition of sites	In rural regions	€2–5/m^2	
Earthworks			
Excavation of soil	Without disposal	€10/m^3	
Integration of soil	With delivery	€25/m^3	
Technical measures			
Modification of passages in agricultural areas	e.g. replacement of 5-m-piping with wide clearance and straight river bottom	€7,500	Schnittstelle Ökologie, 2001
Gabions (2 m high)	Replacement of massive bank reinforcement	€1,500/m	Zumbroich, 2000
Vegetative stabilisation	e.g. fascine work, alder, willow faggot packing	€125/m	Schnittstelle Ökologie, 2001
Rock filling	Layer thickness 20–30 cm	€17.50/m^2	Lange and Lecher, 1993
Fencing	Simple pasture fence	€2.50/m	Schnittstelle Ökologie, 2001
Pasture pumps	Substitute for cattle drinking points in the brook, effective for a brook stretch of about 500 m	€750	Zumbroich, 2000
Continuum			
Fish bypasses at barrages	• up to 3.50 m impounding height • 3.50–5 m impounding height • above 5 m impounding height	€80,000/m €115,000/m €150,000/m	
Diversion canal	Barrages in tributaries of the Ruhr and the Lenne River	€35,000 /structure	
Woods			
Planting of hardwood plain	Ashes, oaks and elms	€4.75/m^2	Schnittstelle Ökologie, 2001
Planting of softwood plain	Willows	€3.50/m^2	Schnittstelle Ökologie, 2001
Riverside planting	Linear element with an average width of 10 m	€4.00/m^2	Schnittstelle Ökologie, 2001
Other			
Succession	No construction costs, if necessary pasture fencing	None	Schnittstelle Ökologie, 2001

- ecological modifications without change of the linear course, with acquisition of land: €45/m to €175/m
- ecological modifications with change of the linear course in rural areas, with land acquisition: €115/m to €225/m
- ecological modifications with change of the linear course in residential areas, with land acquisition: €375/m to €500/m

From experiences gained by Gunkel (1996) with 53 renaturation projects (without acquisition of land), costs of between 60 and €550/m can be derived. And more comprehensive projects even entailed costs of up to €2,000/m. The median (50-percentile) of the specific costs amounted to €175/m.

Estimate of cost for the Ruhr River Basin

The natural river catchment of the Ruhr River, covering an area of 4,485 km^2, is inhabited by around 2.2 million people. This area is characterised by a rural landscape in the upper course of the Ruhr with its tributaries, and by an urban structure in the lower course. The overall waterway system has a length of about 7,000 km. The average population density is 490 persons per square kilometre, and the mean river density is about 1.6 km/km^2. The

Ruhrverband is responsible for water management in the entire catchment. So far it has been concerned with water quantity and water quality, with planning, construction, operation and financing of altogether 8 reservoirs, about 85 wastewater treatment plants and about 500 stormwater detention facilities. On account of great utilisation pressure by both population and industry, above all in the lower course of the Ruhr, many bodies of water in the Ruhr River Basin have undergone severe anthropogenic alterations. With the reorientation of water management towards good ecological status it can be assumed that measures to improve structural boundary conditions will have to be implemented for the most part of the above mentioned anthropogenically modified river segments.

In the following, an attempt is being made to establish a cost estimate, based on the above specified cost approaches, for measures aimed at improving hydromorphology in the Ruhr River Basin. Though previous assessments of hydromorphology are not available continuously and exhaustively for the entire catchment, evaluation of the currently available data for the larger water bodies, like the Ruhr River itself has revealed that structure status, in many parts of these sections, is not satisfactory. It can be assumed that upgrading measures will be required for about 70 to 80% of all water courses in the Ruhr River Basin – including tributaries to the Ruhr River – with an overall length of 5,000 km. This assumption coincides with findings from other federal states in Germany (Liebert *et al*., 2000).

It can be seen as a minimum effort to provide, in rural regions, **border strips** alongside banks and in flood plains to promote the development in the water bodies. With minimum margins of 10 m on each side, serving as natural landscape zone, cost expenditure will amount to €40 to €100 per metre of flow length. This measure would also contribute to a reduction of diffuse pollutant input by intensive cultivation as the water bodies are practically separated from farmland. The required funding for the creation of such border strips – calculated on the basis of the overall water body length of 5,000 km – can be expected to come to at least €200 million.

With regard to the required **renaturation**, the river segments have been classified in accordance with the different categories. Whereby it has been assumed that the larger water bodies in the Ruhr River Basin, with a length of about 1,000 km, are to be assigned to the category "remodelling", some further 2,000 km would fall to the category "development" and the remaining 2,000 km to the category "no modification". In a conservative estimate, based on the specific cost of €300/m, €100/m, and €20/m respectively, the overall expenditure has been found to come to around €640 million. However, it might be possible – at least for the Ruhr River Basin – to reduce the cost in a strictly holistic, systematic approach.

Finally, the expenditure for restoration of **river continuum** has be considered. The water bodies of the Ruhr River Basin have been particularly affected by disturbances in continuum on account of diverse water uses (compare the report by Nusch *et al*., 2002). For restoration of the river's continuum, the costs are listed in Table 2. Based on these figures, the estimated funding requirements for construction of upstream fish bypasses will be in the range of about €17 million for the Ruhr River, about €16 million for the Lenne River, and about €20 million for the other tributaries. And approximately the same amount is to be considered for downstream fish bypasses.

In addition to the funding for the remodelling of water body segments, the fixed costs for **water body maintenance** have to be looked at. It is in the nature of things that these will decrease with increasing water body density – as a result of the then growing share of small waters. Being still in the range of about €1.30/m at a water network density of 0.5 km/km^2 , the costs will decrease to about €0.6/m at a density of 1.5 km/km^2. Accordingly, the latter value is that to be applied for the Ruhr River Basin (Lange and Lecher, 1993). However, ecological improvements are not only attainable by constructional measures within the water bodies but also by an adapted **water quantity management** (see Nusch *et al*., 2002).

It follows from the above that the total cost may well be in the range of approximately €2.6 million per year for regular water body maintenance and of approximately €1.0 billion for renaturation and restoration of water body continuum. But these figures are still estimates and possibly subject to future adjustment; related to the 2.2 million inhabitants living in the Ruhr River Basin, they result in a cost frame of €500 per inhabitant. This amount shows how important it is to plan, develop, and implement such measures for achieving structural change in the water bodies within the scope of a supra-regional concept optimised in space and time. Such an approach would also have to promote self-development and self-dynamics in the water bodies and to minimise hydraulic management measures to the greatest possible extent in order to keep the burden on the citizens, who eventually will have to pay for all measures, as low as possible.

Summary and conclusions

To achieve the stipulated "good status" in surface waters within the specified timescale, a comprehensive programme of actions to improve hydromorphological structure will have to be implemented. This is in response to the objectives set out by the WFD with regard to biological criteria which can only be attained by improving river bed, riverside and river plain areas, and this in particular as the chemico-physical water quality has reached a very high level in the meantime. Pursuant to the integrated, holistic approach towards water management formulated by the WFD, hydromorphological measures may also be seen as an alternative to more advanced (and very expensive) efforts in the field of wastewater and stormwater treatment. For specific sections of the catchment of the Ruhr River (a tributary to the Rhine River in the German State of North Rhine-Westphalia), various development models have been identified and suitable measures described as examples. The costs incurred by the different types of measures are a function of the required expenditure of work. However, the main criterion for all categories is the cost of land acquisition in the water bodies' peripheral regions (border strips with a minimum width of about 10 m on each bank) needed to implement the required measures and to further self-dynamic development in the water bodies. Some additional efforts are described that fall into three categories: "no modification", "development", "remodelling", and the cost of which increase with rising expenditure. To be considered as well are those measures necessary for creating or restoring continuum in the water bodies as well as regular maintenance. Thus, in a conservative approach, the total required funding is expected to be of the order of €200 million to €1 billion. Referred to the population living in the Ruhr River Basin, this corresponds to inhabitant-specific costs of €100 to €500 per inhabitant that would cover all measures to be implemented, pursuant to the WFD, within a period of 15 years. On account of this financial burden and the necessity of ensuring technical-scientific efficiency of the water management-related network of facilities and tasks, all planned measures have to be optimised with regard to space and time.

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