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Koblenz
(German Federal Institute of Hydrology)

BUNDESANSTALT FÜR WASSERBAU
Karlsruhe
(German Federal Waterways Engineering and Research Institute)

Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways

Part 2:

Test Stretch Stolzenau / Weser Km 241.550 – 242.300

R & D Project
(BAW - BfG)

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Summary

Within the framework of the joint research project of the German Federal Waterways Engineering and Research Institute (*Bundesanstalt für Wasserbau*, BAW) and the German Federal Institute of Hydrology (*Bundesanstalt für Gewässerkunde*, BfG) named "Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways", detailed on-site studies are undertaken with a focus on selected reference stretches where alternative bank protection measures have already been applied by the German Federal Waterways and Shipping Administration (*Wasser- und Schifffahrtsverwaltung*, WSV). The current state of the bank protection is examined in each case, the geotechnical and geometrical boundary conditions are recorded, an inventory of vegetation and fauna is taken, and the hydraulic load resulting from navigation is measured for a limited period of time. Furthermore, files from the planning and the implementation of reference stretches are evaluated.

Based on the results of these studies, the load-bearing capacity of the alternative bank protection measures within the area of investigation can be quantified and application criteria can be deduced. Based on the results from all investigated stretches, general remarks and recommendations are finally formulated for the application of technical-biological bank protection measures on waterways.

The test section Stolzenau (Middle Weser Km 241.55 to Km 242.30) has been chosen as the first section for detailed studies. The results are documented and evaluated in the present 2nd sub-report of the project.

Within the scope of the Middle Weser adaptation, in 1988/89, alternative technical-biological bank protection measures were applied at the right bank of the River Weser on a 750 m long stretch on the initiative of the local Waterways and Shipping Office (*Wasser- und Schifffahrtsamt,* WSA) Verden for test purposes. The existing banks were in some parts flattened from a 1:3 to a 1:7 gradient above the water level, in other parts the former slope inclinations were left unchanged. The existing riprap revetment was removed in the major part of the section above the mean water level, but was retained below. The banks were designed in different ways using reeds and woody plants (e.g. with live brush mattresses with willow branches or vegetation mats). In some parts, fascines of deadwood or small stone mounds running parallel to the banks were additionally placed in front of the plantings in order to protect against wave attack. In total, 17 different design variants were created.

The following studies were undertaken on-site within the scope of the in-depth examination:

- Assessment of the current state during an on-site visit of the test section (2004)
- Survey of the current bank geometry (2006)
- Execution of ground explorations (2006)
- Measuring of hydraulic bank load during ship passage (2005)
- Examining the vegetation (1989, 1992, 1999, 2005 and 2006)
- Examining the fauna (2006)

Furthermore, the planning files of WSA Verden as well as the up-to-date River Weser and groundwater levels were scrutinized and interpreted with regard to evaluating the technical-biological bank protection.

All studies result in the judgment that the current state of bank protection can be assessed as being very good. Almost all planting measures executed have developed in such a way that nowadays good erosion protection is provided for the bank slopes. In this context, planting root balls of reed and placing willow brush mattresses, willow cuttings and long branch cuttings have proven to be highly useful. The partial flattening of banks has had a very positive effect as well: noticeably wider reed belts have developed.

The sloped banks are stable under the so far predominant, relatively low hydraulic loads induced by navigation and by the natural river flow. This means that, with technical-biological bank protection measures applied in the slope area above the mean water level and with riprap below, good bank protection is provided under the given boundary conditions. According to the WSA Verden, no maintenance has been necessary in the actual bank area since the completion of the measure in 1989.

Contrary to the initial state, today's vegetation along the test section forms a complex of bank-typical habitats which is of high quality in terms of nature protection. Valuable and sometimes protected biotope types, such as reeds, alluvial shrublands or reed canary grass, have developed. Moreover, several shrub species have settled in the succession areas, which, as a complement to the willow species, represent elements of high biocoenological value.

Compared to the adjacent reference areas, the alternative bank protection also received a higher evaluation result in terms of fauna. The vegetation cover, which is noticeably better compared to traditional bank protection methods, has proven to be advantageous. Not only juvenile fish benefit from this, but also the macrozoobenthos settlements are of higher quality. The number of bird and macrozoobenthic species increased; even endangered species are slightly more frequent. Therefore, alternative bank protection – as applied here – is desirable also in terms of fauna.

In order to provide a basis for transferring the results to other stretches and for the planned elaboration of a general recommendation for alternative bank protection, the most important boundary conditions – such as geometry, ground and hydraulic load – as well as the bank protection measures applied here, have been compiled in a specification.

This report as well as all further study results in the context of this research project will be published on a web portal already created for this specific purpose by BAW and BfG at http://www.baw.de/ufersicherung/index.php.

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1 Motivation

In order to prevent the occurrence of erosion as a result of navigation, the banks of federal waterways are safeguarded over long stretches with suitable measures, for example using riprap. For many construction measures – particularly in regions with a high priority for nature conservation – ecological aspects have, besides the technical standards, increasingly become of greater importance. This means that for the maintenance, development and construction of waterways alternative, more nature-orientated bank protection methods should be considered more frequently. Hitherto little empirical data has been available for these bank protection measures on federal waterways. The German Federal Waterways and Shipping Administration (WSV) does maintain some local test stretches, where vegetation components have been incorporated and monitored, however, the experience acquired in the individual stretches has not yet been compiled and centrally evaluated. Systematic studies of the hydraulic load-bearing capacity of alternative bank protection measures have not yet been carried out. For this reason the Federal Waterways Engineering and Research Institute (BAW) and the Federal Institute of Hydrology (BfG) have initiated a research project that will investigate the feasibility of alternative bank protection measures along waterways with regard to technical and nature conservancy factors. The long-term objective is to provide the planning personnel of the Federal Waterways and Shipping Administration (WSV) with solidly researched information and recommendations on the use of this type of bank protection measure.

The research project "Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways" has, since 2004, been carried out jointly by the departments Earthworks and Bank Protection (G4 – responsible for project management) and Interaction Ship/Waterway, Field Investigations (W4) of the Federal Waterways Engineering and Research Institute (BAW) and the departments Vegetation Studies, Landscape Management (U3) and Fauna and Ecology (U4) of the Federal Institute of Hydrology (BfG).

In mid-2004, all regional Directorates (*Direktionen*) and local Offices (*Ämter*) of the Federal Waterways and Shipping Administration (WSV) participated in a survey for the purpose of recording the existence of test stretches with alternative bank protection measures and obtaining information regarding location, type of measure, boundary conditions and experience. Following extensive feedback in the period until early 2005, the evaluation of the responses led to the drawing up of a first sub-report /BAW-BfG 2006/. On the basis of this report, individual typical sections of these stretches are now being studied more closely. This includes an assessment of the current state of the bank protection measures in each case, a recording of the geotechnical and geometric boundary conditions, an appraisal of vegetation and fauna and measurement of the hydraulic load resulting from navigation within a defined period of time. Similarly, all available older documents from the planning and construction period of the test stretch will be compiled, evaluated and compared with the new studies. In this way the experience that has been gained can be quantified and included in general recommendations. The test stretch Stolzenau (Middle Weser; Km 241.55 to 242.30) was chosen as the first section for this detailed study. The results have been documented and evaluated in this second sub-report.

2 References

In this chapter, all documents with immediate relevance to the research project are listed as well as all the sub-reports and findings that were produced within the framework of the project. General reference works, relevant laws and codes and other sources can be found in chapter 14 (‚Literature') at the end of the report.

/BAW-BfG 2006/ Bundesanstalt für Wasserbau, Bundesanstalt für Gewässerkunde
(Federal Waterways Engineering and Research Institute, Federal Institute for Hydrology)
Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways (R&D project)
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BfG-No.:1484 / BAW-No.: 2.04.10151.00
Eigenverlag *(self-published)*, Karlsruhe / Koblenz May 2006

/BfG 1996/ Bundesanstalt für Gewässerkunde *(Federal Institute of Hydrology)*
Umweltverträglichkeitsuntersuchungen an Bundeswasserstraßen. Materialien zur Bewertung von Umweltauswirkungen
(Environmental impact studies relating to federal waterways. Materials for the evaluation of environmental impacts)
BfG-Mitt. Nr. 9
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/BfG-U4-651 2006/ **Untersuchung und Bewertung von ausgewählten Ufersicherungsmaßnahmen an Bundeswasserstraßen - Teil Avifauna -**
(Analysis and evaluation of selected bank protection measures on federal waterways - Avifauna -)
Beratungsgesellschaft NATUR dbR, Nackenheim
Koordination BfG: Schleuter, M., Koop, J.

/BfG-U4-653 2006/ **Untersuchung und Bewertung von ausgewählten Ufersicherungsmaßnahmen an Bundeswasserstraßen - Teil Fische -**
(Analysis and evaluation of selected bank protection measures on federal waterways - Fish -)
Bürogemeinschaft für Fisch- und Gewässerökologische Studien, Riedstadt
Koordination BfG: Schleuter, M., Koop, J.

/BfG-U4-655 2006/ **Bewertung von alternativen Ufersicherungsmaßnahmen auf der Basis von Makrozoobenthos**
(Evaluation of alternative bank protection measures with regard to macrozoobenthos)
Büro für Gewässerökologie, Karlsruhe
Koordination BfG Schleuter, M., Koop, J.

/IBS 2006a/ Ingenieurbüro Schmid
Bericht zu den Schiffsbeobachtungen an der Mittelweser bei Stolzenau (10. bis 17. August 2005)
(Report on ship observations at the Middle Weser near Stolzenau, 10 - 17 August 2005)
Bericht erstellt im Auftrag der BAW
Eigenverlag *(self-published)*, Kapsweyer 1.2.2006, 19 S. mit 4 Anlagen und 2 Anlage-Bänden

/IBS 2006b/ Ingenieurbüro Schmid
Wellendiagramme zu den Schiffsbeobachtungen an der Mittelweser bei Stolzenau (10. bis 17. August 2005)
(Wave diagrams based on ship observations at the Middle Weser near Stolzenau, 10 – 17 August 2005)
Anlage-Band zum Bericht /IBS 2006a/
Eigenverlag *(self-published)*, Kapsweyer Februar 2006

/IBS 2006c/ Ingenieurbüro Schmid
Geschwindigkeitsdiagramme zu den Schiffsbeobachtungen an der Mittelweser bei Stolzenau (10. bis 17. August 2005)
(Speed diagrams based on ship observations at the Middle Weser near Stolzenau, 10 – 17 August 2005)
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Eigenverlag *(self-published)*, Kapsweyer Februar 2006

/IWS-TB 6/2005/ Franke, J., Kengatharam, T., Wieprecht, S.
Alternative, naturnahe Ufersicherungen an schiffbaren Gewässern - Internationale Literatur, Vorschriften und Erfahrungen -
(Alternative bank protection measures for navigable waterways - International literature, codes, and experiences)
Technischer Bericht Nr. 6/2005, erstellt im Auftrag der BAW
Eigenverlag *(self-published)*, Stuttgart 2005, 43 S.

/WSA Verden 2004/ Wasser- und Schifffahrtsamt Verden *(Waterways and Shipping Board Verden)*
Schleusenstatistik Schlüsselburg und Landesbergen – Jahresbilanzen 1990 - 2003
(Lock statistics Schlüsselburg and Landesbergen – Annual records 1990 - 2003)
Schreiben vom 2.11.2004

3 Area of study

The River Weser, which is 452 km in length, begins as the Oberweser (Upper Weser) in Hannoversch Münden at the confluence of the Werra and the Fulda Rivers, at an elevation of approximately 116.5 m a.s.l. After crossing the Mittellandkanal via the Minden Aqueduct it is known as the Mittelweser (Middle Weser). From Stolzenau, a little further to the north, the Weser then flows through Niedersachsen (Lower Saxony).

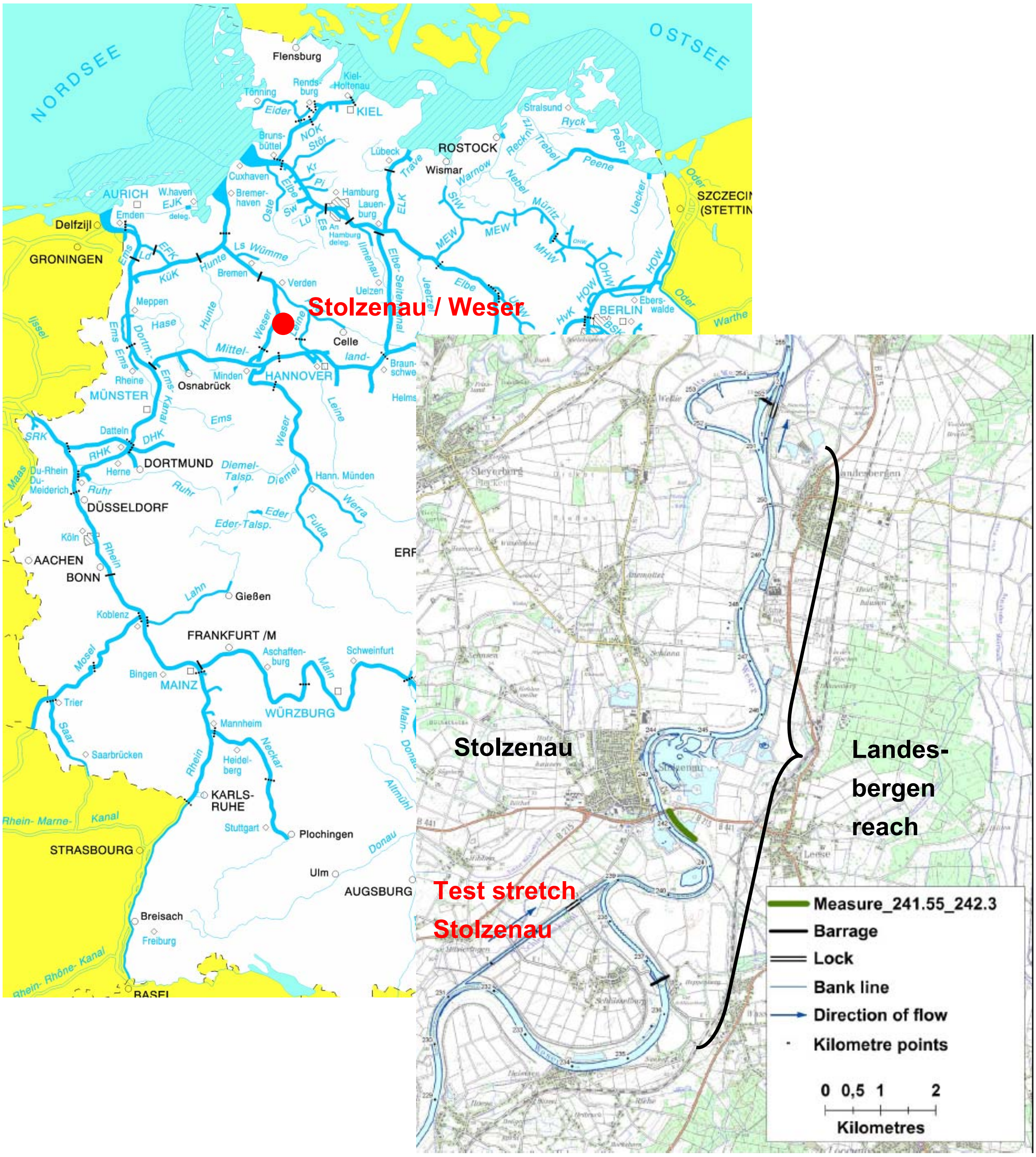


Figure 3.1: Location of the area for study

The test stretch with alternative bank protection measures which has been more closely studied below is located on the right bank of the Mittelweser (Middle Weser) at Stolzenau (Figure 3.1). In Bremen the Mittelweser becomes the Unterweser (Lower Weser) and flows into the North Sea at Bremerhaven as the Außenweser (Outer Weser or Weser estuary).

The study area from Km 241.55 to Km 242.30 lies between the barrages at Schlüsselburg and Landesbergen in the inner radius of a slight bend in the river (slip-off slope zone) in the vicinity of the small town of Stolzenau (administrative district of Nienburg/Weser). This area lies outside protected areas. Here the hydrostatic water level is 26.5 m a.s.l. In the context of the Mittelweser adaptation, measures were carried out in the early 1990s that enabled year-round navigability for ships 1350 t fully laden with a maximum 2.5 m draft. The Mittelweser thus at present fulfils the requirements for a Class IV waterway according to European classification system. An upgrade to a Class Va waterway, while still taking into account the ecological conditions of the Weser area, is planned for the long term in order to increase the depth of the fairway from its present 2.5 - 2.8 m to a maximum of 3 m for navigation by “Europe Ships” (length 85 m) and large motor vessels with lengths of up to 110 m.

In terms of natural space, the area of the study forms part of the “Weseraue” (Weser meadows) and borders the “Stolzenauer Terrasse”, both of which are sub-units of the “Lower Mittelweser”. The predominant soil types are various alluvial soils, gley-like brown earths with primarily sandy/gravelly/loamy texture and, at the edge of the Geest (the North German coastal moorlands), fen soils. The Weseraue region is now largely deforested and is used predominantly for agriculture. Along the banks of the Weser, which mostly are uniformly structured, a narrow belt of reed, willow shrubbery and other riparian plants can occasionally be found in areas in which utilization (particularly grazing) does not extend fully to the banks /Meisel 1959/. The water structure quality in the area of the Landesbergen Reach was accordingly categorised as Class 5 (significantly impaired) /AG Reinhaltung Weser 1998/. The criteria riverbed dynamics, floodplain dynamics, alignment, structure-forming capacity, wooded border, retention and development potential were taken into account. The annual precipitation is approximately 770 mm; the annual mean temperature is around 9.9° C (for the period from 1988 to 2005; cf. Figure 3.2).

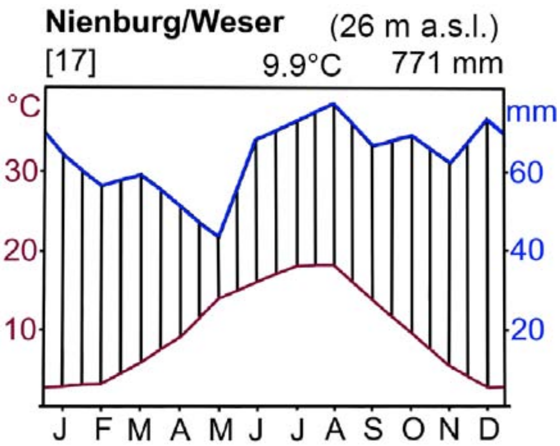


Figure 3.2: Climatic diagram covering 17 years for Nienburg/Weser, showing precipitation (monthly totals) and air temperature (monthly mean values) according to /DWD 1988 - 2003; DWD 2004 - 2005/.

The water quality of the River Weser has for more than 100 years been impaired by a very high salt content. The salts containing potassium and magnesium originate from potash salt production in the catchment area.

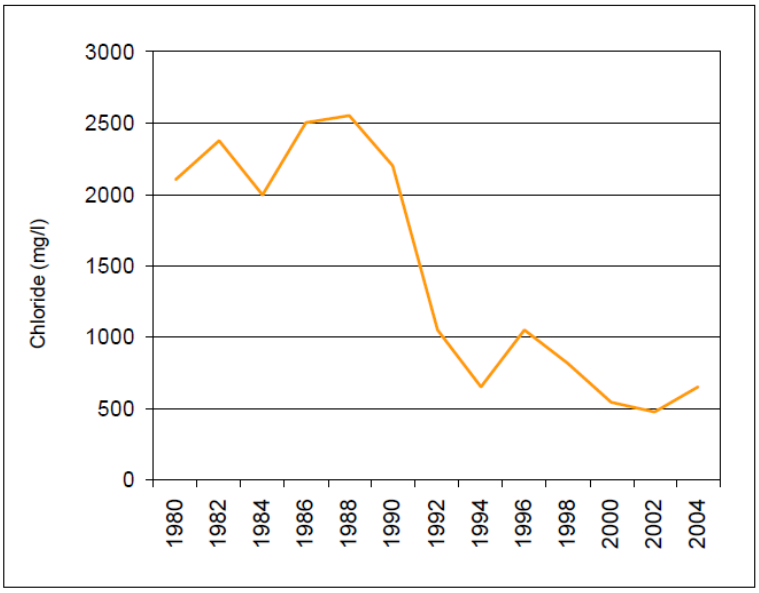


Figure 3.3: Annual mean for chloride concentrations at the quality monitoring station Hemeln (River Weser) /NLWKN 2006/.

During the 1990s it was possible to reduce significantly the salt content of the water (Figure 3.3), but with a value of 250-400 mg/l in the Mittelweser, it is still comparatively high. (A concentration higher than 200 mg/l is detrimental to water organisms.) /NLWKN 2006/

4 Bank protection measures in the test stretch

4.1 Initial condition and description of bank protection measures

In the context of the adaptation of the Middle Weser, alternative technical-biological bank protection measures were installed along a stretch of approximately 750 m (Km 241.55 to Km 242.30) at the initiative of the local Waterways and Shipping Board (WSA) Verden and in cooperation with BfG and BAW. Since, at that time, little experience of this type of bank protection measure for waterways and, in particular, for rivers had been acquired, the stretch was designated a test stretch and was intensively monitored in the following years. Various construction methods were to be tested here.

Initial condition (before installation of the test stretch)

In the upstream section, which is about 300 m long, the bank was divided up by single groynes, and in the downstream section, it was developed with a relatively uniform slope protected by armour stones. The adjoining terrain was used as grazing land (Figure 4.1).

Figure 4.1: Initial condition of the test stretch: used right up to the banks for grazing (18/08/1988)

In the groyne zones, animals could have direct access to the water to drink. In the bank slope zone, two approx. 20 m wide paved bank sections had been designed to serve as a watering place.

The natural plant cover on the bank was restricted to small groups of shrubs, isolated colonies of reed canary grass and some tall forbs (herbaceous perennials). Thus, after the installation of the test stretch, this was still true of the sections of the test stretch in which no measures had been implemented. Approximately 15 to 25 m from the bank, the terrain rises several metres. On the landward side of this, grazing also took place at the time, and still does, while at a distance of 30 to 50 m from the test stretch, a gravel-pit lake has now been developed as a result of commercial gravel digging (Fig. 4.2).

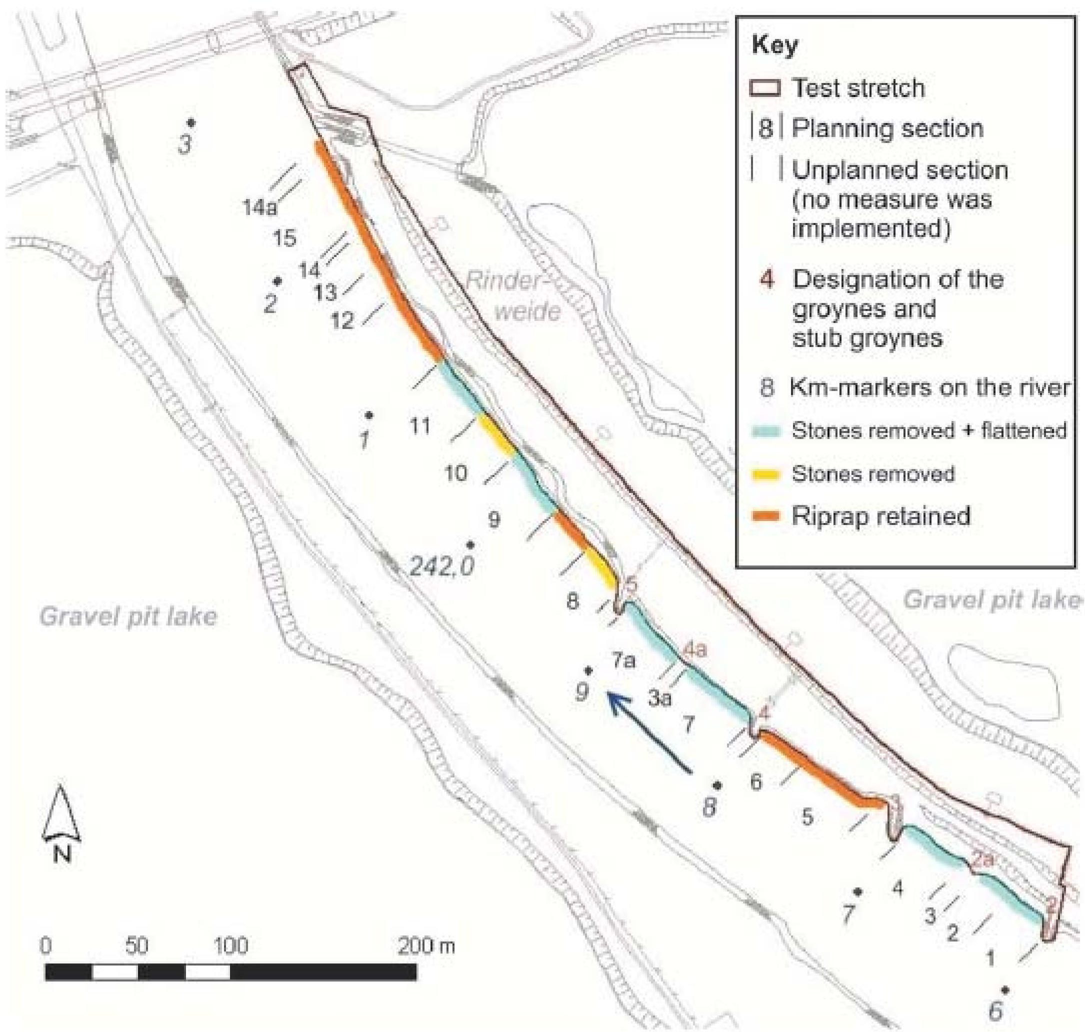


Figure 4.2: The test stretch between Km 241.55 and 242.30 with the planning sections

The four groynes in the first section of the test stretch from Km 241.55 to Km 241.93 were originally constructed in 1908 and had been raised in height during the canalisation work on the Middle Weser in 1960/1961. But since the 1970s no more maintenance work had been carried out. As a result, by 1988 they had largely fallen into disrepair.

Bank protection measures 1988/89

An overview of the measures carried out can be seen in Table 4.1. Detailed information can be found in the map of 1988 (Appendix 4.1), the as-built map of 1989 (Appendices 4.2-1 and 4.2-2), the detailed plans of 1989 in tabular form from the WSA Verden (Appendix 4.3; with slight deviations in the numeration) and the description of the measures of the WSA Verden (Appendix 4.4).

Table 4.1: Measures at the various bank sections: (Comparable sections have been summarised and highlighted in colour.)

Waterway Section Number	Measures
1	- Removal of the armour stones and flattening of the bank slope (1:7) - Stone mound: hydrostatic water level + 20 cm - Shallow water zone: bank slope filled up to hydrostatic water level -10 cm - Dead wood fascine **- Planting of common reed and sedges**
2	- As in Point **1**, but without fascines
4	- Removal of the armour stones and flattening of the bank slope (1:7) - Stone mound: hydrostatic water level + 20 cm without additional backfill **- Willow cuttings / long willow branch cuttings**
7	- Removal of the armour stones and flattening of the bank slope (1:7) - Stone mound: hydrostatic water level -10 cm without additional backfill **- Planting of common reed and sedges and common reed mats** - Protection using vegetation fabric
7a	- Bank structure as in Point **7** - Slope protected by using **willow cuttings / long willow branch cuttings** and **live brush mattresses of willow branches** (live material that can sprout)
5	- Slope inclination and armour stones retained - Island / riprap training structure (mean water level + 10 cm) - Connection to terrain with stone mound: hydrostatic water level + 20 cm - Shallow water zone: filled up to hydrostatic water level -10 cm **- Planting of common reed and sedges**

Waterway Section Number	Measures
6	- Slope inclination and armour stones retained - Island / riprap training structure (mean water level +10 cm) - Connection to terrain with stone mound: hydrostatic water level -10 cm - Shallow water zone: filled to hydrostatic water level -10 cm **- Willow cuttings / long willow branch cuttings**
8	- Armour stones removed (slope inclination retained) **- Planting of common reed and sedges** - Protection using vegetation fabric
13	- Existing bank slope with armour stones retained without any alteration - Dead wood fascines **- Planting of common reed and sedges**
15	- As in Point **13** but without fascines
9	- Removal of the armour stones and flattening of the bank slope (1:7) - 3 m wide berm between hydrostatic water level and mean water level - Dead wood fascines **- Planting of common reed and sedges** - Landward side: **willow cuttings / long willow branch cuttings**
11	- As in Point **9** but without fascines or willows
10	- Armour stones removed (original slope inclination retained) - protected by **live brush mattresses of willow branches** (live material that can sprout)
12	- Existing bank slope with armour stones retained without any alteration **- Willow cuttings / long willow branch cuttings**
14	- Existing bank slope with armour stones retained without any alteration - **Row of alder** planted
14a	- As in Point **14**
3	- **Riprap stub groyne 2a** rebuilt (after removal of armour stones and flattening of inclination to 1:7; according to as-built map of 1989, common reed was additionally planted behind this, in the area adjoining Section 2).
3a	- **Stub groyne (No. 4a in Section 3a)** constructed as a **brushwood double-row palisade** (after removal of armour stones and flattening of inclination to 1:7; according to as-built map of 1989, common reed and willows were planted behind this, as in the adjoining Sections 7 and 7a).
Groyne 2	- Old surface area cleared and groyne rebuilt with **riprap**

Waterway Section Number	Measures
Groyne 3	- Old surface area cleared and groyne rebuilt using **(branch) packing**
Groyne 4	- Old surface area cleared and groyne rebuilt by **paving**
Groyne 5	- Old surface area cleared and groyne rebuilt with **riprap**
Sections without planning	- Left unchanged

The existing bank structures were integrated into the new planning and expanded. Within the existing groyne fields (Planning Sections 1–7a), the bank line was reconstructed by means of excavation work along the bank, and an irregular course was laid out for the bank line.

The four groynes (2–5) and the stub groyne 2a were improved and restored to their original dimensions. To attain a comparable level of the production costs, durability and efficacy of the protection for the riparian vegetation for the various types of groyne structure, the groynes were built with various construction methods (paving, riprap and branch-packing). In addition, a stub groyne (No. 4a in Section 3a) was constructed in the form of a brushwood double-row palisade (cf. Table 4.1). Along with the stub groynes, other flow-deflecting structural elements were installed in the bank area, with the expectation that these would have a positive effect on the diversity of species in the water.

To reduce the hydraulic load on the banks, resulting from navigation and, thus, in order to protect the newly-planted bank protection measures, the three groyne fields were additionally divided up by stone mounds of differing heights, constructed with riprap and running parallel to the bank at a distance of 3.5 m (cf. Appendix 4.1). No filter was located between the soil and the stone, as the in-situ Weser gravel was itself considered to be sufficiently stable in its function as a filter.

The upper edge of the stone mounds was varied in such a way that an exchange of water could take place in front of and behind the stone mounds (up to 20 cm above or 10 cm below the hydrostatic water level at 26.50 m a.s.l.). In sections 1, 2, 5 and 6, the areas between the stone mounds and the bank were filled with gravel to a level of 10 cm below the hydrostatic water level, thus creating a shallow water zone to allow the proliferation of reed bed plants (cf. Figure 4.3).

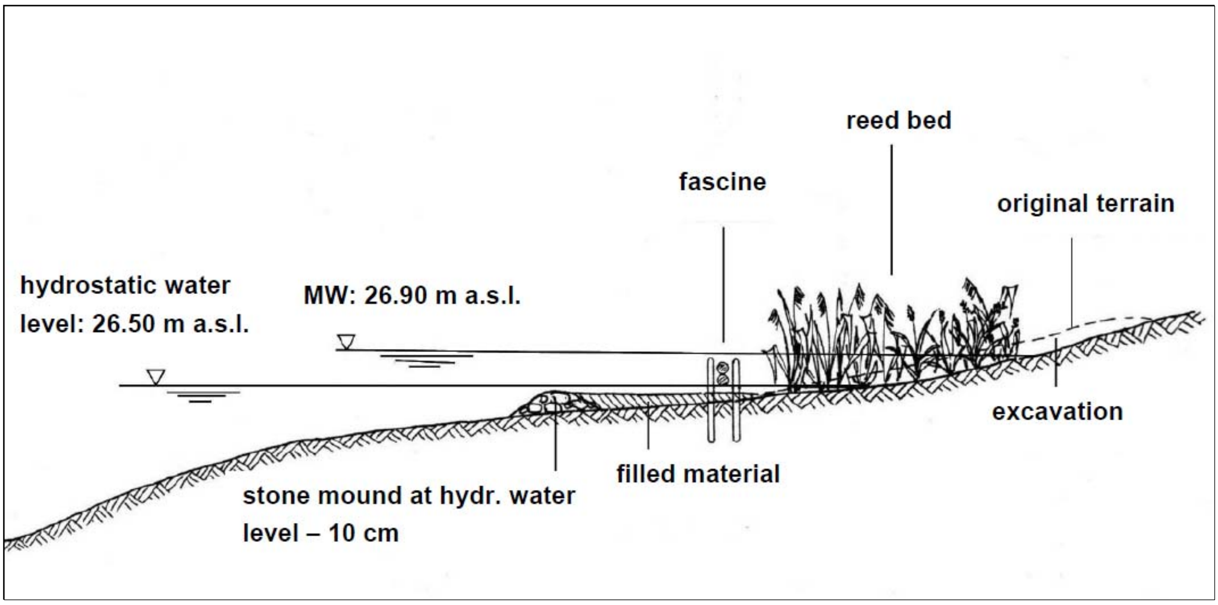


Figure 4.3: Reconstruction of the bank by installation of a stone mound and flattening of the bank: the profile of Section 1 (from the plans; later a stone mound was constructed here at hydrostatic water level + 20 cm).

Because of the filling carried out between the groynes and the stone mounds, the quantity of riprap (Class III) for the stone mounds could be reduced. As the riparian vegetation grew and spread, the stone mounds lost their significance and no further action was taken.

In Sections 5 and 6, an island-like stone mound was filled at a distance of approximately 3.5 m from the bank (mean water level + 10 cm, cf. Figure 4.4)

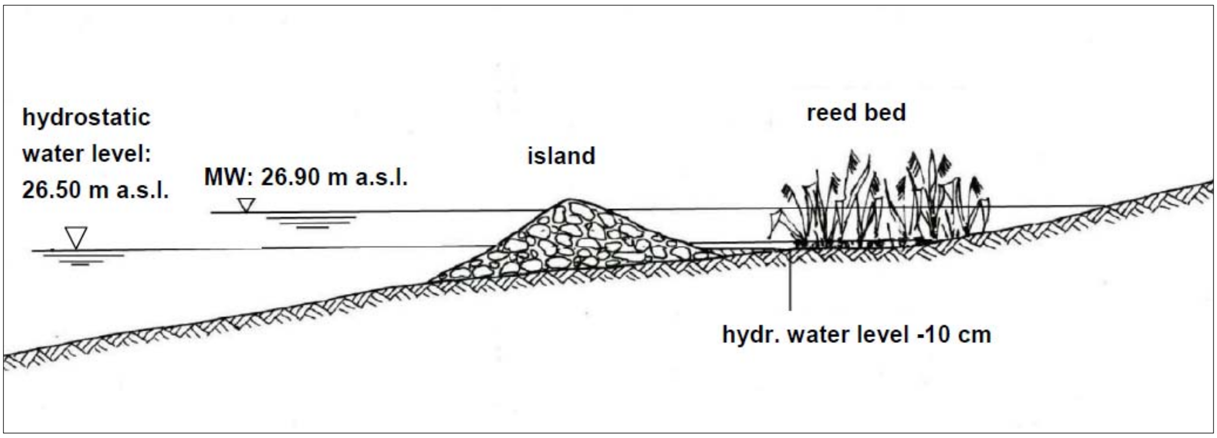


Figure 4.4: Reconstruction of the bank by installation of an island-like stone mound: profile of Section 5 (from original plans)

In most sections, the original riprap of armour stones directly at the bank, between the groynes, was removed above the hydrostatic water level. In several planning sections, the bank there was also flattened from 1:3 to 1:7 along a strip approximately 5 m in width (cf. Figure 4.4 and Table 4.1), in order to break up the previously relatively straight and uniformly sloping bank for the purpose of creating more favourable conditions for planting. Part of the planted area was still given protection from rock-brush fascines installed streamwards, in order also to find out their influence on plant development under these conditions.

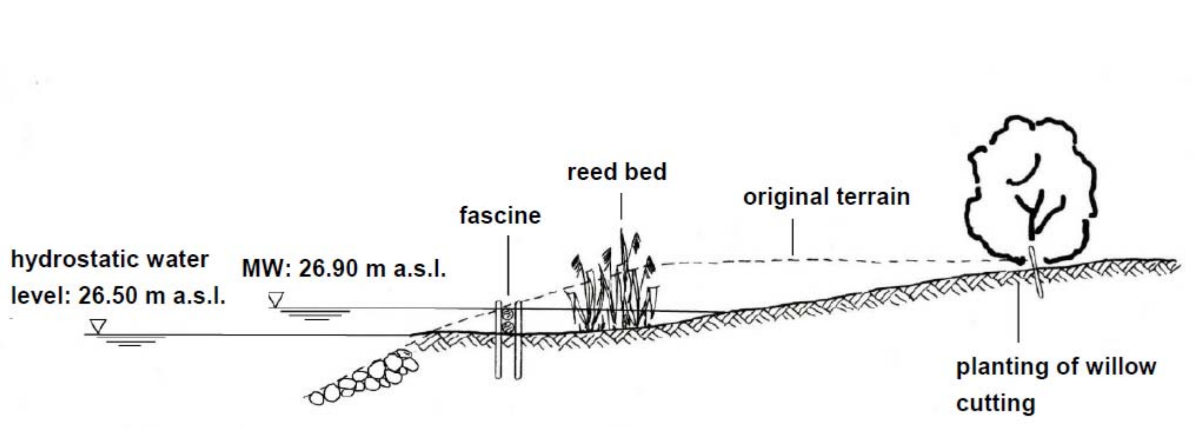


Figure 4.5: Reconstruction of the bank by flattening of the bank slope: profile of Section 9 (from original plans)

In this way a "cliff line", up to one metre in height in places, was formed on the side towards the adjoining terrain (cf. Figure 9.18). This was left in its natural state; transitional remodelling was not undertaken. Some of the gravel material obtained by the flattening of the slope was used for repairing the groynes, and the major part for raising the bed between the groynes.

The slope zone below the hydrostatic water level was not altered as a result of the installation of the test stretch. The old revetment of riprap was retained – in as far as it still existed.

This hydraulic engineering work was carried out during the autumn and winter months of 1988/89, and the planting work in spring/early summer 1989.

Above the hydrostatic water level, various bank protection measures were installed using plants from the following companies: Bestmann, Würfel (both companies for bio-engineering products) and Baltus (gravel works). In addition, especially for the purpose of separating the plant material of the three companies from each other, regional plant material, extracted by the WSA Verden, was used, as agreed with the Regional Nature Protection Office of the District of Nienburg.

The following plant material was used:
- common reed and sedge sods (plugs) extracted by the WSA Verden (dug out spade-wide)
- cultivated common reed and sedge plugs
- cultivated common reed and sedge plugs in connection with a woven coir fabric
- cultivated common reed and sedge plugs in connection with a coir straw fabric
- vegetation fascines
- cultivated vegetation mats or pallets planted with common reed
- willow cuttings (*Salix* spp.) extracted by the WSA Verden
- branch and twig material for brush mattresses of willows (*Salix* spp.)
- cultivated willow plants (*Salix* spp.)
- cultivated alders (*Alnus glutinosa*)

The following varieties of sedges and reed were planted: common reed (*Phragmites australis*), slender-tufted sedge (*Carex acuta*), lesser pond sedge (*Carex acutiformis*) and cypress-like sedge (*Carex pseudocyperus*). These plants were positioned individually, slightly above the hydrostatic water level at regular intervals in the in-situ riparian substrate. The plants from the Würfel company were furthermore wrapped with woven coir fabric.

The following plant varieties were introduced unintentionally (most likely with the sods): reed manna grass (*Glyceria maxima*), meadow foxtail (*Alopecurus pratensis*), creeping thistle (*Cirsium arvense*), red fescue (*Festuca rubra agg.*), purple loosestrife (*Lythrum salicaria*), timothy (*Phleum pratense* s. l.), broad-leaved dock (*Rumex obtusifolius*), comfrey (*Symphytum officinale* s. l.) and stinging nettle (*Urtica dioica*).

The planting measures were varied according to the bank sections, which were prepared in various ways (cf. Table 4.1 and inventory as of 1989, Appendices 4.2-1 and 4.2-2).

By means of fencing in the area and placing notices, further use of the area for grazing of cattle, or by anglers and those seeking recreation, was prohibited at the time of construction of the test section (cf. Chapter 9.1.6 and Appendix 9.5).

4.2 Costs

The BfG had in its possession lists created by the local office of the WSA Verden at Windheim which compile the construction costs (in Deutsche Mark) incurred in 1988/1989 for the alternative bank protection measures above the hydrostatic water level. Extracts of these were handed to the BAW in December 2004 for assessment. According to the latter, the costs are divided up into the following sub-groups:

(1) Earth works

(2) Bank and bed protections (improvements to the groynes; riprap of natural stone for the stone mounds; production and installation of fascines; production and installation of live brush mattresses)

(3) Live material construction: extraction and delivery of plant material (reed beds, cuttings and alder)

(4) Live material construction: installation of vegetation mats and plant material (reed beds, cuttings and alder)

(5) Combined construction methods

(6) Other construction costs

Table 4.2 and Figure 4.6 depict a rough analysis of the costs for the main construction work. The figures are calculated on the basis of the detailed list of costs in Appendix 4.5. The assignment of individual items to the groups in Table 4.2 partially had to be carried out subjectively, as it was not always possible to do this with absolute certainty. For the currency conversion, the rate of € 1 = DM 1.95583 was used. The main conclusions regarding the costs can be drawn as follows:

- The total costs amounted to approx. € 172,000 for 750 m of bank, the equivalent of € 230 / running metre.
- The largest share of the costs, about 2/3 (approximately € 110,000), arises from item (2): ‘Bank and bed protections’ (large percentage of costs for equipment and personnel).
- The largest share of the costs with regard to the biological components of the bank protection measures is formed by the two items: (3) ‘Live material construction: extraction and delivery of plant material’, and (4): ‘Live material construction: installation of vegetation mats and plant material’ with approx. 10 % (€ 17,290), the equivalent of € 23 / running meter – high personnel costs for the extraction of material by internal personnel.

Table 4.2: Compilation of the costs for the main construction works carried out for the installation of the alternative bank protection measures on the River Weser at Stolzenau and the percentage shares thereof

	Percentage [%]	Costs [€]
(1) Earth works	11.16	19,172
(2) Bank and bed protections	64.04	110,051
(3) Live material construction: extraction and delivery of plant material	2.42	4,158
(4) Live material construction: installation of vegetation mats and plant material	7.64	13,131
(5) Combined construction methods	1.04	1,782
(6) Other construction costs	0.67	1,145
Works management costs (15 % of the amounts (1) – (6))	13.04	22,416
Total costs	100.0	**171,856**

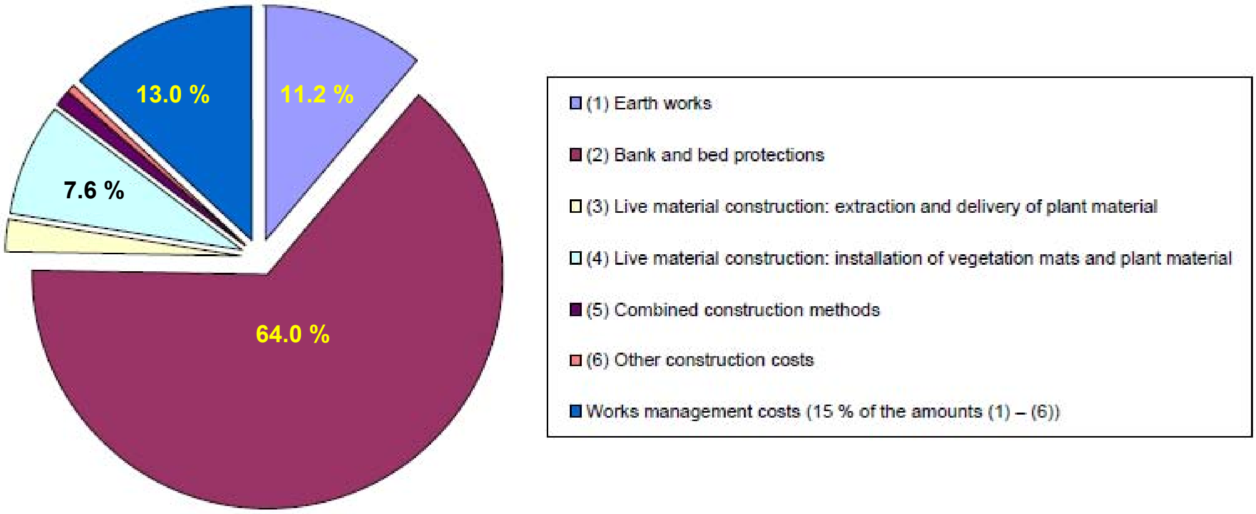


Figure 4.6: Percentage distribution of the costs for the main construction works carried out for the installation of the alternative bank protection measures on the River Weser at Stolzenau

At this point, important single expenses, which have been taken from the detailed list (cf. Appendix 4.5), should be mentioned in extracts. These are average amounts:

- Erection of a stone mound in 3 groyne fields: approx. € 208 / running metre
- Production and installation of fascines: approx. € 35 / running metre (of which installation makes up approx. 74 % = ¾)
- Live brush mattress: approx. € 180 / running metre, that is, € 45 / m²
- Extracting reed sods (€ 3.50 / sod) and installing these (€ 4.60 / sod)
  ➔ total approx. € 8 / sod
- Obtaining cuttings (€ 0.37 / cutting) and planting them (€ 2.05 / cutting),
  ➔ total approx. € 2.40 / cutting
- Combined construction method: approx. € 5.50 / running metre

The cost of the vegetation mats and the reed plugs in this measure was low, as these were provided by the producer partially cost-free, or at a lower price.

A comparison of the production costs for the alternative bank protection measures (without considering maintenance costs) with the corresponding costs for conventional technical bank protection measures is extremely difficult to make for the test stretch and cannot be evaluated in a representative manner, for the reasons shown below:

(1) Generally, because of lack of experience, the use of “new” bank protection measures (testing and implementation of “unconventional” construction methods) requires, as a rule, more resources than the production of a conventional bank protection measure.

(2) In the test stretch area, 17 variants of bank protection measures were set up in various forms over a stretch of 750 m. The length of the individual sections was on average only 50 m. As a rule, this causes higher costs than a uniform solution for the entire stretch. When using technical bank protection measures, the costs for small bank sections are also higher per square metre of revetment surface than in large construction sections.

(3) The costs for alternative bank protection measures also include costs that were incurred during installation of the test stretch for the rebuilding of four largely derelict groynes.

(4) In the scope of the test stretch, some of the plants were provided by the production companies in part at lower prices than usual, and some free of charge.

(5) The extraction and transportation of the reed plants from neighbouring waterway sections was in part carried out by internal personnel from the WSV. Therefore an assessment of these costs in comparison to the delivery of plants by nursery companies cannot easily be made.

(6) The alternative bank protection measures were installed only above the hydrostatic water level. Below this water level, the existing riprap was retained. A possible comparison can thus only refer to the zone above the water. The size of the zone above the water that has to be protected depends crucially on the slope inclination. The usual bank protection of riprap according to /MAR 2008/, which could be used as for comparison purposes, is generally installed on slopes with an inclination of 1:3 – at up to 70 cm above the upper operating water level on canals, and at up to 70 cm above the highest navigable water level on rivers. In the test stretch, the bank slopes have inclinations of 1:7 in some places and of 1:3 in others. The slope area that was protected with vegetative components therefore varies in size.

(7) Furthermore, for the production of technical revetments, “general costs” on which a suitable comparison could be based are unknown. The offers in case of tenders differ very widely according to the boundary conditions affecting the construction measures or the expertise of the company making the offer. As a result, only very rough average values from actual experience are available for technical revetments from the upper edge of the slope to the bed, including formation of the toe, generated from construction sections on waterways with a length of usually 4 km. These amount to around € 19 to € 26 per square metre for a revetment consisting of a geotextile and a 60 cm layer of loose armour stones (see also last sentence in point (2)).

The costs for the production of alternative bank protection measures along the bank stretch investigated in this report amount to € 172,000 for the 750 m of riparian zone (cf. Table 4.2). Assuming that the vegetative slope protection components were planted along a strip of bank of 5 to 10 metres in width, this would represent € 23 to € 46 per square metre.

A statement as to which type of bank protection measure would involve lower production costs in this specific case cannot be made, for the special reasons already described above. However, the list shows that even for the production of technical-biological bank protection measures, costs are incurred which can bear comparison with those of conventional methods. A decision to use alternative technical-biological bank protection measures will, as a rule, not therefore depend on the production costs alone, but also on other factors.

The major advantage of alternative bank protection measures lies, accordingly, not in the financial, but in the ecological considerations. By using technical-biological bank protection measures, clear improvements for the habitat conditions of flora and fauna in the riparian zones, as well as for the appearance of the water landscape, can be expected.

Especially with regard to the implementation of the EU Water Framework Directive (WFD), ecological improvements to waterways are gaining greater significance. This circumstance is currently being accommodated in the area of responsibility of the WSV through a decree dated 11/12/2007 from the German Federal Ministry of Transport, Building and Urban Affairs (BMVBS) with regard to "the consideration of ecological factors in measures applied to federal waterways" /BMBVS 2007/. On the basis of the decree, it is possible *"…that in the scope of traffic-related measures on federal waterways, an ecologically orientated design is also possible, if besides the equivalent traffic-related functionality and the achievement of the objectives, the basic principles of cost-effectiveness are also fulfilled."* Apart from the construction costs, criteria for the assessment of cost-effectiveness are maintenance costs, life cycle, material requirements, disposal costs or the necessity for compensation. *"The ecologically orientated design of traffic-related measures on federal waterways is, as a general rule, to be preferred when, although the sum of the outlay may, indeed, be higher, the ecologically orientated design of the measures will lead to lower costs overall than measures aimed at simply carrying out the traffic function and is, thus, economical. Here further traffic-related benefits (i.e. reduction of costs) can be included."* Otherwise the *"… ecologically oriented design of measures* (can be) *principally planned only as a cooperative measure corresponding to the relevant area of responsibility between the Federal government and third parties (e.g.: federal state* (Land)*, municipalities or associations)."*

5 Technical Boundary Conditions

5.1 Ground / ground water and bank geometry

5.1.1 Ground

The following documents form the basis for the assessment of the ground in the test stretch:

- *Baugrundgutachten für den Schleusenkanal Schlüsselburg* (ground expertise for the lock canal at Schlüsselburg) /BAW 2000/;
- results from borings which were carried out by the company *Geländeaufschlussbohrungen, Bohrbrunnen Hermann Klenke*, Petershagen, in 1991 at the gravel extraction area located northeast of the test stretch and made available by *CEMEX Deutschland AG;*
- results from borings which were sunk by the BAW in the direct vicinity of the river bank in the test stretch in 2007.

The test stretch is located at the area of the Weser meadows, which are mainly characterised by fluviatile deposits of the Weser, a river which has always meandered strongly. Depending on the flow velocities in a given locality, a varied sequence of erosion and sedimentation resulted which, near the surface, has led to sedimentation deposits which vary from place to place. The subsoil contains Pleistocene silt, sand and gravel deposits and, above these, in some places younger Holocene deposits of alluvial clay.

In the period from 25 to 29 June 2007, six small boreholes (drilling diameter 50 mm) were drilled by the BAW in the riparian zone of the test stretch with the objective of typing the sediments, in particular those lying near the surface, above the Weser gravel. Two borings were carried out at each of three cross sections located at Km 241.640, Km 241.930 and Km 242.005, at a distance of approximately 7-14 metres from the bank line. Appendix 5.1 shows the site of the boreholes in the ground plan. Because of the dense vegetation, access was only possible from the water, and it was therefore necessary to position the drilling equipment on the bank from a pontoon, using a crane. As a result, the location of the exploration sites was ultimately subject to these boundary conditions. This is the reason for the irregular distribution of the location of the exploration sites within the test stretch. The depth of the exploration was limited by the bore diameter, which was relatively small in comparison to the granularity of the gravel layer of the Weser gravel type. The objective of the borings, i. e. the typing of the soils lying near the surface for the purpose of assessing the flora and fauna, was achieved with the excavation depths reached, that is: 3 to 6 m. The results of the borings are shown in Appendices 5.2-1 to 5.2-3. Regarding the assessment of the ground layers with regard to location and height, this was depicted in the nearest measured cross sections (cf. Chapter 5.1.3). As an example, Figure 5.1 shows the results of the borings carried out at Km 242.005 – depicted in the cross section of Km 242.000.

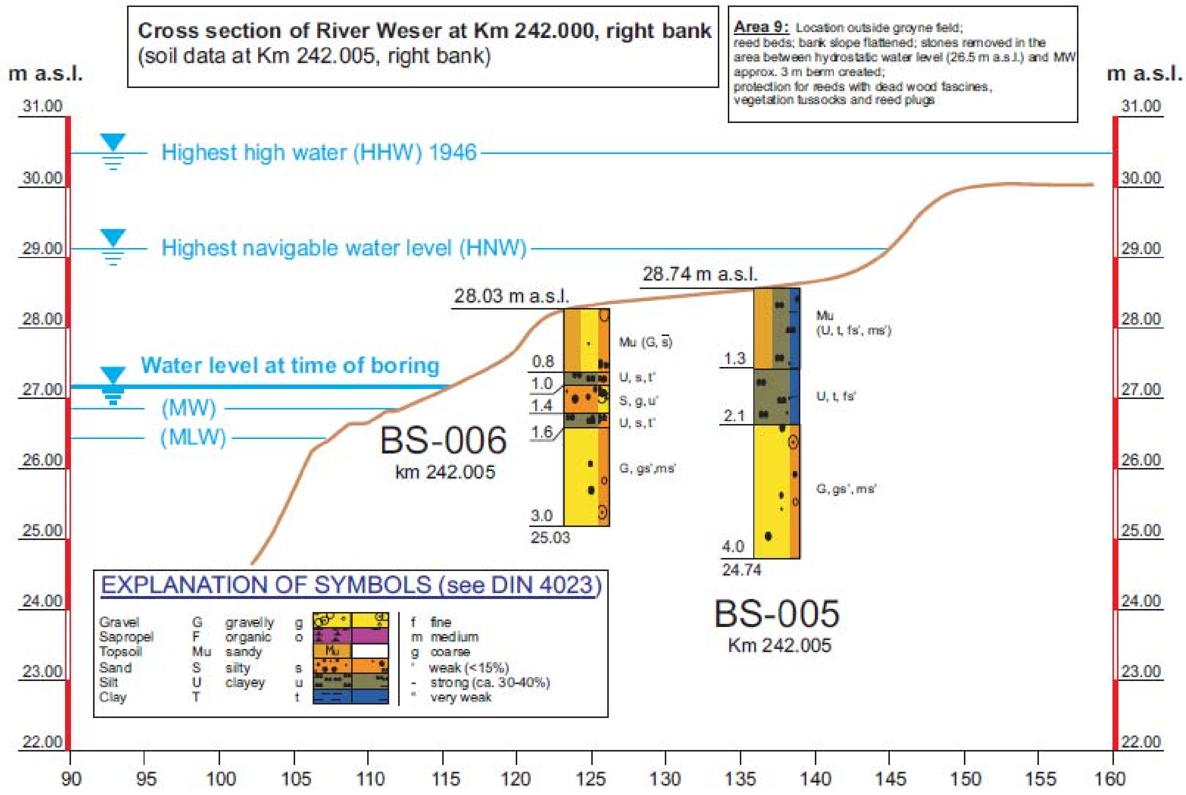


Figure 5.1: Results of exploratory borings depicted in cross section Km 242.000

Below a topsoil layer in the area directly adjoining the bank, the main components are silts with sandy or argillaceous components and, in part, also silty or gravelly sands. Selected particle size distribution graphs of the silts and sands are shown in Appendices 5.3-1 und 5.3-2. The consistency of the silts can be estimated as ranging from soft to stiff. The soils above the Weser gravels have a chalk content of 2 - 5 % (mean value of the seven samples: 3.1 %). The permeable Weser gravel with a depth of around 6 - 8 m begins approximately 1 - 3 m below the ground surface at a height of 26 - 27 m a.s.l. The surface of the gravel layer thus lies approximately between the mean low water (26.53 m a.s.l.) and mean water (26.90 m a.s.l.) levels of the River Weser. The Weser gravel can be described as intermittently to widely graded, medium to coarse sandy gravel with a granularity from 0.2 to 60 mm. According to /BAW 2000/, the Weser gravel is characterised in certain areas by gap grading, which may be more or less pronounced and may affect different categories of granularity. Particle size distributions determined for the samples taken by the BAW in the area of the test stretch are shown as examples in Appendix 5.3-3. On the basis of the results in /BAW 2000/ and the borings undertaken by *CEMEX Deutschland AG*, it can be assumed that, in part, layers of sand are present in the gravel.

A simplified layer structure and ground parameters, as shown in Table 5.1., can be assumed for bank protection calculations in the area of the test stretch.

Table 5.1 Simplified ground structure and calculation parameters

Soil-mechanical parameters	**Layer 1** Ground surface level to + 26.5 m a.s.l. Silts and sands B4 (acc. to /MAR 2008/)	**Layer 2** + 26.5 m a.s.l. to + 20.0 m a.s.l. Gravels B1 (acc. to /MAR 2008/)
Effective friction angle Φ‘ [°]	30	35
Effective cohesion c‘ [kPa]	-	-
Buoyant unit weight γ‘ [kN/m^3]	10	11
Permeability coefficient k [m/s]	$1 \cdot 10^{-6}$	$5 \cdot 10^{-4}$

5.1.2 Ground water

The ground water measurement points near the test stretch from which readings were taken regularly until 2003 are indicated in the site plan in Appendix 5.4. The ground water hydrographs of the measurement points WSV25, WSV26, WSV34 and WSV35 for the period from 1988 to 2003 are shown in Appendix 5.5-1. Supplementing this, the hydrograph of the nearby Stolzenau gauge (Weser Km 243.400) is also shown in the appendix. Appendix 5.5-2 and Figure 5.3 show the readings as examples in an extract for the years 1994 and 1995. In the detailed 2-year diagrams it becomes apparent that the ground water levels – as would be expected – correspond to the water levels of the River Weser. The diagrams in Figure 5.2 and Appendix 5.5-3 provide a quantitative overview of the correspondence between ground water and the River Weser. These depict the ratio of the various flow directions between ground water and the Weser, shown as a percentage, in the analysis of the above mentioned ground water and Weser water level measurements over the period from 1988 to 2002. It can be seen that since the installation of the alternative bank protection measures there has been – as expected – a predominant (77 %) flow of ground water to the Weser. It should be noted that every time a ship passes, generating a drawdown effect at the bank, the differential between the ground water and the Weser is increased for a short time and additional flow of ground water to the river occurs. During high water, flow conditions, especially in the event of a rapid rise in the water level, are reversed, and a flow of water from the River Weser to the ground water (19 %) takes place. This can be seen particularly clearly in Figure 5.3 (Appendix 5.5-2). Equal water levels occur with an incidence of 4 %.

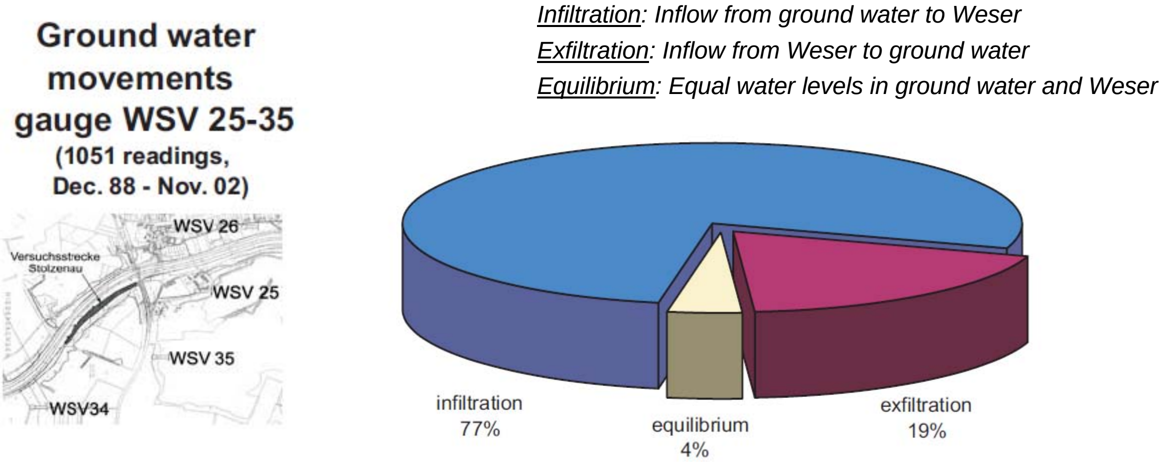


Figure 5.2: Flow conditions in bank zone (overall analysis of gauges WSV 25, WSV 26, WSV 34 and WSV 35)

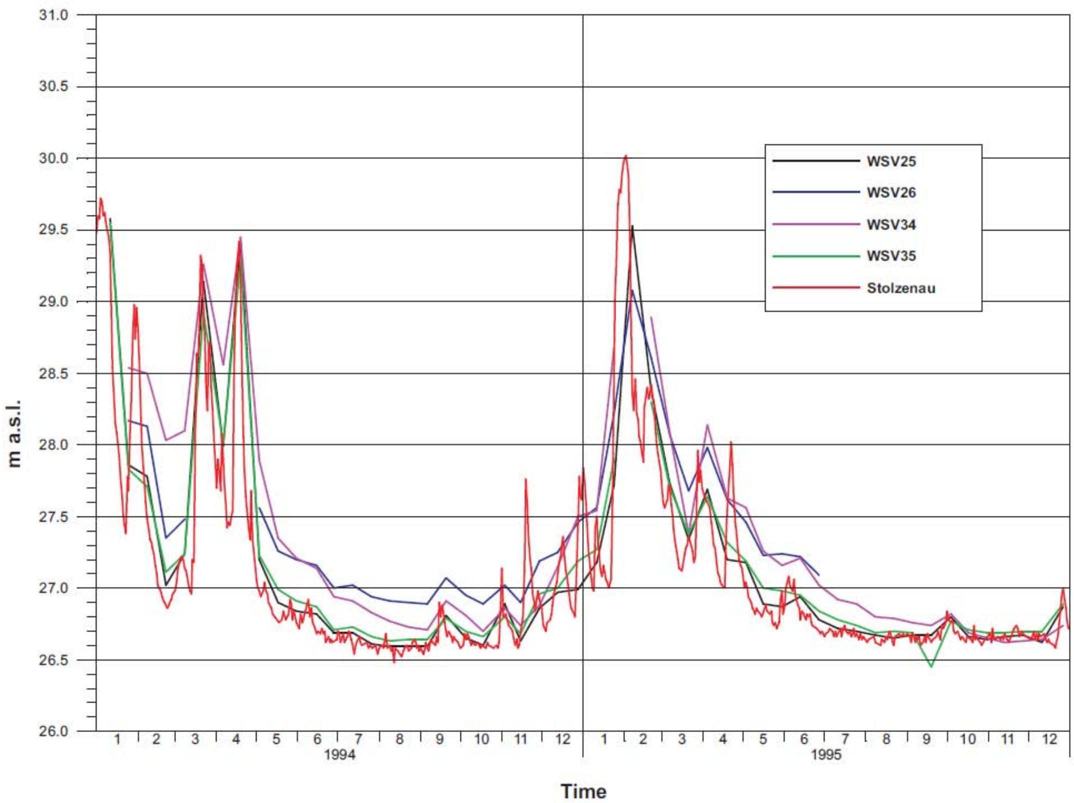


Figure 5.3: Water level hydrographs of various ground water measuring points (location: cf. Figure 5.2) and the River Weser at the Stolzenau gauge for the years 1994 and 1995

5.1.3 Bank geometry

As no soundings were carried out immediately after the installation of the alternative bank protection measures in the test stretch in 1989, no cross sections are available for purposes of comparison. The first soundings with a link to the bank date from 1996 (cross sections at Km 241.500, Km 241.600, Km 241.800, Km 242.000 and Km 242.200). The two most recent cross sections (Km 242.040 and Km 242.170) were produced in the year 2005, during the measurement of hydraulic load on the banks by the company Schmid (cf. Chapter 6). Additionally, in 2007 the local office of the Waterways and Shipping Board (WSA) Verden at Windheim calibrated four up-to-date cross sections at Km 241.650, Km 241.750, Km 241.850 and Km 241.95.

All the existing cross sections in the right bank area of the test stretch are depicted in Appendices 5.6-1 to 5.6-13 with reference to heights above sea level. The type of bank protection measure at each cross section is identified in accordance with Appendix 4.3. Especially for purposes of assessment of the alternative bank protection measures from the point of view of geotechnics, phytoecology and fauna, additional information was added in the appendices regarding water levels in the River Weser (MLW, MW, HNW, HHW) and the hydrograph of the River Weser at the Stolzenau gauge during the period from 1988 to 2006 – that is, since the installation of the bank protection measures. The cross section at Km 241.800 is shown as an example in Figure 5.4.

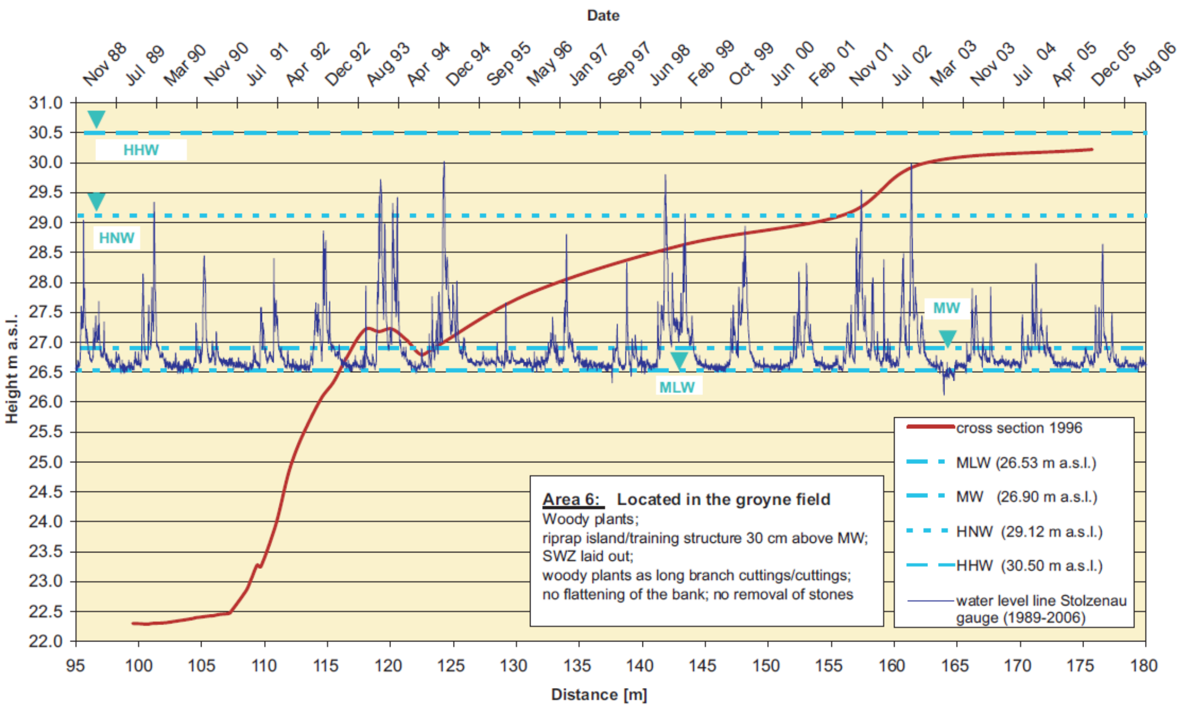


Figure 5.4: Cross section Weser Km 241.800, right bank, including water level hydrograph at the Stolzenau gauge

The cross section recorded in 1996 outside the test stretch, at Km 242.500, can be drawn on approximately as a starting point for purposes of comparison in the area of the test stretch. According to information from the WSA, the slopes in the section from Km 240.750 to Km 241.600 with a 1:3 inclination, as planned, were given protection with Class III riprap in 1961, according to /MAR, 1993/. This applies also to the section from Km 242.250 to Km 242.310; however, the slope inclinations here are 1:2. The bank area of the groyne fields that lie between these markings was also protected with a riprap revetment.

The cross section at Km 242.500 (Appendix 5.6-13) lies 200 m downstream from the test stretch. There are no further groynes here. From the bottom to about one metre above MW the slope has a uniform inclination of approximately 1:3. Above this, the terrain is very flat for about 150 m. The river bank slope is evidently in a stable balance with the existing riprap revetment; the planned inclination has remained constant here.

The geometry of the cross sections recorded within the test stretch in 1996, 2005 and 2007 is, on the whole, very divergent – characterised by slope inclinations produced using differing methods, various types of alternative bank protection measures and, in some cases, by alterations made subsequently to the installation. Five cross sections lie within the groyne fields (Km 241.600 to Km 241.900) and five cross sections are outside the groyne fields (Km 241.950 to Km 242.200). In the individual groyne fields, additional stone mounds or training structures were constructed parallel to the bank as protection for the vegetation that was planted – easily recognisable, for example, in the cross section at Km 241.800 (Figure 5.4). In Appendix 4.3, the planning documentation of the WSA shows precisely which bank protection measures were installed in the individual sections, where existing armour stones were removed and where these were retained, as well as the sites at which flattening of the slopes from 1:3 to around 1:7 was carried out in accordance with the plans.

It can be seen from the cross sections that in the slope zone below MW level, in which the original slope inclinations and riprap revetments were retained everywhere, the existing slopes have widely differing inclinations. It should be remembered that the underwater slopes underwent change in the area of the groyne fields as a result of the installation of the stone mounds and the partial in-filling of the groyne fields during the installation of the alternative bank protection measures. Some cross sections are near a groyne, i.e. sections of the groyne may in such a case also be included in the cross section. For the most part, the slope inclinations below MW level are steeper than the planned inclination of 1:3. In many cross sections (e.g. at Km 241.600, Km 241.750, Km 241.800, Km 241.850, Km 242.000 and Km 242.040) slopes of between 1:2 to 1:2.5 can be identified. Some flatter slope sections (e.g. at Km 241.040) or berms (e.g. Km 241.750 and Km 241.950) are also present concurrently in the zone of fluctuating water level. A continuous slope inclination of around 1:4 can be identified at Km 242.170 outside the groyne fields.

Above MW level – in the area in which the alternative bank protection measures were installed – there are no uniform slope inclinations either. It can be assumed that after the removal of the riprap revetment, the creation of the new profile and the planting of the various types of vegetation, the slopes were at first, to some extent, reshaped by wave action and flow. But that as a result of the development and growth of the vegetation they have become increasingly stable.

With regard to the initial geometric state, three zones can be distinguished:

(1) In the zone of the cross sections at Km 241.600, Km 241.650, Km 241.850 and Km 242.000, the slopes were flattened to an inclination of 1:7 over a width of about 5 m above MW level, and the riprap revetment was removed.

(2) In the zone of the cross sections at Km 241.750, Km 241.800, Km 242.170 and Km 242.200, the existing slope inclinations and armour stones were retained.

(3) In the zone of the cross sections at Km 241.950 and Km 242.040, the existing slope inclinations were retained, while the armour stones were removed.

In **Zone (1)**, the slopes in the area which was flattened to 1:7 in accordance with the plans now have an inclination of around 1:8 in the four cross sections that were measured in 1996 and 2007. This means that the inclination of the slopes has changed only minimally over this period of years.

In **Zone (2)**, there are slope inclinations of approximately 1:3.5 (Km 242.200), 1:4 (Km 242.170), 1:6 (Km 241.750) and 1:7 (Km 241.800) directly above MW level. This shows that the slopes here have in part become flatter – provided that before the installation of the test stretch the slope inclinations actually were 1:3. This cannot be seen from the existing documentation of the WSA, neither are the dimensions and condition of the riprap revetment from that time available. It is more likely that flatter slope inclinations were already present here.

Zone (3) is of special interest. Here slope inclinations of about 1:3.5 (Km 242.040) or 1:4.5 (Km 241.950) can be found in the cross sections of the area for comparison. This means that the relatively steep slope inclinations with the alternative bank protection measures are to a very large extent stable, despite the lack of riprap revetment. According to Appendix 4.1, the protection measures at Km 242.040 were carried out using live brush mattresses of willow branches and, at Km 241.950, vegetation fabric and reeds.

Besides the existing slope geometry, information on the regular flooding of the technical-biological bank protection measures above MLW can also been seen in the diagrammatic representations of the cross sections. The additional depiction of the hydrograph of the River Weser in the area of the Stolzenau gauge illustrates the water levels to which the vegetation in the bank zone had been exposed since planting. It is apparent that for the major part of this time mean to low water conditions were predominant. At periodic intervals short high water phases with maximum water levels of up to about 30 m a.s.l., that is, about one metre above the highest navigable water level, occurred, causing additional load on the slopes as a result of the high flow velocities (cf. Chapter 5.3.2). Figure 5.5 shows the water levels for the year 1999. In all other years the picture is similar. On the one hand, the depictions show the number of days with approximately the same water levels (in steps of 50 cm) (large diagram) and, on the other, in an additional diagram at the top right, the number of days with water levels between MLW and MW, MW and HNW, HNW and HHW and water levels that were higher than HHW – separately in each case for the summer months (April to November) and winter months (December to March) – for a corresponding assessment of the vegetation. It is apparent that for around 65 % of the year water levels were either MW or lower, and for 90 % of the year water levels were below MW + 50 cm. In the winter months, water levels are generally higher than in the summer months. The corresponding diagrams for the years 1989 to 2006 are shown in Appendices 5.7-1 to 5.7-9.

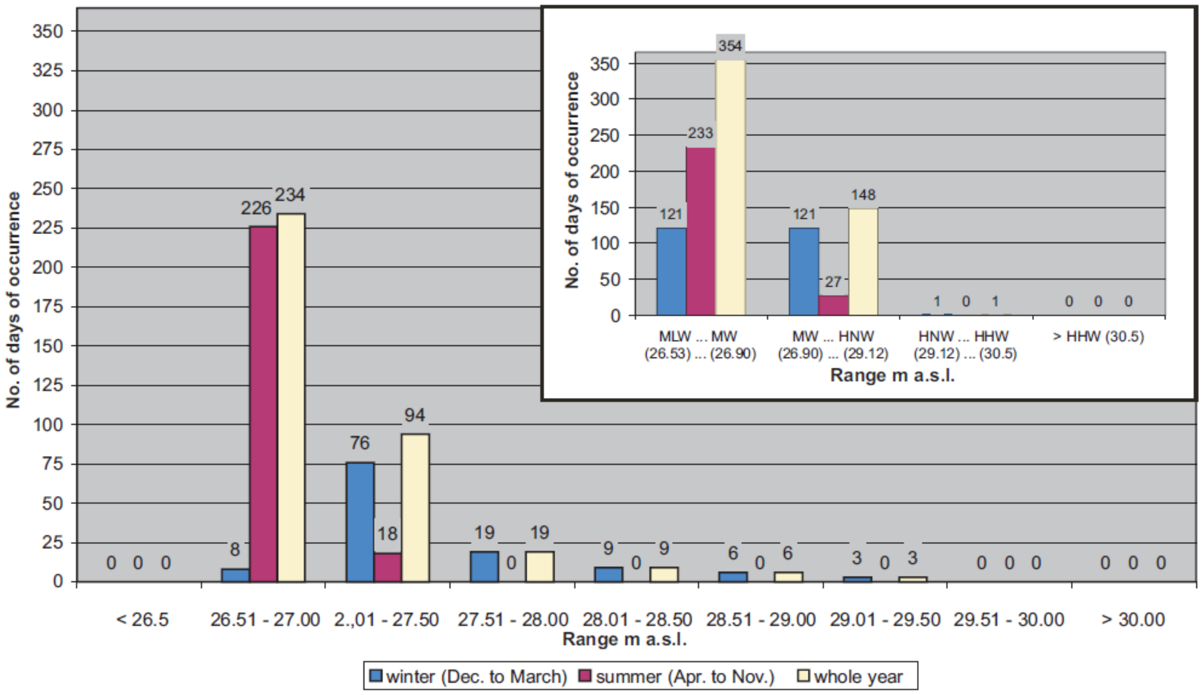


Figure 5.5: Frequency of water levels in 1999 – measured at the Stolzenau gauge

In Figure 5.6 and in Appendix 5.7-0 the flood days are listed in chronological order from the beginning to the end of the year in a comprehensive overview. In the key, identical colours represent identical water levels, and the number in each box represents the number of days in succession on which this water level occurred. The total of the individual figures per year adds up to 365 days. With regard to Figure 5.5, this representation further shows that high water levels above the highest navigable water level (29.12 m a.s.l.) did not occur at all in 10 of the 18 years considered. In the remaining period, these high water levels were usually observed only very briefly – the longest being 12 days in succession in 1994. In contrast, mean water levels predominated without interruption in individual years over periods of 75 days (1998) to 237 days (1997). This can also be seen qualitatively in the water level hydrograph of the River Weser in Figure 5.4.

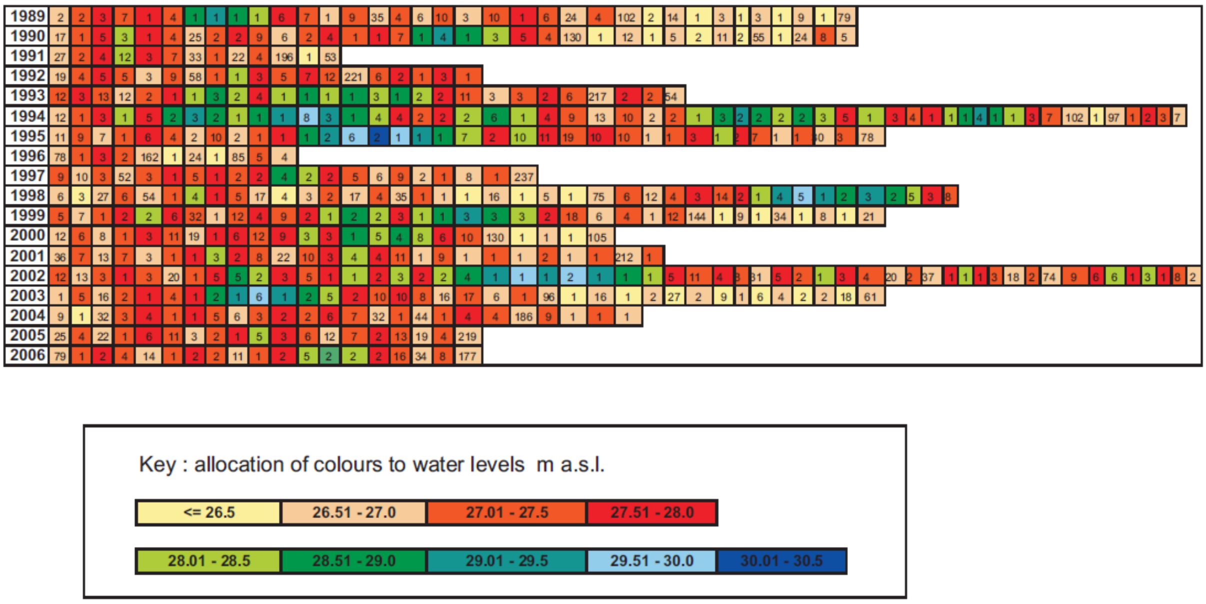


Figure 5.6: Depiction of the number of days of flooding with a specific water level in succession per year, from 1989 to 2006.
Note: For larger diagram cf. Appendix 5.7-0

5.2 Navigation

According to the *Binnenschifffahrtsstraßenordnung* (German Regulations for Navigation on Inland Waterways, hereafter referred to as BinSchStrO) of 1998 / 2005, § 16.02, ships and push-tow units with maximum dimensions of 85 x 11.45 or 91 x 8.25 m are currently permissible at a given channel depth of a maximum of 2.5 or 2.8 m respectively (between Weser Km 206.200 and 213.000). According to the BinSchStrO (§ 16.04) speed restrictions for freight shipping in the Middle Weser region apply only to the lock canals. For pleasure craft the maximum speed limit is 35 km/hour.

In order to demonstrate the changes in shipping traffic since the construction of the test stretch, the statistics for the years 1990 to 2003 from the locks at Landesbergen and Schlüsselburg were analysed /WSA Verden 2004/. In Figure 5.7, the development of the fleet in the years 1990 - 2003 is shown separately for freight ships, passenger ships and pleasure craft plus others (e.g. workboats and patrol boats). The solid lines represent the figures for the Landesbergen lock (Km 251.800) downstream from the test stretch and the broken lines represent the Schlüsselburg lock (Km 238.400) upstream from the test stretch. The following conclusions can be drawn from this diagram:

- With regard to freight traffic, an overall decrease in the number of ships can be observed. This is confirmed by information from the WSA Verden: Since 1989 ships are fewer in number, but larger.
- The number of pleasure craft has decreased by about one half since the early 1990s; a temporary peak was recorded in 1994, and since 1996 the figures have remained nearly constant.
- In passenger shipping, a constant upward trend has been observed; this can generally be explained by an increase in journeys starting at Minden and Nienburg. Transit at the lock at Landesbergen shows a marked increase in 1997, which is related to the increase in passenger shipping upstream, starting from Nienburg Weser.

Regarding pleasure craft, the following should be mentioned:

- This occurs mainly in the months April to September
- Between the Schlüsselburg and Landesbergen locks there is additional local pleasure craft activity – influenced, for example, by the power boat club at Stolzenau – which, however, does not pass the locks and is therefore not recorded there.

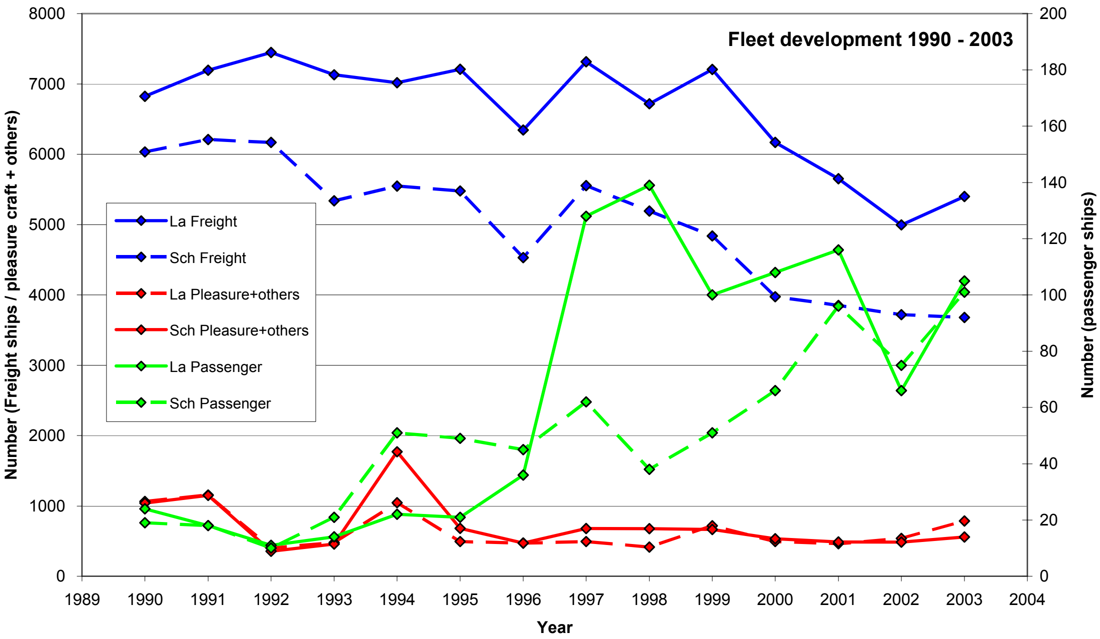


Figure 5.7: Development of the fleet in the years 1990 - 2003, shown separately for **freight ships**, **pleasure craft + others** (ordinates on left) and **passenger ships** (ordinates on right).
Abbreviations:
La – Landenbergen, Sch – Schlüsselburg, Freight – Freight ships, Pleasure + others – pleasure craft and other types of vessel, Passenger – passenger ships

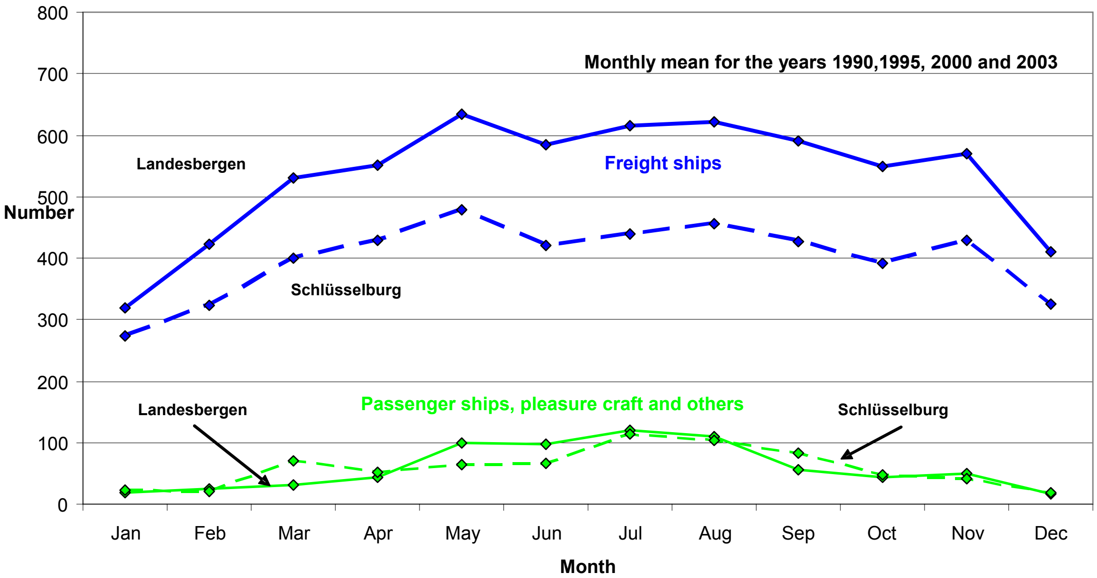


Figure 5.8: Monthly mean values for the years 1990, 1995, 2000 and 2003 showing the shipping peak in the summer months

When planning the field measurement campaign to be carried out in the test stretch for quantifying the hydraulic load on the banks as a result of navigation, it was important to select a period of time with the highest possible frequency of freight traffic, and, at the same time, traffic from pleasure craft. The graph in Figure 5.8 shows the monthly mean values for the years 1990, 1995, 2000 and 2003, clearly revealing a peak in shipping frequencies in the summer months from May to August.

The above mentioned general decrease in the number of ships is also confirmed by comparing the annual mean values and the daily mean values for freight traffic passing the locks at Landesbergen and Schlüsselburg for the month of September in the years 1990 and 2003 (Table 5.2). It is striking that especially in the Schlüsselburg lock upstream from the test stretch, freight ship traffic has decreased significantly by about 40 % (annual mean value). At the Landesbergen lock, a decrease of only about 20 % (annual mean value) was recorded. For the daily mean values for the month of August, the decrease in these figures at 50 % and 27 % is even more drastic. This means without any doubt, however, that in the region of the test stretch the number of freight ships was in continual decline during the 13 years from 1990 to 2003. This trend can be explained by the increase in the change-over from the old Weser ships with a length of only 67 m to the modern Europe Ships which are 80 - 85 m in length, meaning that although there are fewer ships of this new type, a larger transport volume can be achieved with the same number of crew, thanks to the larger load capacity.

Table 5.2: Annual and daily mean values (August) for freight ships passing the locks at Schlüsselburg and Landesbergen daily for 1990 and 2003 (assuming 260 working days = journey days)

		Number of ships per day	
		Schlüsselburg Lock (**upstream** from the test stretch)	Landesbergen Lock (**downstream** from the test stretch)
1990	*Annual mean*	23	26
Aug 1990	*Daily mean*	30	33
2003	*Annual mean*	14	21
Aug 2003	*Daily mean*	15	24
Decrease in [%]	*Annual mean*	39.1	19.2
	Daily mean	50.0	27.3

In Figure 5.8 and Table 5.2 it can be clearly seen that there is a marked increase in shipping traffic during the summer months, and for this reason the observation of shipping described in Chapter 6 was carried out in the month of August. It can therefore be assumed that, on average, approximately 24 freight ships per days passed through the area of the test stretch in the first 13 years.

5.3 Hydrology und hydraulics

5.2.1 Hydrology

The test stretch near Stolzenau (Weser Km 241.600 - 242.300) lies between the gauges Porta (Km 198.400) and Liebenau (Km 256.000). The only inflow of relevance from a tributary upstream from the test stretch is from the Gehle at Weser Km 228.650, the discharge of which is measured at the Bierde gauge (11.09 km upstream from the confluence). The location of the gauges can be seen in Figure 5.9.

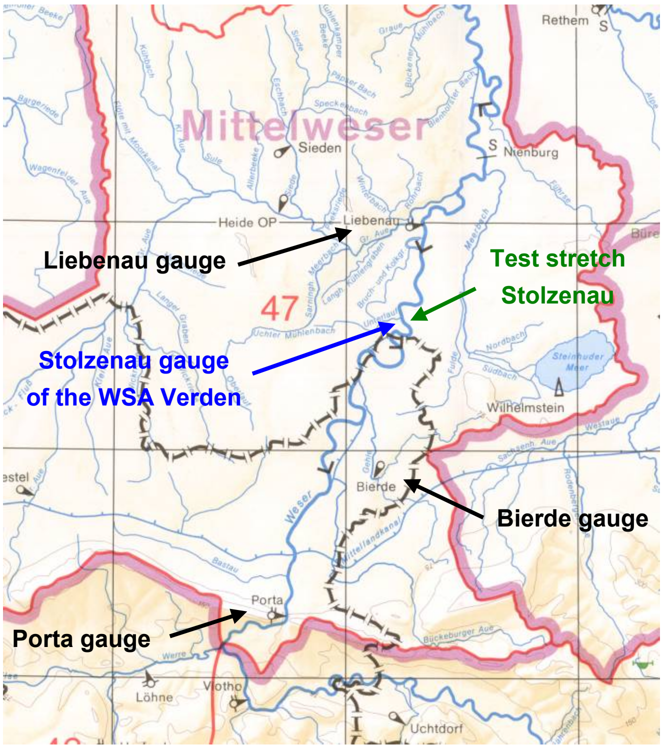


Figure 5.9:

Location of the Porta, Bierde and Liebenau gauges in relation to the test stretch at Stolzenau according to the German Hydrological Yearbook (Deutsches Gewässerkundliches Jahr buch) /DGJ 1998/

As an example, the typical values for the discharges were determined according to the /DGJ 1998/ (German Hydrological Yearbook/Deutsches Gewässerkundliches Jahrbuch) and are listed in Table 5.3. Since there are no other significant inflows between the confluence of the Gehle and the Liebenau gauge 16 km downstream from Stolzenau, the discharge values of this gauge can be assumed for the test stretch. At the Liebenau gauge, the comparison between the long-term mean values and those for the period 1990-1998 is noteworthy.

- Mean low water discharge (MLQ) remained more or less constant.
- Mean discharge (MQ) decreased by around 8 %.
- Mean high water discharge (MHQ) increased by about 10 %.

This reflects the general trend in European rivers: On the one hand, the annual mean discharge is lower, but on the other, high water levels are more extreme.

Table 5.3: Typical discharge values at the Porta, Bierde and Liebenau gauges, according to /DGJ 1998/

			Porta gauge		**Bierde gauge**	Sum of lines 3 + 5	**Liebenau gauge**	
Location		Weser Km	198.400		Tributary Gehle	Downstream from Gehle	256.000	
1		2	3	4	5	6	7	8
Period		-	1941 - 1998	1990 - 1998	1974 - 1998	**-**	1954 - 1998	1990 - 1998
No. of years		-	57	8	24		44	8
Discharge values	MLQ	m^3/s	65	63	0.1	65	65	63
	MQ	m^3/s	184	175	0.9	185	191	176
	MHQ	m^3/s	837	859	16.2	853	777	851

Table 5.4: Water levels and discharges at the Stolzenau and Liebenau gauges during the measuring period

	Stolzenau Gauge Weser Km 243.400 Gauge zero: 23.52 m a.s.l.		**Liebenau Gauge** Weser Km 256.040 Gauge zero: 20.00 m a.s.l.			
Date	**Water level W**		**Water Level W**		**Discharge Q**	
-	[m]	[m a.s.l]	[m]	[m a.s.l.]	[m³/s]	
10.08.2005	3.06	26.58	1.47	21.47	106.0	Start of readings
11.08.2005	3.05	26.57	1.35	21.35	91.0	
12.08.2005	3.06	26.58	1.33	21.33	88.3	
13.08.2005	3.11	26.63	1.45	21.45	103.0	
14.08.2005	3.09	26.61	1.49	21.49	108.0	
15.08.2005	3.12	26.64	1.63	21.63	125.0	
16.08.2005	3.12	26.64	1.61	21.61	122.0	
17.08.2005	3.12	26.64	1.57	21.57	117.0	End of readings
Minimum		26.57		21.33	88.30	
Mean		26.61		21.49	107.54	
Maximum		26.64		21.63	125.00	

The WSA Verden installed a gauge which is located near the test stretch at Stolzenau in November 1988. From this gauge, and from the one at Liebenau, the water levels for August 2005, as well as the discharges from the discharge table for the Liebenau gauge during the period of the field measurement campaign from 10-17 August 2005 were passed on. The values are listed in Table 5.4.

Table 5.5: Compilation of the maximum annual discharges (high water events) at the Liebenau / Weser gauge for the years 1990 - 2003

Year	HQ	Date
-	m^3/s	-
1990	904	04.03.1990
1991	617	04.01.1991
1992	609	14.03.1992
1993	779	16.01.1993
1994	1120	04.01.1994
1995	1270	03.02.1995
1996	424	19.02.1996
1997	779	28.02.1997
1998	1160	30.10.1998
1999	1190	04.11.1998
2000	824	11.03.2000
2001	570	27.03.2001
2002	1050	28.02.2002
2003	1310	06.01.2003

Minimum	**424**
Mean	**900**
Maximum	**1310**

In order to gain an impression of the maximum high water events since the installation of the measures, Table 5.5 shows a compilation of the maximum discharges for each year from 1990 to 2003 at the gauge Liebenau / Weser. The values lie between 424 and 1310 m^3/s. The high water situations occurred predominantly in the months January to March and, in two cases, in October and November. The correlations between discharge and water level there, which are shown in Table 5.6, are derived from the hydraulic calculations for Weser Km 242.100 near Stolzenau (cf. Chapter 5.3.2).

Table 5.6: List of the lowest high water discharges at the Liebenau / Weser for the years 1999 – 2003

Year	**Discharge HQ**	**Water level**
[-]	[m^3/s]	[m]
1996	424	28.01
2001	570	28.61
1992	609	28.75
1991	617	28.78

5.3.2 River hydraulics

For additional and comparative information on the hydraulic situation in the test stretch, it was also possible to draw on a one-dimensional, unsteady hydraulic-numerical model of the Landesbergen reach kept at Section W1 (River Systems I) of the BAW. The hydraulic-numerical model is continually updated with regard to the topography. Figure 5.10 shows the cross section at Weser Km 242.100 from the hydraulic-numerical model, which is situated between the two measuring profiles at Weser Km 242.040 and 242.170 (cf. Chapter 6.4.6) and represents these well in the mean. For calibration, water level specifications from the years 1990 to 2003 with discharges between 73.4 m^3/s and HNQ (highest navigable flow rate) = 735 m^3/s were used. Calculations via HNQ to HHQ (highest high flow rate) = 1350 m^3/s with discharge ratios across the forelands are thus not possible.

This hydraulic-numerical model was used for calculating the correlations between water level, discharge, flow velocity and shear stress for the cross section at Weser Km 242.100 for discharge situations between the hydrostatic water level (normal banked-up water level 26.50 m a.s.l.) and a selected maximum discharge of 735 m^3/s; these correlations have in part made their way into Chapter 6.4 as load factors for the bank. In Figure 5.11, the discharge rating curve (W-Q correlation) and the change of the flow velocity averaged over the cross section are plotted against the increasing discharge. Figure 5.12 shows the relationship between mean flow velocity and water level. In Figure 5.13 the relationship between water level and bed shear stress averaged over the cross section can be seen, with two noticeable “kinks”, namely the points at which, at the right or left bank respectively, bank-full discharge is reached. In all three diagrams the ranges of water level, mean flow velocity and discharge during the field measurement campaign are emphasised, showing that the traffic observation took place in a situation only barely above the hydrostatic water level.

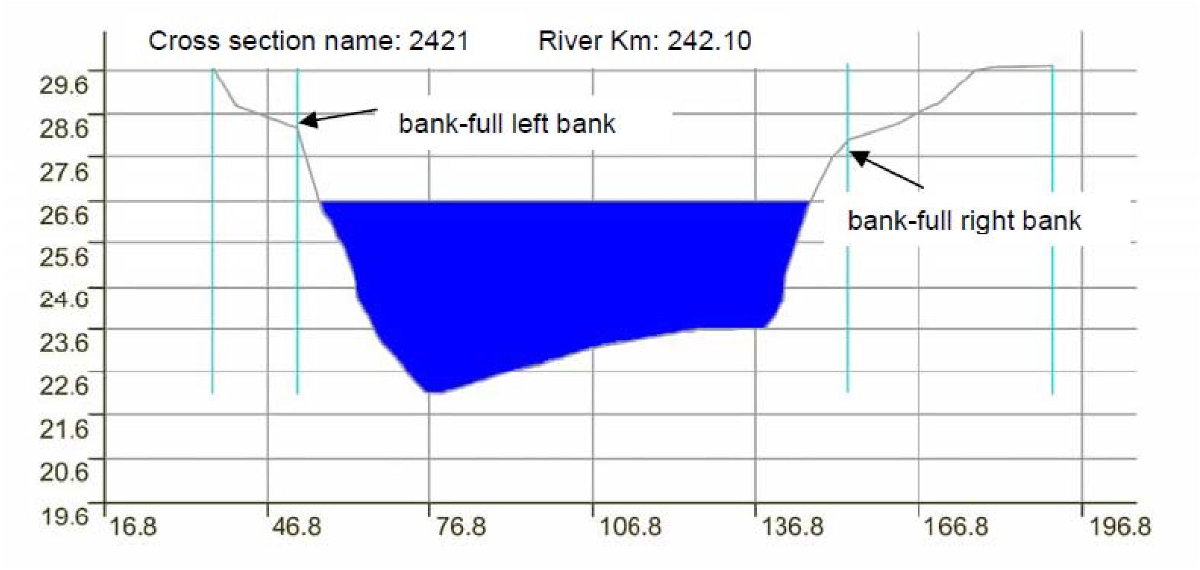


Figure 5.10: Cross section at Weser Km 242.100 from the hydraulic-numerical model; the markings show the difference in height at which bank-full discharge is reached

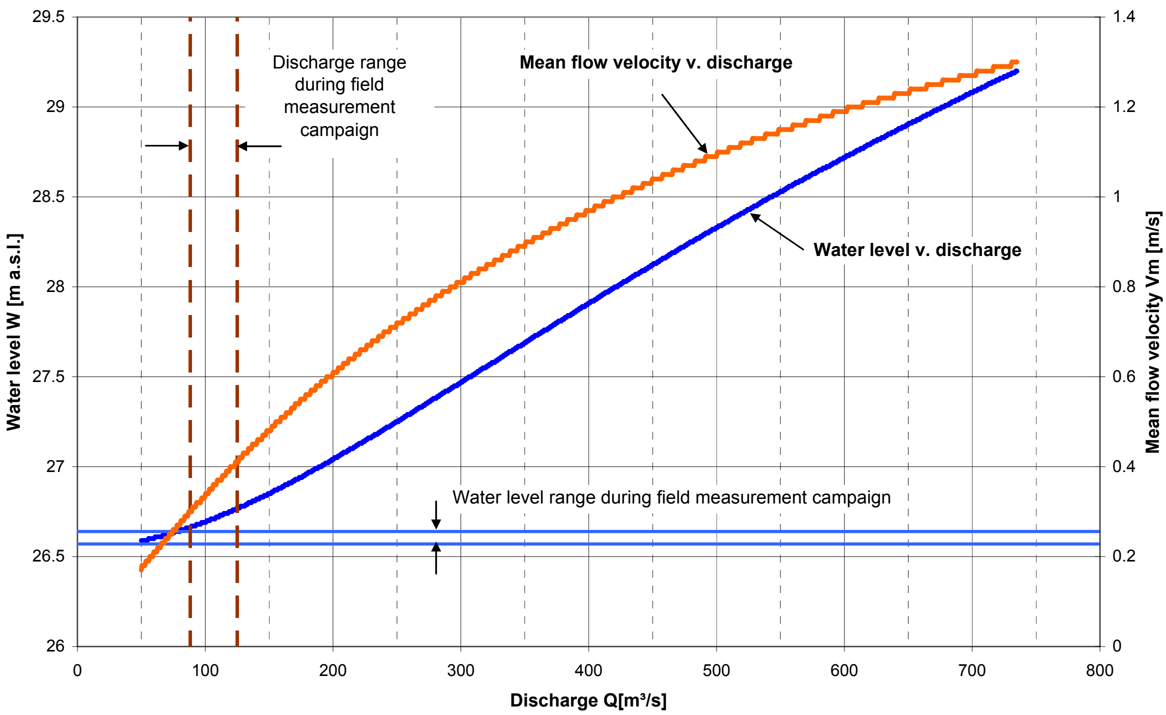


Figure 5.11: W-Q correlation (discharge rating curve) and the change of the flow velocity averaged over the cross section with increasing discharge at Weser Km 242.100 according to calculations with the hydraulic-numerical model

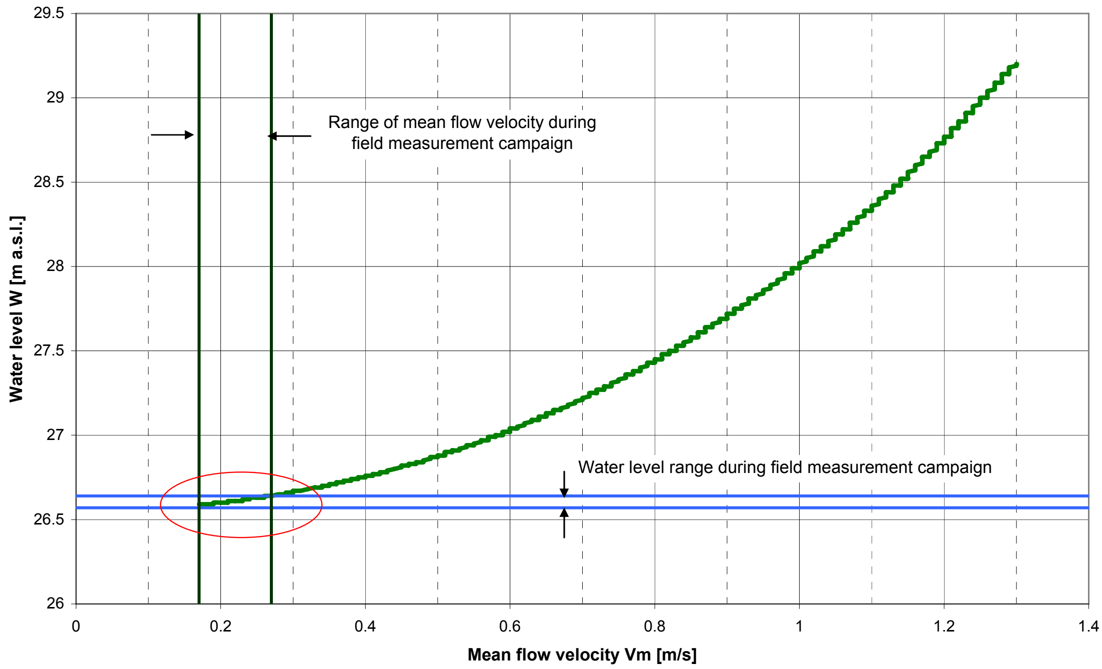


Figure 5.12: Correlation between mean flow velocity and water level at Weser Km 242.100 according to calculations with the hydraulic-numerical model; the red ellipse represents the range during the field measurement campaign

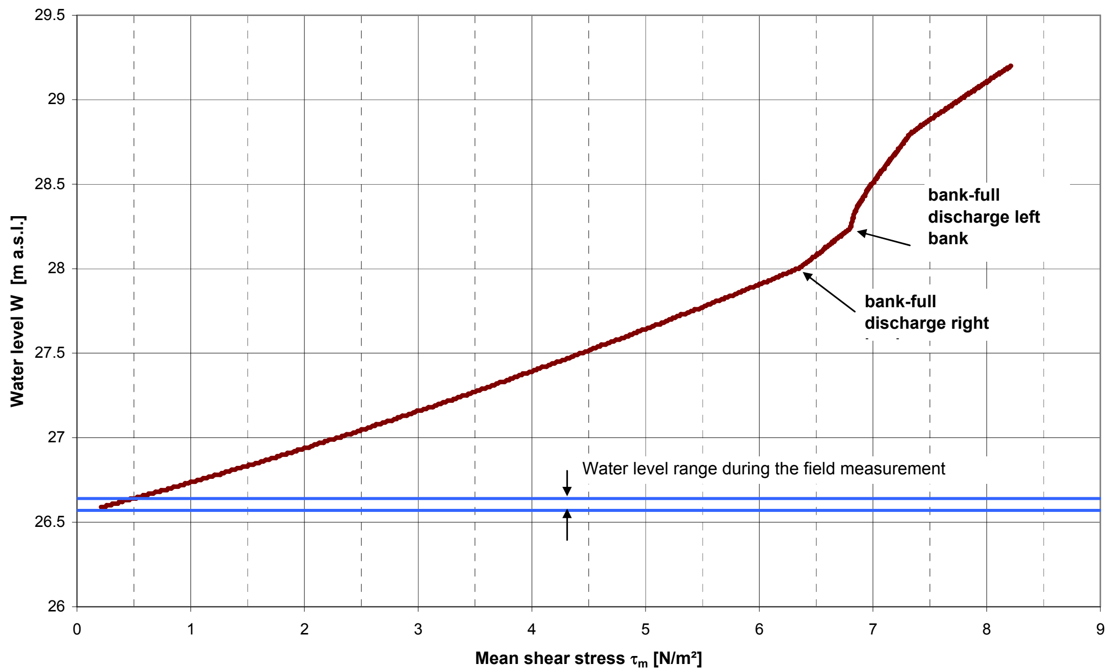


Figure 5:13: Correlation between water level and bed shear stress averaged over the cross section at Weser Km 242.100 according to calculations with the hydraulic-numerical model

In order to make detailed statements about the individual bank zones and to be able to set up possible correlations between hydraulics and the flora and fauna, the mean values of water depth (Figure 5.14), flow velocity (Figure 5.15) and shear stress (Figure 5.16) were determined in bands distributed at various points over the waterway. The width of the band was set at 5 m. The following water surface positions were selected: 26.50 m a.s.l., the height at which traffic was observed and, above this, five more levels in steps of 0.5 m.

For the 5 m wide band close to the bank on the right hand side of the waterway, where the measuring sensors were located, the values calculated for mean flow velocity, mean shear stress, mean water depth and the relevant partial discharge have been listed in Table 5.7. The increases in mean flow velocity and mean shear stress up to a discharge at HNW (highest navigable water level) are documented in Figure 5.17 for the same band.

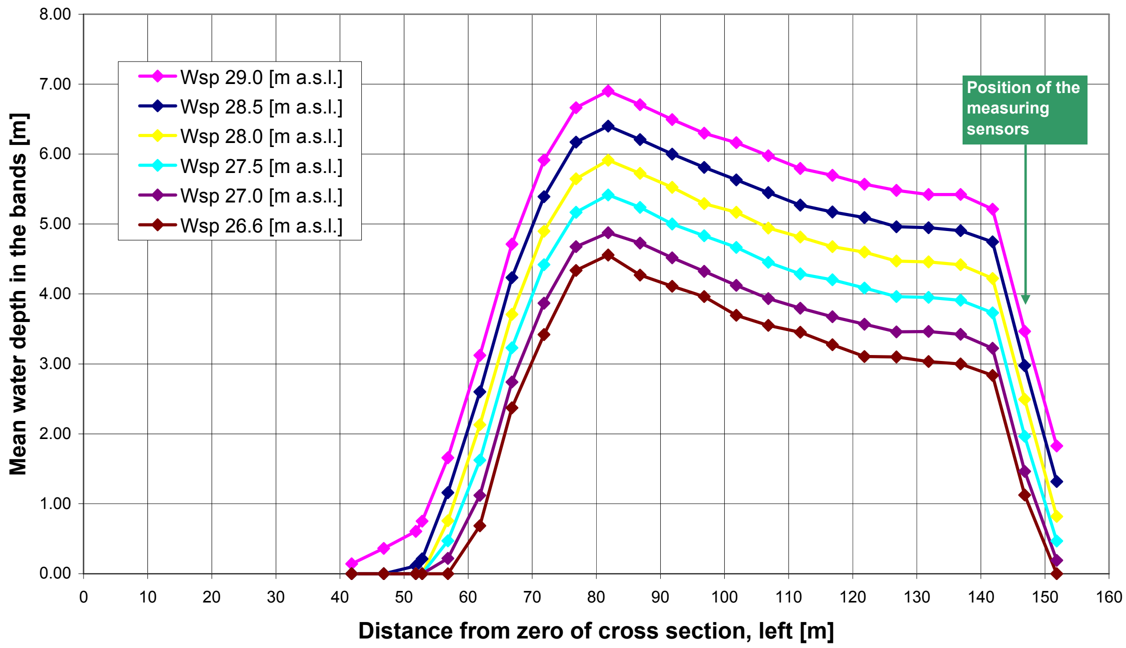


Figure 5.14: Mean water depth in the bands for water levels up to HNW, calculated with the HN model

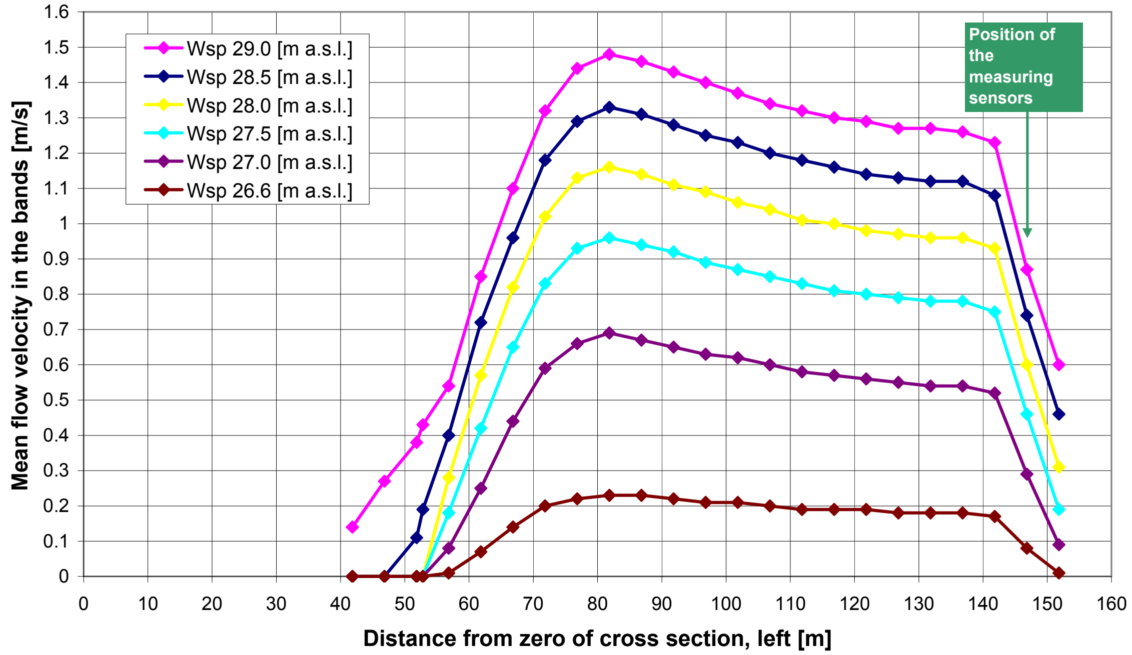


Figure 5.15: Mean flow velocities for water levels up to HNW in the bands, calculated with the HN model

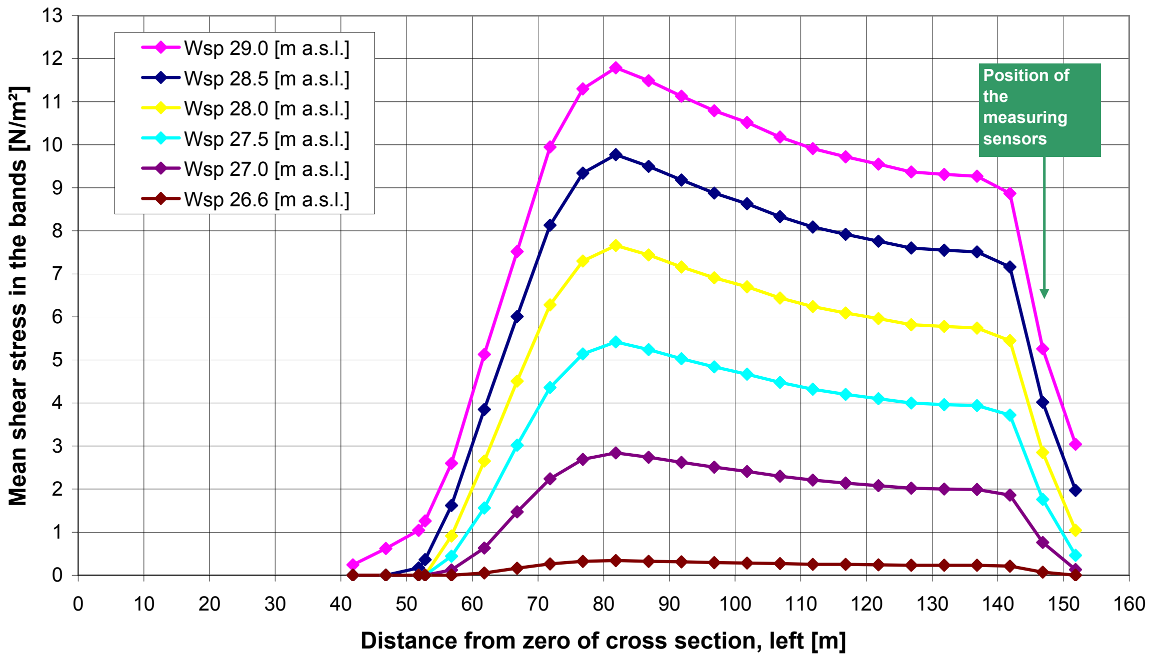


Figure 5.16: Mean shear stress values for water levels up to HNW in the bands, calculated with the HN model

Table 5.7: Calculated mean values for water depth, discharge, flow velocity and shear stress in a 5 m wide band near the bank on the right side of the waterway in the area of the measuring sensors

Water surface position	h_m	Q	v_m	τ_m
[m a.s.l.]	[m]	[m³/s]	[m/s]	[N/m²]
26.60	0.69	0.24	0.07	0.05
27.00	1.12	1.40	0.25	0.63
27.50	1.62	3.41	0.42	1.56
28.00	2.13	6.07	0.57	2.65
28.50	2.60	9.36	0.72	3.85
29.00	3.12	13.27	0.85	5.13

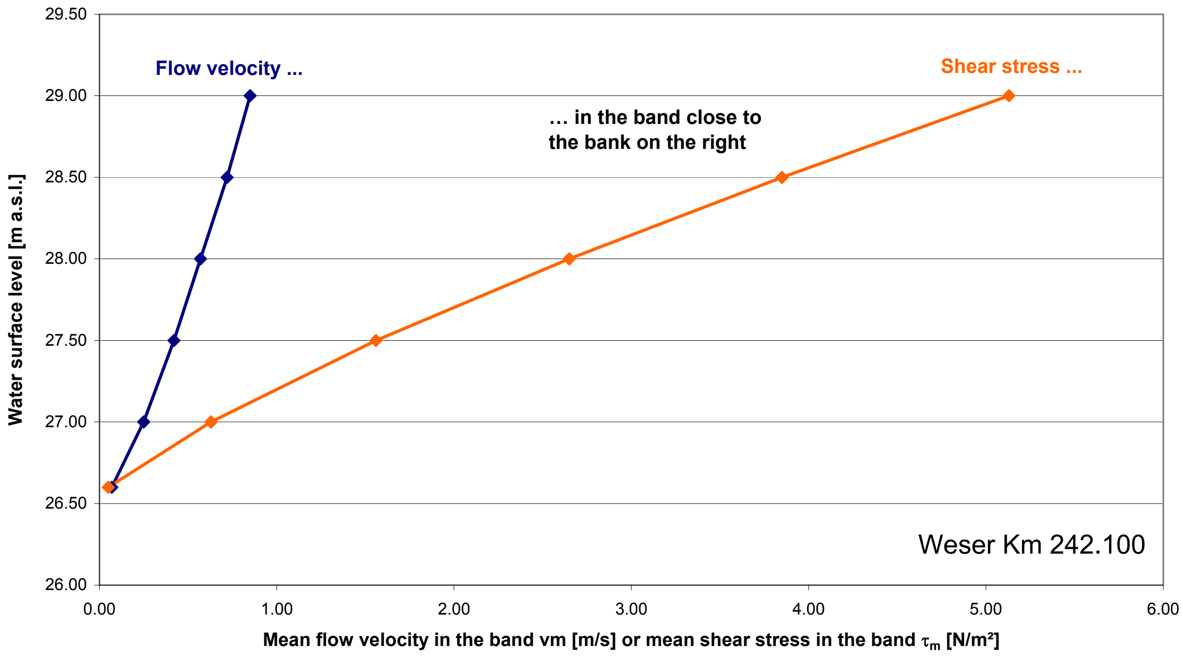


Figure 5.17: Mean flow velocity and mean shear stress at water levels up to HNW in the 5 m wide band at the right close to the bank, in the area of the measuring sensors, calculated with the HN model

A comparison between the calculated values for the flow velocity at the right bank close to the flow measuring sensors and the values measured there at the water level 26.6 m a.s.l. at the time of the traffic observation showed a good degree of conformity. This means the values calculated for the flow velocity and shear stress at the higher water levels can be relied upon for further interpretations.

6 Measurement of the hydraulic load generated by shipping

6.1 Hydraulic load from waves generated by ships

6.1.1 Phenomenon

The aim of this first sub-chapter is to provide a comprehensible view of the hydraulic phenomena related to a ship travelling through a body of water by describing in general how these occur. When a ship travels through a body of water, the reciprocal hydraulic action causes in situ and temporary alterations to the water surface and to the flow of water around the ship. During this process, waves are formed which affect the banks in the form of hydraulic load.

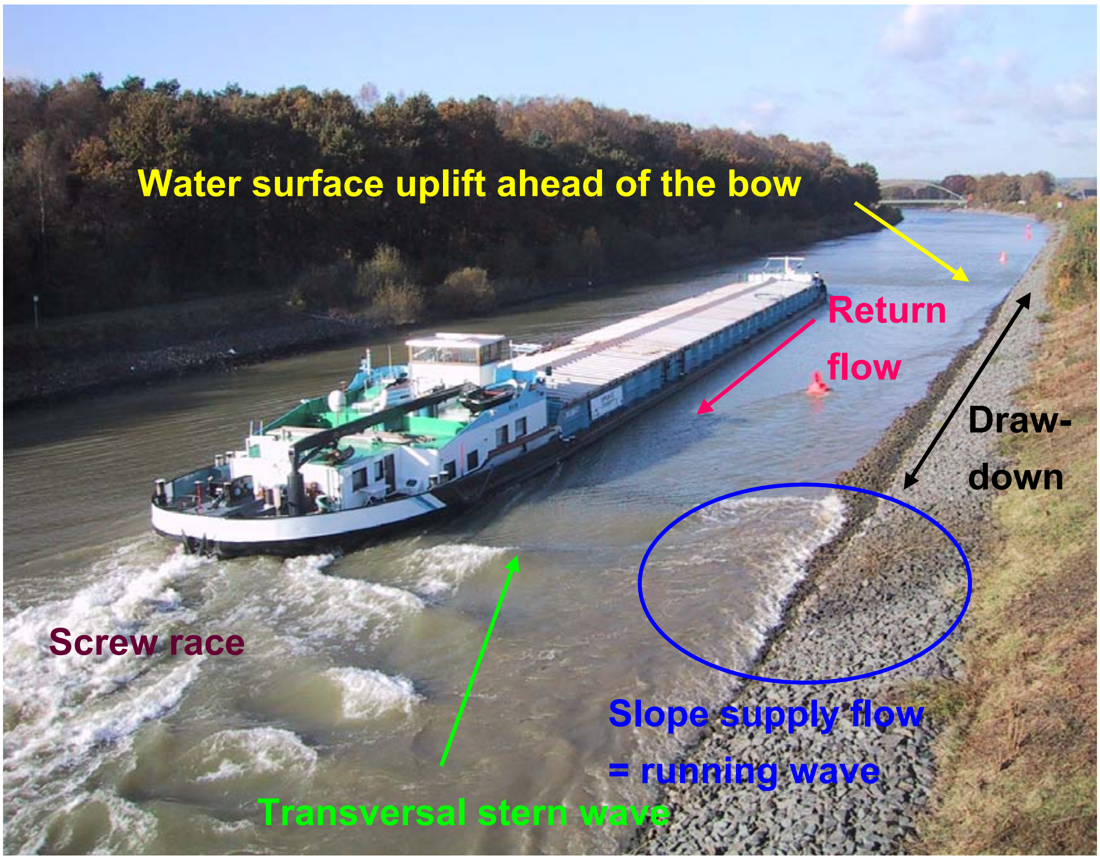


Figure 6.1: Waves generated by a ship in the Wesel-Datteln Canal during a test campaign in October 2002; the fully loaded MS Main is shown travelling close to the bank at a velocity close to the critical ship speed

The phenomenon of reciprocity between ship and waterway is most clearly seen in narrow canals. As it travels, the ship is preceded by an area of water surface uplift of a few centimetres, which is approximately as long as the ship itself (cf. Figure 6.1). Directly in front of the bow of the ship, an elevation is formed in the water which is constantly being pushed ahead of the ship and is known as the **bow wave**. Starting at this point, there is a significant change in the discharge conditions. The hitherto undisturbed cross section of the waterway is diminished by the cross section of the ship. In this reduced cross section area, the discharge must now find its way to the stern of the ship in the form of a **return flow**. This hydraulic effect causes an acceleration of the discharge, which, in turn, is related to a lowering of the water level beside the ship – the **drawdown / the drawdown trough**. At the stern of the ship, these discharge conditions are then balanced out through a rise in the water level – the **transversal stern wave** – and a **slope supply flow** in the form of a **running wave** that accompanies the ship. This entire sequence of bow wave, drawdown trough and stern wave along the ship has the form of a wave and is known as the **primary wave**. Its length corresponds to the length of the ship. The ship constantly sinks into its own drawdown; this phenomenon is known as **squat**. In the first approximation, squat and drawdown are equal.

Simultaneously, at the bow of the ship regular short-period waves occur, which form as circular waves caused by the change in contour from the tip of the bow to the full cross section of the ship. These are known as **secondary waves**. On the one hand, these can be oblique waves which spread out at an angle to the axis of the ship and, on the other, transverse waves, which are aligned almost perpendicularly to the ship's axis (Figure 6.2). The overlapping of the two systems produces an interference line which, depending on the velocity of the vessel, has a characteristic angle to the ship's axis: at normal speeds this angle is 19.3°. As the critical speed is approached it reaches a maximum value of 45°.

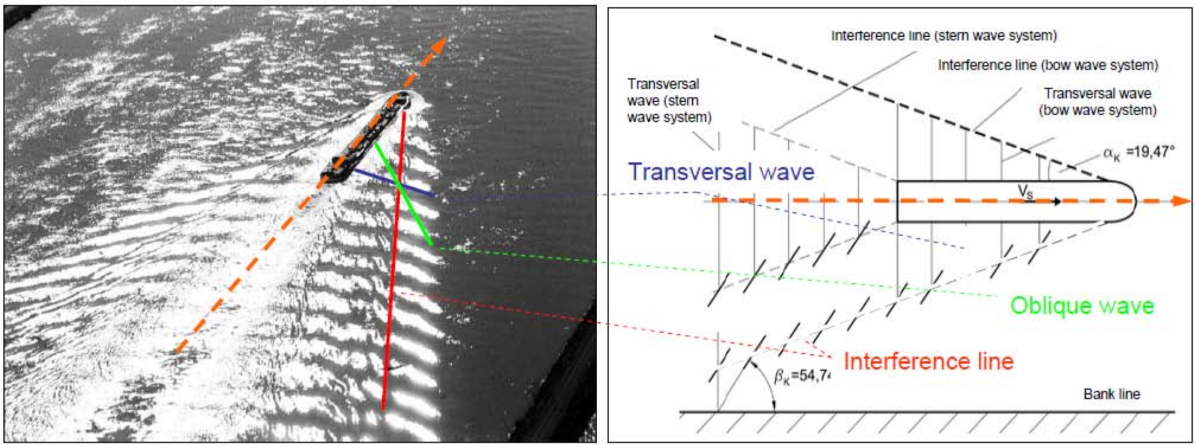


Figure 6.2: Aerial photograph of the secondary wave formation of an inland navigation vessel travelling on the Rhine River; at the stern, the screw race can also be seen.

At the stern of the ship, the means of propulsion – propeller, jet motor or the like – with its **screw race** adds to the wave formation on the water surface (cf. Figure 6.2).

This occurrence is depicted in a simplified form in Figure 6.3 showing a ship travelling through a canal with a trapezoidal cross section. The motion of the ship creates a drawdown under the previously undisturbed water surface. This reduction in the cross section leads to a return flow parallel to the hull of the ship from bow to stern. The ship creates waves which travel to the bank. At the stern of the ship, the screw race becomes apparent.

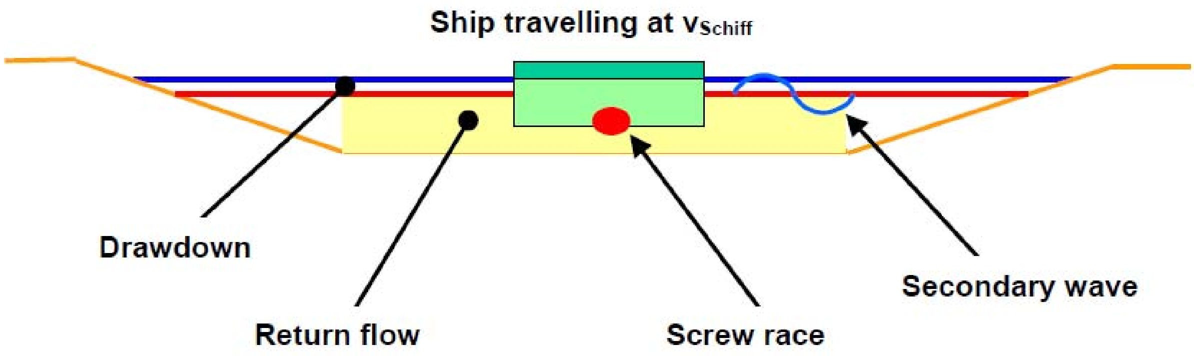


Figure 6.3: Greatly simplified sketch showing hydrodynamic activity around an inland navigation vessel travelling in the trapezoidal cross section of a waterway

As a result of this activity, the following effects can be mentioned:

- The drawdown at the bank leads to pressure changes in the pore water in the subsoil which must be taken into account in the geotechnical dimensioning of the bank protection measures. In particular, the rapid drop in water level at the bow can cause excess pore water pressure in the adjoining ground which – depending on the permeability of the soil – can lead to sliding of a soil layer close to the surface in a direction parallel to the slope.
- The waves cause short-period water surface changes and loading on the bank which should be considered in relation to the definition of the freeboard, wave run-up and with regard to possible effects on flora and fauna in the bank area.
- The return flow causes shear stress at the waterway bed and bank which affects the capacity of the bed material and bank protection revetments to resist erosion.
- The screw race at the waterway bed also causes temporary shear stress.

6.1.2 Wave measurements

Significant knowledge about the interaction of ship and waterway can be acquired only by field measurements and traffic observation, either by recording data during shipping movements, or also with measurements from test traffic under specified conditions. In one instance, the location of the ship is constantly determined by GPS, showing the position in the fairway, the squat and the velocity. A further method is the use of radar, particularly when shipping is to be monitored in its natural course. For another, the changes in water surface level, for example, at the bank are recorded before, during and after the passage of a ship, thus permitting statements to be made about primary and secondary waves and about drawdown and drawdown speed. Figure 6.4 shows a typical reading. The greatest hydraulic load on a river embankment, for instance, for determining the dimensions of individual stones for a riprap in accordance with the GBB /BAW 2005/, is considered to be the **design wave height,** which corresponds to the difference between the wave trough around the stern area and the highest water level directly astern of the ship.

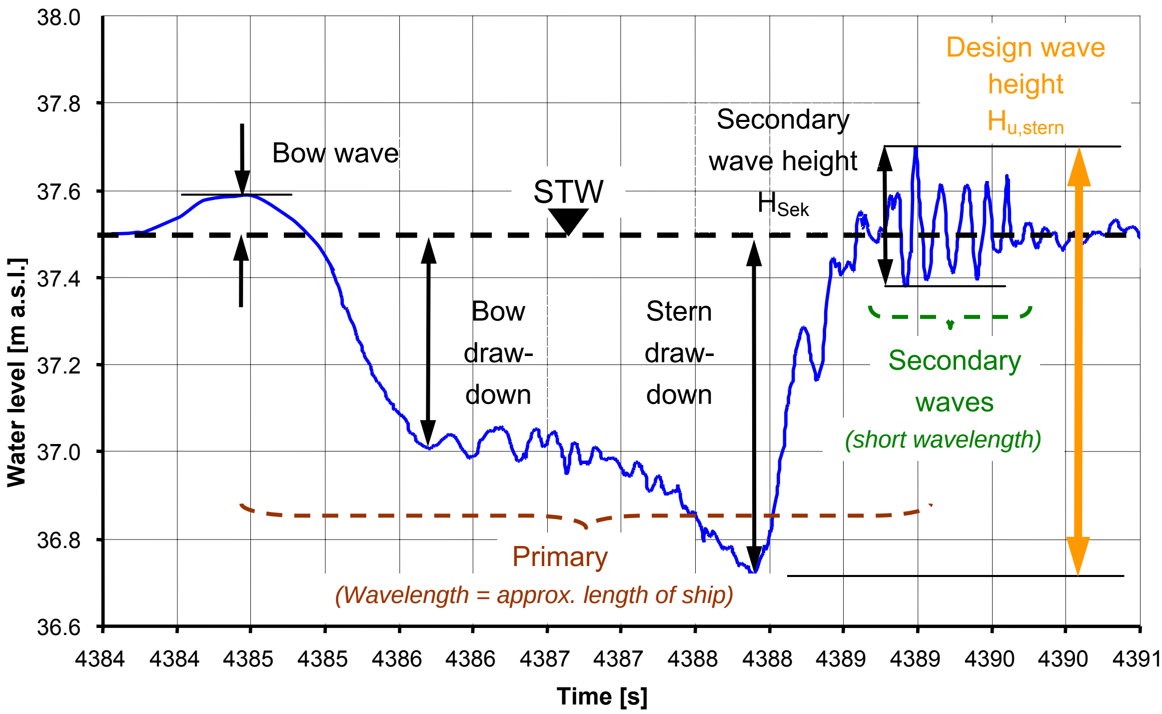


Figure 6.4: Water level fluctuations caused by motion from the MS Main (L/B/D = 105 m / 11.40 m / 2.73 m = fully loaded), measured close to the bank in the Wesel-Datteln Canal (test campaigns in 2002) at a velocity close to the critical speed of the ship

Explanations:
Recording of the two characteristic wave types, primary and secondary waves, the calculated wave height, and their components (for explanation, see text);
Variables in accordance with GBB /BAW 2005/
SWL - still water level

The calculated wave height always consists of one part secondary wave height and one part drawdown which is associated with the primary wave. The part resulting from drawdown is dominant in small cross sections, that is, narrow waterway cross sections and large ship cross sections, whereas in large cross sections it is rather small and in very large cross sections almost negligible. By contrast, the part from secondary wave height is always more or less of a similar size and depends only minimally on the draught of the ship. The effect of the secondary waves – like that of wind waves – rather tends to act as a transverse load. On the contrary, the primary wave draws water away from the bank area down the slope. All of this must be considered in the evaluation of wave heights with regard to load on vegetation and fauna at the bank. In the example in Figure 6.4, the height of the secondary wave is approximately 1/3 of the overall design wave height.

6.1.3 Influencing variables

Important influencing variables for the description of the interaction ship/waterway are geometric and hydraulic variables of the **waterway**, the dimensions and velocity of the **ship** and values from the combination of these as well as results from theoretical derivations concerning the interaction **ship/waterway**. The following can be mentioned as variables for the individual areas (for further details, cf. GBB /BAW 2005/):

Waterway

Width of water surface b_{Wsp}, cross section of waterway A, width of bottom b_{So}, cross section of channel A_F, mean water depth h_m, flow velocity v_{fl}, slope inclination m

Ship

Beam B, submerged midship cross section A_M, length of ship L, speed of ship v_{Sch}, draught T, shape of ship

Interaction ship/waterway

Cross section ratio n, critical ship speed v_{krit}, relative ship speed v_{rs}, remaining cross section during passage of ship A_{netto}, mean maximum water level drawdown (at narrowest discharge cross section) Δh, mean maximum speed of return flow $v_{rück}$, wave height above embankment toe H_{BF}, water level drawdown at embankment toe z_a, eccentricity between course of ship and axis of canal y, H_{BF} during movement in eccentricity H_a, secondary wave height H_{sek}

6.2 Measuring task and equipment

For carrying out traffic monitoring – also known as the measuring campaign – at the test stretch at Stolzenau / Weser (cf. Figure 6.5), the period from 10 to 17 August was selected on the basis of shipping statistics (cf. Chapter 5.2), August being one of the months with the highest volume of traffic. During this period, all vessels – cargo vessels, passenger ships, special vessels and recreational craft – were comprehensively recorded, along with their technical data, position and the hydraulic factors they created, in order to enable links to be made, within the scope of the R&D project, between hydraulic load from navigation on the banks of the Stolzenau test stretch, the stability of the banks and the vegetation and fauna in the riparian zones. Schmid IBS, a company of consulting engineers in Kapsweyer, Germany, was commissioned to carry out these observations. The procedure during the measuring campaign, the evaluation work and presentation of the results are reported in detail in three reports /IBS 2006a, 2006b and 2006c/. All of this will be explained here only in form of a summary.

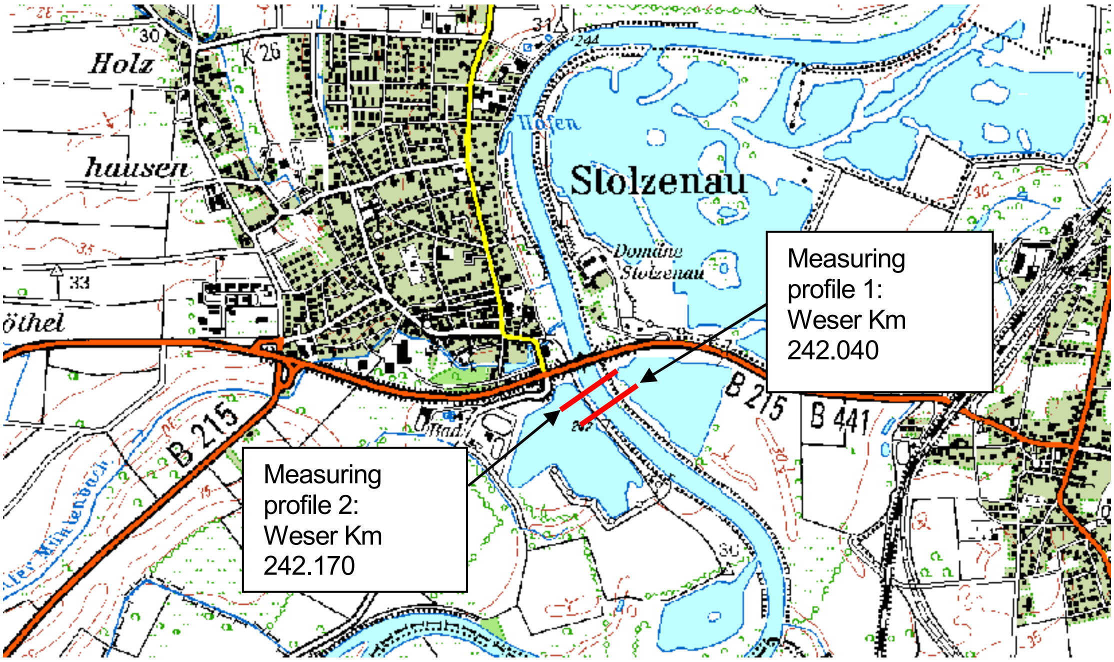


Figure 6.5 Site map of the River Weser at Stolzenau showing the 2 measuring profiles

The two measuring profiles at Weser Km 242.040 and 242.170 inside the test stretch, but downstream from the groyne fields, were chosen as reference cross sections and for coordination of the measuring instruments. The course of the waterway here is still almost straight, so that the ships are able to travel at high speeds (cf. Figure 6.6). This causes a greater hydraulic load on the banks. Navigation positions closer to the bank are also possible, which additionally results in greater loads. Also, distorting effects due to the short stub groynes at the right bank are not expected here. Staying on the safe side, the results of the measurements can be projected onto the upstream test stretch with groynes, for purposes of interpretation of the correlations between load caused by navigation and stability as well as colonisation of the banks by fauna and flora.

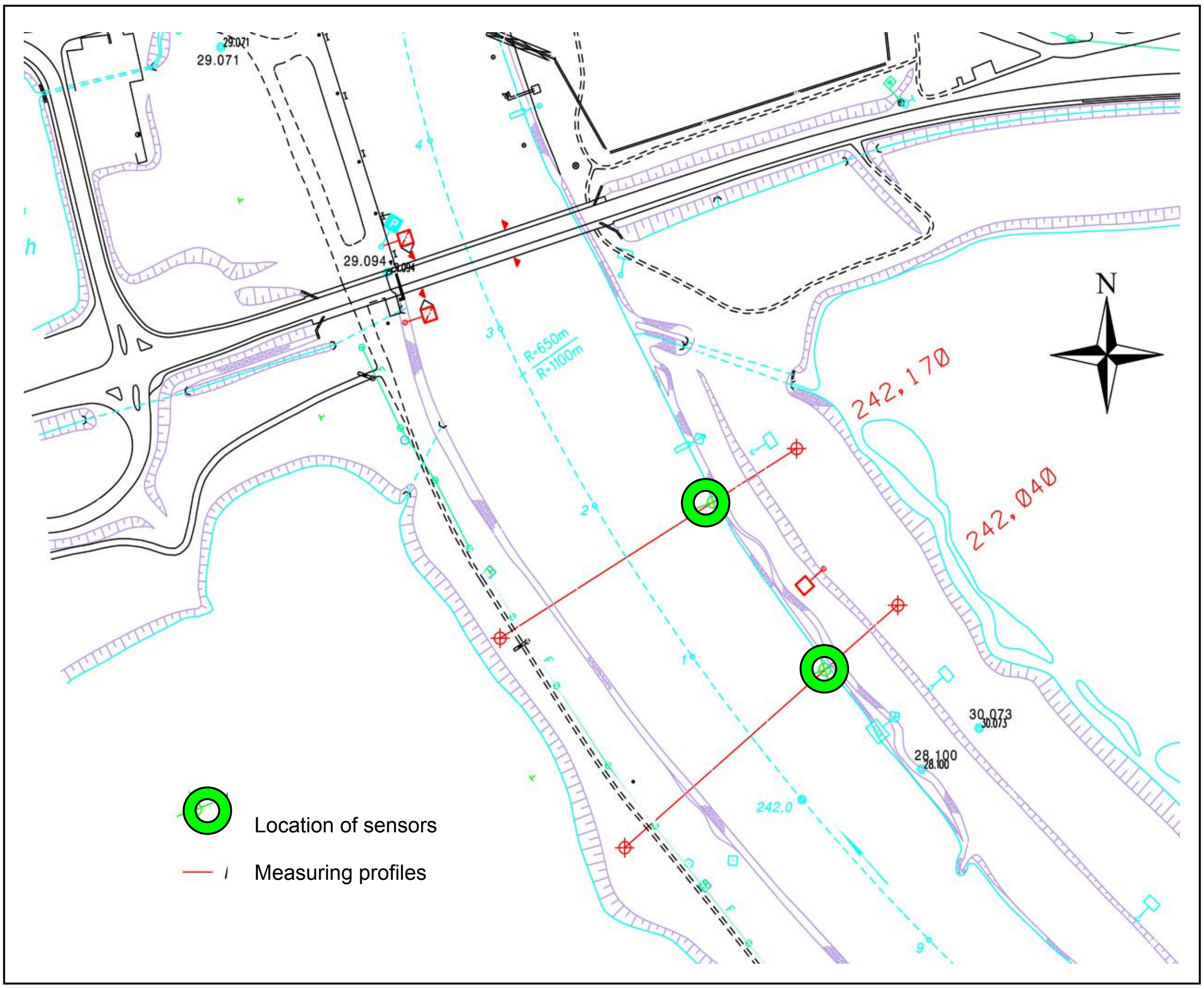


Figure 6.6: Location of the 2 measuring profiles at Weser Km 242.040 and 242.170 for traffic monitoring on the right bank of the Weser

The following were measured or recorded:

- cross sections in the measuring profiles (once) in order to identify the current state of the geometry of the waterway and to carry out recalculations, if required;
- fluctuations of the water surface at the bank in order to determine all wave heights;
- positions of ships in order to calculate the distances from the bank;

- ship speeds to enable, for example, a comparison between permissible and actual speeds;
- dimensions of ships (as per marking) and full load (according to calibration markings) in order to determine the ratio between waterway cross section and ship cross section;
- flow velocities close to the bank in order to be able to derive return flow velocities.

For the measuring of ship positions and speeds, a radar device that was not visible to navigation was used in order to be certain that the ships' masters did not influence measurements with their navigation style. The majority of the ships could further be recorded photographically during passage. In order to acquire as much technical data as possible, especially for cargo vessels, a survey of shipping data at the Landesbergen and Schlüsselburg locks was carried out simultaneously by radio from the navigation surveillance centre Minden. The sheet used for recording data can be seen in Figure 6.7.

Recording of ships at the lock ☐ Landesbergen ☐ Schlüsselburg **August 2005** BUNDESANSTALT FÜR WASSERBAU Karlsruhe

Date	Time	Direction of travel		Art				Name (+ possible remarks)	Length	Beam	Current draught		Shape of bow	
		Up-stream	Down-stream	Cargo vessel	Passenger ship	Recreational craft	Other				at bow	at stern	Pointed bow	Blunt bow
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[m]	[m]	[m]	[m]	[-]	[-]

☒ Please tick appropriate box

Figure 6.7: Record sheet for navigation surveillance centre Minden

The measuring equipment will now be described briefly; details can be seen in the report /IBS 2006a/.

Figure 6.8: View of the hidden measuring equipment north of the road bridge on the left bank

Figure 6.9: View of the measuring profiles (dotted lines) from the measuring tent and the test stretch on the opposite right bank

Figure 6.10: View of the radar equipment in the measuring tent

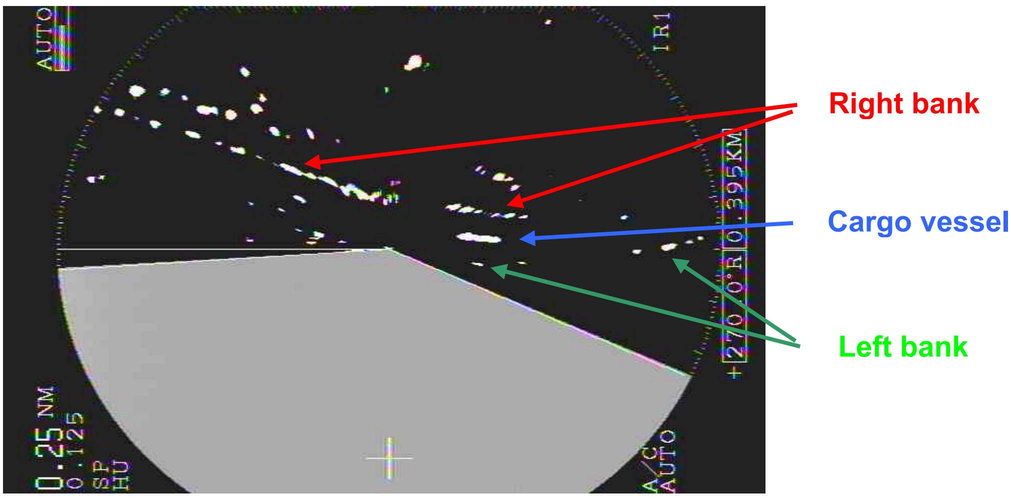


Figure 6.11: Photograph of the radar screen showing a cargo vessel travelling downstream

Digital radar recording system

A high-resolution radar system which was set up in a tent, hidden from view, was used to measure the speed of ships and the distance from the bank (cf. Figures 6.8 to 6.10). Figure 6.11 provides an impression of the radar screen during passage of a cargo vessel.

Wave sensors

The water level fluctuations created by navigation were measured using 2 pressure sensors for each measuring profile (double recording of measured data for safety reasons; internal power supply and data logger, measuring frequency 2 Hz). The sensors were placed approximately 1 m below the water surface (day of installation, 10.8.2004). For an evaluation of the absolute values of the pressures, a barometric pressure transducer was installed on land.

Speed sensor

For determining the spatial flow velocity in proximity to the bank a speed sensor obtained from the BAW was installed (ADV sensor from the company NORTEK; type: VECTOR; measuring principle: acoustic Doppler method). After consultation with the BAW and preliminary adjustment, the sensor was able to record two data values in quick succession every 5 seconds. The measuring volume lay about 40 cm below the water surface (day of installation, 10.8.2004).

Determining locations and heights

All determining of positions (measuring sensors, measuring boat) was carried out using DGPS.

Measuring boat

For the sounding of the two measuring profiles (approximate position, cf. dotted lines in Figure 6.9) with a sonic depth finder, the accompanying measuring boat (L/B/D = 5.1 m / 1.86 m / 24 cm) was also used. Furthermore, before the start of the measurement campaign, several extra passages were made with this boat for the subsequent rectification of the radar images.

6.3 Measuring work

The measuring point was set up on 9 August 2005. The installation and dismantling of the sensors was carried out in cooperation with the WSA Verden. At measuring profile No. 2, the two pressure sensors and the speed sensor were installed on a prefabricated concrete base placed in the vicinity of the bank. The position of the concrete base was marked with a buoy.

At measuring profile No.1, the pressure sensors were placed in the water close to the bank without a base. Their position here was secured by a chain fastened to the bank.

Measurements were taken from Wednesday, 10 August 2005 at 7.00 am until Wednesday 17 August 2005 at 12 noon. The daily observation time lasted from 7.00 am to 9.00 pm.

The river bed soundings, including the surveying of the adjoining land in the measuring profiles, were carried out on 10 August 2005 (Figure 6.6).

As a basis for the spatial rectification of the radar images, the position of the radar equipment and the hectometre markings were measured using DGPS. The course taken by the measuring boat was recorded both as a radar image and by DGPS for use as a reference ship passage.

During traffic monitoring the following data was collected during passage of shipping: *date, time, name, direction of travel, length, beam, type* and – if possible – the draught loaded and the maximum tonnage. The navigation surveillance centre Minden was responsible for collecting the following additional shipping data at the Landesbergen and Schlüsselburg locks: date, time, direction of travel, type of ship, name, length, beam, draught at bow and stern and shape of bow. As it was not possible to identify the length, beam and draught of recreational craft as they passed, the length of the recreational craft was estimated. Furthermore, the passage of each recreational craft was documented by a photograph.

6.4 Interpretation

On the basis of the measured data, the consulting engineers Schmid IBS prepared a final report in three parts on the '*Observation of Shipping on the Weser at Stolzenau*'. The main section /IBS 2006a/ describes the situation, the measuring equipment used and how the measurements were taken, and comments on the analysis and results. In a second part /IBS 2006b/, the wave diagrams of all shipping transits that were monitored and analysed have been compiled. The third part /IBS 2006c/ contains the speed diagrams of the first two observation days, when reliable records could be achieved with the speed sensor (cf. chapter 6.4.2).

For this report, the measurement results made available in the above mentioned reports have been analysed with regard to the following parameters, while allowing for the hydraulic-numerical modelling (cf. Chapter 5.3.2):

- Fleet structure (Chapter 6.4.1)
- Ship speeds (Chapter 6.4.2)
- Distances from the bank (Chapter 6.4.3)
- Wave heights (Chapter 6.4.4)
- Flow velocities (Chapter 6.4.5)
- Cross sections and longitudinal sections (Chapter 6.4.6)

6.4.1 Fleet structure

A total of 156 ships were recorded during the measurement period, of which 72 were motor cargo or motor tank vessels, 8 push-tow units – making a total of 80 cargo vessels – 68 recreational craft, 6 passenger ships and 2 WSA patrol boats. The distribution of the ship types observed is shown in percentages in Figure 6.12.

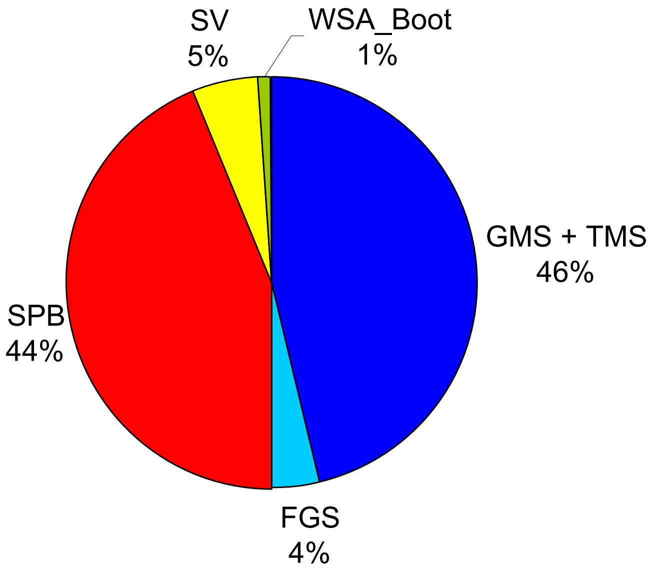


Figure 6.12: Distribution in percentages of all ships by type as recorded during the campaign

Abbreviations:

FGS	Fahrgastschiff (*passenger ship*)
GMS	Großmotorgüterschiff (*motor cargo vessel, excluding large motorised cargo vessels, which do not travel here*)
SPB	Sportboot (*pleasure craft*)
SV	Schubverband (*push-tow unit*)
TMS	Tankmotorschiff (*motor tank vessel*)
WSA	local Office of the German Federal Waterways and Shipping Administration (WSA)
Boot	= boat

6.4.2 Ship speeds

At this point, the speed limits laid down in the BinSchStrO (§ 16.04) (cf. Chapter 5.2) should be mentioned again as a guideline for orientation and classification of the ship speeds that were observed, now with particular respect to the test stretch:

- Cargo vessels: no restrictions
- Recreational craft: maximum speed limit 35 km/hour

Cargo vessels

The results of the observation show characteristic distribution patterns for cargo vessels (Figure 6.13). Ships travelling downstream generally travel at higher speeds (over ground) than those travelling upstream. Minimum, mean and maximum can be seen in Table 6.1. The fastest upstream vessel travels at 13.1 km/h; the fastest downstream vessel at 16.6 km/h.

The most frequently occurring speeds, however, all lie below the respective mean values (cf. Figure 6.13).

Table 6.1 also contains all characteristic values for ship dimensions and hydraulic measurements. The ship dimensions all lie within the permissible limits, with the exception of length (cf. Chapter 5.2). The longest vessels with 114 m exceed the permitted 91 m by far; however, those were push-tow units with special authorisation.

Table 6.1: Statistical key figures of the 80 cargo vessels observed (motor cargo vessels – GMS, motor tank vessels – TMS and push-tow units – SV); variables as far as possible in accordance with GBB /BAW 2005/

					Direction of travel: Upstream	Direction of travel: Downstream	Direction of travel: Up + Down
				No. of vessels:	**42**	**38**	**80**
Ship dimensions	**Length**	**L**	[m]	Min	34	34	34
				Mean	75	77	76
				Max	**114**	**114**	**114**
	Beam	**B**	[m]	Min	7.2	7.0	7.0
				Mean	8.5	8.5	8.5
				Max	**9.5**	**9.5**	**9.5**
	Draught stern	T_{Heck}	[m]	Min	0.9	0.9	0.9
				Mean	1.7	1.9	1.8
				Max	**2.5**	**2.5**	**2.5**
	Tonnage	**-**	[t]	Min	720	777	720
				Mean	1085	1160	1118
				Max	**1583**	**1537**	**1583**
Measured values	**Ship speed**	v_S	[km/h]	Min	7.4	7.0	7.0
				Mean	10.5	12.7	11.5
				Max	**13.1**	**16.5**	**16.5**
	Distance from bank	**u**	[m]	Min	38	41	38
				Mean	55	49	52
				Max	**67**	**61**	**67**
	Draw-down	$H^*_{u,H}$	[m]	Min	0.03	0.05	0.03
				Mean	0.12	0.16	0.14
				Max	**0.28**	**0.39**	**0.39**
	Stern wave height	$H_{u,Heck}$	[m]	Min	0.03	0.04	0.03
				Mean	0.11	0.19	0.15
				Max	**0.30**	**0.64**	**0.64**
	Secondary wave height	H_{sek}	[m]	Min	0.02	0.02	0.02
				Mean	0.06	0.05	0.06
				Max	**0.18**	**0.1**	**0.18**

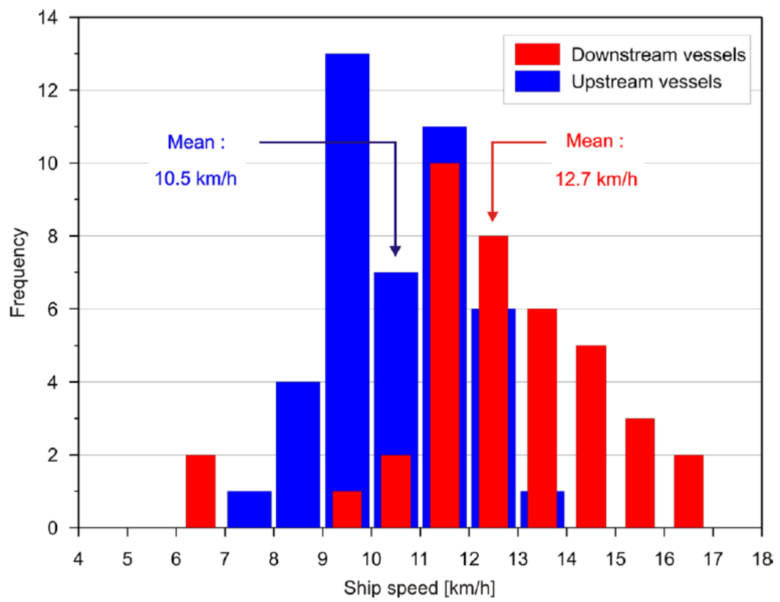


Figure 6.13: Distribution of speeds of all 80 cargo vessels, divided into upstream and downstream categories

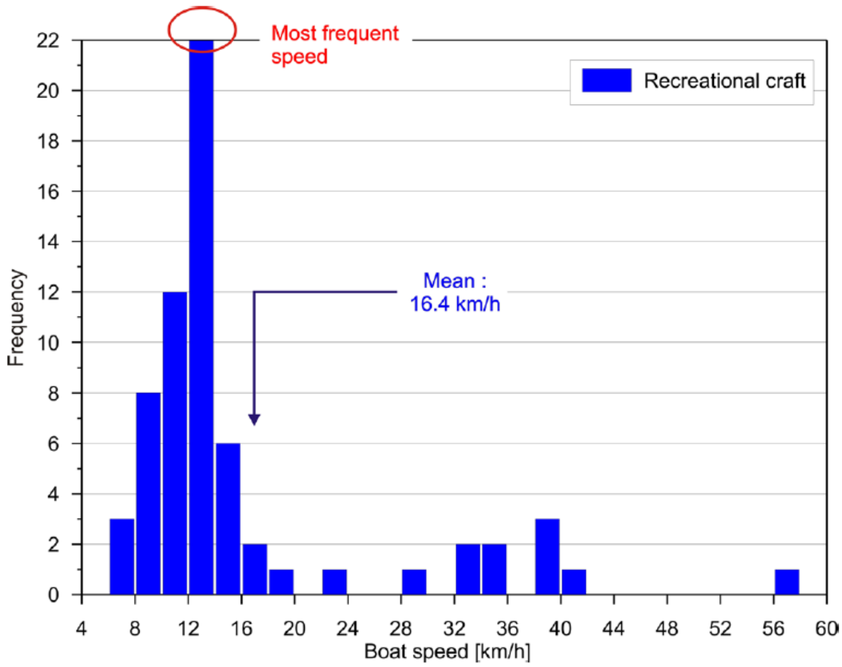


Figure 6.14: Distribution of speeds for recreational craft

Recreational craft

The analysis of the speeds of recreational craft shows a marked cluster at around 13 - 14 km/h, which is considerably below the mean value (Figure 6.14). This range roughly corresponds to the permissible speed in lock canals and lies significantly below the generally permitted limit of 35 km/h. One recreational boat was travelling very fast, at 58 km/h, (cf. also Table 6.2) and five boats exceeded the upper limit of 35 km/h.

The length of the fastest recreational boat (ship speed: 58 km/h) could only be estimated at 5 m – which is short – its beam and draught could not be recorded. It was a boat travelling downstream very close to the bank, at a distance of only about 27 m from the sensor and yet it created a wave with a height of only 9 cm. At this high speed, a recreational boat has already been in a gliding mode for a long time; it displaces almost no water and creates only minimal secondary wave heights.

Table 6.2: Statistical key figures of the 68 recreational craft that were observed; variables where possible according to GBB /BAW 2005/

					Direction of Travel: Upstream + Downstream **No. of vessels:** **68**
Ship dimensions	**Length**	**L**	[m]	Min	5
				Mean	9.1
				Max	**15**
	Beam	**B**	[m]	Min	2.2
				Mean	3.37
				Max	**4**
	Draught	T_{Heck}	[m]	Min	0.4
				Mean	1.0
				Max	**1.6**
Measured values	**Ship speed**	v_S	[km/h]	Min	7.7
				Mean	16.4
				Max	**58**
	Distance from bank	$H^*_{u,H}$	[m]	Min	15
				Mean	47
				Max	**75**
	Secondary wave height	H_{sek}	[m]	Min	0.02
				Mean	0.08
				Max	**0.41**

6.4.3 Distances from bank

In order to assess the load on the banks of the test stretch, the transit positions of the ships observed in the waterway cross section (corresponding to distances from the right bank) are significant. The consulting engineers IBS placed temporary reference points on the left bank for the 2 measuring profiles, as these do not match the hectometre markings. The distances of cargo vessels (50 usable) and recreational craft (54 usable) to the left bank calculated from these points are plotted as absolute values in Figure 6.15. Furthermore, the positions of the wave sensor, of both banks and of the thalweg – all at Weser Km 242.170 – are indicated in this diagram.

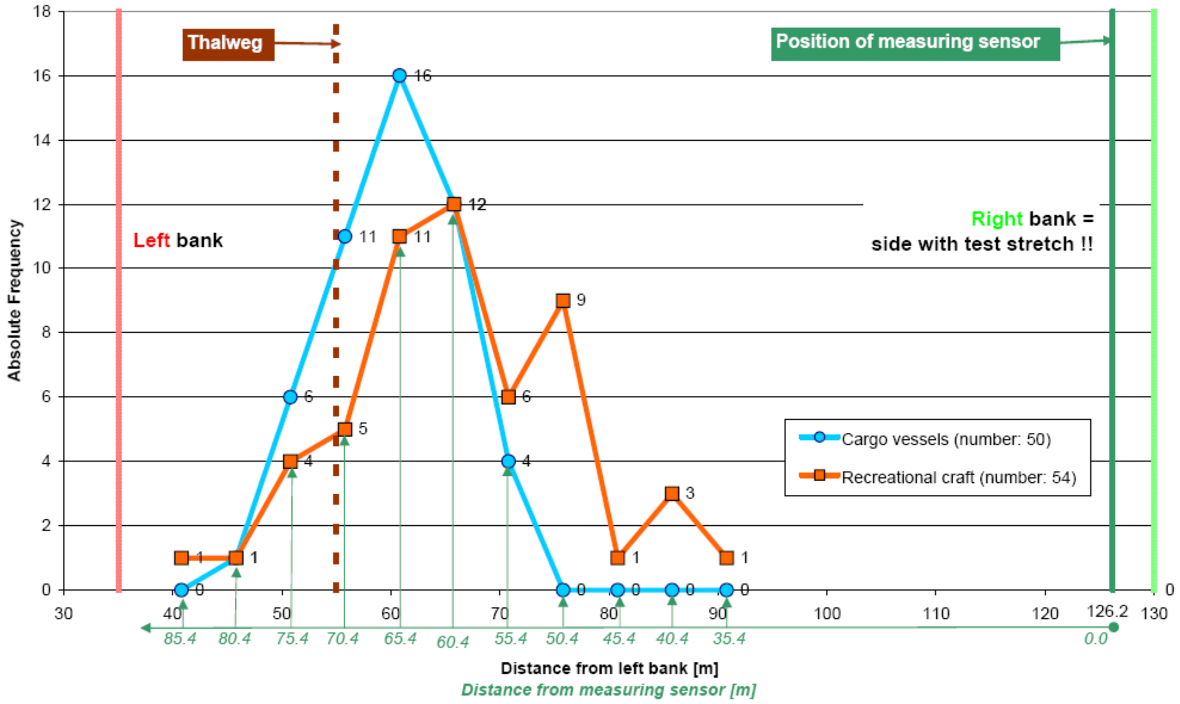


Figure 6.15: Distribution of the distances from the bank of cargo vessels and recreational craft with reference to the left bank point (using measuring profile at Weser Km 242.170) and to the sensors

Figure 6.16 further provides the frequency distribution of the distances from the right bank (= measuring sensor) for cargo vessels and recreational craft. Cargo vessels travel normally at about 52.5 m from the bank and recreational craft at about 47.5 m.

Both graphs show that all cargo vessels – with one exception – pass the test bank at a distance of 40 - 65 m, which corresponds to a range of 25 m. 39 of 50 cargo vessels, i.e. 78 %, travel mainly at 45 - 60 m from the right bank; this represents a narrow range of about 15 m. Recreational craft pass the right bank in a wider zone, 30 m in width, representing distances to the bank of between 35 and 65 m. Recreational craft thus travel much closer to the test bank than freight traffic, in individual cases, sometimes as close as 25 m. The smaller draught of recreational craft allows them to cruise in the shallower bank zone.

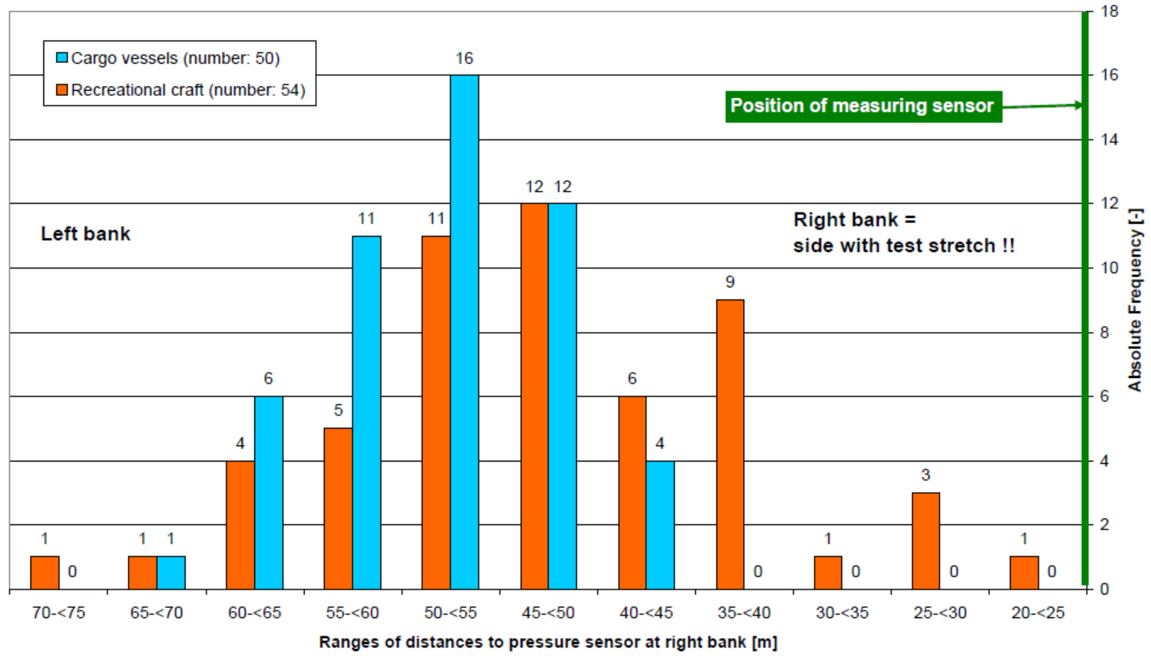


Figure 6.16 Distribution of the distances from the right bank (= measuring sensor) for cargo vessels and recreational craft

6.4.4 Wave heights

Consideration of positive and negative surge

The possible effect of positive and negative surge waves caused by the locking of ships upstream and downstream from the test stretch was estimated roughly. An estimation of the durations yielded a result of 10 minutes for a surge wave from the Schlüsselburg lock, about 4 km upstream, and about 30 minutes for a negative surge wave from the Landesbergen lock, about 10 km downstream. The analysis of the measurement records showed that only positive surge waves were recorded. Ship passages for which the measurements were superimposed by positive surge waves were excluded in the further analysis.

Determining bow and stern wave height (primary wave) from the measurement results

The hydraulic load on the banks is caused by the flow of water around the passing ship and the related wave action. For this reason; the wave heights are a significant value in the assessment of their quantity. This phenomenon was described in detail in Chapter 6.1.

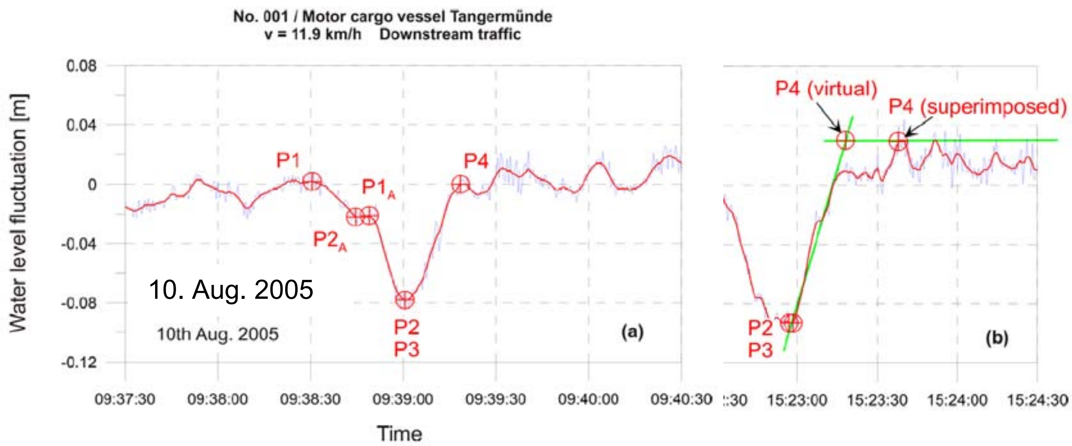


Figure 6.17: (a) Example of a wave event with the characteristic values P1 to P4 and the additional points $P1_A$ and $P2_A$
(b) Example of a supplemented value P4 (virtual) as the maximum water level in the stern zone

The determining of bow and stern wave heights and the deepest drawdown value – which form the primary wave – was carried out optically using the edited measurement records. Normally four typical values P1 to P4 were recorded (cf. Figure 6.17 (a)):

- the difference between P1 and P2 – bow wave height and also bow drawdown as design value for thickness of revetment;
- the difference between P3 and P4 – stern wave height and also design wave height as calculation variable of the size of individual stones, according to GBB /BAW 2005/.

In special cases the additional points, $P1_A$ and $P2_A$ were added and correspondingly taken into account in the evaluations. In the stern wave height zone, P4 was sometimes assumed to be higher than the recorded measurement in order to obtain values on the safe side. The procedure is described in detail in the report /IBS 2006a/.

The interpretations showed that primary waves occurred only with cargo vessels, passenger ships and push-tow units.

Determining secondary wave height

The secondary wave heights are of particular interest in the case of recreational craft, since as a result of their slight water displacement, these do not create a primary wave. However, the secondary wave heights from cargo vessels were also analysed in order to have information about their size, and to enable a comparison to be made between the secondary wave heights from freight traffic and recreational craft.

For determining the secondary wave height two readings were necessary, for example, a wave crest and a wave trough in immediate succession. The measuring frequency of 2 Hz meant that secondary wave heights could not be fully recorded at higher frequencies (cf. Figure 6.18). By agreement between the contractor IBS and the BAW, in these cases the maximum possible secondary wave deflections were logically adjusted (cf. Figure 6.18, linear extrapolation) and thus included in the interpretation.

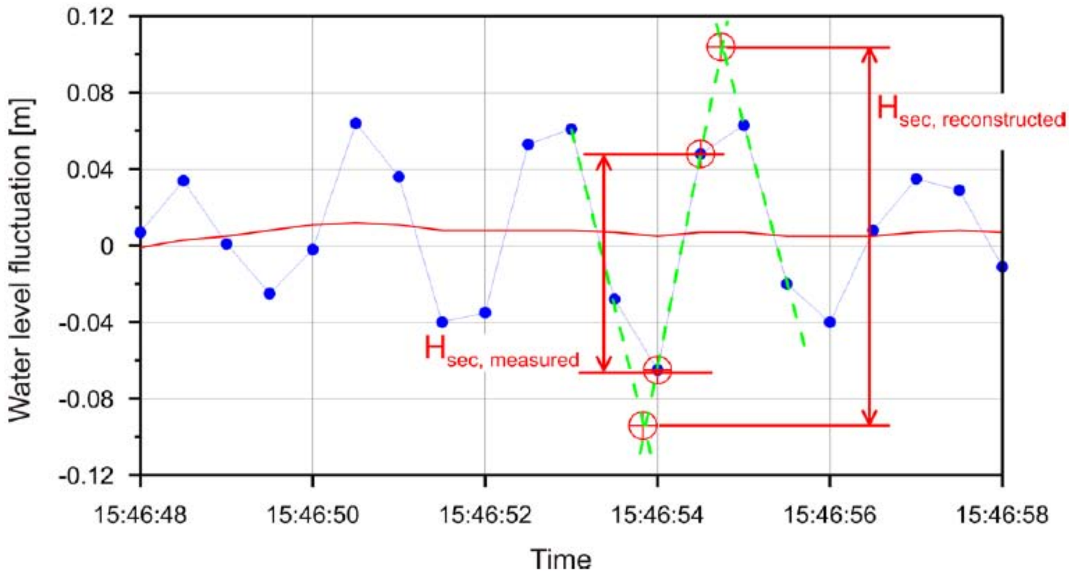


Figure 6.18: Example of measured and adjusted secondary wave heights (recreational craft ‘*Daniel N’,* downstream transit with v_{Schiff} = 15.8 km/h)

Note: The red line in the area of the abscissae is the sliding mean for defining primary wave height (cf. Figure 6.17)

Measured wave heights

The results show the wave heights for cargo vessels and recreational craft separately. For cargo vessels, a distinction was made according to the rapid water level drawdown directly at the bow (also known as bow drawdown or bow wave height), the wave height at the stern of the ship (also known as stern wave height or design wave height) and the secondary wave height.

- The bow wave height is of significance for the reaction of the pore water pressure in the soil of the slope because of its short drawdown time. Thus, it is critical for the stability of the slope as well as of any existing bank protection measure.
- The stern wave height results of the lowest drawdown beside the cargo vessel near the stern area and the first wave crest behind the stern. It is used to calculate the position stability of individual stones of a revetment, but it can also be drawn on for estimating the load capacity of bank vegetation and fauna.
- Secondary waves are created at the bow and stern of cargo vessels. The secondary waves at the bow run towards the bank during the drawdown; the secondary waves at the stern are superimposed on the stern wave. Their dimensions are considerably smaller than the bow and stern waves of the primary wave system.

Recreational craft only create short-period secondary waves which, however, are higher than those from cargo vessels. This is because the travel speeds are higher and the distances to the banks are smaller.

Secondary waves are in general not relevant to the dimensioning of bank protection measures. In individual cases, they may, however, lead to erosion problems. This must be considered in matters of flora and fauna.

In Figure 6.19 bow wave heights and, in Figure 6.20, stern wave heights are shown for all the cargo vessels that could be analysed, with values for upstream and downstream traffic shown separately. The mean bow wave heights are around 15 cm; the highest value of 39 cm was from a downstream vessel. The mean stern wave heights are 11 cm for upstream traffic and 19 cm for downstream traffic; the maximum difference was 30 cm for upstream and 64 cm for downstream traffic. Only two individual examples of extreme values between 45 and 65 cm occurred in downstream traffic; generally values of only 40 cm are reached here. Superimposition effects from other wave patterns, which were not filtered out, could possibly be the explanation for this. These and other values are also listed in detail in Table 6.1.

Figure 6.21 presents the secondary wave heights for cargo vessels and recreational craft, in as far as they could be analysed. The cargo vessels created an average wave height of 6 cm, regardless of whether travelling upstream or downstream. The maximum values were: upstream: 18 cm; downstream: 10 cm. (The maximum must be higher in the upstream direction, as the ship has a greater relative speed to the water, a factor that is decisive in creating the wave systems.) Recreational craft had a mean value of 8 cm, only minimally higher, but their maximum value was 41 cm. For further details regarding this point, please also refer to Table 6.1 and Table 6.2.

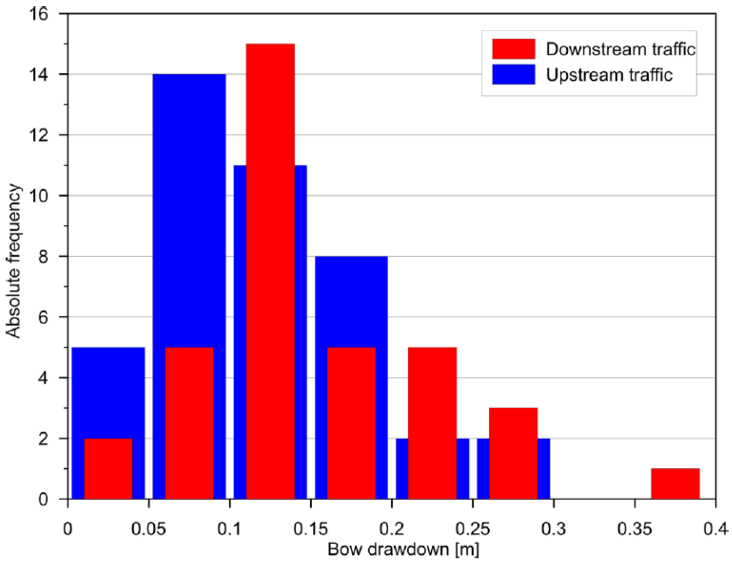


Figure 6.19:

Bow drawdown for all cargo vessels, separately for up-stream and downstream traffic

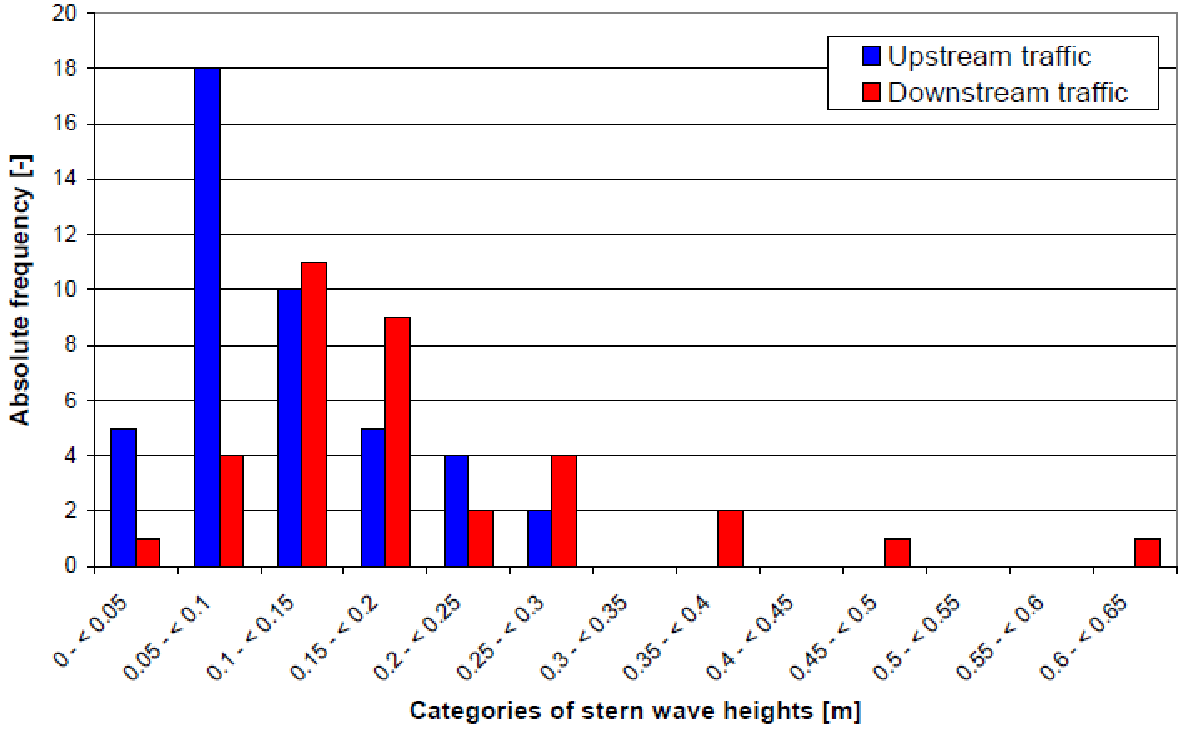


Figure 6.20: **Stern wave heights** for all cargo vessels, separately for upstream and down-stream traffic

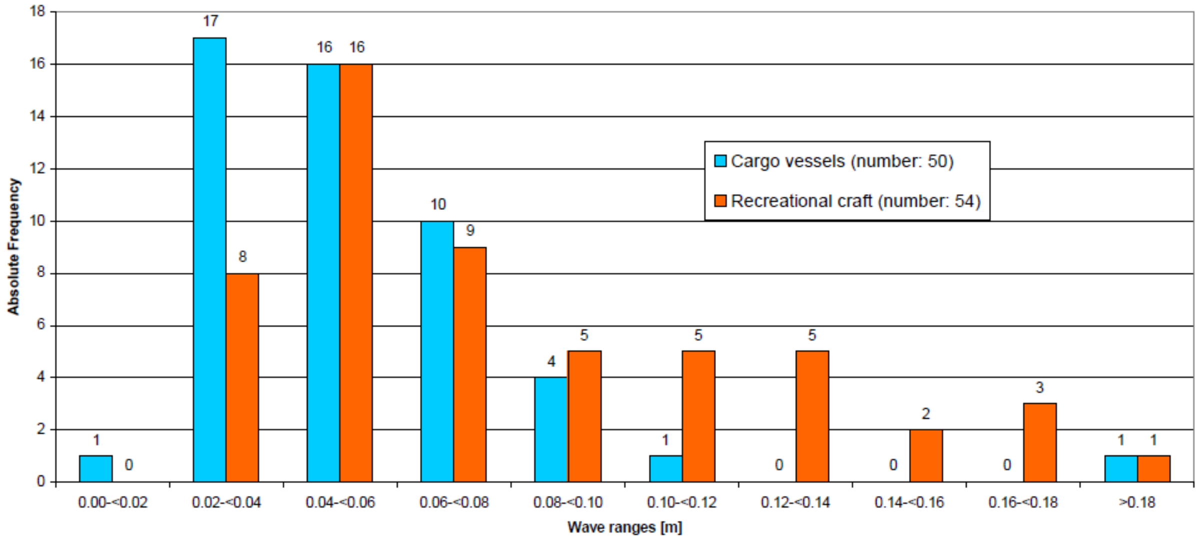


Figure 6.21: Secondary wave heights for 50 cargo vessels (motor ships /MS, motor tank vessels/ TMS and push-tow units/ SV) and 54 recreational craft (in the other cases the secondary wave height could not be measured)

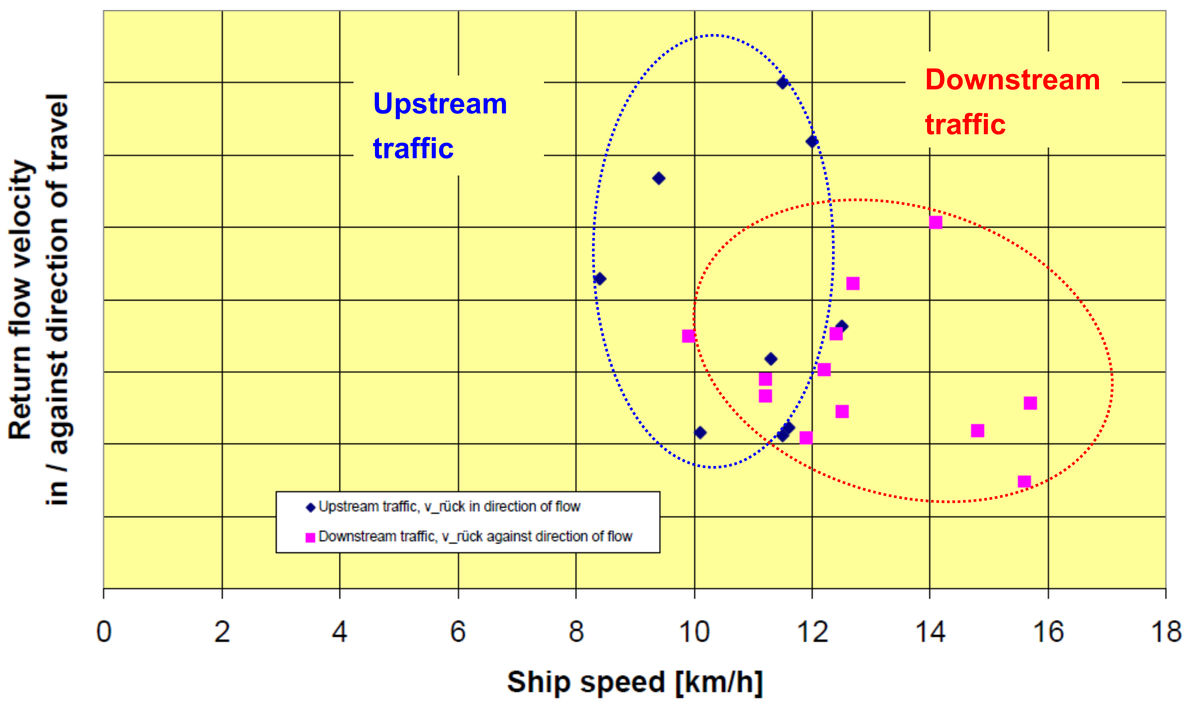


Figure 6.22: Return flow velocities from 21 cargo vessels (only MS and TMS) from the first two days of the measurement campaign, showing upstream and downstream traffic separately

6.4.5 Flow velocities

Measurements of the flow velocities, which represent a direct load for animals and plants on the bank, could be taken only during the first two days. In the period 10 - 12 August (9.35 am) the data for 21 cargo vessels (without push-tow units) were collected. As expected, alterations in flow behaviour in the vicinity of the measuring sensor occurred only during the transit of cargo vessels (large cross section) but not when recreational craft passed (very small cross section). The analysis focused on the return flow velocities, which occur alongside the ship opposite to the direction of travel. In Figure 6.22, the correlations between ship speed and return flow velocity are depicted. The following conclusions can be drawn:

- Vessels moving upstream travel as expected at a lower speed[1)] than vessels travelling downstream. The speed range for upstream traffic is smaller than for downstream traffic:

  Upstream v_{Schiff} from 8.4 to 12.5 km/h
  Downstream v_{Schiff} from 9.9 to 15.7 km/h

- Upstream traffic creates higher return flow velocities than downstream traffic and the range is larger than for downstream traffic:

  Upstream $v_{rück}$ from 0.21 to 0.70 m/s
  Downstream $v_{rück}$ from 0.15 to 0.51 m/s

The return flow is predominantly oriented in a direction parallel to the ship and to the bank. This was demonstrated by the comparison of the readings for the speeds in the direction of flow with the actual speeds, which are caused by a small constituent part perpendicular to the main direction of flow. The extremely small discrepancies amount to 0.3 % upstream and 1.1 % downstream.

The flow velocity of the base flow of the River Weser was estimated roughly with the hydraulic-numerical model of the Section W1 of the BAW (cf. Chapter 5.3.2). As a mean value over the whole waterway cross section, this is about 0.2 m/s, and at the bank, in the vicinity of the test surfaces, as well as at the measuring sensor, 0.05 m/s. This was taken into consideration in the analysis.

The ship speeds were measured over ground. The upstream traffic travels against the base flow and the downstream traffic with it, which is reflected in the above mentioned interpretation.

A pronounced slope supply flow, the speed of which would match approximately the speed of the ship, was not found here as at the measuring point, considerably larger cross section ratios $n = A_{waterway} / A_{vessel}$ exist than in narrow canals, where such effects clearly occur.

[1)] **Note:** The ranges for ship speeds stated here are not shown in Table 6.1, as the entire measurement campaign is analysed there, but here only the two days on which the flow velocities could be recorded.

For a Europe ship, with a 2.5 m maximum loaded draught at a water surface position of 26.6 m a.s.l. the value is taken as n ≈ 12.21 at Weser Km 242.100 in contrast to the same ship in a normal trapezoidal cross section with n ≈ 7.24. For this reason, significant running waves, which move with the ship in the stern area at the bank, – an effect that may be seen in canals – are not generated here.

6.4.6 Cross sections and longitudinal profile

At the start of the measurement campaign, the consulting engineers IBS measured the two cross sections at Weser Km 242.040 and 242.170 from their own measuring boat using a sonic depth finder and supplemented the findings with a GPS survey on the right bank. Figure 6.23 shows these cross sections. They again reflect the fact that the test stretch lies in a slight right hand curve which typically has a deeper bottom (thalweg in Figure 6.23) at the left. At Weser Km 242.040, the bottom is approximately 3.6 m below the water surface, and at Weser Km 242.170, 3.8 m. It should be noted that the reference water level is 15 - 20 cm lower than is shown in the diagrams, due to measuring errors at a gauge temporarily placed at the left bank under the abutment of the bridge for the road B 215. This was accounted for in the analysis.

Furthermore, a longitudinal sounding was carried out roughly in the middle of the river (Figure 6.23). The results show that in the area of the navigation channel irregularities in the bottom of about ± 0.7 m may occur. As mean water depths in this area are still around 4 m, this does not represent any hindrance to shipping as far as nautical aspects are concerned.

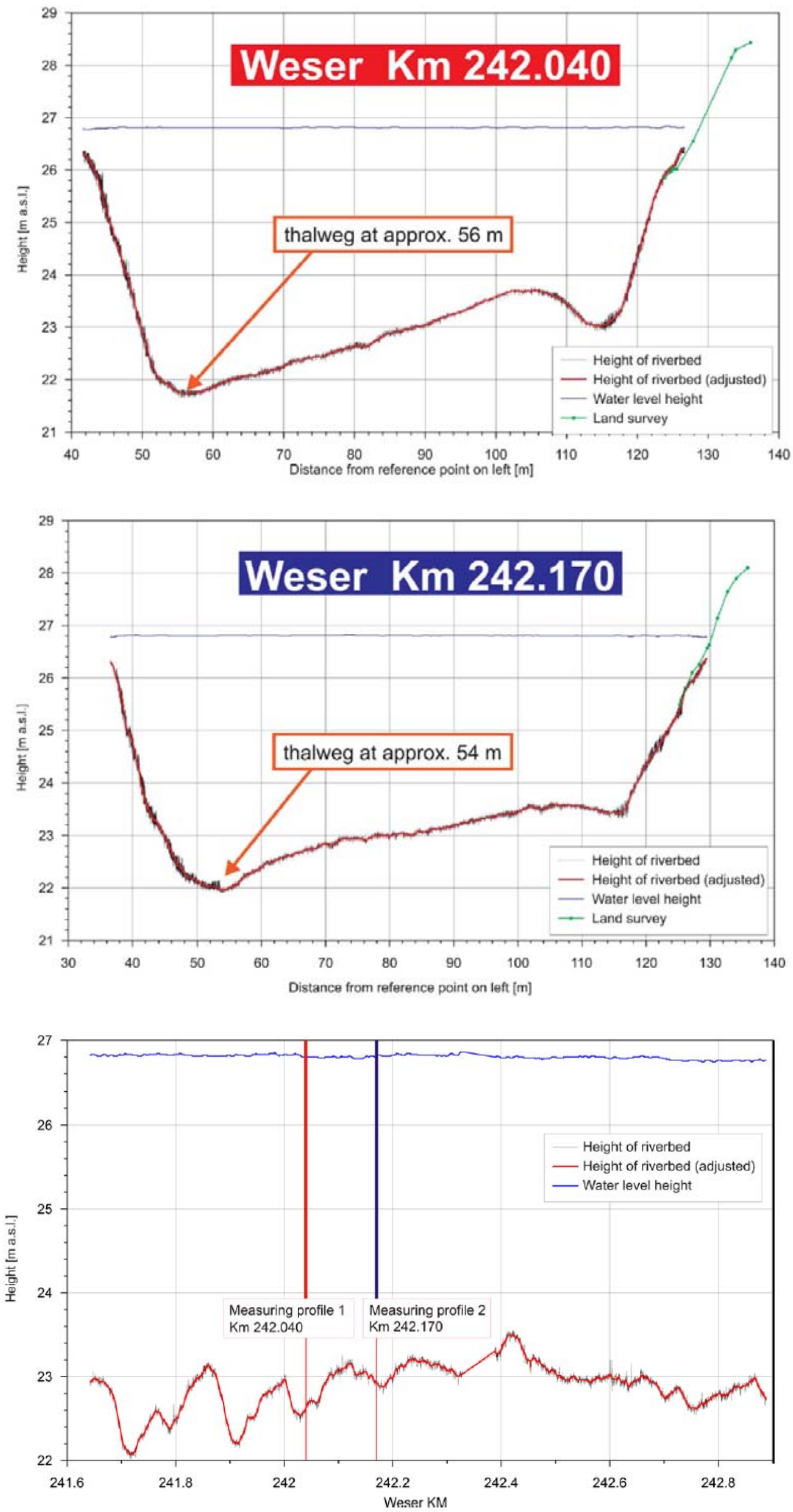


Figure 6.23: Measurement results from the cross section soundings in the two measuring profiles (top 2 diagrams) and the longitudinal sounding showing the position of the 2 measuring profiles (lower diagram)

7 Significant hydraulic load factors at the bank

The hydraulic calculations and measurements explained in Chapters 5 and 6 are included in the further considerations regarding bank stability and vegetation – as presented in the following chapters. Relating the mean values as well as the maximum values of the most significant hydraulic load factors such as flow velocities, the shear stress resulting from these, drawdown and heights of the stern wave and the secondary wave to the various bank protection measures at the bank under investigation is essential in this research project. Therefore, Table 7.1 shows the (available) mean and maximum values of the most significant hydraulic load factors in the test stretch with the alternative bank protection measures.

Table 7.1: Main values of the most significant hydraulic load factors

	Variable	Symbol	Unit	Mean	Acc. to Fig./Table	Maximum	Acc. to Fig./Table	Ship type
River hydraulics	**Flow velocity**	v_{Str}	[m/s]	-	-	1,00 [1]	Figure 5.17	
	Shear stress	τ	[N/m²]	-	-	6,00 [1]	Figure 5.17	
Navigation	**Return flow velocity**	$v_{rück}$	[m/s]	0.34	Figure 6.22	0.70	Figure 6.22	Cargo vessels
	Drawdown	$H^*_{u,H}$	[m]	0.14	Table 6.1	0.39	Table 6.1	- " -
	Stern wave height	$H_{u,Heck}$	[m]	0.15	Table 6.1	0,64 [2]	Table 6.1	- " -
	Secondary wave height	H_{sek}	[m]	0.08	Table 6.2	0.41	Table 6.2	Recreational craft
				0.06	Table 6.1	0.18	Table 6.1	Cargo vessels

Field colours/patterns:
- calculated
- measured
- recreational craft
- no value

Remarks:
[1] extrapolated for bank-full discharge
[2] includes approx. 2/3 stern drawdown; i.e. stern wave height alone is max. 22 cm

8 Assessment of the technical conservation status

According to information from the WSA Verden, no further maintenance work has been necessary at the test stretch area from 1989 until the present day. This means that there has been no significant bank erosion or detrimental sliding of the slope, and the banks are, to the greatest possible extent, stable. Correspondingly, it can be assumed that the existing "old" riprap revetment below the water level and the newly installed alternative technological-biological bank protection measures above MW (mean water level), as described, provide good protection under the present hydraulic load. This is also confirmed by the cross sections measured in the area of the test stretch (cf. Chapter 5.1.3). Since no initial depth soundings were made, there is no precise record of the initial state; however, the geometrical data has not shown any evidence of distortion of the slope that would impair its stability.

In the area above MW it can be assumed that the slopes were at first reshaped by wave action and flow to some extent after the removal of the riprap revetment, the subsequent creation of the new profile and the planting of differing types of vegetation, but that as a result of the development and growth of the vegetation, these have become increasingly stable. The areas that were flattened to 1:7 as planned have overall become only slightly flatter, with a present slope inclination of 1:8. The shallow water zones that were laid out are still, without exception, silted up. This means sedimentation has taken place in the flow shadow areas of the groynes. Even areas in which the old slope inclination of 1:3 was retained, as planned, but in which the armour stones were removed, have remained stable to a very large extent with the various alternative protection measures. There is no discernible difference between the areas with and without groynes.

The hydraulic loads result principally from navigation (Chapter 5.2) and flood events (Chapter 5.3).

Navigation

Based on the measurements, the load resulting from navigation can be estimated as small in comparison to the load in canal reaches which meet the requirements of Class Vb waterways. On average, only around 16 freight ships pass here per working day (measurement in the test stretch in 2005; cf. Chapter 6.4.1). As expected, the hydraulic load at the bank when a ship is passing is, on average, small (cf. Table 7.1), as the cross section ratio (quotient of waterway cross section and submerged ship cross section), with a value of 12, is substantially larger than in canal reaches. Furthermore, the navigation channel is at a relatively large distance from the bank of the test stretch. Freight ships therefore travel – as shown in the measurements – at a large distance from the bank, at around 55 to 80 m; 65 m on average (cf. Figure 6.15).

For purposes of comparison, a study was conducted for the section of the test stretch on the right bank of the River Weser in order to ascertain to what extent bank protection from navigation load in the form of a technical revetment would theoretically be necessary under the existing boundary conditions. For this purpose, calculations were made according to /GBB 2004/ (Principles for the Design of Bank and Bottom Protection for Inland Waterways) using the programme GBBSoft, which was developed for the BAW by Swift Engineering GmbH in Karlsruhe. The layer thickness required from a geotechnical point of view and the required size of individual stones for a riprap revetment on a geotextile with embedded toe were determined according to /MAR 2008/.

From a geotechnical point of view, a failure mechanism has to be analysed which, as a result of a rapid drawdown in the water level due to passing ships and the related occurrence of excess pore water pressure in the ground, can lead to the sliding, parallel to the embankment slope, of a soil layer close to the surface as well as of an existing revetment. In order to achieve adequate security, the revetment must have a certain weight in the form of superimposed load in proportion to the hydraulic load. The decisive zone is the slope area below the lowered water level. This means that for water levels up to about MW, the permeable Weser gravel in the slope area is crucial; it can be classified as soil type B1 according to /MAR 2004/ (cf. Chapter 5.1.1). Because of the relatively high permeability, only little or no excess pore water pressure in the ground can be expected when ships are passing. The silts and sands lying on top of it, which according to /MAR 2008/ can be classified as soil type B4, must be taken into account for situations of HNW. In the depiction of the hydrograph of the River Weser at the Stolzenau gauge (cf. Figure 5.4), it can be seen that these high water levels occurred only for about nine brief periods between 1988 and 2006. For the majority of the time, water levels were around MWL. The key figures for soil in accordance with Table 5.1 were used for the calculations.

The cross section recorded at Km 242.170 (cf. Figure 6.23) during the measuring work in 2005 was chosen as the basis for the waterway cross section. As it is only possible to make calculations for a trapezoidal cross section, the relevant simplifications had to be made. The slope inclination on the left bank was assumed to be 1:3, corresponding to the planned target inclination. At the right bank, according to the cross section measurements, the slope inclination below MW ranges from 1:2 to 1:4, and above MW from 1:3.5 to 1:8 (cf. Chapter 5.1.3). As only a uniform slope inclination can be considered, the calculations were carried out assuming a slope inclination of 1:3 for MW conditions and a mean slope inclination of 1:5 for HNW conditions.

With regard to the load from navigation, the Europe ship was used for the study, as it is at present the largest vessel travelling here. In accordance with the measurements, it was assumed that it travels at a distance of 55 m from the test stretch (the smallest recorded distance from the bank; cf. Figure 6.15).

The calculations for navigational load at various water levels show the following results:

1. Navigation at mean water level (MWL)

A water depth of 4 m and a slope inclination of 1:3 were taken as the basis for the calculations, assuming a Europe ship travelling at 0.97 % of the critical ship speed. The soil type of importance here is the Weser gravel (soil type B1 acc. to /MAR 2008/). The results of the calculations show that because of the high permeability of the Weser gravel, no additional weight is required on the slope in order to guarantee the desired stability. From a geotechnical perspective, a revetment is not required. The necessary individual single-particle size D_{50} (mesh size) for prevention of erosion in the slope area as a result of waves and flow generated by navigation is 70 mm and is thus larger than the existing granular size of the Weser gravel, which is 0.06 to 60 mm (cf. Chapter 5.1.1 and Appendix 5.3-3). This means that without any protection of the slopes, erosion of the banks in the underwater zone could be expected at mean water levels.

2. Navigation at the highest navigable water level (HNW)

In this case, a water depth of 6.5 m and a continuous mean slope inclination of 1:5 were taken as the basis for calculations. It was assumed that the Europe ship travels at a speed of 16.5 m/s (the fastest measured ship speed), as no ship can travel at 0.97 % of the critical ship speed under high water conditions. Below the water level, silts and sands (soil type B4 acc. to /MAR 2008/) are also found on top of the Weser gravel (cf. Chapter 5.1.1 and Appendix 5.3-1). They are critical to the calculation, as they are around 2.5 m thick, and due to their lower degree of permeability they yield less favourable values with respect to geotechnical calculations regarding possible excess pore water pressure in the ground.

The hydraulic load variables are only marginally larger than at MW. But because of the characteristics of the soil mechanics of the silts and sands, a superimposed revetment with a layer thickness of 35 cm as an extra weight is necessary here to ensure the geotechnical stability of the slope (with an assumed stone density of 2650 kg/m³). The individual stone or particle size required to avoid erosion here is also 70 mm, while the range of granularity of the in-situ sands and silts lies only between 0.001 and 1 mm. This means that without any kind of bank protection measure, not only can erosion be expected, but also the sliding of the slopes.

The calculation results show that, theoretically, at water levels up to the mean water level, protection at least of the slope surface is necessary for the prevention of erosion as a result of navigation. At higher water levels, a revetment in the form of superimposed weight is additionally required to guarantee geotechnical stability. At present, the area below the water level is secured with Class III armour stones with D_{50} = 22 cm (mesh size – corresponding to

D_{50TLW} = 30 cm), acc. to TLW 1997, installed with a thickness of 60 cm. For the prevention of erosion, however, class $CP_{45/125}$ stones (acc. to TLW 2003), i.e. granular sizes between 4.5 and 12.5 cm, integrated into a 35 cm thick layer are sufficient to guarantee adequate inner stability of the stone structure. A layer of this thickness would also provide sufficient weight to stabilise the slope even when higher water levels occur. That means the present slope protection below the water level is theoretically over-dimensioned with regard to the load caused by navigation. The zone above the water level has no continuous riprap revetment, but is secured with technical-biological means. This zone, however, is only subject to load at water levels above MW, which have tended to occur only rarely (cf. Chapter 5.1.3).

Flood events

Not only can the loads generated by navigation impair the stability of the banks but also the natural current of the river – particularly during flood. At mean water levels (26.90 m a.s.l.) the existing flow velocities close to the bank are around 0.1-0.5 m/s and the drag forces are at most 2 N/m^2 (cf. Chapter 5.3.2). During high water, these key figures are, by contrast, at HNW (29.12 m a.s.l.) around 0.60-1.25 m/s and 3-9 N/m^2 respectively and at HHW (30.50 m a.s.l.), 1.5 m/s and more and 9 N/m^2 and more respectively (values from Figures 5.15 and 5.15; for the last instance extrapolated from Figure 5.17).

The in-situ Weser gravel is a sandy to very sandy, fine-to-medium gravel with particle or granular sizes between 0.06 and 60 mm; Appendix 5.3-3 shows the typical particle size distribution. The soils on top of it are predominantly fine-sandy and clayey silts and sands with particle sizes between about 0.001 and 1 mm; the typical particle size distribution can be seen in Appendix 5.3-1.

Table 8.1 shows a comparison of the existing flow velocities and drag forces with the permissible values for the in-situ soils at which, according to /Wendehorst 1989/, erosion can be expected to begin. It is apparent that at MW levels, the in-situ relatively coarse-grained Weser gravel is hardly at risk of erosion. Only the fine-grained components, smaller than 0.63 mm (representing about 15 % of the total), can be transported away by the current. At higher water levels the risk of erosion increases, as larger particles also begin to move, and at HHW the limit of the speed or drag force for all particle sizes of this gravel is exceeded. By contrast, as for the silts and sands on top of the gravel, the permissible flow velocities and drag forces are reached and, in part, exceeded at loads that already occur at MW. That is, erosion could be expected in the sandy, silty slope zone at all water levels above MW, if no protection measures were in place. This means that with regard to the natural stress from the current, measures to prevent erosion are also necessary – in this case especially for water levels higher than MW.

Table 8.1: Comparison of existing and permissible flow velocities and drag forces /Wendehorst 1989/

Soil in-situ	**Critical water levels**	**Existing flow velocities** **v**	**Permissible flow velocities** v_0	**Existing drag forces** τ	**Permissible drag forces** τ_0
		[m/s]	[m/s]	[N/m^2]	[N/m^2]
Weser gravel *(sandy fine-to-medium gravel)*	MW	0.1... 0.5	0.35 ... 1.25	0 ... 2	2 ... 15
	HNW	0.6 ... 1.25		3 ... 9	
	HHW	> 1.5		> 9	
Sands and silts *(silt to medium-grained sand)*	MW	0.1 ... 0.5	0.20 ... 0.45	0 ... 2	1 ... 2
	HNW	0.6 ... 1.25		3 ... 9	
	HHW	> 1.5		> 9	

For the present bank protection measures, this means that with the existing riprap revetment of Class III armour stones, which has a thickness of 60 cm, there is adequate protection for the underwater slopes during mean and high water conditions, and even that this protection is over-sized. This also explains why the underwater slopes in the measured cross section (cf. Chapter 5.1.3) are still stable with slope inclinations of 1:3, and in some cases, of 1:2.

In the zone above the water level in mean water conditions, the technical-biological measures are subject only to minimal hydraulic load. If the relatively rare higher high water levels are to be taken into account, then the alternative measures must be able to provide a degree of protection equivalent to a 35 cm thick revetment consisting of loose class $CP_{45/125}$ armour stones (acc. to /TLW 2003/). This is a small category of armour stone with stone dimensions (mesh diameter) of between 45 and 125 mm, roughly corresponding to the former Class 0 (acc. to /TLW 1997/). On the basis of the condition of the bank protection measures in the study, it can be expected that under the hydraulic loads that exist so far, it has been possible to achieve a good level of protection against erosion. A corresponding quantification of the load capacity is dealt with in Chapter 9.2.3.2.

9 Assessment of the vegetation

The nomenclature for the species follows /Wisskirchen, Haeupler 1998/. For the determining of species and the designation of the vegetation units, /Oberdorfer 2001/ has been used.

The nomenclature for the English species follows the Integrated Taxonomic Information System: http://www.itis.gov/servlet/SingleRpt/SingleRpt.

9.1 Development of the test stretch

In order to document and compare the development of the variously structured bank sections from the phytosociological point of view, mapping was carried out in the years 1989, 1992, 1999, 2005 and 2006. The applied methods and the results of this will be presented briefly below. The data collection was carried out by Herz (1989, 1999, 2005), Horchler (1992) and Bauer (2006).

9.1.1 Initial status report in 1989, the year of completion

Condition of the non-woody species, in particular the reed beds

In June 1989, immediately after the planting work, records were made of the location of the plants, the lengths of their shoots, the number of their sprouts and their vitality. A renewed data collection was carried out in September 1989 (cf. Appendices 4.2-1 and 4.2-2).

By September of that year, the reed beds had become well established in all planting sections except for the loss of single plants (Figures 9.1 – 9.5).

Figure 9.1: Common reed and sedge planting at the flattened bank slope: Streamwards, the rock fill of the stone mound close to the bank is visible (Sections 1 and 2; Sept. 1989; for locations of the photographs in Chapter 9, cf. Appendix 9.3)

Figure 9.2: Planting of reed beds on the flattened bank slope; view from the bank to the cliff line (Section 2; Sept. 1989; the red metre stick protrudes 1 m above ground)

Figure 9.3: With runners sometimes more than 3 m in length (a light-coloured runner on the surface can be seen here next to the white metre stick), the common reed *(Phragmites australis)* that was planted in the spring are spreading out towards the river (Section 5, shallow water zone and island/training structure; Sept. 1989)

Figure 9.4: Reed bed planting on the flattened slope with a stone mound. In the background: loading facility of the gravel works on the opposite bank (Section 7; Sept. 1989)

Figure 9.5: Reed bed planting on the flattened slope with protection from a willow fascine (Section 9; Sept. 1989)

Condition of the woody plants

In the planning sections 14 and 14a, two rows of alder with a total of 21 black alders (*Alnus glutinosa*) were planted (in June 1989 these were 1.55 - 2.30 m high). In Sections 4, 6, 7a, 9, 10 and 12, basket willow (*Salix viminalis*) and other varieties of willow (*Salix spp.*) in the form of cuttings, long branch cuttings and live brush mattresses were introduced. The live brush mattresses had already formed strong shoots by September of the same year (Figure 9.6).

Figure 9.6: The newly installed willow brush mattresses have sprouted vigorously. In the background: the road bridge between Stolzenau and Leese (Section 7a; Sept.1989)

9.1.2 Condition of the test stretch in 1992

Development of the non-woody species, in particular of the reed beds

The reed beds planted had developed well almost everywhere, in particular the common reed (*Phragmites australis*). Only the reed beds of the common reed mats in Planning Section 7 demonstrated poor growth and little vitality. Some loss of area was observed for the varieties of sedge that were planted (Figures 9.7 and 9.8).

In the bank sections with protection in the form of stone mounds or fascines, the reed beds spread more strongly than in the unprotected areas (cf. Figures 9.7 and 9.8). In the former, they reached or overgrew the fascines and stone mounds, while in the unprotected sections, they spread out only partially beyond the original area.

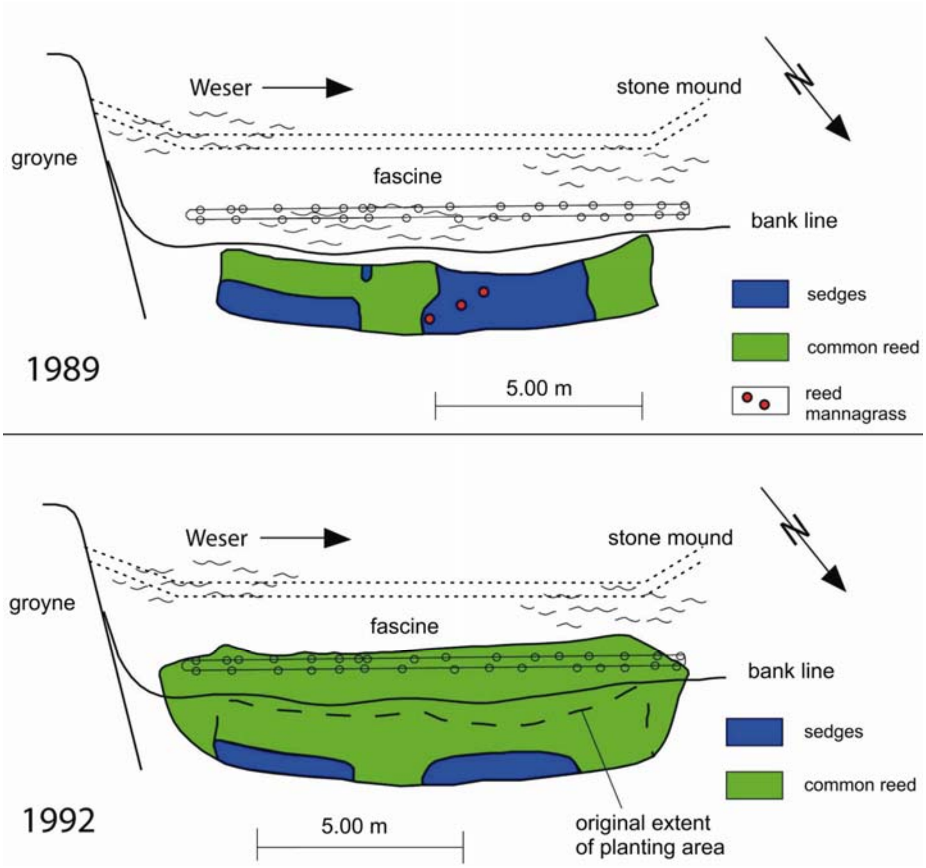


Figure 9.7: Development of vegetation at the flattened bank in the groyne field zone protected with a fascine and stone mound (Planning Section 1)

The areas of bank that were not planted had developed in line with the grazing exclusion: There was typical riparian vegetation, dominated in the immediate vicinity of the bank by reed canary grass (*Phalaris arundinacea*); on the landward side a quack grass flood meadow (with *Elymus repens*) adjoined, which extended to the bank line only in places. Mixed with these were species such as creeping thistle (*Cirsium arvense)* and garden angelica (*Angelica archangelica*). Next to this was a strip of grassland that was in places strongly ruderalised.

Development of the woody plants

The development of the woody plants was not equally positive in all locations. The best growth was seen in the woody plants planted in the form of live brush mattresses and in individual willows that developed from fascines. Many cuttings and long branch cuttings, especially those at the unmodified banks, died off within the first three years.

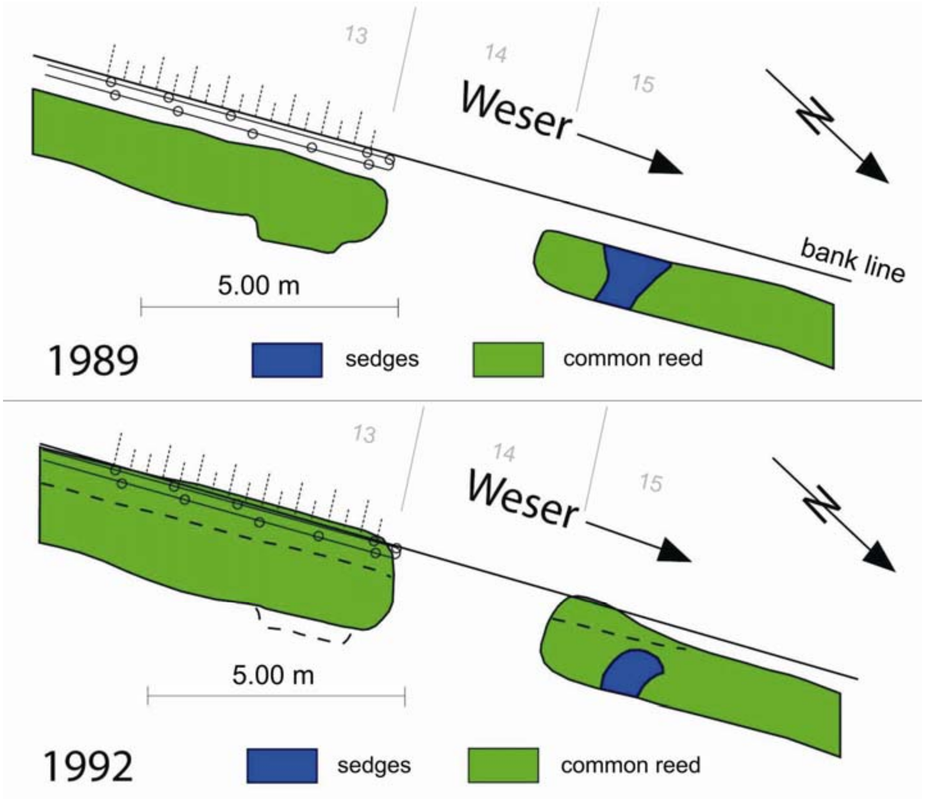


Figure 9.8: Vegetation development at the unmodified bank outside the groyne field area: on the left (Section 13) with a fascine as protection, and on the right (Section 15) without a fascine as protection

9.1.3 Condition of the test stretch in 1999

Mapping of the vegetation was carried out on the scale 1:500 (cf. Appendices 9.1-1 and 9.1.2).

Development of the non-woody species, in particular of the reed beds

Meanwhile, the reed beds had spread along the entire test stretch right to the bank line; that is, also into the areas not protected from wave action. Common reed was still dominant. The sedges showed a certain degree of persistence, and had thus frequently maintained the position in which they were planted, but without spreading. The reed bed plantings of both companies (cf. Chapter 4.1) and of the WSA Verden had developed equally well.

Along the entire test stretch, typical riparian zoning had developed: In the water there were, in some places, submersed macrophytes, such as the salt-tolerant nitrogen indicator fennel pondweed (*Potamogeton pectinatus*), which could now be verified at more growth locations than in 1989, and the alkaline and calcareous indicator species Eurasian water milfoil

(*Myriophyllum spicatum*). A belt of reed beds dominated by common reed and reed canary grass lined the bank. On its landward side a belt of vegetation adjoined in which quack grass (*Elymus repens*) was predominant. On the highest elevations of the banks a belt of tall forbs rich in stinging nettles (*Urtica dioica*) was found.

Development of the woody plants

In the bank section outside the groyne fields, on the slopes which had been left in their natural state, only the live brush mattress plantings were successful, while all other planting methods more or less failed. Almost all the alder that had been planted had died. By contrast, the woody plants planted inside the groyne fields on the flattened slopes had developed well. In addition, along the entire test stretch there had been a spontaneous succession of woody plant growth. The distinguishing species here were: oneseed hawthorn (*Crataegus monogyna*), various types of wild rose (*Rosa spp.),* blackthorn (*Prunus spinosa*), common buckthorn (*Rhamnus cathartica*), basket willow (*Salix viminalis*), hybrid crack-willow (*Salix x rubens*), black or European alder (*Alnus glutinosa*) and common or European ash (*Fraxinus excelsior*).

9.1.4 Condition of the test stretch in 2005

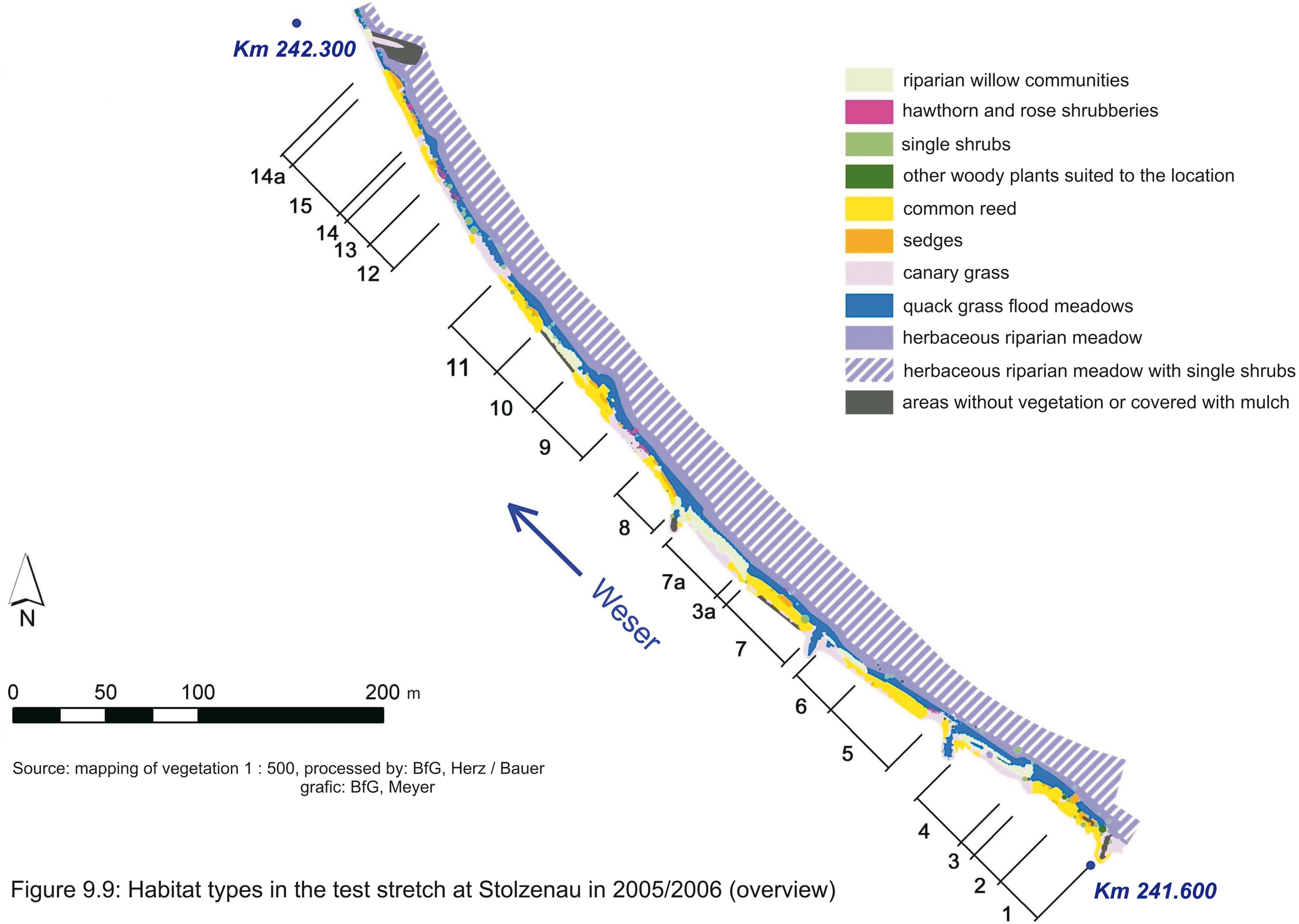
A repeat mapping on the scale 1:500 was carried out (cf. Appendices 9.2-1 and 9.2-2 and overview map, Figure 9.9).

Development of the non-woody species, in particular of the reed beds

The zoning corresponded to the mapping of 1999, while a certain dynamic effect was noticed. The woody plant succession had led to a reduction in area of non-woody plants, particularly among the (sparser) reed canary grass stands, in the transition areas between the vegetation belts and in the stands of tall forbs and, also – but to a smaller extent – among the common reed and sedge stands. In the reed bed belt, the yellow flag (*Iris pseudacorus*) had multiplied. The boundaries of areas dominated by tall forbs and quack grass had shifted slightly in some places, and a marginal increase in the area covered by quack grass was noticed. Some stands of pondweed had increased while others had disappeared.

Development of the woody plants

The woody plant succession had continued to develop. Several spontaneous incidences of black alder had in the meantime died off. A new tree variety, hedge maple (*Acer campestre*), had appeared.



Source: mapping of vegetation 1 : 500, processed by: BfG, Herz / Bauer
grafic: BfG, Meyer

Figure 9.9: Habitat types in the test stretch at Stolzenau in 2005/2006 (overview)

9.1.5 Condition of the test stretch in 2006

(See photographic documentation, Appendix 9.4)

In the years 2005 and 2006, a total of 75 higher plant species was recorded in the test stretch area (see list of species in Appendix 9.8).

Development of the non-woody species

The four dominant herbaceous vegetation types were substantiated with photographs of the vegetation (cf. Table 9.1). **Vegetation type (1) reed bed of common reed** (Phragmitetum australis (Gams 1927) Schmale 1939) (Figure 9.10) has become well established in the test stretch and has spread in the vicinity of the banks (cf. also Figure 9.22, page 89).

Figure 9.10: **Vegetation type (1) reed beds of common reed** *(Phragmites australis)* in the area of vegetation (photographic) record No. 1 (14.09.2006); cf. Table 9.1)

In unplanned areas close to the bank, the dominant vegetation type is **Vegetation type (2), reed canary grass** (*Phalaris arundinacea*) **reed beds** (Phalaridetum arundinaceae Libb. 1931) (Figure 9.11). To the landward side, adjoining the reed bed belt, as **Vegetation type (3)** there is a **quack grass-flood meadow** dominated by quack grass (*Elymus repens*) and turniproot chervil (*Chaerophyllum bulbosum*) (Figure 9.12). Quack grass is a root creeping pioneer, a nitrogen indicator with deep roots that can withstand flooding and, like turniproot chervil, is frequently found on clay soils. The species of chervil is generally fairly rare, but is frequently found in drift line communities on riverbanks.

Figure 9.11: **Vegetation type (2):** Stand of **reed canary grass** *(Phalaris arundinacea)* rich in tall forbs with garden angelica *(Angelica archangelica)* in the area of the vegetation photograph no. 2 (14.09.2006; cf. Table 9.1)

Figure 9.12: **Vegetation type (3) quack grass flood meadow**, dominated by quack grass (*Elymus repens)* and turniproot chervil *(Chaerophyllum bulbosum)* in the area of vegetation photograph no. 3 (14.09.2006; cf. Table 9.1)

In the part of the test stretch far from the bank, which was not restructured and which, like the entire area of the study, was excluded from the use as grazing land in 1989 by the erection of fencing, the **Vegetation type (4), herbaceous riparian plants** developed as fallow ground vegetation dominated by stinging nettle (*Urtica dioica*), turniproot chervil (*Chaerophyllum bulbosum*) and false baby's breath (*Galium mollugo agg.*), all of them species which require nutrient-rich soils, (Figure 9.13).

Figure 9.13: **Vegetation type (4) herbaceous riparian plants** as fallow ground vegetation, dominated by stinging nettle *(Urtica dioica)* and turniproot chervil *(Chaerophyllum bulbosum)* in the area of vegetation photograph no. 4 (14.09.2006; cf. Table 9.1)

In 2006, no aquatic macrophytes (aquatic plants) were found. It is natural for the incidence of these plants to fluctuate widely.

Development of the woody plants

Of the eight 1.20 to 6 m high black alders, five are diseased and two have died (Figure 9.14 - 9-16). The diseased specimens showed symptoms of the lethal alder disease (*Phytophthora*-infestation, alder root collar rot), a disease that was discovered for the first time in Germany in 1995 and which is now widespread in almost all the German federal states /BBA 2003/. The symptoms seen here include tarry spots at the base of the stem and orange-red discolouration below the bark. The only tree that appears to be still healthy is a young specimen (1.20 m tall).

Table 9.1: Photographs of vegetation for the most important mapping units (14.09.2006)

No. of photograph of vegetation	**1**	**2**	**3**	**4**
Total coverage (%)	**100**	**100**	**100**	**100**
Number of species	**9**	**10**	**10**	**6**
Hedge bindweed *(Calystegia sepium* s. l.*)*	1	1	+	.
Ground ivy *(Glechoma hederacea)*	+	1	.	.
Gipsywort *(Lycopus europaeus)*	r	+	.	.
Marsh woundwort *(Stachys palustris)*	+	.	1	.
Tansy *(Tanacetum vulgare)*	r	.	+	.
Common reed *(Phragmites australis)*	5	.	.	.
Lesser pond sedge *(Carex acutiformis)*	+	.	.	.
Common comfrey (*Symphytum officinale* s. l.)	+	.	.	.
Creeping thistle *(Cirsium arvense)*	.	1	+	1
Reed canary grass *(Phalaris arundinacea)*	.	5	.	.
Yellow flag *(Iris pseudacorus)*	.	1	.	.
Garden loosestrife *(Lysimachia vulgaris)*	.	1	.	.
Sneezeweed *(Achillea ptarmica)*	.	+	.	.
Garden angelica *(Angelica archangelica)*	.	r	.	.
Quack grass *(Elymus repens)*	.	.	3	1
Turniproot chervil *(Chaerophyllum bulbosum)*	.	.	2m	2a
False baby's breath (*Galium mollugo* agg.)	.	.	+	2m
Orchard grass (*Dactylis glomerata* s. str.)	.	.	3	.
Common wormwood *(Artemisia vulgaris)*	.	.	+	.
Stinging nettle *(Urtica dioica)*	1	+	2m	4
Eltrot *(Heracleum sphondylium)*	.	.	.	+

Mapping units (Vegetation types)

1 **Reed beds of common reed** (*Phragmites australis*) (Gams 1927, Schmale 1939
2 **Reed canary grass** (*Phalaris arundinacea*) **reed beds** with rich variety of forbs with garden angelica (*Angelica archangelica*) (Phalaridetum arundinaceae Libb. 1931)
3 **Quack grass flood meadow** dominated by quack grass (*Elymus repens*) and turniproot chervil *(Chaerophyllum bulbosum)* (Rumici crispi-Agropyretum repentis Hejný in Hejný et al. 1979)
4 **Herbaceous riparian meadows** dominated by stinging nettle (*Urtica dioica*) and turniproot chervil (*Chaerophyllum bulbosum*)

Vegetation cover data according to /Reichelt, Wilmanns 1973/

r single plant at < 5 % cover
+ 2 -5 single specimens with < 5 % cover
1 6-50 single specimens at < 5 % cover
2 m > 50 single specimens at < 5 % cover
2a 5-15 % cover
2b > 15-25 % cover
3 > 25-50 % cover
4 > 50-75 % cover
5 > 75-100 % cover
Surface areas: 10 m² each

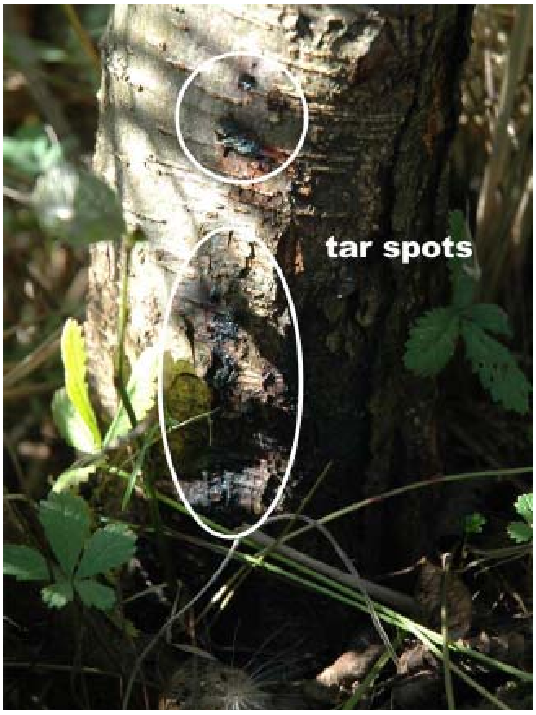


Figure 9.14: Black alder (*Alnus glutinosa*) with symptoms of *Phytophthora* infestation (alder disease): left: with irregular crown and strong fruit setting; right: so-called tarspots at the base of the stem. In 2006, 5 of 6 alder trees in the test stretch showed these symptoms (Alder 1, Section 14a, 13.09.2006)

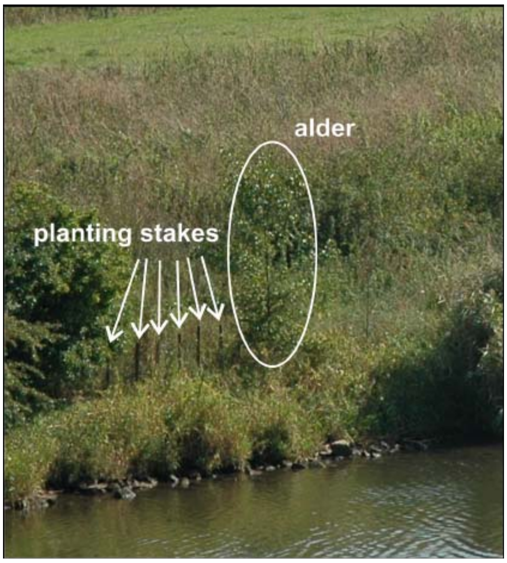


Figure 9.15: The planting stakes of the alder planted in Section 14a were still there in 2006. Centre of photo: The only surviving, but diseased, alder tree (see above; 13.09.2006)

Figure 9.16: Stem base of a dead black alder tree (Alder no. 2; Planning section 14a; 13.09.2006)

9.1.6 Implemented maintenance measures

According to information from the WSA Verden, no maintenance work had been required in the direct vicinity of the bank since installation of the test stretch. Only in the area of the groynes, the riprap embankment was renewed and the vegetation on the back of the groynes removed at regular intervals. The signposting for shipping was also kept free of vegetation.

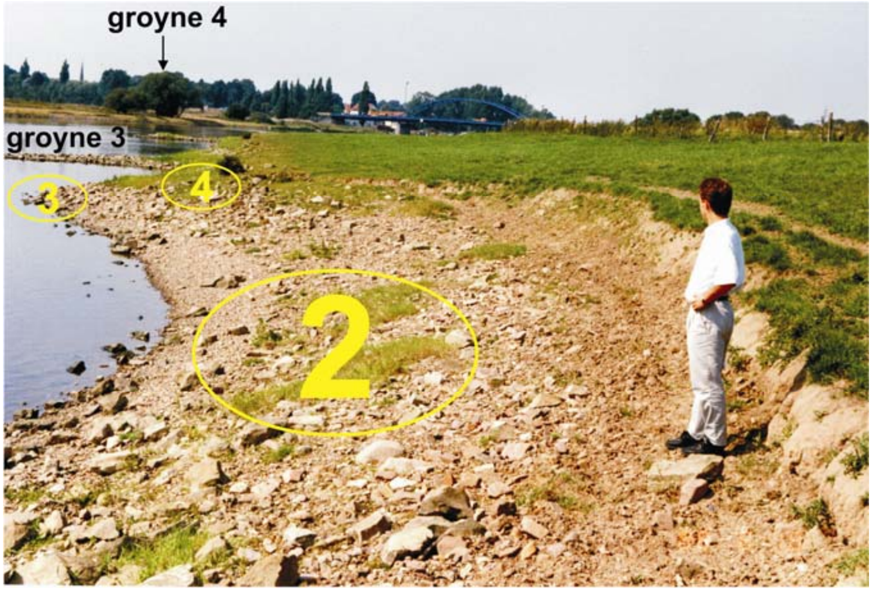
After completion in 1989, signs prohibiting angling were set up to prevent human impact on the bank protection measures. According to the WSA Verden, the prohibition of angling at the heads of the groynes was repealed in 1995 following an inspection. Access to the heads of the groynes was, however, correspondingly fenced off.

Figure 9.17: Beaten tracks, waste material (mainly bottles, but also items such as a nylon cord) and the remains of bonfire area (on groyne 3) prove that the test stretch is accessed and probably used by anglers (14.09.2006)

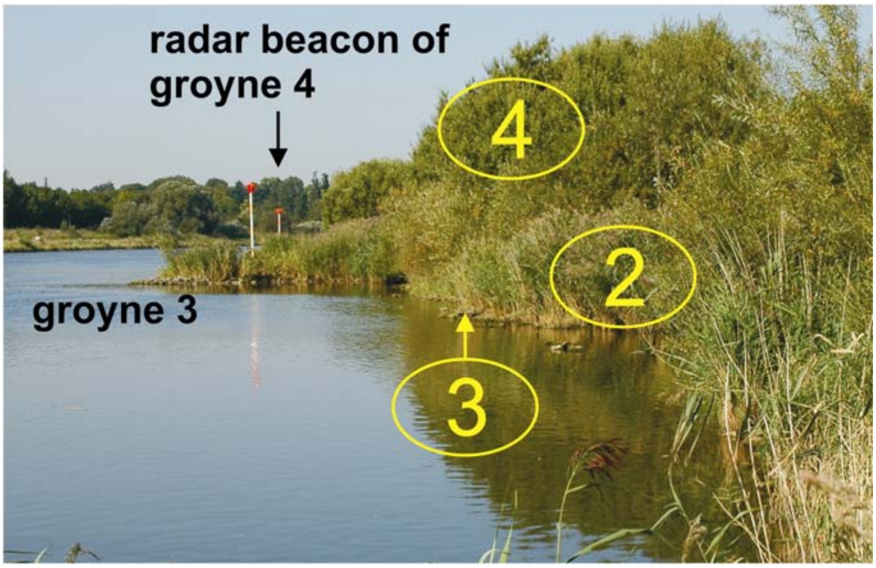
9.2 Comparative analysis of the present studies

9.2.1 Spatial and temporal development

Time comparison: Planning sections 2 to 4 in the years 1988 and 2006



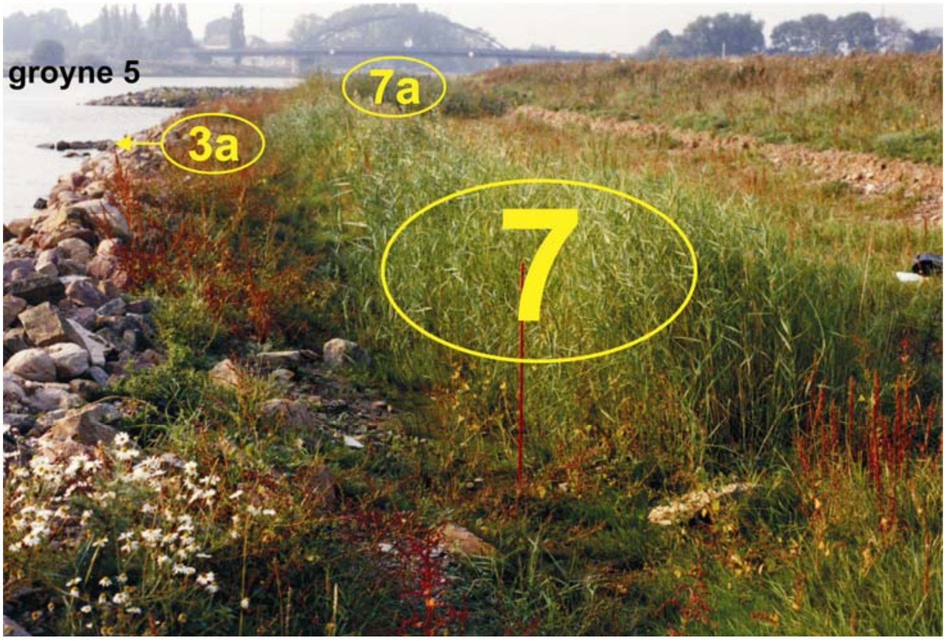
1988



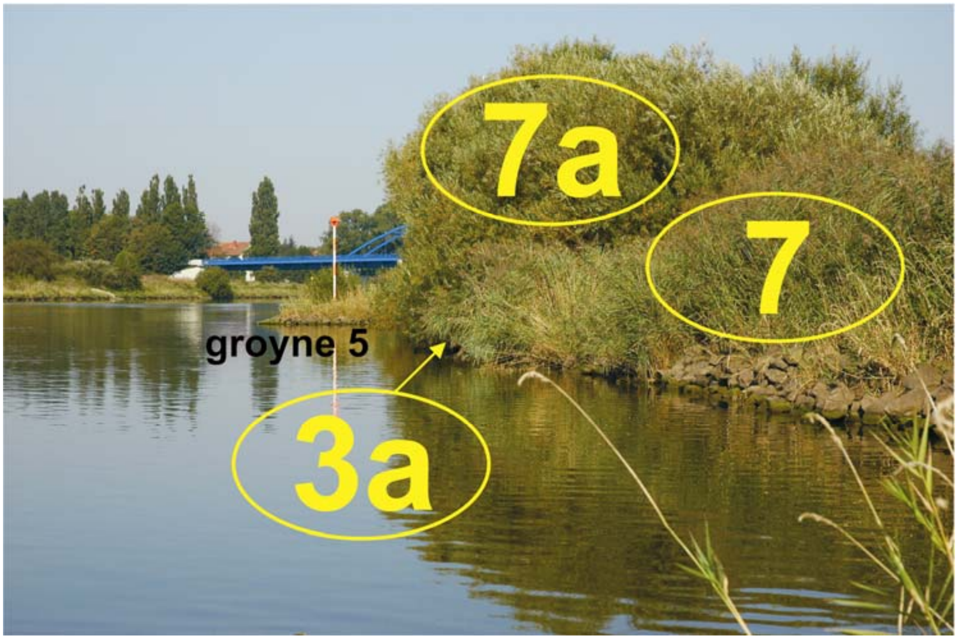
2006

Figure 9.18: Flattened bank slope with “break in the cliff line”, **2:** 1988: before the planting of the reed beds, 2006: with dense belts of reed beds, **4:** 1988: before setting of the willow cuttings, 2006: with 7 m high willow shrubbery; **3:** stub groyne

Time comparison: Planning sections 7 to 7a in the years 1989 and 2006



1989



2006

Figure 9.19: Flattened bank slope, **7:** with reed beds, **7a:** with willow live brush mattresses; **3a:** stub groyne (in 2006 overgrown)

The time comparison (Figures 9.18 and 9.19) illustrates the overall positive development of the reed beds and willow plantings. Between 1989 and 1999, the area of the common reed spread out to more than ten times its original size (Figure 9.20). By contrast, between 1999 and 2005, there was a loss of area of common reeds of more than 5 %. On the other hand, the woody plants continued to increase.

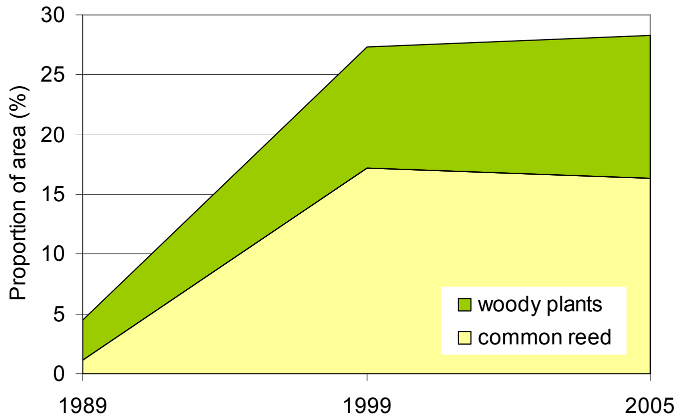


Figure 9.20: Development of the vegetation units common reed and woody plants from 1989 to 2005 on the surfaces in proximity to the bank, mapped on a scale of 1:500 (excluding the hinterland, which is dominated by tall forbs and is shown in Figure 9.9 as a shaded area).

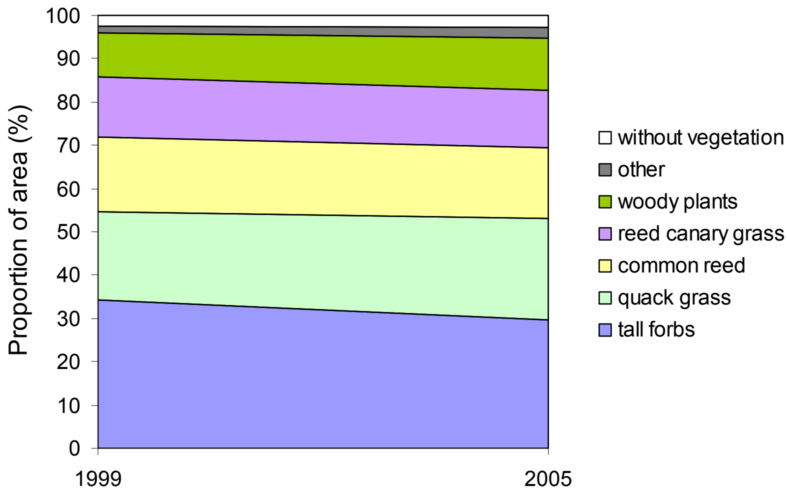


Figure 9.21: Development of all vegetation units from 1999 to 2005 on the surfaces in proximity to the bank, mapped on a scale of 1:500 (excluding the hinterland that is dominated by tall forbs and is shown in Figure 9.9 as a shaded area).

The spread of both vegetation units was planned; however, in the meantime a situation has developed in which the two are in competition. The spread of the woody plants took place at the expense of the common reed and reed canary grass reed beds (Figure 9.21), which can be explained by the increase in the amount of shade. The displacement of the common reed is seen as a negative trend, and an appropriate maintenance measure will be proposed (cf. Chapter 11.2). With the increase in the quack grass meadows between 1999 and 2005, it was mainly tall forbs which were lost. Between 1999 and 2005, however, there was, on the whole, no large percentage of change in the surface areas of the different vegetation units.

Figure 9.22: The reed bed of common reed in Section 13 has spread out on the riverward side beyond the level of the fascine that was built here in 1989 (photo, left). In the photograph on the right, the stakes for the fascine can still be seen (13.09.2006)

All reed beds of common reed that were planted spread out both to the bank line and along the bank. Between 1989 and 2005, the reed beds spread out parallel to the bank along an average distance of 5.70 m (maximum 17 m) in both directions.

As expected (cf. /Bestmann 1991/), the reed beds could develop better on the flattened banks than on the natural banks with steeper, unmodified slopes. On these flattened banks, the belts of reeds became wider, as they had favourable conditions both on the riverward side and on the landward side (Table 9.4, cf. Figure 9.23).

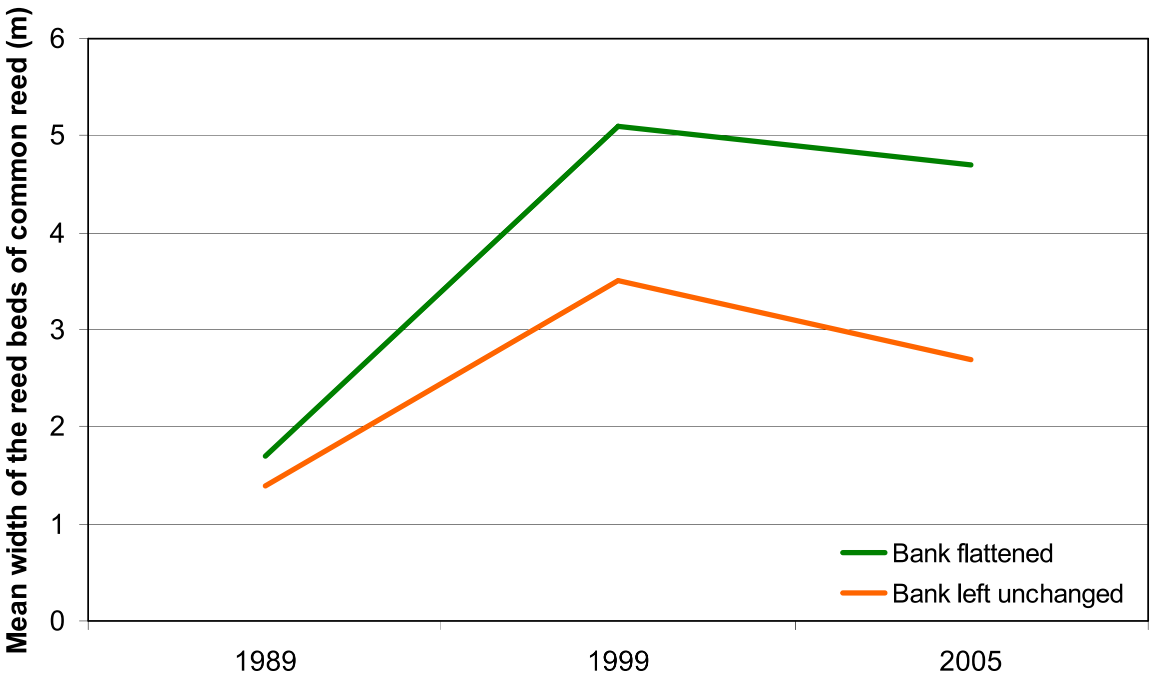


Figure 9.23: Development of the reed beds of common reed depending on the morphology of the banks (six reed bed plantings on flattened banks and three on unmodified bank slopes)

The planted woody plants, in particular the black alder trees, showed a noticeably high mortality rate. Of the 21 black alder trees in Sections 14 and 14a, the majority had died by the third year after planting; in 1999, black alder specimens were no longer found in these sections. The willow cuttings and long branch cuttings in Sections 9 and 12, about 150 in number, had, by 1992, also largely died off. In 1999 only two willows were still found in these areas. There are several possible reasons for this high mortality rate. In Sections 12, 14 and 14a, the slope inclination and the protection with armour stones were retained. The woody plants were placed in each case in the higher zone of the embankment both in these sections and also in Section 9 (Appendix 4.2-2). Furthermore, the precipitation between 1989 and 1991 was well below the long-term mean (Figure 9.24).

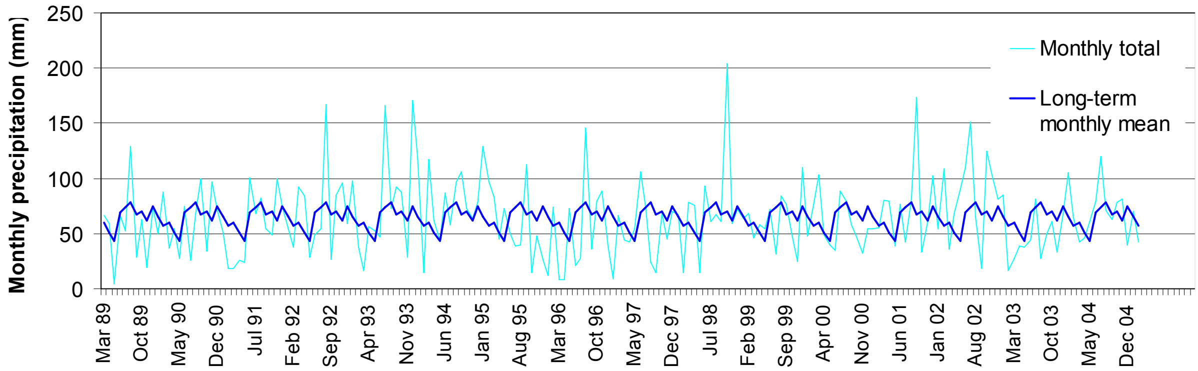


Figure 9.24: Monthly precipitation total at Nienburg/Weser and the long-term mean of the monthly totals for comparison; statistics from German Weather Service /DWD 1988 - 2003; DWD 2004 - 2005/

The water levels in the vegetation periods of this time span were also frequently below normal levels (cf. Appendices 5.6 and 5.7 and Figure 9.26). Consequently, a large part of the woody plants probably dried up.

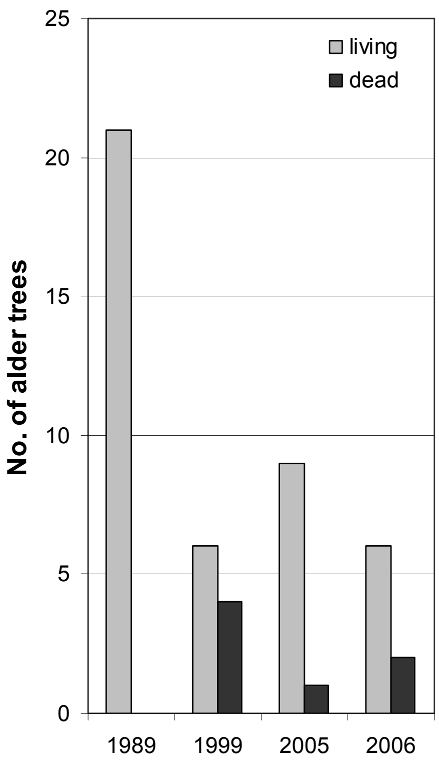


Figure 9.25:

Number of black alder trees *(Alnus glutinosa)* in the test stretch between 1989 and 2006

In the case of black alder, another possible cause exists. In 2006, symptoms of alder disease were found in several alders in the test stretch, which explains the loss of at least some of the trees of this species (cf. Chapter 9.1.5). Apart from the alder that was planted, this species of tree also played a certain role in the spontaneous succession of woody plants (Figure 9.25).

9.2.2 Vegetation zoning in relation to water levels

Figure 9.26 shows the incidence of the mapping units in relation to sea level and to water levels. Common reed and reed canary grass occur in strongly overlapping height zones, mainly at around MW (26.90 m a.s.l.) 50 cm. For these two units no significant difference in height could be demonstrated (the dents in the two box plots in Figure 9.26 overlap). On the contrary, the main incidences of quack grass meadow (27.50 m a.s.l. to 27.90 m a.s.l.) and tall forb meadow (28.25 m a.s.l. to about 30 m a.s.l.) are clearly distinct from the reed beds and from each other.

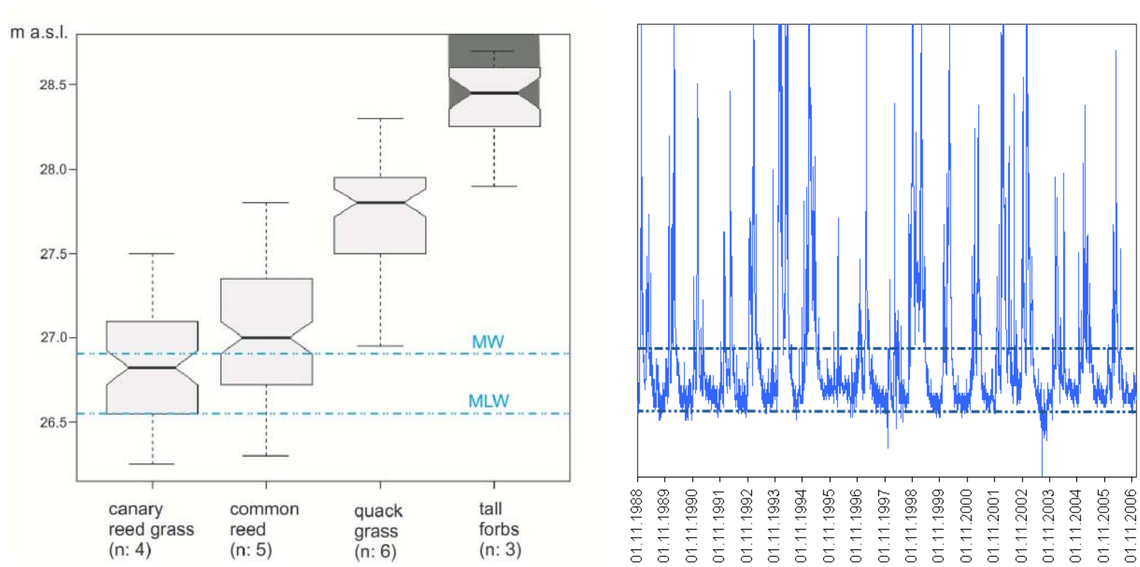


Figure 9.26 Incidence of the mapping units in relation to sea level and to the water levels
Explanation: Derived from 7 cross sections and 2 vegetation maps, which were each recorded in the same period of time. As not all mapping units are represented in all cross sections, the survey sample sizes (n) differ. The upper limit of the tall forb meadow was not noted in the vegetation maps that were available for this, so the right box plot reflects only the stands up to 28.70 m a.s.l., as indicated by the shading. It can be assumed that the upper limit of the tall forb meadows lies between HNW (29.12 m a.s.l.) and HHW (30.5 m a.s.l.).

The main stands (75 %) of common reed or reed canary grass reed were under water on average for 47 or 68 days respectively (and for a maximum of 108 or 131 days respectively) during the years since planting. For the quack grass meadow, this figure was 18 (maximum 63) and for the tall forbs (assuming a 75 % limit of 29.30 m a.s.l.) 3 days (maximum 15 days). As common reed and reed canary grass both have aeration tissue, not only does the submerging of their location play an important role, but also the submerging of the entire plant. With an average height of 2 m for common reeds and 1 m for reed canary grass, and without including the bending of the plants in the current of the river, it can be assumed that the main stands of the common reed were completely submerged for an average of 3 days (maximum 15 days), and those of the reed canary grass for an average of 14 days (maximum 52 days) per vegetation period.

The duration of the flooding periods for the common reed and reed canary grass, as recorded here, lies below the aforementioned limit values that would normally be expected. The literature speaks of flooding periods for common reed of 50 to 250 days per annum and for reed canary grass of 50 to 150 days per annum /Duel 1991, Hensens et al. 1998/. This explains the competitive pressure on the reed beds from woody plants. The areas with reed beds are, at least in part, also able to support woody plants.

Similar submergence tolerances for common reed and reed canary grass are not surprising, as both are typical reed bed plants in the zone of fluctuating water levels. However, as is well known, these two species react differently to flow velocities and wave action /Sundermeier et al. 2008/.

As demonstrated in Figure 9.9, common reed occurs within the test stretch mainly in the bank sections parallel to the river, where the current is relatively gentle, whereas reed canary grass also frequently colonizes the groyne heads which are exposed to current and wave action (Figure 9.27). In Figure 9.28, the common reed also shows signs of damage where it extends into deeper water, even in a bank section parallel to the river; this damage is obviously the result of wave action.

As expected, no distinct salt indicators were found among the plant species. Fennel pondweed (*Potamogeton pectinatus*), however, was one salt-tolerant aquatic plant found here. Among the riparian plants, a series of salt-tolerant species was present, e.g. garden angelica (*Angelica archangelica*), British yellowhead (*Inula britannica),* purple loosestrife *(Lythrum salicaria*) and silverweed (*Potentilla anserina*). These were mainly concentrated in the mapping unit of reed canary grass, the unit which is flooded for the longest period.

Figure 9.27: The reed canary grass *(Phalaris arundinacea)* at the left-hand edge of the photograph, and the almond willow *(Salix triandra)* at the right-hand side, showed a relatively high degree of tolerance to wave action at exposed locations (such as here at groyne head 5) (14.9.2006, at low water)

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Figure 9.28: Common reed “outlier”, with visible damage from wave action: broken blades and puny shoots (Section 12, 13.09.2006 / at low water)

9.2.3 Evaluation

9.2.3.1 Success of planting and level of target achievement

The conversion from technical to technical-biological bank protection measures in the test stretch was successful. The planting of both reed beds and woody plants succeeded in almost all sections (cf. Figure 9.33).

An overview of the planting methods that were successful or unsuccessful in the test stretch can be found in Table 9.2.

Apart from vegetation mats, all reed bed planting methods (plugs and sods, partially protected by woven coir fabric) were successful. In 1992, the common reed plants in the vegetation mats showed poor growth and little vigour. However by 1999, a dense stand of common reed had developed in the entire section, also in the area with mats. Among the species of reeds and sedges that were introduced, the common reed spread out substantially, while various types of large sedges remained more or less limited to the location in which they were originally planted. The flattening of the bank slopes in certain areas had a very positive effect. In these areas, wider belts of reed beds have developed, which, in turn, is advantageous for bank protection (Chapter 8), the appearance of the landscape and for the fauna (Chapter 10). In the bank sections with protection in the form of stone mounds or fascines, the reed beds spread more quickly than in the unprotected areas. In the former, they already reached or overgrew the fascines and stone mounds within the first three vegetation periods, while in the latter, they spread only partially beyond the original planting area during this period. In the areas without bank protection, however, the reed beds of common reed beds did, in the end, reach the bank line (at the latest by 1999).

Willow shrubberies from cuttings or long branch cuttings developed both on the flattened and on the unmodified bank slopes, provided they had been placed in the lower zone of the slope close to the hydrostatic water level. The introduction of woody plants on an otherwise unaltered slope was not successful if they were placed in the upper zone of the slope, i.e. at a greater distance from ground water. There they presumably dried up. In the areas in which the revetment was removed, vigorous willow shrubs developed from the live brush mattresses, even when the steep angle of the embankment slope was retained.

The diseased and dead alder trees which are obviously suffering from an infestation with *Phytophthora* (alder disease), or have died as a result of this, represent a threat of infection for the single apparently still healthy alder tree, as well as for any that may in future grow from seed.

The stands of woody plants require maintenance (Figure 9.33) and suitable measures are proposed for this in Chapter 11.2.

The significance of the groynes for the development of the vegetation cannot be determined, as differing bank topographies were selected inside and outside the groyne field. The overall development of the vegetation stands was positive, both inside and outside.

Table 9.2 Overview of the planting methods which were successful or unsuccessful in the test stretch

Planting methods	**Success of planting**			
	Very good	Good	Mo-derate	Failed
Planting of common reed and sedges				
a) Planting of root plugs and sods of common reed on flattened bank slopes with protection in the form of a stone mound or berm, and in some sections also with fascines or vegetation fabric	X			
b) Planting of root plugs and sods on steep bank slopes after removal of stones, with vegetation fabric as protection		X		
c) Planting of root plugs and sods of common reed on unmodified bank slopes (i.e. steep and with armour stone protection) with or without protection in the form of a training structure or fascine		X		
d) Planting of root plugs and sods of sedges (differing topography and protection, as in a) to c))		X[1)]	X[2)]	
e) reed mats on flattened bank slope				
Planting of woody plants				
f) Willow cuttings / long branch willow cuttings on flattened bank slopes with a training structure or fascine as protection	X			
g) Willow cuttings / long branch willow cuttings on an unmodified bank slope, if set close to the waterline and protected by a stone mound	X			
h) Willow brush mattresses on both flattened and steep bank slopes, where armour stones were removed beforehand	X			
i) Planting of alder trees in the upper zone of an unmodified bank slope				X
j) Willow cuttings / long branch willow cuttings, if placed in the upper zone of the (flattened or unmodified) bank slope				X

1) The sedges show a certain degree of persistence, and have thus frequently maintained the position in which they were planted, but without spreading.

2) In 1992 the common reed plants in the vegetation mats showed poor growth and little vitality. However by 1999, a dense stand of reeds had developed in the entire section, also in the area with mats. It is not possible to trace whether these plants originated from the common reed mats themselves or if they are the result of colonisation from neighbouring stands.

In both the unplanned sections of the test stretch and in the areas in which the settlement of woody plants at first had failed, spontaneous vegetation units typical for riparian sites developed.

9.2.3.2 Erosion control function and hydraulic load capacity of the measures

Almost all the planting measures that were carried out have developed in such a way that very good erosion control for the bank slopes exists today. Under the given conditions, reed beds of common reed provide better erosion protection than willow shrubs close to the bank (Figures 9.29 - 9.31 and 9.33). In comparison with other construction methods, reed beds of common reed do not tolerate large hydraulic loads, but these do not occur in the test stretch (Table 9.3).

Figure 9.29: Reed beds of common reed provide good erosion control, even on a bank section that has not been flattened and without a fascine as protection (Section 15, on 13.09. 2006, at low water)

Figure 9.30: Undergrowth below willows, close to bank, in Section 10 (14.09.2006, at low water)

Figure 9.31: More erosion of fine material close to the surface takes place under the willows (Section 10) than under common reeds because there is no continuous grass layer (14.09.2006, at low water)

Table 9.3: Hydraulic load capacity of the technical-biological bank protection measures in the test stretch according to the literature, as well as the actual hydraulic loads that occurred

	Parameters in vicinity of the bank			
	Shear stress τ	**Flow velocity v**	**Wave heights**	**Approach angle**
	Measurement and calculated results for the test stretch (Figure 5.17, Table nos. 6.1, 6.2 & 7.1)			
	≤ 6 N/m²	**≤ 1 m/s**	Drawdown: **Mean 0.14 m (Maximum 0.39 m)** Stern waves: **Mean 0.15 m (Maximum 0.64 m)** Secondary waves: **Mean 0.06 - 0.08 m (Maximum 0.18 m cargo vessels, 0.41 m recreational craft)**	non-critical, as slip-off slope
	Load capacity of technical-biological bank protection measures according to literature			
Plantations of reed beds	acc. to /LfU 1996/[1]: **55 - 65 N/m²**	acc. to /LfU 1996/[1]: **2.0 – 2.5 m/s**	*not specified*[2]	The lower τ- or **v** value in /LfU 1996/[1] applies to exposed stretches, and the higher value to straight stretches of waterways.
Dead-wood fascines	acc. to /LfU 1996/[1]: **70 - 100 N/m²**	acc. to /LfU 1996/[1]: **2.5 - 3.0 m/s**	*not specified*	The lower τ- or **v** value in /LfU 1996/[1] applies to exposed stretches, and the higher value to straight stretches of waterways.
Willow cut-tings	acc. to /LfU 1996/[1.3]: **100 - 150 N/m²** acc. to /Gerstgraser 2000/[4]: **80 - 120 N/m²**	acc. to /LfU 1996/[1.3]: **3.0 - 3.5 m/s** acc. to /Gerstgraser 2000/[4]: **2.2 - 2.8 m/s**	*not specified*	The lower τ- or **v** value in /LfU 1996/[1] applies to exposed stretches, and the higher value to straight stretches of waterways.
Willow brush mattresses	acc. to /Florineth 1982/[5]: **195-218 N/m²**	acc. to /Gerstgraser 2000/[4]: **3.2 - 3.5 m/s**	*not specified*	*not specified*

Data highlighted in grey: mean values for the entire body of water
[1)-5)] Annotations: see next page

1) The data in /LfU 1966/ refers, both for τ and for **v**, to the zone in close proximity to the bank and consists of calculated values a flood event on the Enz River in 1993 in the range of the calculated discharge 2 years after the installation of the protection measures. The values shown are load capacity values which were tolerated by the individual bank protection measures or are values for which it can be assumed that they lie below the load capacity limit in each case.

2) According to /Sundermeier et al. 2008/ the common reed cover at banks which were left in their natural state decreases sharply from a wave height of ≥ 20 cm (secondary waves and wind waves); for aquatic plants in general /PIANC 2008/ states that secondary waves > 15 cm have a considerable effect.

3) The information in /LfU 1996/ refers to willow cuttings in riprap.

4) The information in /Gerstgraser 2000/ refers to willow cuttings combined with a woven coir fabric. The mean flow velocity in the main channel and the shear stress at the bed are shown. The values shown were tolerated by the bank protection measures or it can be assumed that they lie below the load capacity limit in each case.

5) /Florineth 1982/ states the shear stress for the zone with the willow live brush mattresses. A 15-month-old willow brush mattress withstood the load without damage while a 3-month-old brush mattress was slightly damaged.

The values calculated for shear stress and flow velocity for the test stretch (cf. Chapter 5.3.2) are very low when compared with the load capacity known from the literature on the type of technical-biological measures used here (Table 9.3). This is due to the large cross section ratio, the large distance of the navigation channel from the relevant bank, water level regulation and the location of the test stretch in the slip-off slope zone. The positive development of the vegetation corresponds to this condition, in particular that of the most sensitive type of measure, the planting of reed beds.

Since more research still needs to be carried out regarding the load capacity of technical-biological bank protection measures in regard to ship-generated waves, no general boundary values could be specified in Table 9.3. From the results from the test stretch, however, it can be concluded that the technical-biological bank protection measures applied here are able to withstand the wave heights generated by shipping as stated in Table 9.3. These values can thus be regarded as initial boundary values that lie on the safe side. Whether larger waves can be absorbed without damage cannot be determined until more experience has been gathered in the scope of the present research project.

9.2.3.3 Assessment from the point of view of nature conservation

Neither mapping material nor an assessment of the initial situation before installation of the test stretch was available; only a brief description exists. According to this, the area of the test stretch was grazed right to the banks (cf. Chapter 4.1 and Figure 4.1, page 7) and along the bank there were small groups of bushes, isolated colonies of reed canary grass and some tall forbs.

In Figure 9.32 the assessment of the habitats of the test stretch according to /Bierhals et al. 2004/ is depicted cartographically.

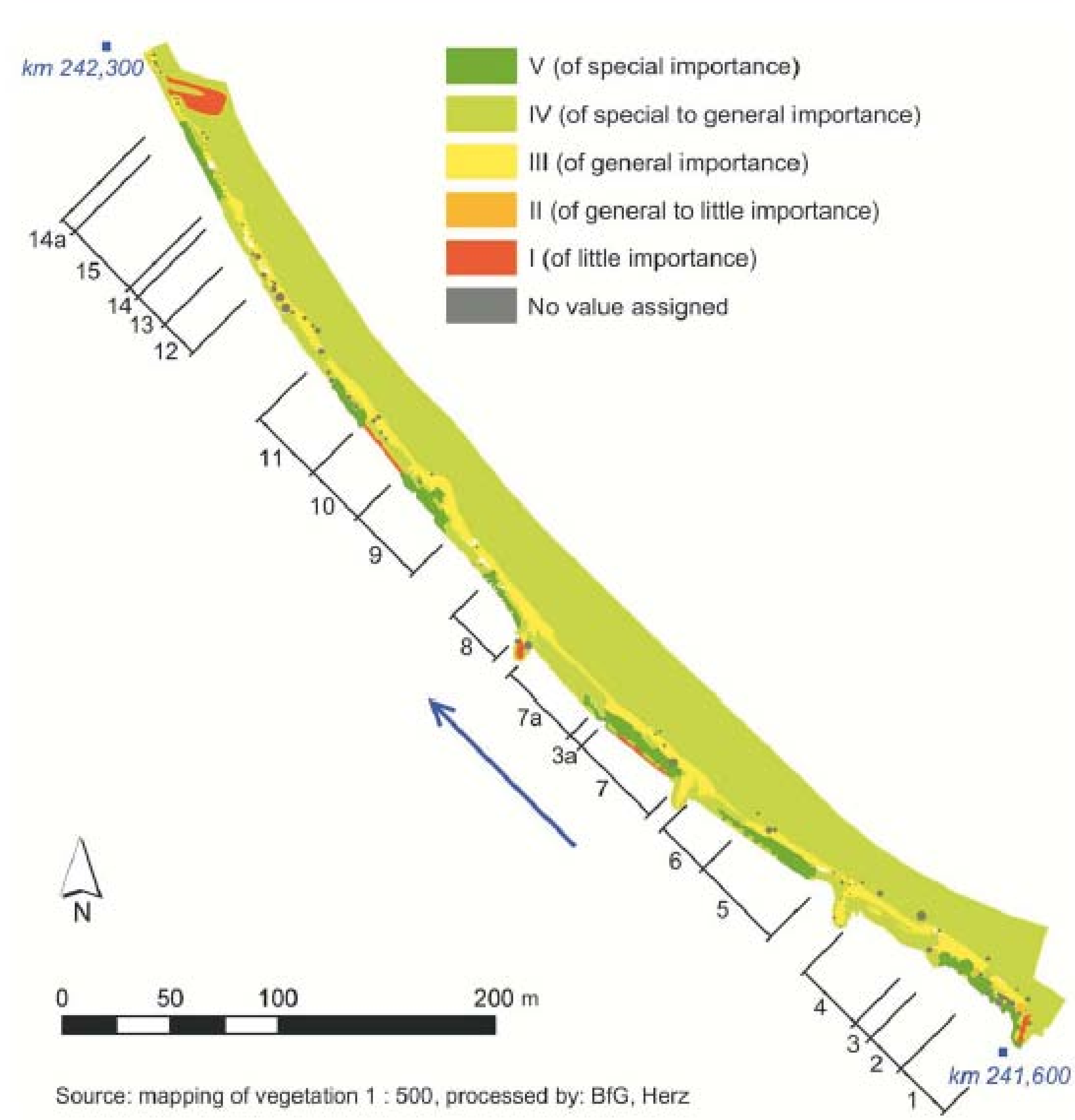


Figure 9.32 Value of the biotopes (habitats) according to /Bierhals et al. 2004/ (as in 2005/2006) (habitat types cf. Figure 9.9)

This evaluation method takes the following criteria into account: closeness to natural state, threats, scarcity and "significance as a habitat for plants and animals". In particular the criterion "closeness to natural state" can be applied only to a certain extent to technical-biological bank protection measures. As no evaluation system has been developed so far for biotopes along waterways, the study mentioned above was used as a basis.

According to § 30 BNatSchG (Section 30, Federal Nature Conservation Act), reed beds are protected throughout Germany. According to /Bierhals et.al. 2004/, reed beds of common reed are, as a rule, considered to be biotopes **of special importance**. In Lower Saxony they are protected in accordance with § 28a NNatG (Section 28, Nature Conservation Act of Lower Saxony) if they are at least 50 m^2 in area and at least 4 – 5 m in width /Drachenfels 2004/. In the evaluation map (Figure 9.32), the highest value level was assigned exclusively to large protected common reed areas of this type. According to /Bierhals et al. 2004/, biotopes such as riparian willow communities (also protected under certain conditions), reed canary grass areas (which are protected by the NNatG under the same specifications regarding area as common reed) and herbaceous riparian meadows are **of special to general importance**. Quack grass flood meadows are assigned the value level "**of general importance**". According to /Bierhals et al. 2004/, biotopes such as "other woody plant stands suited to the location" are of **general to little importance** and sealed surfaces or vegetation-free areas are of **little importance**. Single bushes are not assigned any special value. The large sedges that were planted show some persistence. They did not expand significantly in area, but they have maintained the location in which they were planted and thus contribute to the diversity of species in the area.

In contrast to its initial state, the vegetation in the test stretch today provides a high-quality complex of typical riparian habitats in terms of nature conservation. The bank sections which experienced uninterrupted succession and in which the reed bed belt is dominated by reed canary grass (*Phalaris arundinacea*) /Pott, Remy 2000/, which is resistant to current, flooding and sedimentation, are distinguished by their relative closeness to a natural state and the outstanding richness in species. In these reed bed zones, the yellow flag (*Iris pseudacorus),* which is specially protected, is present in large numbers. On the landward side, these sections are enriched by bushes such as common dogwood (*Cornus sanguinea),* oneseed hawthorn (*Crataegus monogyna*), blackthorn (*Prunus spinosa*), common buckthorn (*Rhamnus cathartica*), dog rose (*Rosa canina*), sweet-briar rose (*Rosa rubiginosa agg*.) and European black elder (*Sambucus nigra*), all of which with their various blossom and fruiting periods complement the willow varieties as biocoenologically valuable elements.

Common reed (*Phragmites australis*) is a typical reed species in stagnant and slow-flowing waters with wave action that is not too strong /Wörz 1998/. It did probably not exist at the main channel of the Middle Weser before the impounding of the river. Under the present-day conditions, this species has, however, become well established and has developed stands which are of great significance for the avifauna, amongst others (cf. Chapter 10).

The high overall value of the test stretch in terms of nature conservation lies in the diversity of its habitats which clearly exceeds that of neighbouring areas (Appendices 9.6. and 9.7.).

9.2.3.4 Overview of the evaluation

Table 9.4 summarises the development of the vegetation and contains, like Figure 9.33, an assessment of each planning section with regard to the success of the planting or the degree to which the target has been achieved, erosion control and an assessment in terms of nature conservation.

Table 9.4: Development of vegetation on bank sections with comparable layout (summarised here individually and highlighted in the same colour; cf. Table 4.1 and Figure 9.33) and the assessment thereof

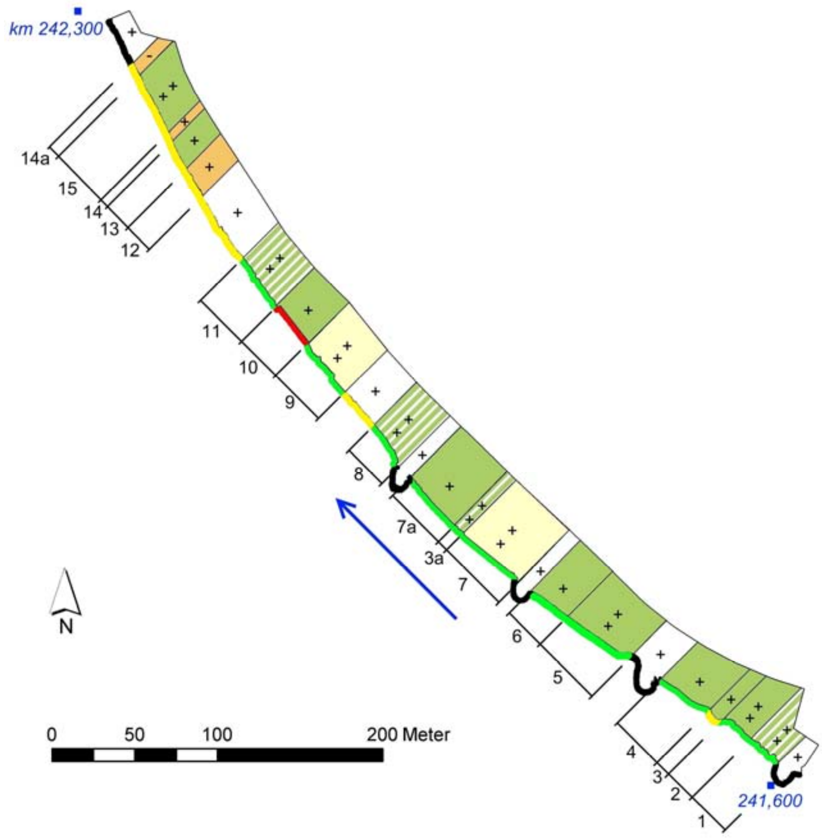
Section number	Development of the vegetation	Target achievement level	Erosion control	Value for nature conservation
1	- By 1992, common reed had already spread streamwards beyond the fascine - Belt of common reeds in 2005: 3 m wide - Succession of woody plants	Very good, in the long term, with care[1)]	Good	Very valuable
2	- By 1999, reed bed of common reed had developed as well as in **1** - 2005: 5.50 m wide	Very good	Good	Very valuable
3	- By 2005, especially common reed and reed canary grass had developed	Very good	Good[2)]	Valuable
3a	- By 2005, especially the reed beds of common reed and willow shrubs had developed - Succession of woody plants	Very good, in the long term, with care[1)]	Good	Very valuable
4	- By 2006, a 7 m high shrubbery of crack-willow hybrid and basket willow and a large grey willow bastard (*Salix x rubens, S. viminalis* and bastard *S. cinerea* bastard) had developed with a reed bed belt of reed canary grass (*Phalaris arundinacea*) and common reed (*Phragmites australis*) in front (riverward side).	Very good	Good	Valuable
7	- Good development of the reed beds of common reed (in 2005: 5 m wide), with exception of the common reed mats - Succession of woody plants	Partially successful	Good	Very valuable

Section number	Development of the vegetation	Target achieve-ment level	Erosion control	Value for nature conservation
7a	- By 2006, a 6 m high shrubbery of basket willow and a basket willow bastard (*Salix viminalis* and bastard *S. viminalis*) developed with a reed bed belt of reed canary grass (*Phalaris arundinacea*) and common reed (*Phragmites australis*) in front (riverward side).	Very good	Good	Valuable
5	- Good development of the reed beds of common reed (in 2005: 6 m wide) - Succession of woody plants	Very good	Good	Very valuable
6	- By 2006, a 7 m high shrubbery of basket willow and a basket willow bastard (*Salix viminalis* and bastard *S. viminalis*) developed with a reed bed belt of reed canary grass (*Phalaris arundinacea*) and common reed (*Phragmites australis*) in front (riverward side).	Very good	Good	Valuable
8	- Good development of the reed bed of common reed (in 2005: 2.50 m wide) - Succession of woody plants	Very good, in the long term, with care[1)]	Good	Very valuable
13	- By 1992, common reed had already spread streamwards up to the fascine - In 2005: 2 m wide	Very good	Good[2)]	Valuable
15	- By 1992, common reed had only spread in places streamwards beyond the planting area - By 1999, the reed bed of common reed had de-veloped as well as in **13** - in 2005: 3.50 m wide	Very good	Good[2)]	Very valuable

Section number	Development of the vegetation	Target achieve-ment level	Erosion control	Value for nature conservation
9	- Several fascine stakes, contrary to the intention, sprouted and by 2006 produced a 6.5 m high shrubbery of basket willow and a bastard basket willow (*Salix viminalis* and bastard *S. viminalis*). - Apart from this, good development of the common reed (in 2005: 5.50 m wide) - The willow cuttings / long branch willow cuttings on the landward side did not develop into the desired shrubbery (represented in 1999 only by one individual).	Partially successful	Good	Very valuable
11	- The reed bed of common reed had developed well (in 2005: 3.50 m wide), but was threatened by the succession of woody plants	Very good, in the long term, with care[1)]	Good	Very valuable
10	- By 2006, a 6.5 m high shrubbery of basket willow and a bastard basket willow (*Salix viminalis* and bastard *S. viminalis*) had developed	Very good	Unsatis-factory	Valuable
12	- The willow cuttings / long branch willow cuttings have largely died off. In 2005, the woody plant succession in this section was dominated by one-seed hawthorn (*Crataegus monogyna)* and some varieties of rose (*Rosa spp.*). Apart from these, individual specimens of basket willow and a bastard grey willow (*Salix viminalis*, bastard *S. cinerea*) were found, with a belt of reed canary grass (*Phalaris arundinacea*) reed beds, yellow flag (*Iris pseudacorus*) and common reeds (*Phragmites australis*) in front (riverward side).	Failed	Good[2)]	Valuable
14	- By 1999, almost all the alder that had been planted had died. - Close to bank: reed bed belt of reed canary grass *(Phalaris arundinacea)*	Failed	Good[2)]	Valuable
14a	- In 2006, one planted alder (diseased) was still present - Close to the bank: reed bed belt of reed canary grass *(Phalaris arundinacea)*	Failed	Good[2)]	Of little value

Section number	Development of the vegetation	Target achieve-ment level	Erosion control	Value for nature conservation
Un-planned sections	- Close to the bank: reed bed belt mainly of reed canary grass - Partial succession of woody plants	Very good	Good[2)]	Valuable
Section with groynes or over-flow[4)]	- Close to the bank, growth of vegetation with a fairly large number of gaps	-	Good[3)]	Valuable

[1)] cf. Chapter 11.2
[2)] dense growth of reed beds in riprap
[3)] with technical protection only
[4)] overflow between the neighbouring gravel pit lake and the River Weser



Assessment of the success of the planting project		
	Very good	Measure successful; developed as intended
	Very good, with care	Measure successful; however, preservation requires soon maintenance action (removal of woody plants to protect the reed beds).
	Partially successful	Cuttings / long branch cuttings (Section 9) and common reed mats (Section 7) did not take root or took root only poorly, but the planting of common reed plugs was successful.
	Failed	Cuttings / long branch cuttings or planting of alder did not take root.
		Unplanned or with only technical protection (above all groynes)
Assessment of bank erosion control by means of vegetation		
	Good	Dense growth of reed beds at the bank where stones were removed and in the shallow water zones
	Good	Dense growth of reed beds in riprap
	Unsatisfactory	Shade of woody plants prevents dense undergrowth
	No data	With technical protection only
Assessment in terms of nature conservation (cf. Figure 9.32)		
++	Very valuable	With a noteworthy share of biotopes “of special importance”
+	Valuable	Predominantly biotopes “of general to special importance”; no noteworthy share of biotopes “of special importance”
-	Of little value	Biotopes “of little importance” dominate

Figure 9.33: Assessment of the vegetation of the planning sections in 2005 with regard to success of planting, bank erosion control and value in terms of nature conservation

10 Evaluation of the fauna

10.1 General Remarks

Complex processes of ecological reciprocity lead to the formation of a characteristic colonisation and typical features of the fauna in a given habitat. The faunistic component of diverse habitats cannot, therefore, always be compared. For this reason it is always necessary to draw on a reference situation for the evaluation of alternative bank protection measures with regard to their suitability as a habitat for fauna. For the Weser at Stolzenau, the stretches with alternative bank protection measures (AU) were compared with stretches which had conventional technical bank protection (RU), that is, riprap revetments on a bank with an inclination of 1:3. In order to evaluate the quality of aquatic, semi-aquatic and terrestrial habitats that are affected by various kinds of bank protection measures in terms of fauna, the avifauna (birds, Chapter 10.2), fish fauna (Chapter 10.3) and macrozoobenthos (MZB, benthic invertebrates, Chapter 10.4) were studied. The offices mentioned below carried out the studies of the fauna under the auspices of the BfG (Dept. U4, Fauna and Ecology); for further details please cf. Chapter 2.

- Beratungsgesellschaft NATUR dbR, Nackenheim (avifauna)
- BFS, Riedstadt (fish)
- Büro für Gewässerökologie, Karlsruhe (MZB)

The results for the Stolzenau test stretch are summarised here and evaluated with regard to the questions addressed by this research project.

10.2 Avifauna (birds)

10.2.1 Methodology of the study

In 2006, a survey on avifauna was conducted in the area of the alternative bank protection measures from Km 241.550 to 242.300 on the right bank of the Weser near Stolzenau. The avifauna of the opposite left bank (RU), which is protected by a conventional riprap revetment, was used as a reference.

The aim of the study was the mapping of all birds in an area of 30 m on each side of the accessible bank line (total width of study area = 60 m). The recording of the birds was mainly done by means of visual-acoustic methods (song) and observations on the basis of a combination of territory mapping and line transects. In particular, the following aspects should be noted:

- For the recording of particular species, quantitative territory mapping was used.
- Territories were derived from observations made during the breeding season.

- Between April and June, four inspections were made on the AU bank (protected with alternative bank protection) in the morning between 5.00 am and 10.00 am, with one additional inspection on the opposite reference bank (RU) and one more in the test stretch at night between 8.00 pm and 1.00 am. The data material is thus based on a total of at least six mapping sessions, each lasting several hours, in the period from April to June 2006.
- Breeding season: The observation period of the evaluation covers almost the entire breeding season of the birds. Some species that are expected to be found in the areas studied begin their breeding activity earlier (for instance, woodpeckers, from February onwards) while other species, in some instances, return very late from their winter quarters in Africa (spotted flycatcher, golden oriole) or may arrive late at their breeding habitat for reasons influenced by climate or, locally, by high water events. The observation period for these groups is slightly outside the value limits for the verification of a breeding status.
- A distinction was made between breeding birds and visiting birds (classification: cf. Table 10.1). The standard protocol for each single observation, apart from the data about the bird itself (age, sex, type of call) also includes behavioural parameters such as mobility, covey size, feeding and breeding behaviour, migration and flight parameters (height, direction), and information on the biotope, habitat and niche, as well as other parameters.

Table 10.1: Classification and abbreviations used for bird observations

Designation	Status
B	breeding bird (BP – breeding pair)
B-Rand	breeding at the edge of the study area
BV	suspicion of breeding
G	feeding guest, winter guest or migratory bird
N	invasive species, (zoo) escapees

10.2.2 Notes on the evaluation of bank protection measures as a habitat for birds

The criteria for evaluation of the bank protection measures as a habitat for birds are summarised in Table 10.2. The overall conclusion of all the ecological evaluations regarding avifauna is summarised in Table 10.5. The evaluation model "Fauna" /BfG 1996/ of the German Federal Institute of Hydrology (BfG) was used as the basis for the evaluation of the implemented bank protection measures as a habitat for birds and was adapted to the features of the river stretch studied and to the animal group "birds". To attain a specific value level in accordance with Table 10.2, it is sufficient if one of the following criteria is fulfilled:

- naturalness of species inventory;
- habitat structures (biotope structures and interconnectedness) and functional significance;
- anthropogenic impairment;
- restorability (the time required for a species typical of this habitat to become re-established after restoration of a specific or destroyed habitat).

For this evaluation method it is also necessary to undertake a characterisation of the species typical of this biotope (Chapter 10.2.3).

Table 10.2: Evaluation criteria for avifauna

Value level		**Naturalness of species inventory**	**Habitat structures (biotope structures and interconnectedness) and functional significance**	**Anthropogenic impairment**	**Restorability**
5 Very high	Dark green	The total number of species of breeding birds / guests is higher than the average value expected for the region. Indicator species and rare / threatened species are present, in part, at a high density. Possibly of high significance for feeding and/or winter guests.	Soil and vegetation are ideally constituted and provide birds with food and places for nesting. Size and interconnectedness of the biotopes are also adequate for more exacting species. Diverse and different biotope types also provide living space for biotope complex inhabitants. Very high potential for the proliferation of species typical of biotopes.	Not present, or minimal	Very long-term > 150 years
4 High	Pale green	The species population of breeding birds / guests reaches the value expected for the region. Indicator species and threatened species are present. Generalists are not dominant.	Through their size or interconnectedness, the biotope structures provide a good basis for colonisation and support a high potential for proliferation of species typical of biotopes.	Low	Long-term 81 - 150 years

Value level		Naturalness of species inventory	Habitat structures (biotope structures and interconnectedness) and functional significance	Anthropogenic impairment	Restorability
3 Average	Yellow	In the biocoenosis, generalists are dominant, but species typical of the biotope also occur. An average diversity of species is prevalent.	While the structures of significance for birds provide possibilities for colonisation, the constitution of the biotope is only of average quality. This area, however, only exists on a small scale – disturbing areas and accessible habitats are present in equal measure, and there is no disturbance or separation effect on other biotopes.	Clearly perceptible	Medium-term 31 - 80 years
2 Poor	Orange	The number of species is low and species typical of the biotope are mostly absent. Generalists are dominant. The area has, at most, some significance for feeding guests.	The biotope structures are poorly suited to colonisation by species typical of the biotope. The area has a separation effect for very exacting species and yet for other species it may have an interconnecting function.	Frequent or periodically recurrent	Short-term 4 - 30 years
1 Very poor	Red	Only a few species exist, exclusively generalists. Species typical of the biotope and threatened species are absent.	The habitat is completely characterised by anthropogenic influences and provides no or very few structures which could serve birds in their search for food or as nesting places. As a result of too much disturbance, little interconnectedness or unfavourable structures, the biotope is moreover rarely used as a resting place.	Permanent or very frequently recurrent	Very short-term 1 - 3 years

10.2.3 Evaluation basis for the naturalness of the bird species inventory and threat and protection aspects

The indicator species model /Flade 1994/, which provides detailed principles regarding indicator species, stenotopic species and regular accompanying species for various types of habitat was consulted for the characterisation of the naturalness of the species inventory that was found. The indicator species system takes into account the existence or lack of species groups with a relatively high degree of specialisation. In the flood plains, it is common to find semi-open, richly structured mosaic landscapes with park-like character in which small areas of wet grassland, copses, shrubberies, hedges, reed beds, wet fallow ground and, often, bodies of water alternate. It is not really possible to divide these different moist landscapes into their various elements and assign them to other landscape types; furthermore they host a number of very characteristic bird species. The demands made by indicator species on a habitat reflect the diversity of the habitat of the meadows. Because of the divergent structure, the linear and surface area evaluations for the indicator species of the "meadows" were combined. The indicator species model was supplemented by the indicator species list taken from the "Auen-Fauna-Datenbank /AUA/" (Flood-Plain Fauna Database) produced by the ETH Zürich (Swiss Federal Institute of Technology Zürich) (http://www.agroscope.admin.ch/auen-fauna-datenbank/index.html?lang=en). The latter is often used in the field of nature conservation. The aim of the study is to determine whether the species inventory for the area of the study corresponds to the value normally expected for the region. For the evaluation of species categorised according to the "Red List", the value levels according to Table 10.3 apply. In addition, a study was made as to whether typical and interconnecting habitat structures are present for birds in these meadows.

Table 10.3: Value levels of the Red List for Germany /Rote Liste D 2002/

Red List Germany (2002)	
0	Population extinct
1	Threatened by extinction
2	Strongly threatened
3	Threatened
R	Species with geographic restrictions
V	Near-threatened
-	Not threatened
IV	Insufficient data
II,III	No criteria survey

10.2.4 Evaluation principles for biotope structures, interconnectedness and functional significance

A study was conducted to prove whether typical habitat structures exist in the floodplains or not. If a small scale mosaic of habitat structures is present for an area, this leads to a high density of breeding birds. These habitats may, for instance, be more or less well structured remnants of lowland riparian forest which are connected to dense bank vegetation by mostly small areas of common reed. In addition, the study examined whether certain areas have a high potential for the proliferation of species typical of the biotope. Sand or gravel banks with little vegetation form a typical habitat for some limicoles (waders) such as the common sandpiper and little (ringed) plover. Nonetheless, these soils and vegetation types that are distinctly shaped by the dynamics of water frequently prove to be species-poor, as other bird species do not settle these areas. In such a case, an evaluation at the value level “very high” (Table 10.2) would seem inappropriate. This is all the more true when bank structures have originated as isolated measures without being integrated into a biotope complex. However, they are certainly valuable in terms of species protection for the little (ringed) plover. In connection with the creation of habitats typically found in floodplains, they represent a temporary sub-habitat, the value of which can at best be classified as high.

10.2.5 Evaluation principles for anthropogenic impairment

Anthropogenic impairment of an area of riverbank occurs principally as a result of light, noise and particle emission, the discharge of pollutants, movement of vehicles, leisure pursuits, agriculture, grazing and hunting. The impairments may be classified as low when, for example, dense vegetation ensures that no leisure pursuits are possible in the area. Even a nearby camp site will then often have no effect on this evaluation. An area can be subject to a higher degree of anthropogenic influence when a frequently-used cycle path leads directly along its boundary. Proximity to urban districts frequently leads to higher impairment as well as, as the number of dogs being walked can be quite high. Some areas are also intensively cultivated, for instance, as orchards. Popular locations for angling also play a role in the evaluation, as access paths to the banks are often used by motorised vehicles. Noise emission from road traffic is another cause. High levels of impairment lead to a lower evaluation, for instance, to the value level “poor”.

10.2.6 Evaluation principles for restorability

The restorability of the habitat structures in a given area is categorised as long-term (81-150 years), especially when it features an existing tree stand of the remnants of riparian forest (poplars, oak and also walnut trees). A mid-term restorability can be assumed, for example, on the basis of the absence of remnants of riparian forest and the currently existing inventory of other trees. The evaluation naturally also takes the age of a bank measure into consideration. If it has been created only in recent years, it will have a very short-term restorability. This does not in every case lead to a devaluation of the measure. These short-lived succession stages, which generally occur along rivers in the form of gravel banks or undercut banks with sandy steep faces, are not important because of their long-term restorability, but because of their existence – even if it is only short-lived.

10.2.7 Results in detail

10.2.7.1 Characterisation of biotope and habitat structures available to birds in the area of the alternative bank protection measures and the reference stretch

A relevant factor for the existing bird populations is the fact that the 30 to 50 m wide strip of bank is particularly well protected from anthropogenic disturbance because it cannot be accessed easily. The area of study lies in what is now a narrow strip of land bounded on one side by the Weser and on the other by a complex of gravel pit lakes from which sand and gravel are still being extracted. The cattle pastures adjoining the area are of additional significance for the bird population. On the riverbank side, birds find a habitat in shrubberies, grasses and reeds. Unlike the reference bank, the alternative bank protection measures by and large provide the avifauna with a relatively flat riverbank area which has continuous protection in the form of loose armour stones only in the aquatic zone up to the hydrostatic water level. On a strip of bank approx. 30 m in width, reeds, willow shrubberies and tall forbs provide a habitat for birds (cf. Chapter 9). Included in the bank protection measures between Km 241.550 and 241.930, there are also four stone groynes, about 10 to 15 m in length and lying 100 m apart, which can also be intensively used by birds.

Figure 10.1: Breeding bird (Eurasian reed warbler) typically found in reed vegetation at the bank of the River Weser near Stolzenau

10.2.7.2 Qualitative definition of the avifauna in the area of the alternative bank protection measures, possible impairments, condition and restorability

In the breeding season, a bird world of great diversity with species typical of the location was found in this relatively short, 750 m section of bank (Table 10.4). The indicator species included the following breeding birds: nightingale and common grasshopper warbler with one breeding pair (BP) each; Eurasian reed warbler (cf. Figure 10.1), willow warbler, reed bunting, common blackbird, chaffinch, common whitethroat, common chiffchaff and marsh warbler with several pairs. Of the threatened or strictly protected species, only one pair of common buzzards was breeding in the area of the alternative bank protection, in one of the few older trees. The indicator species included the following feeding guests: Eurasian penduline tit, sand martin (a large colony on the bank of a neighbouring gravel pit lake) and common tern. Numerous greylag geese and several Egyptian geese (invasive species) were breeding in the neighbouring gravel lakes and were regular feeding guests, but no nest was discovered in the studied area.

Table 10.4: Bird species on the Weser near Stolzenau; strictly protected and threatened species are marked in red

Abbreviations: AU - alternative bank protection, RU - reference bank, /VSR EU 1979/ - EU Birds directive 1979, /BArtSchV/ 2005 - German Federal Ordinance on the Conservation of Species, 2005, /BNatSchG 2002/ - German Federal Nature Conservation Act 2002

B - breeding birds, G - guest birds, b - specially protected, s - strictly protected, V - near threatened status, “ - ” - no special protected status.

English names: British Ornithologists Union (B0U) (1992): *Checklist of Birds of Britain and Ireland* (6th Edition, 1992), 50 pp., commonly used name appears in brackets

Species	*Latin name*	AU	RU	/Red List D 2002/	/VSR EU 1979/	/BArt SchV 2005/	/BNat SchG 2002/	Remarks
Carrion crow and hooded crow	*Corvus c. corone and c. cornix*	B	B	-	-	-	b	
Common blackbird	*Turdus merula*	B	B	-	-	-	b	
Eurasian oyster-catcher	*Haematopus ostralegus*	G		-	-	-	b	
White wagtail	*Motacilla alba*	G		-	-	-	b	
Eurasian hobby	*Falco subbuteo*	G		3	-	-	s	
Common snipe	*Gallinago gal-linago*	G		2	-	s	s	
Eurasian penduline tit	*Remiz pendu-linus*	G		-	-	-	b	
Common coot	*Fulica atra*	B		-	-	-	b	
Blue tit	*Parus caeruleus*	B		-	-	-	b	
Common shelduck	*Tadorna tadorna*	G		-	-	-	b	invasive species
Chaffinch	*Fringilla coelebs*	B	B	-	-	-	b	
Great spotted wood-pecker	*Picoides major*	B		-	-	-	b	
Eurasian jackdaw	*Corvus moned-ula*	G	G	-	-	-	b	
Common whitethroat	*Sylvia commu-nis*	B	B	V	-	-	b	
Eurasian jay	*Garrulus glan-darius*	B		-	-	-	b	
Black-pilled magpie	*Pica pica*	B		-	-	-	b	
Common pheasant	*Phasanius colchicus*	B	B	-	-	-	b	
Common grasshopper	*Locustella*	B		-	-	-	b	

Species	Latin name	AU	RU	/Red List D 2002/	/VSR EU 1979/	/BArt SchV 2005/	/BNat SchG 2002/	Remarks
warbler	*naevia*							
Willow warbler	*Phyloscopus trochilus*	B	B	-	-	-	b	
Common tern	*Sterna hirundo*	G		-	App. 1	s	s	
Goosander	*Mergus mer-ganser*	G		3	-	-	b	
Garden warbler	*Sylvia borin*	B	B	-	-	-	b	
Greylag goose	*Anser anser*	G		-	-	-	b	
Grey heron	*Ardea cinerea*	G		-	-	-	b	
European greenfinch	*Carduelis chloris*		B	-	-	-	b	
Great crested grebe	*Podiceps cristatus*	B		-	-	-	b	
Hedge accentor (dun-nock)	*Prunella modu-laris*	B	B	-	-	-	b	
Mute swan	*Cygnus olor*	G		-	-	-	b	
Hawfinch	*Coccothraustes coccothraustes*	G		-	-	-	b	
Great tit	*Parus major*	B		-	-	-	b	
Great cormorant	*Phalacrocorax carbo*	G	G	V	-	-	b	
Common cuckoo	*Cucculus canorus*	B		V	-	-	b	
Black-headed gull	*Larus ridibundus*	G	G	-	-	-	b	
Northern shoveller	*Anas clypeata*	G		-	-	-	b	
Common buzzard	*Buteo buteo*	B		-	-	-	s	
Black cap	*Sylvia atricapilla*	B	B	-	-	-	b	
Common nightingale	*Luscinia megarhynchos*	B	B	-	-	-	b	
Egyptian goose	*Alopochen aegyptiacus*	B		-	-	-	b	invasive species
Barn swallow	*Hirundo rustica*	G	G	V	-	-	b	
Tufted duck	*Aythya fuligula*	G	G	-	-	-	b	
Common wood pigeon	*Columba palumbus*	B	B	-	-	-	b	
Reed bunting	*Emberiza schoeniclus*	B		-	-	-	b	
Gadwall	*Anas strepera*	G		-	-	-	b	
Herring gull / Caspian (or Pontic) gull	*Larus argen-tatus/ L. cachinnans*	G	G	-	-	-	b	

Species	Latin name	AU	RU	/Red List D 2002/	/VSR EU 1979/	/BArt SchV 2005/	/BNat SchG 2002/	Remarks
Song thrush	*Turdus philomelos*	B	B	-	-	-	b	
Common starling	*Sturnus vulgaris*	B	B	-	-	-	b	
Mallard	*Anas platyrhynchos*	B	B	-	-	-	b	
Common gull	*Larus canus*	G	G	-	-	-	b	
Marsh warbler	*Acrocephalus palustris*	B		-	-	-	b	
Eurasian reed warbler	*Acrocephalus scirpaceus*	B		-	-	-	b	
Sand martin	*Riparia riparia*	G	G	V	-	s	s	
Willow tit	*Parus montanus*		B	-	-	-	b	
Winter wren (wren)	*Troglodytes troglodytes*	B	B	-	-	-	b	
Common chiffchaff	*Phylloscopus collybita*	B	B	-	-	-	b	

Among the potential breeding birds, species typical of riparian forests, such as Eurasian penduline tit, willow tit and icterine warbler were absent. The red-backed shrike, a breeding bird typical of open landscapes, was also missing. Except for one single common snipe in a neighbouring gravel pit, no waders were observed. Potential feeding guests such as the black kite and osprey were not found either.

The anthropogenic impairment was classified as low. This essentially reflects the fact that adjoining areas on the side towards the bank were demarcated by an electric fence and the area with alternative bank protection measure was therefore not accessible for cattle from the neighbouring pasture. There is merely a low level of impairment or disturbance of the avifauna from the access paths (overgrown and unusable from July onwards) located every 100 m, which hobby anglers use to reach the groynes. As a result of the natural dynamics of high water, large parts of the area of the study are flooded regularly. Maintenance is not carried out. Maintenance action does not, therefore, disturb the habitat conditions that are important to avifauna. An evaluation of this situation can be found in Table 10.4 (strictly protected species are highlighted in red) and Table 10.5.

Table 10.5: Conclusion: Evaluation of the avifauna at the River Weser bank bearing alternative protection measures at Stolzenau

Criterion	**Results**	**Evaluation**
Naturalness of species inventory	52 species of bird 30 species of breeding bird (58%) 22 species of guest bird (42%) 13 indicator species present: 3 breeding and 3 guest bird species, 7 accompanying species, 1 guest bird indicator species 5 endangered / strictly protected species (1 breeding, 4 guest) Abundance of threatened / strictly protected breeding bird species: 1 BP per 700 m (0.1 BP per 100 m of riverbank) Bank with alternative bank protection more valuable than reference bank; fewer indicator and accompanying species at the latter	High
Habitat structures (biotope structures and interconnectedness) – functional significance	Strong interconnectedness Biotopes form a small-scale mosaic pattern Natural vegetation, predominantly initial succession directly at the bank, soft-wood riparian elements on the bank side and on the higher elevations of the bank, ruderal areas; no management High availability of food	High
Anthropogenic impairment	Adjoining terrain extensively used as pasture; seasonal strip grazing; hobby anglers; every 100 m an access path to the riverbank; shipping traffic; pollutant discharge as a result of flooding	Average
Restorability	Young deciduous trees; little erosion by floodwater with permanent initial successions	High
Summary of the evaluation		**High**

10.3 Fish

10.3.1 Recording of fish populations using electrofishing

In the present study, sampling was carried out exclusively by means of electrofishing. The *point abundance method* was used. For this method, the electrode is held at a certain point and electric current is passed through the electrode for a brief moment. The stunned individuals in the electrical field (observed radius around the electrode: approx. 45 cm) can be removed with a landing net. In the area with conventional bank protection measures (reference bank), 50 points were set and, in the section with alternative bank protection measures, 100 points. The stationary direct current device EFGI 4000 with a capacity of 4 kW direct current, from the manufacturer Bretschneider, was used. The fishing took place in July 2006 and was carried out in the immediate vicinity of the bank. The reed bed areas were partially flooded.

10.3.2 Evaluation criteria for evaluating the fish population

Important principles for evaluation of the fish population are abiotic and biotic features as well as, in particular, the characteristics of the substratum. There are no differences between the bank with alternative protection measures and the reference bank with regard to the technical design/construction of the underwater slope. However, the two stretches differ with regard to the present vegetation and the resulting influence on the relevant environmental factors (light/shade, temperature, entry of food). During the study the following types of substratum were distinguished:

- block or armour stones
- stone
- gravel
- sand
- mud
- wood

If more than one type of substratum was present in the reaction area of 0.159 m^2 per point, the predominant substratum was noted. In addition, four different degrees of vegetation cover in proximity to the bank were distinguished for the sampling:

- no vegetation 0 % cover
- little vegetation 1-33 % cover
- average vegetation density 34-66 % cover
- high vegetation density 67-100 % cover

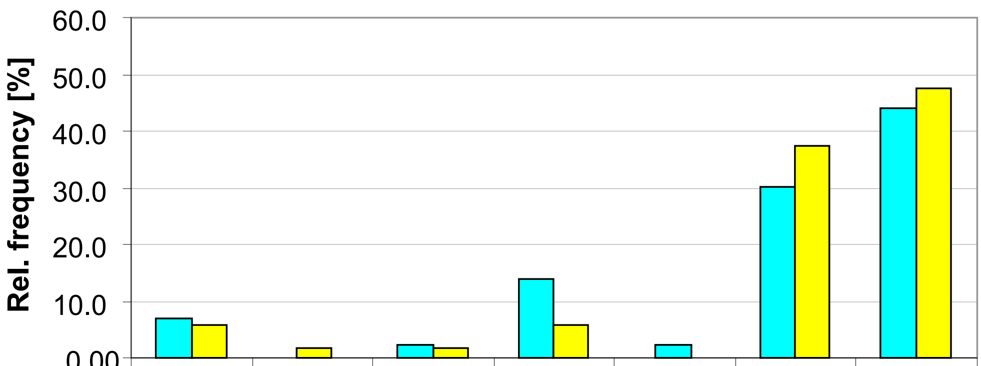
The strength of the current at the sampling sites was also divided into four categories (none, low, moderate and high) and estimated for every sampling point. The influence of water movements at the bank generated by shipping (waves, drawdown, current) was also assigned to four different categories of strength (none, low, moderate, high). If waves from a ship or a boat reached the sampling point during fishing, this was also noted. Chapter 6 contains a more precise definition of the current and wave movements.

In the present study, the relative frequency of occurrences of fish at conventional and alternative bank protection measures is determined and compared. The following biocoenotic parameters were used as the criteria for evaluating the fish fauna:

- dominance (relative frequency): percentage of one species of the entire catch in a particular time interval or area of study;
- abundance (frequency) of species and individuals of a species per sampling area (individuals per m^2);
- dependence of juvenile fish density on the parameters vegetation cover, substratum type and depth.

10.3.3 Fish species in the River Weser near Stolzenau

The relative frequency of fish species in the areas of the bank with alternative protection (AU) and the reference bank (RU) is depicted in Figure 10.2. Only seven fish species were found in the River Weser at Stolzenau, six species at each bank. The ide was found only in the zone of the bank with alternative protection, while the European perch was found only in the reference bank zone. In both bank protection zones, common roach and common dace were dominant, together making up 70 % of the total. Otherwise, only the European chub (pollard) (Figure 10.3) with almost 14 % reached a noteworthy percentage.



	Eel	Ide	Carp bream	Europ. chub	Europ. perch	Dace	Roach
RU	6.9	0.0	2.3	13.9	2.3	30.2	44.1
AU	5.8	1.6	1.6	5.8	0.0	37.5	47.5

Figure 10.2: Depiction of relative frequency of the fish species at the sampling sites in the River Weser (reference bank (RU) 43 individuals, alternative protection (AU) 120 individuals)

Figure 10.3: The European chub – a fish found frequently in the River Weser

10.3.4 Juvenile fish densities and their dependence on various features in the River Weser at Stolzenau

In the stretch with conventional bank protection measures (reference stretch, RU) consisting of loose riprap, a juvenile fish density of 4.28 juvenile fish per m^2 was attained. As the vegetation density is generally low here, all samples had to be taken at points with no vegetation. By contrast, in the area of the alternative bank protection measures (AU), samples could be taken at points with no vegetation, little vegetation and some with average vegetation density. The density of juvenile fish was similar for all three degrees of vegetation cover (Figure 10.4).

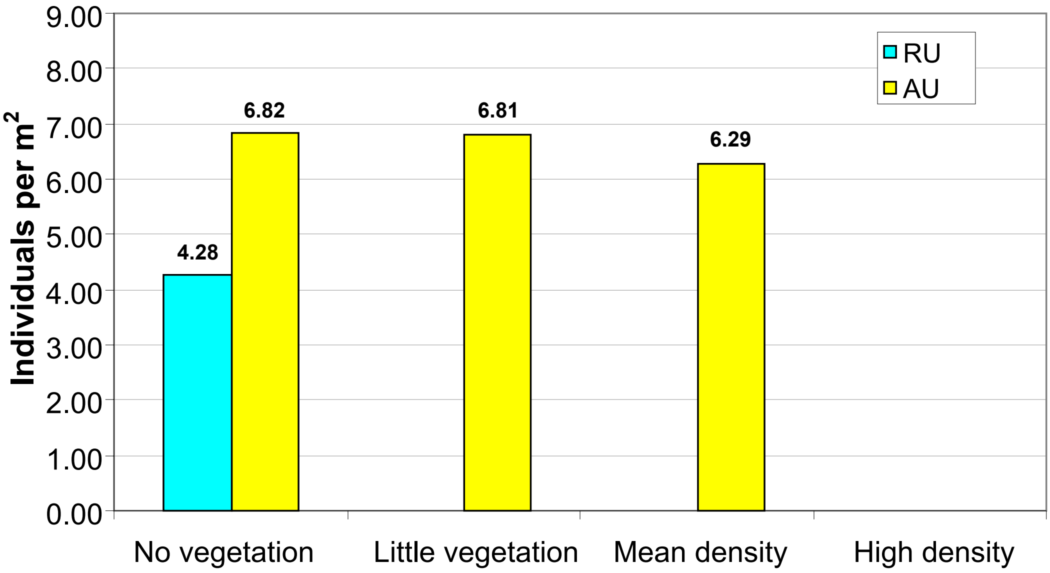


Figure 10.4: Mean juvenile fish density at the sampling sites with differing degrees of vegetation cover

In the section with alternative bank protection measures (AU), there were three different types of substratum (Figure 10.5). The highest density of juvenile fish was recorded in the loose riprap revetment (7.42 juvenile fish per m²) and the lowest in the substratum type “stones” at 2.1 juvenile fish per m².

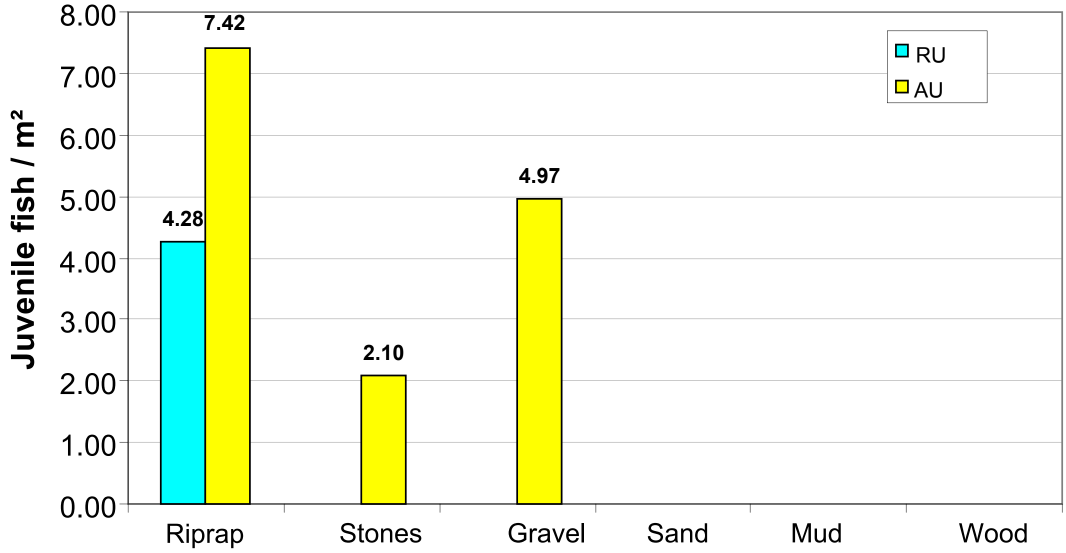


Figure 10.5: Mean juvenile fish density at measuring points with differing substratum types

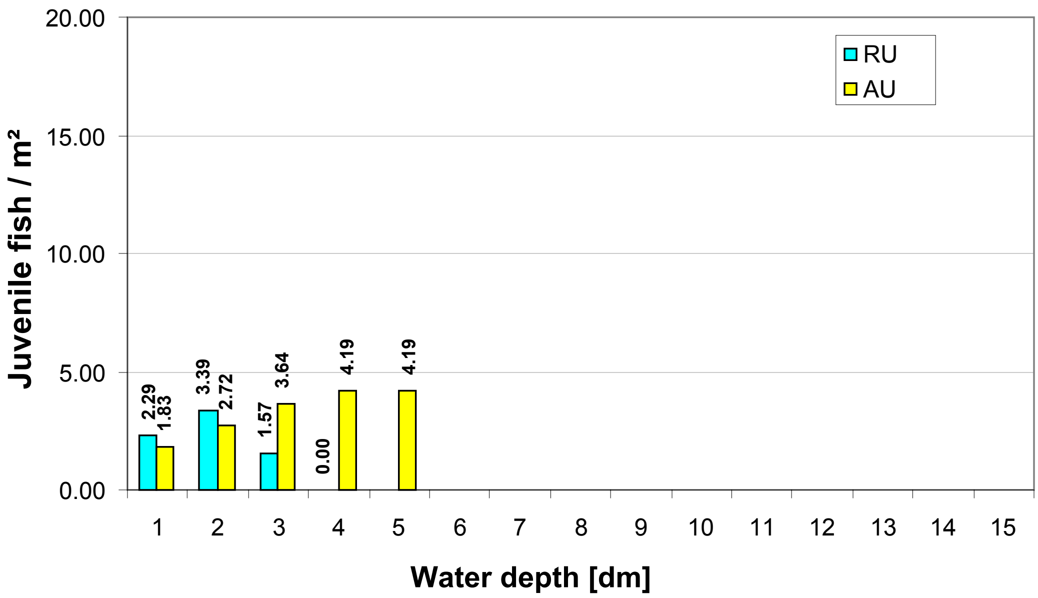


Figure 10.6: Mean juvenile fish density at differing water depths in decimetres

In the area with conventional bank protection measures (RU), the juvenile fish were sampled at depths of 1 to 4 dm. The highest density of juvenile fish measured was 3.39 juvenile fish per m² at a depth of 2 dm (Figure 10.6). At the bank with alternative protection, the morphology also permitted the setting of sample points at a depth of five decimetres. The highest density was found in this measure at depths of 4 or 5 dm (4.19 juvenile fish per m²). The densities of all depths in both measures were less than 5 juvenile fish per m² and thus all in the same range. As neither cargo vessels nor passenger ships nor pleasure craft passed the section of the study during the entire fishing period, i.e. no sample point was set during a positive and negative surge event, no direct statement can be made on the influence of such events on the density of juvenile fish at the bank protection measures.

10.3.5 Fish ecology evaluation of the AU and RU according to the Water Framework Directive

Figure 10.6 shows the evaluations regarding their naturalness for both banks of the Weser at Stolzenau according to /Brunken 1986/ (5 categories from “natural” to “extremely non-pristine”) and according to the Water Framework Directive (5 categories from “very good (1)” to “very poor (5)”). The evaluations “non-pristine” and “poor” correspond to the estimations from the survey for the entire body of water in this area. A substantially better evaluation of the ecological state of the River Weser in the section of the bank with alternative bank protection measures was not generally expected because the effect of the measures is restricted to a very small area.

Table 10.6: Evaluation of the River Weser at Stolzenau at the two bank sections that were fished, according to /Brunken 1986/ and on the basis of the WFD and the significance of the bank protection measures for the fish fauna

Evaluation of naturalness /Brunken 1986/		Evaluation on the basis of the WFD		Significance of the bank protection measures for the juvenile fish fauna	
RU	AU	RU	AU	RU	AU
non-pristine	non-pristine	4 (poor)	4 (poor)	minor	minor

10.3.6 Conclusion regarding the fish fauna of the River Weser

At the sampling site near Stolzenau, the densities of individuals and of juvenile fish in the stretch with alternative bank protection measures (AU) lie slightly above those of the reference stretch (RU). A reason for this could be that the bank with alternative bank protection measures is partly covered by common reed and is less easily fished than open areas or areas with only light vegetation cover, such as are found in the reference bank zone. If these methodological problems did not exist, the difference in the densities between the conventional and alternative bank protection measures would probably be more apparent. With regard to the level of vegetation cover, there is a major difference between the two types of bank protection. In the area of the alternative bank protection measures, the areas with no vegetation, little vegetation and areas with average vegetation cover all showed relatively similar densities of juvenile fish, which demonstrates their importance as a habitat for juvenile fish. The diversity of substratum types, another important factor for fish, was also higher in the AU than in the RU, where there was only riprap revetment. In the areas with alternative bank protection measures, there were also (natural) stones and gravel, besides the riprap, all of which were inhabited by juvenile fish in various densities. At both bank protection measures, six species of fish were found. The combination of species varies only slightly. For example, in the gravel of the AU, at least two juvenile fish of the gravel-spawning ide were caught. The European perch, which is frequently found in riprap revetments, was observed only at the reference bank. However, in the case of the perch seen here, it was also only a single observation of a juvenile animal. On account of the overall low figures recorded, it is therefore not possible to speak of a statistically proven influence of the type of bank protection measures on the species inventory (adult fish). The slight differences are understandable from the viewpoint of fishery biology. In comparison with the reference stretch, the alternative bank protection, therefore, has only had a very slight influence on the adult fish fauna or no influence at all. In contrast to this, the comparison of juvenile fish densities in the RU and AU shows that, at least in the case of the commonly occurring species common dace and roach, the density of juvenile fish is higher in the areas with alternative bank protection measures than in the reference stretch.

10.4 Makrozoobenthos (benthic invertebrates)

10.4.1 Sampling methods

The samples of the macrozoobenthos in the individual sections of the Weser at Stolzenau were taken in May 2006 (cf. Appendix 10.1). Thirty samples were taken of which 20 samples were from the area of the alternative bank protection measures (AU) (2 x 10 samples from 2 typical substratum types AU1: main component, gravel, and AU2: main component, silt) and 10 samples from the area of the reference stretch (RU: main component, riprap). All samples were taken during mean water level conditions. The quantitative survey took place at soil substrata close to the bank (generally not less than 0.5 m deep) for a defined projection area of 1/8 m^2. Two different techniques were used for taking the samples (see below). Finally, the animals were identified and the assemblages evaluated.

10.4.1.1 Hand samples

Hard substratum (= riprap) was carefully removed from the water and placed in a plastic basin (Figure 10.7), until the bottom of the basin (⅛ m^2) was covered.

Figure 10.7: Typical hard substratum sample (River Weser at Stolzenau)

Delicate or firmly-fastened animals, such as the Turbellarians, the zebra mussel *(Dreissena polymorpha)* and sponges, were transferred directly from the substratum to the sample vessel using spring steel tweezers and the frequencies or degree of cover were noted. Then the specimens on the substratum were removed in a plastic bucket filled with water by means of careful brushing. The material obtained by this method was finally placed in a sieve (diameter 20 cm, mesh size 0.63 mm), separated from the coarse organic material and conserved in wide-necked one litre bottles with 98 % ethyl alcohol.

10.4.1.2 Landing net catches

All soft substrata were stirred up by kicking with boots at a depth of 2 - 5 cm and the suspended particles were collected by moving a hand landing net (frame size 25 x 25 cm; mesh size 500 µm) rapidly back and forth in a figure of eight pattern (= kick sampling). For processing an area of 25 x 25 cm per kick, two kicks were required for each ⅛ m^2 sample. The contents of the landing net were transferred to a 10 litre bucket and the mineral fraction separated with the help of a slurry technique /Meier et al. 2006/. To do this, a bucket with sample material was half-filled with water and the sample material carefully washed out by rotating it by hand. The stirred-up organic material was subsequently caught in a sieve (diameter 20 cm, mesh size 0.63 mm). The mineral substratum remained at the bottom of the bucket. The separation procedure was repeated several times until only mineral material remained in the bucket. The entire organic material retained in the sieve was separated from the coarse organic material and conserved in wide-necked one litre bottles with 98 % ethyl alcohol. The mineral portion was inspected in a white dish for remaining organisms, such as Trichoptera (caddis fly) with cases or mollusca (molluscs such as snails and bivalve shellfish) and then disposed of.

10.4.2 Processing and identification of the samples

For the evaluation, the samples acquired in the field were soaked in water and cleaned using a stainless steel sieve (diameter 20 cm, mesh size 0.63 mm) and then sorted, identified and the animals were counted on a glass dish under a stereo magnifying glass. The identification of the macrozoobenthos was carried out according to current taxonomical norms. The organisms of the Oligochaete (oligochaetes, amongst others annelids) were, with some exceptions, not identified more specifically.

10.4.3 Principles for evaluation of the macrozoobenthos

For the assessment, the following parameters, which are summarised in Table 10.7, were used:

Besides the **total number of taxa**, the **mean number of taxa** per sample was also determined for every area type. The **Red List species** were determined with the help of the “Rote Liste gefährdeter Tiere Deutschlands” /Binot et al. 1998/ (Red List of Threatened Species in Germany). For determining the number of **invasive species**, the list of known invasive species of the macrozoobenthos known in German waterways, as of 1999 /Tittizer et al. 2000/ was consulted. The **dominance of invasive species** indicates the percentage of invasive species individuals compared with the total number of individuals. Furthermore, the **distribution of constancy, dominance and taxa group** at the individual types of area were compared (cf. Appendix 10.2). The constancy of a taxon is shown by the percentage of the samples in which the taxon was found. The dominance and percentage of a species are calculated from the ratio of the number of individuals of the taxon or of a group of taxa respectively to the total number of individuals and are also shown as percentages. Besides the above mentioned criteria, various **ecological characteristics** of the organisms were studied (cf. Appendix 10.2). These include the **biocenotic region**, the **preference for flow and habitat** and the **type of locomotion and feeding**. These were shown as a percentage of the total of all abundance classes.

Table 10.7: Overview of all evaluation parameters used with regard to the macrozoobenthos

Evaluation parameters	Dimension
Cluster analysis	
Total number of taxa	Taxa
Mean number of taxa	Taxa/sample
Red List species	Species
Invasive species	Species
Dominance of invasive species	% of all individuals
Constancy distribution	% verified of all samples
Dominance distribution	% of all individuals
Distribution of animal groups	% of all individuals
Ecological characteristics	% of all abundance classes
r dominance	% of all individuals
Species diversity	
Potamon Typie Index	
Saprobity index	

The assemblages were described by the r/K relation (see glossary for r and K strategists) and by showing the **r dominance**. The r dominance is calculated from the ratio of the number of individuals of the r strategists to the total number of individuals and is also shown as a percentage. High r dominance values (> 80 %) indicate disturbed biocenoses; r dominance values < 50 %, on the other hand, indicate stable biocenoses /Schöll et al. 2005/. However, since the r dominance must be observed over a period of several years for a reliable statement, these studies can only be regarded as a snapshot in time. An estimated value for the species diversity that is independent of random sampling is the **Diversity Index α** according to /Fisher et al. 1943. It describes the structural complexity of the biocenocis taking into consideration abundance and number of species. For the ecological evaluation of the waterway sections and their various types of area, the **Potamon Typie Index** (PTI) was calculated. The theoretical approach and methodology of the PTI procedure have been described in detail by /Schöll, Haybach 2001/ and /Schöll et al. 2005/. A low PTI value reflects a good ecological state and a high PTI value a poor one. In order to document the load of biologically degradable, organic material in the different stretches of the waterway, the **saprobity index** (SI) according to /DIN 38410/ was calculated.

10.4.4 Results for the macrozoobenthos

The **influences of the habitat characteristics** are significant when evaluating the results for this animal group. According to the map of biocenotically significant flowing water types in Germany /Lawa 2003/ (Lawa = Working Group of the Federal States for Water), the River Weser in the section of this study corresponds to waterway type 20, “sand streams”. According to the guiding principles for waterway morphology of /Pottgiesser, Sommerhäuser 2006/, sand streams are characterised by very wide and shallow single or multiple bed channels, with fairly fine bed substrata (sand, gravel) and a current which is “predominantly slow-flowing”. As it is confined here, the Weser is not, however, able to form multiple bed channels with natural bed structures such as sills, islands, scours, deep rills, roots and fords. The natural secondary substratum essential for a larger habitat diversity, dead wood, is only present in small quantities.

According to the **cluster analysis**, the colonisation structure in the reference stretch (RU) can easily be separated from that of the alternative bank protection measures (AU) (cf. Figure 10.8: AU1 = KFL1, AU2 = KFL2 und RU = RFL). All 10 samples from the reference stretch are summarised at aggregation knot 51. A separation between the samples from the two types of substrata that were investigated from the alternative bank protection measures is not possible.

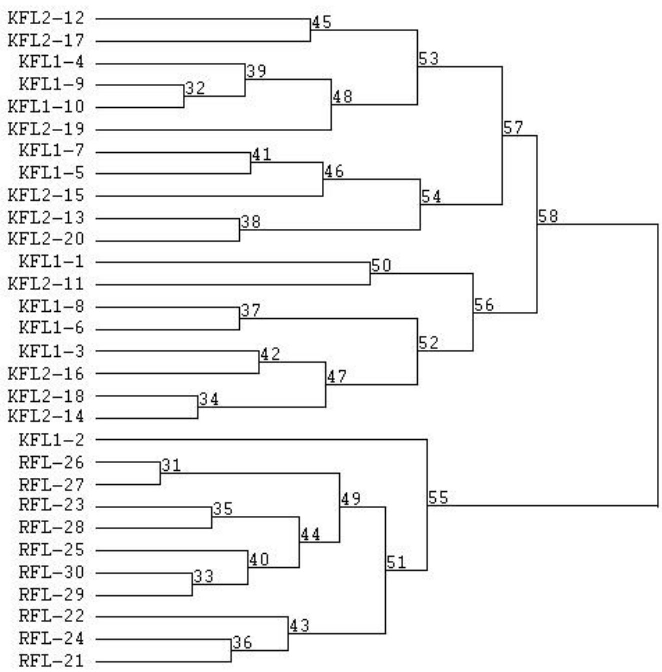


Figure 10.8: Dendrogram of the cluster analysis (agglomerative method) of the MZB samples from the River Weser near Stolzenau 2006 (objects = 30 taxonomic lists)

Reference stretch (RFL = RU) with conventional bank protection measures summarised at aggregation knot 51, and alternative bank protection measures (KFL = AU) at knot 58. (The greater the difference in the composition of the samples, the further apart the knots lie).

In Table 10.8 all the parameters that were used for the evaluation are depicted together in an overview. All results, including a complete taxonomic list, are shown in Appendices 10.1 and 10.2.

Table 10.8: Total number of taxa, mean number of taxa, Red List species, number of invasive species, r dominance, species diversity, Potamon Typie Index and saprobity index in the study section of the River Weser at Stolzenau in the year 2006

Explanations: AU1= alternative stretch 1, predominantly gravel substrate (10 samples), AU2= alternative stretch 2, predominantly silt substrate (10 samples), RU = reference stretch (10 samples), overall = complete section of study (30 samples)

	AU1	*AU2*	*RU*	*Overall*
Total number of taxa	*44*	*43*	*30*	*61*
Mean number of taxa	*19.5*	*18.7*	*17.7*	*18.63*
Red List species	*2*	*2*	*1*	*3*
Number of invasive species	*11*	*12*	*8*	*13*
Dominance of invasive species [%]	*95.98*	*71.97*	*53.33*	*67.06*
r dominance [%]	*3.99*	*12.46*	*8.42*	*-*
Species diversity	*4.16±0.7*	*4.66±0.7*	*2.74±0.5)*	*-*
Potamon Typie Index	*3.41±0,40 (IV)[1) 2)]*	*3.42±0,37 (IV)[1) 2)]*	*3.57±0,26 (IV)[1) 2)]*	*-*
Saprobity index	*2.32±0,11 (II)[1)]*	*2.44±0,12 (III)[1)]*	*2.20±0,08 (II)[1)]*	*-*

1) Quality classification of the modules "general degradation" and "saprobity" according to /Meier et al. 2006/ for flowing water type 20

2) Validity conditions of the PTI not fulfilled

10.4.5 Discussion and evaluation of the results for the MZB

The **total number of taxa** in the AU zones was 43 and 44 taxa respectively, which is significantly higher than in the RU zone (30 taxa). The **mean number of taxa** at all three area types is relatively similar (between 17.7 and 19.5). The samples from AU1 and AU2 thus demonstrate a greater diversity of species than those taken at the reference bank. Typical **characteristic species** in flowing water type 20 included the humpbacked pea clam (*Pisidium supinum)* and the mayfly species C*aenis macrura*. In the whole section of the study three **Red List species** were verified, two in the AU and one in the RU. The humpbacked pea clam *(Pisidium supinum)* and the caddis fly species *Hydroptila forcipata* (both in category 3 = threatened) are especially noteworthy.

Of the 37 taxa in the entire section which were classified as far as their species, 13 can be classified as **invasive species** and of these, 9 species alone belong to the Crustacea (crustaceans). The percentages of the total number of individuals in the samples of the AU amount to 96.0 % (AU1) and 72.0 % (AU2), at the RU 53.3 %. The lower percentage of invasive species, mainly in the RU samples, can be attributed to the increased incidence in these samples of the river limpet *(Ancylus fluviatilis)* and the Naidinae (a sub-family of the sludge worms). The total number of individuals is therefore also significantly higher in these samples. The opossum shrimp species *Neomysis integer* (Figure 10.9) is a euryhaline brackish water species which normally colonises the coastlines of the North Sea and the Baltic Sea. Its existence in the Weser has been verified for a considerable period of time.

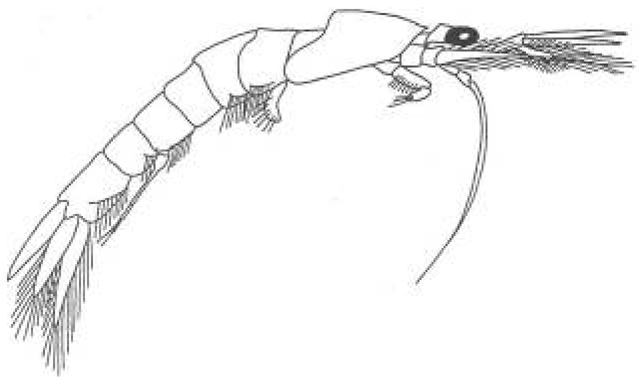


Figure 10.9: The opossum shrimp *Neomysis integer* (from /Köhn 1992/)

The greatest **constancy** in all 30 samples was attained by the river limpet *(Ancylus fluviatilis)* and the crustaceans *Dikerogammarus villosus* (killer shrimp, Figure 10.10), *Jaera istri* and *Chelicorophium curvispinum* (Caspian mud shrimp). For stretches with alternative bank protection measures (AU), a higher constancy of the lake fingernail clam *(Musculium lacustre)* was verified, a species which was not found in the samples from the reference stretch. In contrast to this, species with a higher constancy such as the zebra mussel *(Dreissena polymorpha)* and the pond snail species *Radix balthica* were found in the samples from the RU, but only seldom or not at all in the samples from the AU. A review of the **dominance distribution** shows that the killer shrimp *(Dikerogammarus villosus)* (Figure 10.10) has adopted a dominant position in the stretches with alternative bank protection measures. This is in contrast with the strong dominance of the river limpet *(Ancylus fluviatilis)* and the family of the Naidinae in the samples from the RU.

Figure 10.10: The killer shrimp *(Dikerogammarus villosus)*, an invasive species, dominates the macrozoobenthos of the alternative bank protection measures of the River Weser at Stolzenau

Mayflies, dragonflies and water beetles are in general much underrepresented in the section of the study. The very high individual percentages of crustaceans with values of up to 95.5 % correspond exactly to those of the invasive species. The results of the ecological typing of the colonisation with the help of **ecological features** reflect the existing biocenoses very well. According to these, the taxa of all area types primarily settle in the epipotamal zone. The flow preference of the taxa is different in each of the three areas. For the organisms of the reference stretch, it lies in the rheophilic zone, for organisms from the alternative bank protection measures in the rheophilic to limnophilic zone. With a value of 52 %, the habitat preference for the taxa from the reference stretch shows a clear emphasis in the lithal zone, which, as this consists exclusively of riprap revetment, is not surprising. The favoured locomotion for all three area types is creeping/ walking and the preferred feeding types are detritivores and grazers.

The classification of the individuals into r and K strategists shows a low **r dominance**, both in the AU and in the RU; i.e. all the biocenoses studied are sufficiently stable. The calculation of the **species diversity** produced values of 4.16 and 4.66 for the alternative bank protection measures (= moderate biodiversity), while with a value of 2.7, the diversity for the reference stretch is poor. The **Potamon Typie Index** for AU and RU lies between 3.41 and 3.57, which corresponds to the quality category IV (= unsatisfactory) of the module “general degradation” for both types of bank protection measures. For all three values, however, the validity conditions of the PTI were not fulfilled, meaning that the values can only be used with reservation. The **saprobity index** is very similar for both types of bank protection measures, but was a little lower in the reference stretch. This can presumably be attributed to the fact that when using the saprobity system to assess flowing waters with the same degree of contamination, waters in which the flow velocity is greater, the temperature lower and the substrata coarser are principally evaluated as having a better quality. This evaluation is based on the fact that, in spite of the unchanged load of effluent water, these factors promote species that require more oxygen. In particular, rheophilic species may erroneously indicate a better water quality that does not correspond to the reality /Marten, Reusch 1992; Braukmann 1987/.

10.4.6 Conclusion regarding the macrozoobenthos in the River Weser at Stolzenau

Through the alternative bank protection measures, the macrozoobenthos assemblage was appreciably enhanced. This is proved by the higher overall taxa numbers and by the increased species diversity in the area of the alternative bank protection measures, even though this can be mainly attributed to the invasive species. Of important insect groups such as mayflies, dragonflies and bugs, single specimens were observed in the zone with alternative bank protection measures, whereas in the reference bank zone they were completely absent. In the bank area with alternative protection measures, one more species from the Red List was found than at the bank with conventional protection.

10.5 Overall conclusions regarding the fauna

The alternative bank protection measures (AU) at the River Weser could be qualified as valuable to the living conditions of the fauna. They have promoted an increase in the colonisation by birds and a higher density of juvenile fish. Also, a higher density of macrozoobenthos could be observed in the modified area. In particular the improved vegetation cover of the alternative bank protection measures had a positive effect on the juvenile fish population as opposed to the conventional bank protection measures (RU). A greater diversity of species, both of birds and in the macrozoobenthos, has become established. This also includes more endangered species in both animal groups in the area of the alternative bank protection measures than in the area with the conventional measures. The Weser is still far from fulfilling the geomorphological guidelines according to the WFD in this section, as through its function as a waterway, it so far does not have sufficient potential for a development towards a near-natural state. The stretch remains relatively poor in species, in many cases invasive species are dominant and the ecological indices (Potamon Typie and saprobity) point to polluted conditions. Nonetheless, alternative bank protection measures, such as those at Stolzenau, can be given a positive evaluation from the faunistic point of view, as they favour structural diversity and, consequently, diversity of the fauna. For this reason, the more frequent use of alternative bank protection measures, such as those found at Stolzenau, is desirable in the interest of the fauna. The essential differences in the faunistic results between the two types of bank protection measures have been summarised in Table 10.9.

Table 10.9: Summary: Comparison of alternative bank protection measures (AU) with conventional bank protection measures (RU) in the same stretch of the Weser near Stolzenau in terms of the fauna

	Conventional bank protection measures (RU)	**Alternative bank protection measures (AU)**
Birds		
Number of breeding species per stretch	18	**30**
Number of species found as guest birds	8	**22**
Number of bird species from the Red List	none	**3**
Overall evaluation of bird colonisation	average	**high**
Fish		
Number of adult fish species	6	7
Density of juvenile fish (individuals per m^2)	4.3	**6.8**
Macrozoobenthos		
Total number of taxa found	30	**44**
Number of Red List species	1	2
Species diversity acc. to /Fisher et al. 1943/	<3	**>4**
Number of invasive species alien to the region	8	11

11 Summary of assessment and recommendations for bank protection in the test stretch at Stolzenau / Weser

11.1 Assessment of current conditions and development until now

11.1.1 Vegetation

The reconstruction from technical to technical-biological bank protection in the test section has been completed successfully. Almost all planting measures executed have developed in such a way that nowadays a very good erosion protection is provided for the bank slopes.

Under given conditions, common reed provides better erosion protection than willow bushes close to the banks. Compared to other types of construction, common reed planting cannot withstand large hydraulic loads; however, these types of load are not found in the test section. Apart from the vegetation mats, all reed planting methods were successful. Of all reeds and sedges introduced, the common reed grew to a massive extent, while some tall sedge species remained more or less in their original planting location. The section-wise flattening of bank slopes proved very positive. Here wider reed belts developed than on the bank slopes that were left unchanged, which in turn is advantageous for bank protection, attractive landscaping and fauna. The reed beds spread more quickly along bank sections protected by stone mounds and fascines than in unprotected areas. In the former sections, the reeds reached and/or overgrew fascines and stone mounds already during the first 3 periods of vegetation, while in the latter they only spread out in some areas beyond their original planting location during this period. However, common reed ultimately reached the bank line also in the unprotected areas (until 1999 at the latest).

Willow bushes from cuttings and long branch cuttings developed on both flattened and unchanged bank slopes, whenever they were planted in the lower areas of the respective slope. Adding woody plants to slopes which otherwise had been left unchanged proved unsuccessful whenever they were planted in upper areas of the slope, i.e. set at larger distances from the ground water. They most likely dried out at these locations. Where revetment had been removed, vital willow bushes of live brush mattresses developed, even where a steep bank inclination had been retained.

The impact of groynes for vegetation development could not be determined, since within and outside the groyne field different bank topographies had been selected. Within and outside this field, plant stands developed in an overall positive manner.

From the perspective of nature protection, in addition to their function as bank protection, the newly created types of vegetation represent an enhancement to this section of the River Weser.

The bank sections whose succession was undisturbed and where the reed belt is dominated by reed canary grass *(Phalaris arundinacea),* that is resistant to flow, flooding and sand accumulation /Pott, Remy 2000/, are relatively close to a natural state and feature a special biodiversity. In these reed areas, the specially-protected yellow flag *(Iris pseudacorus)* can be found frequently. Landwards, these stretches are enriched by shrubs such as common dogwood *(Cornus sanguinea),* common hawthorn *(Crataegus monogyna),* blackthorn *(Prunus spinosa),* European buckthorn *(Rhamnus cathartica),* dog rose *(Rosa canina),* sweet briar *(Rosa rubiginos*a agg.) and black lace *(Sambucus nigra),* which, with their variety of blossom and fruiting periods, represent elements of high biocoenological value that supplement the willow species.

Common reed *(Phragmites australis)* is a characteristic type of reed found in still and slow-running waters without strong wave run-up /Wörz 1998/ which probably was not found along the main channel of the Middle River Weser prior to its regulation by impoundments. Under today’s conditions, however, this species was successfully established and has built up stands many of which have exceeded the minimum size of 50 m². These represent valuable habitats protected in Lower Saxony /Drachenfels 2004/. Within the Red List of plant communities in Germany (Rote Liste der Pflanzengesellschaften Deutschlands) /Rennwald 2000/ common reed appears on the pre-warning list, i.e. it is a type of vegetation that is shrinking across Germany.

The high overall value of the test section in terms of nature protection is due to its variety of habitats which clearly surpasses that of neighbouring areas.

The stands of woody plants require maintenance. Suitable measures for care are suggested in Chapter 11.2.

11.1.2 Fauna

The alternative bank protection measures examined in this report helped the River Weser to achieve a higher evaluation regarding animal ecology. Compared to conventional protection measures, advantages result from the improved vegetation cover. Not only juvenile fish benefit from this, but also the macrozoobenthos settlements are of a higher quality within areas that use alternative bank protection. The variety of bird and macrozoobenthic species is higher; even endangered species are slightly more frequent. Therefore, in terms of fauna, alternative bank protection – as applied here – has to be positively evaluated. A more frequent use of alternative bank protection, such as that found in the Stolzenau test section, would thus be desirable. For the banks tested near Stolzenau, follow-up tests should be conducted in the form of continuative monitoring. However, this should be limited to intervals of 5 to 10 years in order to estimate the long-term development potential of alternative bank protection from a faunistical perspective.

11.1.3 Bank stability from a geotechnical perspective

Under the so far predominant hydraulic loads induced by navigation and natural river flow, the sloped banks in the area of the test section are permanently stable. This means that, with the riprap remaining below the water surface and the technical-biological bank protection measures applied in the slope area above roughly the mean water level, good bank protection is provided.

With respect to the durability of the bank protection, the following two aspects must be considered:

- Targeted maintenance will be required in order to preserve plant elements used for bank protection (cf. Chapter 11.2).
- Currently, planning is underway for a Middle River Weser adaptation in order to allow passage along the River Weser for larger ships, such as large motor vessels (*German abbreviation:* GMS) with lengths of 110 m and very large self-propelled barges (*German abbreviation:* üGMS) with lengths of 135 m. We can assume that the hydraulic loads on the banks will correspondingly increase. It is not possible to predict how the various plant elements that are part of the technical-biological bank protection along the test section will be able to hold up against these loads. After the implementation of this waterway development measure, the bank along the test section thus should be carefully monitored.

11.2 Recommendations for future maintenance

In contrast to many other technical-biological construction methods, stands of woody plants require medium- and long-term maintenance /Schiechtl, Stern 2002; DIN 18919/. The following maintenance plan is suggested for the Stolzenau test section.

Table 11.1: Maintenance plan with short-term and long-term maintenance measures

A Maintenance goals and causes for maintenance requirements:
1 Achieving a **thinned-out stand of riparian woody plants of different age classes**
- for the long-term preservation of the woody plants' functions while avoiding area-wide overageing
- for promoting underwood (improved erosion protection)
- for achieving a more richly-structured and thus higher quality habitat

2 Reeds conservation
- for the purpose of optimal erosion protection
- to preserve habitat as protected by the BNatSchG and NNatG regulations

3 Combating the lethal phytophthora disease in alder
- by removing sick or dead alder trees (cf. Chap. 9.1.5 and 9.2.1)

B Required maintenance measures (cf. Figure 11.1):

	Plan Sections	**Months**	**Year**
M1 Cutting and burning all alder trees diseased with or that have died from lethal phytophthora disease; avoid composting them and using as deadwood, cf. /BBA 2003/	Immediately: in **1** (1 tree), between **4** and **5** (2 trees), between **8** and **9** (2 trees) as well as in **14a** (2 trees); long-term: everywhere needed	As soon as possible	As soon as possible, later as required
M2 Thinning-out and increasing the percentage of young willow bushes by pruning to the base of around 25 % of stems per bush	**4**, **6**, **7a**, **10**	Oct.-Feb.*	Soon, then every 8 - 10 years
M3 Removal of all woody plants in the reed belt area while preserving the reed bed	**1**, **8**, **9**, **11** (currently more intensive care is needed here)	Oct.-Feb.*	Soon, then every 3 - 4 years (as long as necessary, later same as M4)
M4 Removal of all woody plants in the reed belt area while preserving the reed bed	**1**, **2**, **5**, **7**, **8**, **9**, **11**, **13**, **15**	Oct.-Feb.*	Soon, then every 6 - 8 years

* Times taken from /SMUL 2005/, whereas starting in November no measures should be taken whenever possible in consideration of the winter rest of migrating birds.

C Checking the success: Every 10 - 15 years check whether maintenance goals have been achieved or not and adapt measures if required. Regarding lethal phytophthora disease, however, an annual check should be conducted until the combat of acute infestation can be regarded as successful (control rebudding individuals if needed).

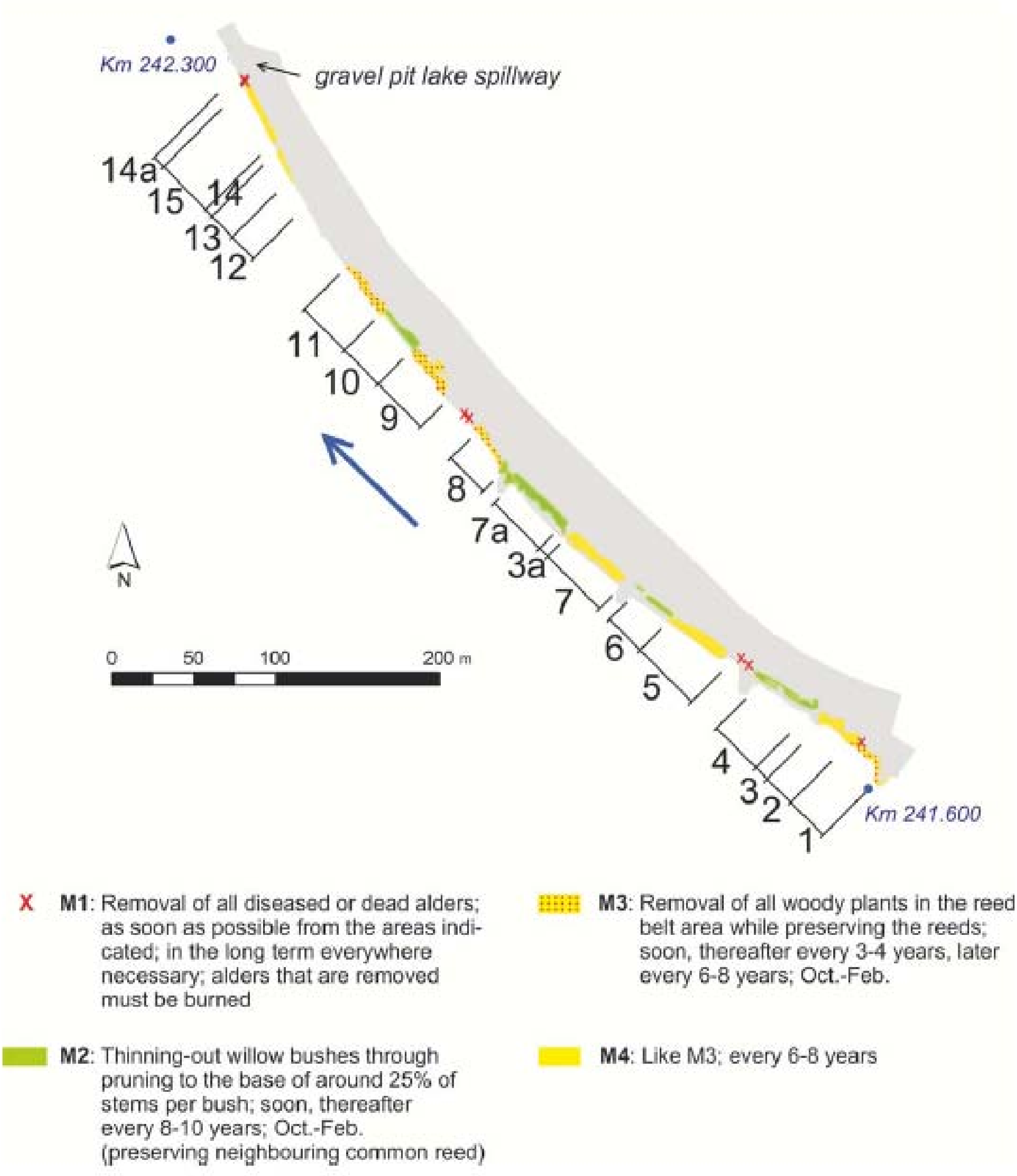


Figure 11.1: Recommended maintenance measures for the Stolzenau / River Weser test section

12 Conclusions with regard to further application of alternative technical-biological bank protection measures on inland waterways

The consideration of ecological aspects during construction measures on waterways will in future become of even greater significance – in particular when the requirements of the European Water Framework Directive (WFD) have to be individually implemented. This directive aims for the gradual improvement of the condition of surface waters. For this reason, alternative technological-biological bank protection measures will in future be increasingly used in waterway development and construction projects as well as within rehabilitation measures. The bank protection measures that were studied in the Stolzenau test section can also be applied to further sections with similar boundary conditions. The parameters of the test section – including the hydraulic load resulting from navigation – have been compiled to form the basis for further application on waterways in a Specification in Appendix 12.1. It should be noted that, when assessing the load-bearing capacity of the technical-biological bank protection measures, besides the hydraulic factors, the existing geometrical (e.g. present slope inclinations) and the geotechnical (e.g. in-situ soil type) boundary conditions are also to be taken into account. Figure 12.1 shows an overview of the most important influential factors.

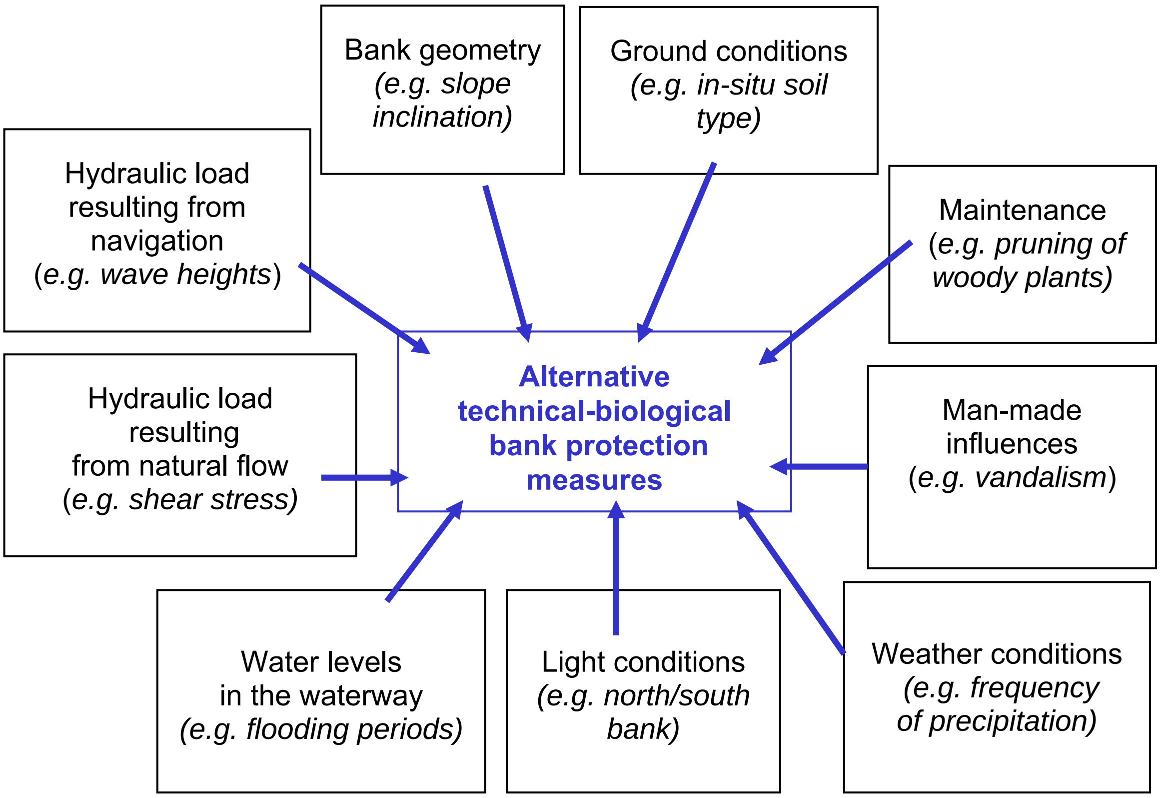


Figure 12.1: Factors influencing the load-bearing capacity of alternative technical-biological bank protection measures

When planning the application of alternative technical-biological bank protection measures, the aim should generally be to acquire in advance large and connected stretches of bank together with a broad strip of hinterland in order to ensure attractive landscaping. Apart from maintaining a flat and irregular shaping of the banks, while ensuring that existing structures and bank-protecting or valuable, nature-conserving vegetation are extensively preserved, and apart from erecting bank protection against wave action e.g. in the form of fascines, streamward stone mounds or riprap islands and planting alternately with reeds and woody plants suited to the location, a larger proportion of the area should be set aside for succession on hitherto unoccupied areas. The virgin soils that are uncovered by construction measures are, however, susceptible to settlement by woody plants and neophytes. The type and extent of this settlement depend on the vegetation in the area surrounding the construction measure (seeding trees) and the timing of the measure (seed maturity). If soil material is introduced from other areas, it may contain seeds or parts of plants of unwanted species, which may hinder the success of the measure and would lead to an increase in maintenance work. This should be taken into account when selecting the soil that is to be brought in. The areas affected by the measure should in any case be monitored during the first few years with regard to settlement by unwanted species. If this is the case, these should be removed (guided succession). At the Stolzenau test section, there were no problems with neophytes or spontaneous massive growth of woody plants, as no soil material from other locations was brought in, and as the area already lacked structure, there were scarcely any potential mother plants already in existence.

When planting common reed under conditions comparable to those at Stolzenau, plug and sod planting is to be preferred over vegetation mats. Protection provided by fascines or stone mounds results in a more rapid establishment of vegetation. Flattened banks permit the development of wider reed belts. To achieve the development of vigorous sedge stands, areas covering several square metres should be planted. Willow bushes can also be located on steeper slopes; here, various planting methods are suitable: willow cuttings and long branch cuttings should be placed at the lower zone of each slope to prevent them from drying up, although flooding should also be prevented before they come into leaf. Live brush mattresses allow rapid development of wide and dense bushy growth. To introduce live brush mattresses, any existing riprap should first be removed; for cuttings and long branch cuttings this is not necessary. Because of the lethal alder disease, only alder specimens that are free of *phytophthora* should be used (*phytophthora* is the pathogen that causes the root collar rot in alder). If possible it is advisable to fall back on local, healthy natural rejuvenation /Wild 2002; FVA 2005/. During the establishment stage, an adequate supply of water must be ensured for all planting methods. For reed plants and woody shrubs, whenever possible, only plant material that has been acquired from the immediate surroundings or regional sources should be used.

For every newly constructed technical-biological bank protection measure, it is advisable to carry out monitoring, in order to document the success and durability of the measures. This is also important in order to gain further experience with alternative bank protection measures on inland waterways. Advice how to implement a monitoring programme is included in Appendix 12.2.

13 Looking to the future

The test section Stolzenau on the Middle Weser River from kilometre 241.550 to 242.300 was the first section that was monitored in detail within the research project "Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways" that featured with this type of bank protection measures. The geometric, geotechnical and hydraulic boundary conditions were individually recorded and the state of vegetation and fauna was assessed. The various bank protection measures implemented here can be regarded as a successful solution under the existing boundary conditions. In view of the hitherto rather low hydraulic load affecting the banks, these provide good erosion protection for the banks. The key data of the test section have been compiled in a data specification sheet.

Other sections of waterways with alternative bank protection measures are being studied using the same method. In the following sections of waterways, which are characterised by widely differing geometric, geotechnical and hydraulic boundary conditions, the relevant studies are already being carried out:

- Mittellandkanal: Km 189.500 to Km 190.00 (Haimar)
- River Rhine: Km 793.500 to Km 795.00 (parallel structure at Walsum-Stapp)
- Lower Havel Waterway: Km 35.500 to Km 35.800 (Ketzin)

Furthermore, within the scope of current construction measures on waterways, new test sections with alternative bank protection measures are being set up as a result of previous experiences and accompanied by monitoring programmes.

In this way, greater experience with alternative bank protection measures is gradually being acquired, evaluated and quantified. Data specification sheets with application limits for individual bank protection measures are being drawn up. The most significant results will finally flow into general recommendations for the application of technical-biological bank protection measures on inland waterways which, for the planning engineer from the German Federal Waterways and Shipping Administration (WSV), will represent a sound basis for the planning and execution of construction measures with regard to new construction and upgrading projects and for maintenance and redevelopment measures.

Up-to-date information on current studies within the frame of this research project and their results can be found on the joint web portal of BAW and BfG:
http://www.baw.de/ufersicherung/index.php.

Karlsruhe/ Koblenz, August 2008

p.p.	p.p.	Engineer responsible
(Dr.-Ing. Kayser, BAW)	(Dipl.-Ing. Liebenstein, BfG)	(Dipl.-Ing. Fleischer, BAW)

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15 Glossary

Anthropogenic (man-made): Created by humans.

Biocenosis: Ecological community of plants and animals that can be found in the same (→) biotope due to similar biotope requirements and unilateral or reciprocal dependencies.

Biotope: Habitat of a (→) biocenosis i.e. all abiotic factors acting upon a biocenosis.

Boxplot (or box-and-whisker-plot): A diagram used to present a series of numerical data. In addition to the median, the lower and the upper quartile are depicted as the boundaries of a rectangle, the “box”. This means the box includes 50 % of the values of a distribution. The lines which exceed the box are known as “whiskers”. In the figure shown here, these represent the sample maximum and sample minimum values. The notches correspond to confidence regions of 95 %. If the notches of two box plots do not overlap, this demonstrates a significant difference between the two medians.

Brushwood Fence (“Lahnung”): Construction for the protection of banks (e.g. with reed growth) in the form of a double-row palisade filled with stones or with branches and twigs of willows capable of sprouting and/or brushwood which is not capable of sprouting.

Constancy: Frequency of occurrence of a species, age group of a species or similar at a series of sampling sites (expressed as a percentage of the sampling sites with occurrence of the respective species and age group).

Coppicing: Pruning down to the base.

Dead wood: Pieces of dead wood or woody plants which are used, for example, either to produce fascines or which remain in the biotope as dead material and contribute to the ecological balance of the area by providing a habitat or source of food for organisms (beetles, insects and the like) that cause decomposition.

Detritivore: Organisms that feed on organic waste and fine material.

Diversity: Measure of appearances (species and structures) and of their uniform distribution in ecosystems related to the number of organisms, to a (→) biocenosis, an (→) ecosystem or a unit of space.

Dominance: Term used for the predominance of a species in a unit of surface or space when compared with other species. Dominant species can be determined by the best-adapted life-form, physical strength, life expectancy or resistance.

Ecology / ecological: Science of the relationships between living organisms (humans, animals, plants etc.) and of their relationship to their environment.

Ecosystem: Functional unit of (→) biotope and (→) biocenosis.

Epipotamal: In running water zonation, the upper section of the lower reaches of a river, also known as the *barbel zone.*

Erosion: Erosion is described as the process by which mainly soil material is removed from its original site through weathering influences, such as wind (drying up, break-up of soil crumbs, formation of dust which is then transported away by the wind) or water (precipitation, waves or the like).

Euryhalin: Tolerant of wide ranges of surrounding salinity.

Fascine: Cylindrical body (compressed to form a roll or interwoven) of *live or dead vegetation material* (branches, twigs, reed etc.; frequently in the form of a sinking fascine i.e., with additional filling of soil or stones to provide extra weight), however, usually consisting of shoot-forming willow rods and branches, for the purpose of securing the toe of the slope or the bank line in the mean water zone; they may also be permanently installed in the zone of fluctuating water levels, which is subject to wave action; usually also with an additional double row of stakes, wedge-shaped, anchored in the subsoil; in the mid-term, live fascines will form a fringe of shrubs which, as the roots become increasingly intertwined, will provide stable protection for the bank.

Freeboard: Difference between a given water level (e.g. a predetermined retention target) and the lowest point of an overflowable surface edge or of a crest of a structure over which the water should not to flow.

Gap grading: Soil with an unsteady grading curve (particle distribution curve) in which certain particle sizes are lacking.

Gley: Soil type formed under the influence of ground water. It originates through so-called gleying, during which processes of oxidation and reduction take place. Sequence of horizons: Ah horizon (Ah = humus layer; uppermost soil horizon, moist, humus-rich); Go horizon (Go = gley-oxidation; middle horizon in the ground water fluctuation zone, with periodic aeration, resulting in oxidation and rust-coloured patches); Gr horizon (Gr = gley-reduction, lower horizon, permanently waterlogged due to the presence of ground water, oxygen-deficient, blue-grey in colour).

Grazer: Organisms which graze, that is, move around while feeding on the biofilm on stone surfaces.

Hydraulic load: Banks of water bodies are subject to natural impacts such as flow, wind waves and flood discharge and to man-made impacts such as waves, drawdown and return flow caused by navigation.

Hydrostatic water level: The effect of backwater in running waters, characterised by a rise in the water level. The cause is an obstacle to discharge, in this case the locks at Landesbergen. The backwater level or "hydrostatic water level" in an impounded river corresponds to the local low water conditions (hydrostatic water level in the test stretch area: 26.5 m a.s.l.; mean low water here is 26.53 m a.s.l.).

Initial (also primary) succession: Predominantly pioneer species which colonise a habitat or are planted in an area after disturbances (high water, bank relocations, erosion activity, construction measures etc.) and which form a starting point for a new succession sequence.

Invertebrates: Animals without an inner bone skeleton (e.g. planarians, snails, insects).

K strategists: → r and K strategists

Limicoles: Wader birds

Limnophile: Preferring slowly-running or stagnant water sections.

Lithal: Habitat on coarse gravel and stones

Live brush mattress: Layer of pole wood spread flat and secured on the surface of a bank toe (usually consisting of shoot-forming willow species).

Long branch cutting: Freshly cut, live pole wood (usually shoot-forming species of willow) which in accordance to its direction of growth is placed at a sufficient depth into the subsoil perpendicularly (by driving or ramming) to allow the section of wood above ground surface to produce new shoots.

Macroinvertebrates: (→) Invertebrates which can be seen with the naked eye and live in or on the bottom of water bodies and on the bank as well as on aquatic plants and reed beds.

Macrozoobenthos: (→) Macroinvertebrates living on the bottom of water bodies; "bottom fauna" in water bodies.

Maintenance: Serves to sustain the function of the current state of a stand of vegetation.

Naidinae: Sub-family of the sludge worms (tubifex worms).

Natural: Not modified by man, left in the original state.

Nature-oriented / Close to nature: Quite close to the natural state.

Neophytes / Invasive species: *Newly introduced* plants or animals (invasive species) which owe their existence in a certain area directly or indirectly to human influence and which were brought to Europe intentionally or unintentionally after the discovery of America (since around the year 1500) and grew up alongside the native flora and fauna. In some places they can cause massive problems through inordinate growth rates.

Potamon Typie Index (PTI): The Potamon TypieIndex uses indication values of the taxa as the basis for describing the closeness to nature of the macrozoobenthos cenoses of large rivers (potamon = Greek: river).

Pruning down to the base (also: coppicing): Woody plants (above all types of willow) are *cut back rigorously and completely to the root stock or immediately above it*, which normally causes them to produce a large number of new shoots (from dormant eyes) in the next growth period.

r and K strategists: Organisms with opposing strategies for reproduction; r strategists mainly invest their energy in producing a large number of offspring and make little effort in caring for them, for example, frogs; whereas K strategists have few offspring but care for these more intensively, for example, human beings.

Reed and sedge plugs: Pre-cultivated plants with root balls (consisting of underground shoots and roots). These include, for example, vegetation tussocks from the company Best-mann, which were cultivated in degradable fibre textiles.

Reed and sedge sods: General definition: sections of reeds or sedges with attached sub-soil, which have been dug out. In this document: refers to plant material gathered by the WSA in Verden, dug out as spade-wide sections.

Reed bed: Plant communities mostly of tall growth in the siltation zone in the aquatic area of running and stagnant water bodies; some reed bed species have their roots mainly in the soil substrate below water-level and develop the green biomass predominantly above the water-line.

Revetment: Banks can be protected from unwanted erosion e.g. by permeable loose or grouted (→) riprap, impermeable surface linings or alternative technical-biological protection measures, as studied in this report.

Rheophile: Preferring flowing water.

Riprap: Form of technical bank protection consisting of crushed stones – mostly with an average size of 20 - 30 cm – spread over a filter on the sloped bank. In most cases this con-sists of loose stone, in specific cases it may also be (partially) grouted.

Row of stakes / piles: Construction of weather-resistant single wooden stakes at bank zones of low water depth; installed as a single row of stakes driven in directly beside one another in order to protect the bank from wave action; also as a double row of piles – for example, piles driven in at intervals and connected with wattle fencing – possibly with stone filling and, as required, with plants; function: for instance as a (→) live brush mattress.

Saprobity (or saprobial) index (SI): The type-specific, conceptual saprobity index assesses the effect of organic pollution on the macrozoobenthos. The calculation is based on a frequency classification.

Screw race: Propulsion current; localised area of flow to the aft of the ship caused by the driving element (e.g. propeller).

Shallow-water zone (in inland areas): A section of bank that does not follow the usual waterline with a markedly lower water depth than the main channel and, if necessary, protected from the main channel by wave deflectors or smootheners, e.g. in the form of a stone mound.

Ship speed, critical: The speed – V_{krit}" – of a ship in shallow water, or while passing through a canal, when the water displaced by the ship can no longer be transported in full measure in the direction opposite to the direction of travel of the ship in a condition of flow. At the narrowest cross section alongside the ship, the transition from a state of flow to a state of shooting flow sets in. The smaller the ratio of the cross section of the body of water to the cross section of the ship, the lower is the V_{krit} for hydraulic reasons. V_{krit} cannot normally be exceeded by displacement hulls (for instance, freight ships).

Succession area: An area which is left to natural succession.

Succession: A natural process over a period of time characterised by a *sequence of interdependent vegetation states*, with one state giving rise to the next; after several vegetation phases, depending on the soil type, water and climatic conditions, these develop, for instance, from pioneer vegetation, via open meadow vegetation towards closed woodland vegetation as the stable final stage.

Sunk fascine (also: sunken, sinking): (→) Fascine

Thalweg: A line connecting the lowest points of all cross sections of a river or canal along its lengthwise course. Changes in water level and riverbed or bottom may lead to fluctuations in the position of the thalweg. Its course is generally not identical with the middle line of the body of water.

Vegetation mats, reed mats: Woven mats made, for instance, from coir fabric and planted with vegetation that has already formed roots. This may be reedy plants or grasses and herbs. The mats are cut into sizes that can easily be transported and are simply laid with the roots downward onto an area of open soil (close to the riverbank). They are pegged down at the corners until the plants have firmly taken root.

Vegetation zoning: Occurrence of varying vegetation units in zones that are differentiated by specific features of their location, for instance, in the bank zone by differing flooding periods, depending on the predominant water levels.

16 List of abbreviations

AU	Bank stretch where alternative bank protection measures have been installed
B	Breeding bird
BAW	German Federal Waterways Engineering and Research Institute *(Bundesanstalt für Wasserbau)*
BfG	German Federal Institute of Hydrology *(Bundesanstalt für Gewässerkunde)*
BMVBS	German Federal Ministry of Transport, Building and Urban Development *(Bundesministerium für Verkehr, Bau und Stadtentwicklung)*
BNatSchG	Federal Nature Conservation Act *(Bundesnaturschutzgesetz)*
BP	Breeding pair
B-Rand	Breeding at the edge of the study area
BV	Suspicion of breeding
cf.	Confer
DGPS	Differential Global Positioning System
DWD	German Meteorological Service *(Deutscher Wetterdienst)*
G	Feeding guest
GBB	Principles for the Design of Bank and Bottom Protection for Inland Waterways /BAW 2005/ *(Grundlagen zur Bemessung von Böschungs- und Sohlensicherungen an Binnenwasserstraßen)*
GBBSoft	GBB Software
GPS	Global Positioning System
HHQ	Highest high flow rate
HNQ	Highest navigable flow rate
HHW	Highest high water
HN	Hydraulic-numerical
HNW	Highest navigable water level
m a.s.l.	Metres above sea level
MHQ	Mean high water discharge
MLQ	Mean low water discharge
MLW	Mean low water
MQ	Mean discharge
MW	Mean water
MWL	Mean water level
MZB	Macrozoobenthos, benthic invertebrates
N	Invasive species
NNatG	Nature Conservation Act of Lower Saxony *(Niedersächsisches Naturschutzgesetz)*
PTI	Potamon Typie Index
Q	Discharge
R&D	Research and Development

RU	Reference bank (conventional bank protection measures)
SWL	Still water level
SWZ	Shallow water zone
SI	Saprobity index
spp.	Species (plural)
W	Water level
WFD	Water Framework Directive
WSA	Waterways and Shipping Board *(Wasser- und Schifffahrtsamt)*
Wsp	Water surface position
WSV	German Federal Waterways and Shipping Administration *(Wasser- und Schifffahrtsverwaltung)*