# DELIVERABLE 2.1.1
# IWT FLEET AND OPERATION

**Final version**

Report for:
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# 1. Introduction

Climate change may affect water levels and thereby also Inland Waterway Transport (IWT), e.g. in terms of decreasing load factors and increasing costs. Accordingly, one of the objectives of ECCONET is to identify the impacts on IWT e.g. in terms of possible additional costs and to identify and recommend measures to reduce the impacts. Also, shipping industry may adapt logistics and/or production to mitigate the effects of climate change. For example shippers can increase volume of stock in order to avoid transportation during periods with extreme water levels. Transport service providers can change the fleet (e.g. light weight or more smaller vessels) in order to reduce the average draft of the vessels. Moreover, waterway managers can adapt infrastructure to some degree in order to limit or to avoid water level decreases. Finally, water level prediction methods could be improved in terms of checking possibilities of seasonal water-level forecasts.

Subtask 2.1.1 and this report (Deliverable D 2.1.1) deal with the identification and the analysis of promising adaptation strategies and concrete measures addressed to transport issues:

- technical changes of the fleet (vessels),
- changes in operation of the fleet and eventually
- changes in logistic solutions.

This refers to various options like e.g.:

- increasing the payload of a ship keeping the main dimensions (L x B x T) unchanged (lightweight structures)
- reducing the number of days per year when the navigation of a ship is physically not feasible (e.g. by installing retractable tunnel aprons, adjustable blisters)
- upgrading of smaller, less low-water-sensitive vessels from only daytime- and semi-continuous operation-mode to continuous operation-mode and thereby increasing the annual number of operating hours of these vessels
- co-operation with the railway mode in order to shift parts of the IWT-transport-volume in low water periods to the railway mode
- implementation of a larger number of smaller, less low-water-sensitive vessels

Besides transport related adaptation measures as listed above, Task 2.1 will consider measures dealing with the adaptation of the waterway infrastructure (2.1.2), the improvement of water level prediction procedures (2.1.3) and the adaptation of production processes and storekeeping (2.1.4). These aspects will be dealt with in separate deliverables.

# 2. Overview of representative ship types

On the European waterways, a large variety of ships can be identified. An even larger variety of parameters would be necessary to describe them. Besides a division in self-propelled vessels and convoys consisting of unpropelled barges pushed by another ship, the ships can be classified by ship types based on their main dimensions. These ship types are identified as generalized ships representing a group of ships with similar size, load carrying capacity, and hydrodynamic properties.

Figures 1 and 2 give an impression of the most relevant ship types on the river Rhine and the Danube Waterway respectively. The order of appearance in the table is based on the ship size and not on the frequency of occurrence at the particular river.

On the Rhine River common ship types are besides the Gustav-Königs and the Johann-Welker class the Large cargo vessels. They are operated stand-alone as well as so-called coupled convoys. Most pushed convoys are operated with 4 barges, although 6-barge trains are also possible at the Duisburg-Rotterdam track.

On the Danube Waterway, the self-propelled ships and pushed barge trains as shown are the usual configurations. Vessels like the Large cargo vessel of the GMS-95 type (or so-called "Stein"-class) are almost exclusively operated as coupled convoys and very seldom as stand-alone units, especially on long-range voyages. Vessels smaller than or equivalent with the Gustav Koenigs type are usually used for short-range local traffic.

Larger convoys like 6-barge trains are only are able to be operated downstream of Vienna. Even 9-barge trains could theoretically appear downstream of Komarom/Komarno (Danube km 1767) however they are not very usual nowadays.

## Vessel types typical for the river Rhine

| | | |
|---|---|---|
| 1 | **Gustav Koenigs-type (extended version)** | 80 x 8.20 m (L x B)<br>$T_{max}$= 2.50 m, payload about 1.100 t<br>$T_{min}$= 1.10 m, payload about 250 t |
| 2 | **Johann Welker-type (extended version or Europe-type)** | 85 x 9.50 m (L x B)<br>$T_{max}$= 2.60 m, payload about 1.400 t<br>$T_{min}$= 1.20 m, payload about 300 t |
| 3 | **Large cargo vessel (GMS-type , 110 m)** | 110 x 11.40/11.45 m (L x B)<br>$T_{max}$= 3.50 m, payload about 2.900 t<br>$T_{min}$= 1.35 m, payload about 400 t |
| 4 | **Large cargo vessel (GMS-type , 135 m)** | 135 x 11.40/11.45 m (L x B)<br>$T_{max}$= 3.50 m, payload about 3.800 t<br>$T_{min}$= 1.35 m, payload about 670 t |
| 5 | **JOWI-type (containership)** | 135 x 16.80 m (L x B)<br>$T_{max}$= 3.50 m, payload about 5.200 t<br>$T_{min}$= 1.60 m, payload about 1.300 t |
| 6 | **Europe II barge (E II-barge)**<br>(to be combined with pushing unit) | 76.5 x 11.4/11.45 m (L x B)<br>$T_{max}$= 4.00 m, payload about 2.750 t<br>$T$ = 3.50 m, payload about 2.300 t<br>$T_{min}$= 1.35 m, payload about 600 t |
| 7 | **Coupled convoy**<br>consisting of GMS-110 + 1 E II-barge | 186.5 x 11.4/11.45 m (L x B)<br>$T_{max}$= 3.50 m,<br>payload about 2.900 + 2.300 = 5.200 t<br>$T_{min}$= 1.35 m, payload about 400 + 600 = 1000 t |
| 8 | **Pushed convoy**<br>consisting of push boat + 2 x 2 E II-barges | 153 x 19.00 m<br>(L x B, without pushb.)<br>total length about 193 m<br>$T_{max}$= 4.00 m,<br>payload about 4 x 2.750 = 11.000 t<br>$T_{min}$= 1.75 m[1],<br>payload about 4 x 900 = 3.600 t |

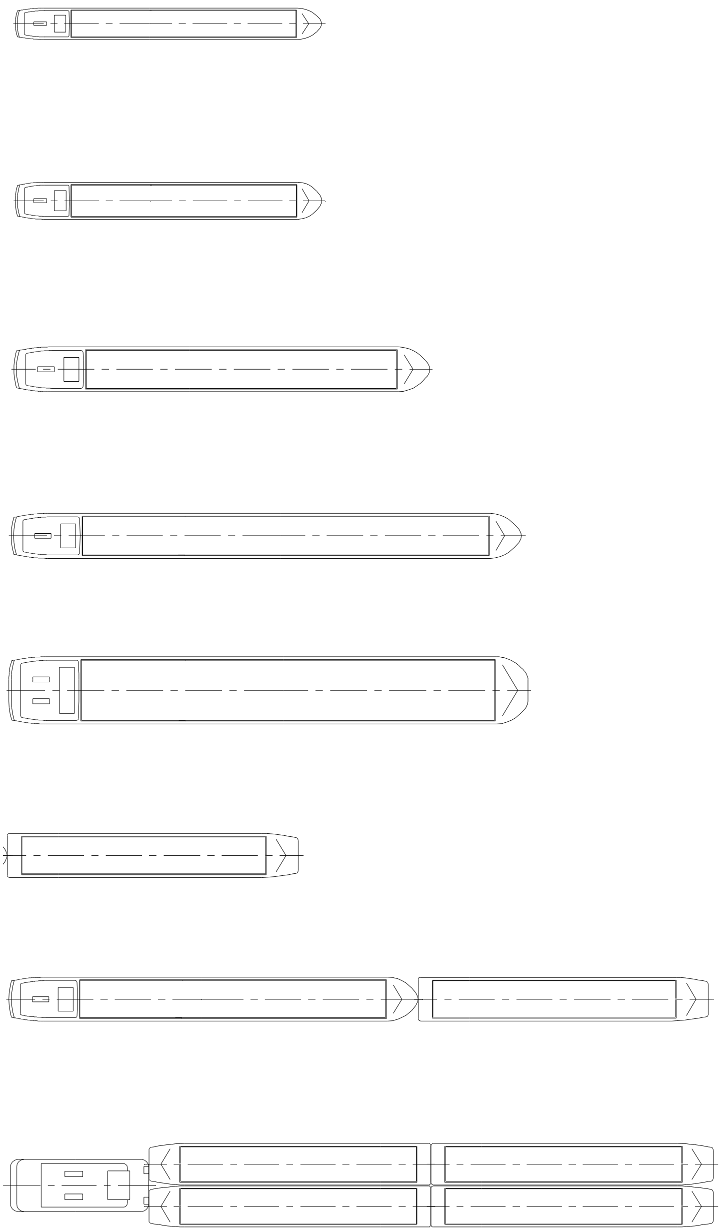

*Fig. 1: Vessel types typical for the river Rhine and main dimensions (L, B, $T_{max}$ and $T_{min}$) with the corresponding cargo capacities*

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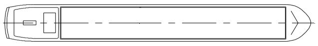
[1] The relatively high empty draught ($T_{min}$= 1.75 m) belongs to the large push boat. The coupled barges have an empty draught of only about 0.60 m

## Cargo Vessels typical for the Danube Waterway

**1 Gustav Koenigs-type (extended version)**

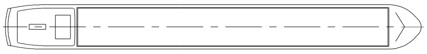
80 x 8.20 m (L x B)
$T_{max}$= 2.50 m, payload about 1.100 t
$T_{min}$= 1.10 m, payload about 250 t

**2 Johann Welker-type (extended version or Europe-type)**



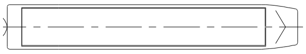
85 x 9.50 m (L x B)
$T_{max}$= 2.60 m, payload about 1.400 t
$T_{min}$= 1.20 m, payload about 300 t

**3 Large cargo vessel (GMS-95 type, "Stein"-class)**



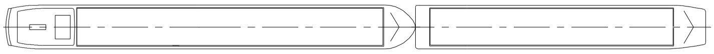
95 x 11.00/11.40 m (L x B)
$T_{max}$= 2.70 m, payload about 1.910 t
$T_{av}$ = 2.50 m, payload about 1.650 t
$T_{min}$ = 1.35 m, payload about 265 t

**6 Danube-Europe II barge**
(DE II-barge,
to be combined with
pushing unit)



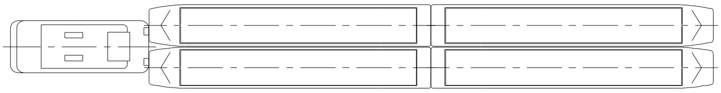
76.5 x 11.0 m (L x B)
$T_{max}$= 2.50 m,
payload about 1.550 t

**7 Coupled convoy**
consisting of GMS-95 +
1 DE II-barge



171.5 x 11.0/11.40 m (L x B)
$T_{max}$= 2.50 m,
payload about 1.650 + 1.550 = 3.200 t
$T_{min}$= 1.35 m,
payload about 265 + 665 = 930 t

**8 Pushed convoy**
consisting of push boat
+ 2 x 2 DE II-barges



153 x 22.00 m
(L x B, without pushb.)
total length about 193 m
$T_{max}$= 4.00 m,
payload about 4 x 1.550 = 6.200 t
$T_{min}$= 1.60 m[2],
payload about 4 x 865 = 3.450 t

*Fig.2: Vessel types for the Danube Waterway and main dimensions (L, B, $T_{max}$ and $T_{min}$) with the corresponding cargo capacities*

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[2] The relatively high empty draught ($T_{min}$= 1.60 m) belongs to the large push boat. The coupled barges have an empty draught of only about 0.60 m

# 3. Adaptation options: fleet, operation and logistics

As said above, diferent kinds of adaptation measures to match the expected water level changes like e.g. reduction of annual average water depth or increase of variation amplitude will be investigated. Thereby, the following groups will be considered:

| **A** | Technical | **B** | Operational | **C** | Logistics |
|---|---|---|---|---|---|
| 1 | Lightweight structures | 1 | Small, less low water sensitive vessels: Upgrade to continuous instead of daytime operation | 1 | Strategic alliances between IWT and railways |
| 2 | Adjustable tunnel (retractable tunnel aprons) | 2 | Implementation of smaller instead of larger vessels | | |
| 3 | Side blisters | 3 | Implementation of coupled convoys instead of single motor vessels | | |
| 4 | Flat hulls<br>(multi-screw push boats) | | | | |

*Table 1: Overview of fleet, transport and logistics adaptation options*

As regards the groups A (Technical measures) and B (Operational measures) the expected effects as regards to climate change might be in the gained ability of the ship:

- to take more load at the same draught,
- to be able to operate (navigate) safely even at lower draught (and with less payload) or to
- to make more turnovers within the same time period (e.g. during the same year), thereby realizing a higher transported volume.

Each of the particular transport related adaptation measures would cause certain effects but also would require certain investment in monetary terms.

The quantification of effects, the particular measures can bring in monetary terms vs. the payload capacity mainly relates to investment costs. Differences in operational costs as well as in maintenance costs before and after are considered as small (and are expected to remain within the estimation of error margins). It is also assumed that the lifetime of the adaptation measure is equal to the lifetime of the ship the measure has been applied to.

# 4. Fleet

## 4.1 Lightweight structures

### 4.1.1 Description

This type of measures enables the vessel to carry more payload at the same draught or to operate at lower draught with the same payload through the reduction of own weight. Hulls of commercial conventional ships are built of so-called “mild steel” – steel plates and profiles of standard quality (mechanical characteristics and chemical components) dedicated to shipbuilding. Thereby the hull structure must satisfy the prescribed strength requirements. However, standardized structures (cross sections, bar scantlings and plate thicknesses) have been usually developed that way to minimize the building costs and not the weight.

A certain reduction of the hull weight can be achieved through the implementation of lighter structural components like e.g.:

- high tensile steel instead of mild steel (reduced scantlings and plate thickness)
- reduced frame and/or longitudinal spacing enabling hull construction with thinner plates and lighter stiffeners
- sandwich plate systems or I-Core panels
- different concept solutions for the midship section in the range of the cargo hold (see below)

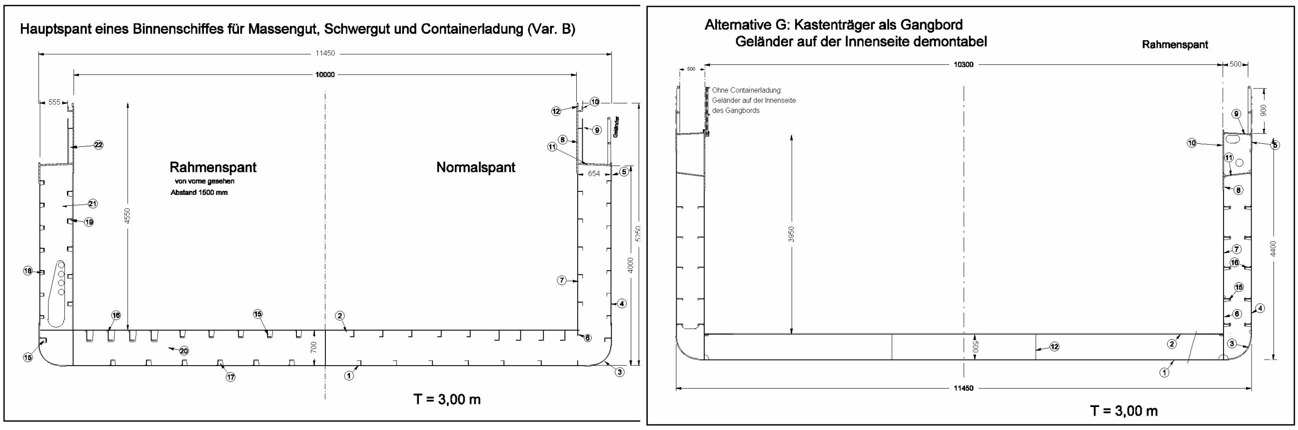


*Fig. 3: A conventional midship section of a large Rhine motorship (left) and an alternative solution with box girder as gangway (right)*

The right structural solution in the above figure brings about 60 t savings on the cargo hold weight if applying the same material (mild steel) and maintaining the same stress limits as for the conventional solution.

Such methods of lightening the hull can be applied to newbuildings as well as to reconstructions of existing ships, for instance by replacing the parallel middle section by a new, light-weight structure.

According to the state-of-the-art technology the most realistic approach seems to be the reduction of the frame spacing and consequently the savings on plate thickness. However, this method has its weak points as for instance the use of grapples for the reloading of bulk, which requires thicker plates applied to the cargo hold, inner bottom and side walls. Also the labour-related building costs become higher.

### 4.1.2 Expected effects

Possible own weight savings for different ship types used on the Rhine and Danube are estimated on the base of previous studies /1/, /2/, /3/ and shown in the table beneath.

| | | | More carrying capacity at reduced draught for x[cm] - corresponds to the same drop of water depth and unchanged carrying capacity | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | savings | immersion | water level drop [cm] | | | | | | | | | | |
| | [t] | [t/cm] | 5 | 6 | 7 | 8 | 9 | 10 | 15 | 20 | 25 | 30 | Compensation of carrying capacity [t] |
| Gustav Koenigs extended | 45 | 6,1 | 31 | 37 | 43 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | |
| Johann Welker extended | 55 | 7,5 | 38 | 45 | 53 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | |
| GMS 110 | 90 | 11,1 | 56 | 67 | 78 | 89 | 90 | 90 | 90 | 90 | 90 | 90 | |
| GMS 135 | 150 | 14,3 | 72 | 86 | 100 | 115 | 129 | 143 | 150 | 150 | 150 | 150 | |
| JOWI | 200 | 21,1 | 105 | 127 | 148 | 169 | 190 | 200 | 200 | 200 | 200 | 200 | |
| Europe II Barge | 70 | 8,0 | 40 | 48 | 56 | 64 | 70 | 70 | 70 | 70 | 70 | 70 | |

*Table 2a: Possible weight savings on typical Rhine vessels*

| | | | More carrying capacity at reduced draught for x[cm] - corresponds to the same drop of water depth and unchanged carrying capacity | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | savings | immersion | water level drop [cm] | | | | | | | | | | |
| | [t] | [t/cm] | 5 | 6 | 7 | 8 | 9 | 10 | 15 | 20 | 25 | 30 | Compensation of carrying capacity [t] |
| Gustav Koenigs extended | 45 | 6,1 | 31 | 37 | 43 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | |
| Johann Welker extended | 55 | 7,5 | 38 | 45 | 53 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | |
| GMS 95 | 75 | 10,1 | 50 | 60 | 71 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | |
| Danube Europe II barge | 40 | 8,0 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | |

*Table 2b: Possible weight savings on typical Danube vessels*

Savings on own weight lead to the reduction of the empty draught and consequently to an increase of the payload at the same draught. The figures in the shaded fields in the above table indicate how much more payload can be transported by the ship after the implementation of the adaptation measure in comparison to the same ship built in conventional way. In other words, the table demonstrates how many centimetres of the water level drop can be compensated by applying the lightweight construction principles simultaneously keeping the same payload as for the conventionally built vessel. It can be concluded that a water drop compensation of 10 and more centimetres can be achieved only by the most modern large Rhine vessels. Thereby the question is whether the very slender GMS 135 type can be lightened by as much as 150 tons without affecting the longitudinal strength requirements, especially for loading heavy bulk (e.g. ore) in one shift. Another problem which may suspend or at least restrict the application of thinner plates for the cargo hold is the usage of grapples for the unloading of bulk. Due to this reason the bottom and side walls of the cargo holds of inland ships and barges dedicated to dry bulk transport are much thicker than required by the stress analyses and classification requirements (Germanischer Lloyd, Bureau Veritas, etc.). Ships dedicated only to container or Ro-Ro transports are not affected by the above consideration.

As regards the Danube vessels, the feasible weight savings are lower than for the corresponding Rhine ships due to two main reasons. First of all the Danube GMS 95 is considerably shorter (about 15 m) than the Rhine GMS 110 and has a smaller design draught – about 2.6 m vs. 3.2 to 3.5 m respectively. From this follows a smaller volume of the cargo holds and thereby less potential for weight savings. The second reason is that principally the hulls of the Danube vessels are already built of thinner plates and smaller stifeners thus leaving less possibility for additional structure lightening.

The corresponding reconstruction costs (replacement of the cargo-hold section of the hull) are estimated and shown in Tables 3a and 3b.

| | total costs | max. water drop compensation | costs [K€] for the drop compensation of | | | costs [K€] for 1 ton capacity gain | costs [K€] for 1 cm water drop compensation |
|---|---|---|---|---|---|---|---|
| | [€] | [cm] | 5 cm | 10 cm | 15 cm | [1000 €/t payload] | [1000 €/cm depth] |
| Gustav Koenigs extended | 330000 | 8 | 330 | - | - | 7333 | 41250 |
| Johann Welker extended | 400000 | 8 | 400 | - | - | 7273 | 50000 |
| GMS 110 | 650000 | 9 | 650 | - | - | 7222 | 72222 |
| GMS 135 | 1000000 | 15 | 1000 | 1000 | 1000 | 6667 | 66667 |
| JOWI | 1400000 | 10 | 1400 | 1400 | - | 7000 | 140000 |
| Europe II Barge | 420000 | 9 | 420 | - | - | 6000 | 46667 |
| Coupling train (GMS+E II) | 1070000 | 9 | 1070 | - | - | 6688 | 118889 |
| Pushed train (PB+4E II) | 1680000 | 9 | 1680 | - | - | 6000 | 186667 |

*Table 3a: Estimated costs for lightening the hull of the Rhine vessels and typical convoys*

| | total costs | max. water drop compensation | costs [K€] for the drop compensation of | | | costs [K€] for 1 ton capacity gain | costs [K€] for 1 cm water drop compensation |
|---|---|---|---|---|---|---|---|
| | [€] | [cm] | 5 cm | 10 cm | 15 cm | [1000 €/t payload] | [1000 €/cm depth] |
| Gustav Koenigs extended | 330000 | 8 | 330 | - | - | 7333 | 41250 |
| Johann Welker extended | 400000 | 8 | 400 | - | - | 7273 | 50000 |
| GMS 95 | 550000 | 8 | 650 | - | - | 7333 | 68750 |
| Danube Europe II barge | 300000 | 5 | 420 | - | - | 7500 | 60000 |
| Coupling train (GMS+DE II) | 850000 | 7 | 1070 | - | - | 7391 | 121429 |
| Pushed train (PB+4DE II) | 1200000 | 5 | 1680 | - | - | 7500 | 240000 |

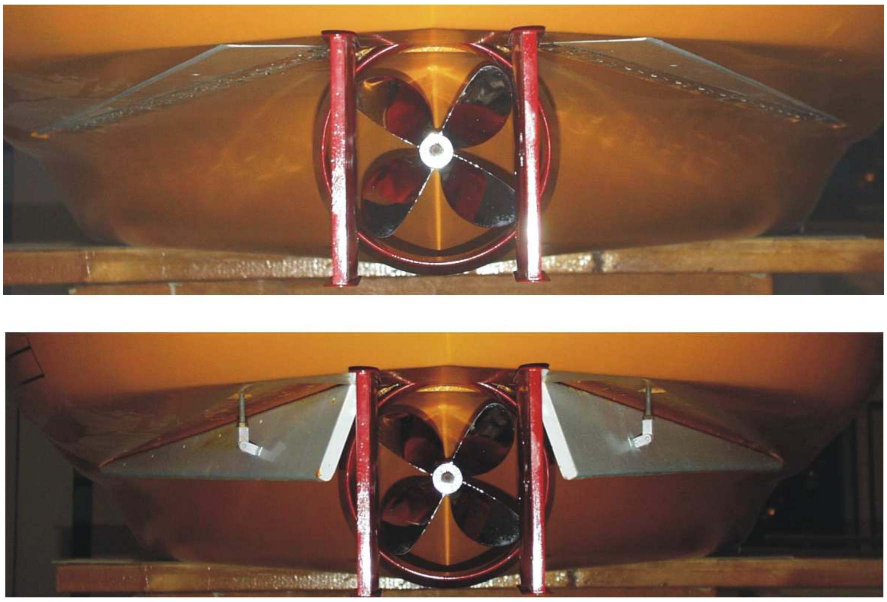
*Table 3b: Estimated costs for lightening the hull of the Danube vessels and typical convoys*

## 4.2 Adjustable tunnel (retractable tunnel aprons)

### 4.2.1 Description

At extremely low water levels and corresponding draughts the risk rises that the propeller is not fully immersed anymore. This results in a considerable loss of propulsion efficiency. A reasonable approach to solve this problem is to build a so-called “tunnel” in the range of the propeller shaft. Such a form of underwater hull prevents the non-desirable air suction into the rotating propeller and hence enables a favourable water inflow also at low water levels and small draughts. According to a very rough estimate some 90 % of inland self-propelled vessels and push boats on European waterways are already equipped with firm tunnels. Such a firm tunnel with a constant geometry brings good effects in low water conditions but on the other side – in case of favourable water depths – its presence causes negative effects on the propulsion performance. This happens due to the hindering of a free water flow into the propeller disc from aside over the lower edge of the tunnel aprons.

From a hydrodynamic point of view an installation of adjustable tunnel aprons /4/ seems to be a good solution to overcome losses in propulsion effects in operation of inland vessels at fluctuating water depths. Applying this adaptation measure the water levels of navigability can be extended by around 30 cm, e.g. from 110 cm to 80 cm for Gustav Königs type vessels or from 135 cm to 105 cm for GMS type vessels and coupled convoys.



Source: DST

*Fig. 4: Adjustable tunnel aprons (in functional model scale)*
*- to be retracted into the hull if the ship utilizes its full draught in deep water (above)*
*- to be extracted when the ship operates with small draught in low water (below)*

### 4.2.2 Expected effects

The benefits are that the vessels equipped with adjustable tunnel aprons are able to operate efficiently and safely within a wide range of water depths, from deep to extremely low ones including safe operation at small draught to maintain services during the periods of low water. The number of days per year when the navigation is not possible due to extremely low water would be considerably reduced. Thereby, a higher reliability of services can be realised, while on the other hand the rate of capacity utilisation remains limited on these journeys with small draught.

| | $T_{min}$ | | costs | max. water drop compensation | payload reduction for the drop of water level for | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | without aprons | with aprons | | | | | | | | |
| | [cm] | [cm] | [€] | [cm] | 5 cm | 10 cm | 15 cm | 20 cm | 25 cm | 30 cm |
| Gustav Koenigs extended | 110 | 80 | 70.000 | 30 | 31 | 61 | 92 | 122 | 153 | 183 |
| Johann Welker extended | 120 | 90 | 100.000 | 30 | 38 | 75 | 113 | 150 | 188 | 225 |
| GMS 95 | 135 | 105 | 130.000 | 30 | 51 | 101 | 152 | 202 | 253 | 303 |
| GMS 110 | 135 | 105 | 130.000 | 30 | 56 | 111 | 167 | 223 | 278 | 334 |
| GMS 135 | 135 | 105 | 130.000 | 30 | 72 | 143 | 215 | 286 | 358 | 429 |
| JOWI | 160 | 120 | 150.000 | 40 | 105 | 211 | 316 | 422 | 527 | 633 |
| Coupling train (GMS 110+E II) | 135 | 105 | 130.000 | 30 | 95 | 191 | 286 | 382 | 477 | 573 |
| Coupling train (GMS 95+DE II) | 135 | 105 | 130.000 | 30 | 90 | 181 | 271 | 361 | 451 | 542 |

*Table 4: Estimated costs for the installation of retractable aprons and payload reduction due to a water level drop (affecting the appropriate draught reduction)*

## 4.3 Side blisters

### 4.3.1 Description

In order to achieve a maximal efficiency an inland ship – like all other vehicles – is optimised for certain average nautical conditions which will most likely occur during its service lifetime. A very illustrative example can be found in road transportation:

*Fig. 5: Road vehicles optimised to road conditions*

The lorry on the left is optimized for off-road conditions and the large “18-wheeler” to the right for modern motorways. If comparing the transport performance potential of these two trucks – taking into account the loading capacity, speed and usual daily distance – the 18-wheeler will probably have an even 10 times higher potential than the “Unimog” - also an excellent and ideally optimized load vehicle, but for quite different road conditions /5/.

But opposite to more or less constant conditions on segments of the road network, the nautical conditions on the inland waterways are subject to considerable and relatively frequent changes, especially on free-flowing rivers. The most influencing change is the fluctuation of the water depth. The water depth determines the load and in extreme cases even the physical limits - is the passage with any load possible at all or not.

The previous two measures (A1 – lightweight structure and A2 – retractable tunnel aprons) aim to increase the payload ratio of the ship and widen the range of a safe and efficient use at different water depths respectively. The idea of side blisters is based on additional buoyancy which can be engaged upon the need. In case the voyage should take place when low water occurs the blisters will be coupled. Under favourable conditions (near to those for which the ship is actually optimized) the blisters would be uncoupled and the ship would continue the service with optimal performance.

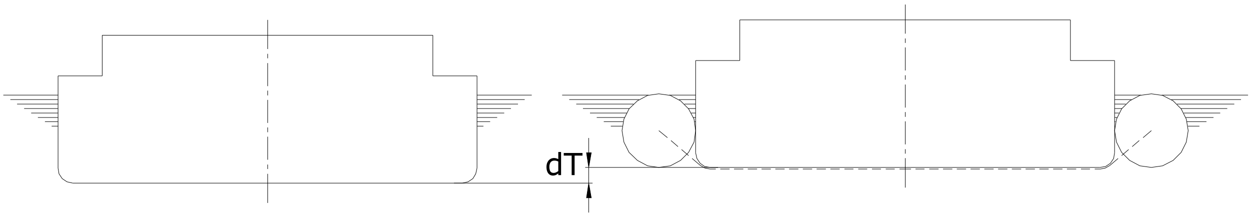


*Fig. 6: Inland vessel without and with side blisters*

### 4.3.2 Expected effects

The effects in operation unify the good performances of conventional ships in standard waterway conditions and the relatively simple mean to reduce the draught in situations with extremely low water levels. However, due to additional width of a coupled formation "ship + 2 blisters" the direct passage on waterways with lock dimensions below the given limit would not be possible.

A rough estimate of the hydrostatic properties of selected inland vessels with additional buoyancy provided by cylindrical steel blisters (first technical approach) is given beneath.

Thereby, certain general assumptions are made:

- This type of blisters is of uniform dimensions and applicable to different ship sizes
- It makes sense to use blisters on slender self-propelled cargo vessels only:
    - "Gustav Koenigs" extended: L x B = 80 x 8.2 m
    - "Johann Welker" extended: L x B = 85 x 9.5 m
    - "GMS-95"[3]: L x B = 95 x 11.4 m
    - "GMS-110"[4]: L x B = 110 x 11.4 m
- Cylinders' and ship's base lines are aligned (sea Fig. 4)
- Length and cylinder diameter have to be selected to match the size of the ships suitable for application.

The following dimensions /6/ and assumptions are adopted:

- Cylinder length – 55 m
- Diameter – $\Phi$2 m
- Total weight of two cylinders including equipment – 80 t
- Specific building costs for cylinders – 5€/kg of total weight

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[3] So-called „Stein"-class, used on the Danube

[4] Most typical large motorship on the Rhine

| | Displacement without blisters | | | | Displacement with blisters | | | |
|---|---|---|---|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [m³] | [m³] | [m³] | [m³] | [m³] | [m³] | [m³] | [m³] |
| 1,10 | 560 | | | | 675 | | | |
| 1,20 | 620 | 836 | | | 756 | 972 | | |
| 1,30 | 680 | 914 | | | 838 | 1072 | | |
| 1,35 | 710 | 953 | 1117 | 1307 | 878 | 1121 | 1285 | 1475 |
| 1,40 | 740 | 992 | 1178 | 1365 | 918 | 1170 | 1356 | 1543 |
| 1,50 | 800 | 1070 | 1300 | 1480 | 998 | 1268 | 1498 | 1678 |
| 1,60 | 860 | 1148 | 1421 | 1595 | 1076 | 1364 | 1638 | 1812 |
| 1,70 | 920 | 1226 | 1543 | 1711 | 1153 | 1459 | 1776 | 1944 |
| 1,80 | 980 | 1304 | 1665 | 1826 | 1228 | 1552 | 1912 | 2074 |
| 1,90 | 1040 | 1382 | 1786 | 1942 | 1299 | 1641 | 2045 | 2201 |
| 2,00 | 1100 | 1460 | 1908 | 2057 | 1366 | 1726 | 2174 | 2323 |
| 2,10 | 1160 | 1538 | 2030 | 2172 | 1426 | 1804 | 2295 | 2438 |
| 2,20 | 1220 | 1616 | 2151 | 2288 | 1486 | 1882 | 2417 | 2553 |
| 2,30 | 1280 | 1694 | 2273 | 2403 | 1546 | 1960 | 2539 | 2669 |
| 2,40 | 1340 | 1772 | 2395 | 2519 | 1606 | 2038 | 2660 | 2784 |
| 2,50 | 1400 | 1850 | 2517 | 2634 | 1666 | 2116 | 2782 | 2900 |

*Table 5: Displacement of selected ship types with and without blisters vs. draught*

| | Draught savings at unchanged payload | | | |
|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [cm] | [cm] | [cm] | [cm] |
| 1,10 | 19 | | | |
| 1,20 | 22 | 18 | | |
| 1,30 | 26 | 21 | | |
| 1,35 | 28 | 22 | 17 | 15 |
| 1,40 | 29 | 24 | 18 | 16 |
| 1,50 | 32 | 26 | 20 | 18 |
| 1,60 | 35 | 29 | 21 | 19 |
| 1,70 | 38 | 31 | 23 | 21 |
| 1,80 | 41 | 33 | 25 | 22 |
| 1,90 | 42 | 35 | 26 | 23 |
| 2,00 | 44 | 35 | 26 | 24 |
| 2,10 | 44 | 35 | 26 | 24 |
| 2,20 | 44 | 35 | 26 | 24 |
| 2,30 | 44 | 35 | 26 | 24 |
| 2,40 | 44 | 35 | 26 | 24 |
| 2,50 | 44 | 35 | 26 | 24 |

| | Costs to maintain the same load at certain draught | | | |
|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [€/cm] | [€/cm] | [€/cm] | [€/cm] |
| 1,10 | 21263 | | | |
| 1,20 | 17876 | 21979 | | |
| 1,30 | 15464 | 19013 | | |
| 1,35 | 14508 | 17837 | 24021 | 26399 |
| 1,40 | 13679 | 16818 | 22648 | 24891 |
| 1,50 | 12322 | 15150 | 20403 | 22423 |
| 1,60 | 11277 | 13865 | 18671 | 20520 |
| 1,70 | 10469 | 12872 | 17334 | 19050 |
| 1,80 | 9855 | 12117 | 16317 | 17933 |
| 1,90 | 9417 | 11578 | 15592 | 17135 |
| 2,00 | 9188 | 11296 | 15212 | 16718 |
| 2,10 | 9188 | 11296 | 15212 | 16718 |
| 2,20 | 9188 | 11296 | 15212 | 16718 |
| 2,30 | 9188 | 11296 | 15212 | 16718 |
| 2,40 | 9188 | 11296 | 15212 | 16718 |
| 2,50 | 9188 | 11296 | 15212 | 16718 |

*Table 6: Draught reduction of selected ship types after using blisters vs. draught (left)*

*Investment costs estimated to maintain the same payload at the respect. draught (right)*

| | Payload gained through draught savings | | | |
|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [t] | [t] | [t] | [t] |
| 1,10 | 115 | | | |
| 1,20 | 136 | 136 | | |
| 1,30 | 158 | 158 | | |
| 1,35 | 168 | 168 | 168 | 168 |
| 1,40 | 178 | 178 | 178 | 178 |
| 1,50 | 198 | 198 | 198 | 198 |
| 1,60 | 216 | 216 | 216 | 216 |
| 1,70 | 233 | 233 | 233 | 233 |
| 1,80 | 248 | 248 | 248 | 248 |
| 1,90 | 259 | 259 | 259 | 259 |
| 2,00 | 266 | 266 | 266 | 266 |
| 2,10 | 266 | 266 | 266 | 266 |
| 2,20 | 266 | 266 | 266 | 266 |
| 2,30 | 266 | 266 | 266 | 266 |
| 2,40 | 266 | 266 | 266 | 266 |
| 2,50 | 266 | 266 | 266 | 266 |

| | Costs per 1 ton of gained payload | | | |
|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [€/t] | [€/t] | [€/t] | [€/t] |
| 1,10 | 3486 | | | |
| 1,20 | 2931 | 2931 | | |
| 1,30 | 2535 | 2535 | | |
| 1,35 | 2378 | 2378 | 2378 | 2378 |
| 1,40 | 2242 | 2242 | 2242 | 2242 |
| 1,50 | 2020 | 2020 | 2020 | 2020 |
| 1,60 | 1849 | 1849 | 1849 | 1849 |
| 1,70 | 1716 | 1716 | 1716 | 1716 |
| 1,80 | 1616 | 1616 | 1616 | 1616 |
| 1,90 | 1544 | 1544 | 1544 | 1544 |
| 2,00 | 1506 | 1506 | 1506 | 1506 |
| 2,10 | 1506 | 1506 | 1506 | 1506 |
| 2,20 | 1506 | 1506 | 1506 | 1506 |
| 2,30 | 1506 | 1506 | 1506 | 1506 |
| 2,40 | 1506 | 1506 | 1506 | 1506 |
| 2,50 | 1506 | 1506 | 1506 | 1506 |

*Table 7: Investment costs per each gained ton of payload at the respective draught*

If the evaluation is based on 1 ton payload gained through the buoyancy added by the cylindrical blisters the result does not depend on the ship type. Quite reasonably the maximal effect is achieved by totally submerged blisters (draught of 2.0 m)

Besides cylindrical steel blisters there is a series of other technical solutions based on the same principle of providing additional buoyancy during the low water periods and switching this feature off during favourable nautical conditions thus enabling the vessel to achieve its optimal hydrodynamic performances.

These could be for instance inflatable blisters carried onboard as a permanent part of the ship's equipment and blow them up and off upon the need, as well as steel made blisters of a shape other than cylindrical in order to mitigate resistance through the water.

A very interesting idea is also the application of foldable buoyancy elements integrated into the ship's body and laterally extractable. The vessel is being lifted to its necessary draught due to pressurised air filled into the extracted elements. Thus, this vessel is able to economically operate both in high and low water depth carrying the same cargo volume /7/.

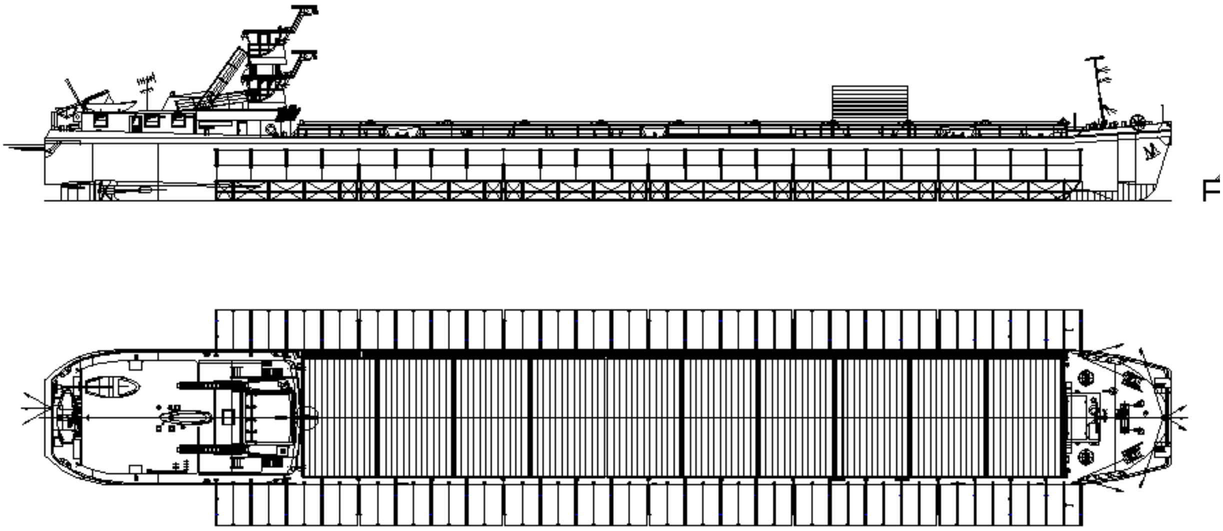


*Fig. 7: General arrangement plan of a ship with laterally extractable buoyancy elements*

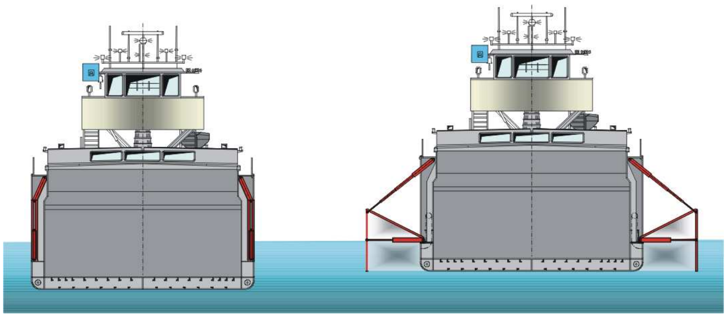


*Fig. 8: Cross section of a ship with laterally extractable buoyancy elements*

The necessary power supply, hydraulic, pneumatic and electric equipment, fittings and piping are almost independent of the ship size between G. Koenigs and GMS-110, while the costs for the production and the installation of the foldable steel structure depend mostly on the length of the ship. (Contrary to the first solution of standardised cylindrical blisters, this type is tailored to the individual vessel sizes.) A rough estimate of the investment costs follows:

| Total investment costs | | | |
|---|---|---|---|
| **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [€] | [€] | [€] | [€] |
| 356.000 | 372.000 | 404.000 | 452.000 |

*Table 8: Investment costs per ship size*

Probably, this system could be applied to longer vessels too like a GMS-135 and eventually also to in-line coupled trains on both coupled motorship and pushed barge. The question is whether the relatively high refitting costs of about 400.000 € (making about 50 % of the building costs of a conventional Europe II barge) can be justified.

| | Draught savings at unchanged payload | | | |
|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [cm] | [cm] | [cm] | [cm] |
| 1,10 | 23 | | | |
| 1,20 | 26 | 27 | | |
| 1,30 | 29 | 30 | | |
| 1,35 | 30 | 32 | 33 | 35 |
| 1,40 | 32 | 33 | 35 | 36 |
| 1,50 | 35 | 36 | 38 | 40 |
| 1,60 | 38 | 39 | 41 | 43 |
| 1,70 | 41 | 42 | 44 | 46 |
| 1,80 | 44 | 45 | 47 | 49 |

| | Costs to maintain the same load at certain draught | | | |
|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [€/cm] | [€/cm] | [€/cm] | [€/cm] |
| 1,10 | 15.731 | | | |
| 1,20 | 13.883 | 13.722 | | |
| 1,30 | 12.424 | 12.349 | | |
| 1,35 | 11.804 | 11.760 | 12.240 | 12.998 |
| 1,40 | 11.243 | 11.226 | 11.707 | 12.432 |
| 1,50 | 10.267 | 10.290 | 10.770 | 11.437 |
| 1,60 | 9.446 | 9.498 | 9.972 | 10.589 |
| 1,70 | 8.747 | 8.819 | 9.284 | 9.859 |
| 1,80 | 8.145 | 8.231 | 8.685 | 9.223 |

*Table 9: Investment costs estimated to maintain the same payload at respective draught*

| | Payload gained through draught savings | | | |
|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [t] | [t] | [t] | [t] |
| 1,10 | 138 | | | |
| 1,20 | 156 | 203 | | |
| 1,30 | 175 | 226 | | |
| 1,35 | 184 | 237 | 333 | 386 |
| 1,40 | 193 | 249 | 349 | 404 |
| 1,50 | 212 | 271 | 379 | 439 |
| 1,60 | 230 | 294 | 409 | 474 |
| 1,70 | 248 | 316 | 440 | 509 |
| 1,80 | 267 | 339 | 470 | 544 |

| | Costs per 1 ton of gained payload | | | |
|---|---|---|---|---|
| **T** | **G.Koenigs-e** | **J.Welker-e** | **GMS-95** | **GMS-110** |
| [m] | [€/t] | [€/t] | [€/t] | [€/t] |
| 1,10 | 2.579 | | | |
| 1,20 | 2.276 | 1.830 | | |
| 1,30 | 2.037 | 1.647 | | |
| 1,35 | 1.935 | 1.568 | 1.212 | 1.171 |
| 1,40 | 1.843 | 1.497 | 1.159 | 1.120 |
| 1,50 | 1.683 | 1.372 | 1.066 | 1.030 |
| 1,60 | 1.549 | 1.266 | 987 | 954 |
| 1,70 | 1.434 | 1.176 | 919 | 888 |
| 1,80 | 1.335 | 1.097 | 860 | 831 |

*Table 10: Investment costs per each gained ton of payload at the respective draught*

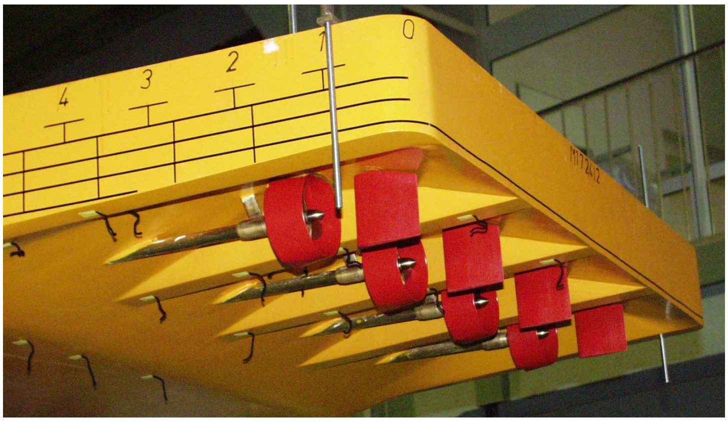
At present, practical experiences of side blisters in use, be it cylindrical or laterally foldable solutions are not known yet. It is however expected, that such systems - besides possible handling and lock-passing problems – might be rather sensitive against damaging.

## 4.4 Flat hulls (multi-screw vessels)

### 4.4.1 Description

Empty pushed barges usually have a draught of only 50 to 60 cm and an immersion of about 8 t/cm (standard Europe II barges on the Rhine and Danube). Accordingly, already at a limited draught of 100 cm the carrying capacity of one single barge is about 350 t (i.e. about 1400t for convoys with 4 barges). Contrary to this, the draught of the presently existing push boats usually is much higher; nowadays such usually twin-screw push boats on the Danube have a draught of about 160 to 180 cm, irrespective of the load of the barges they push. Hence, during low water periods the draught of the push boat and not the draught of the barges is decisive to determine whether the convoy can run or not.

In this context flat hulls and multiple-screw vessels are considered as a possible approach to overcome this situation. Thereby, the draught of the ship could be reduced by delivering the required thrust not only to 1 or 2 propellers (usual solution nowadays) but to 3 or even 4 smaller propellers. This approach is considered as promising esp. for the push convoy technology due to the large draught differences between push boat and barges (see figures 5 and 6).



Source: DST

*Fig. 9: Example of a shallow draught quadruple-screw push boat (testing model)*

An initial conceptual design for a very shallow draught triple-screw long-range Danube push boat has recently been developed /8/. The vessel would have a length of 30 and beam of 11 metres. The propulsion output of 3 x 700 kW with a propeller diameter of 1.5 m would allow a draught of only 1.4 m thereby maintaining all the valid standards referring to safety and economic performance in operation. The estimated building costs are about 6 million € per unit (price of material and labour at 2009 level in shipyards on the middle and lower Danube).

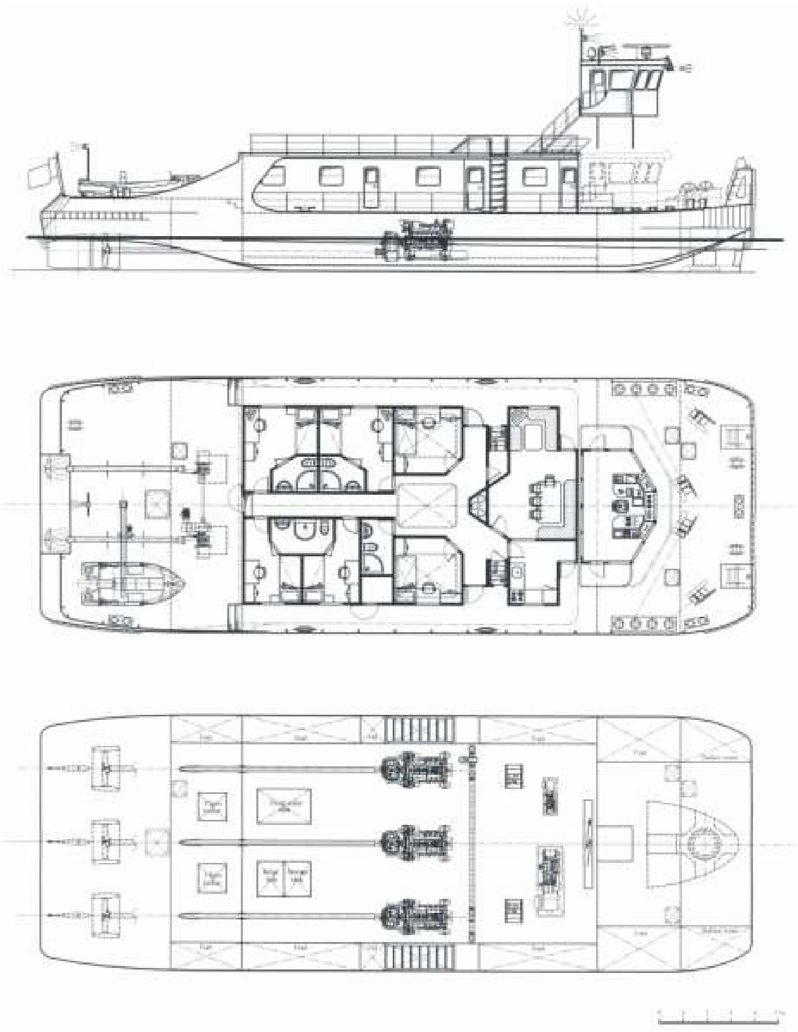


*Fig. 10: Example of a shallow draught triple-screw push boat (conceptual design for the Danube)*

### 4.4.2 Expected effects

This aproach enables a draught reduction from standard 1.7 m to desired 1.4 m. Thereby, the entire fleet of pushed barges can be used as it is, without any adaptation. On the other hand, the flat-hull multi-screw push boats are more expensive than the standard twin-screw push boats of the same size (15-20%) and the propulsion efficiency might be a little bit lower (in the order of magnitude of ~5%).

# 5. Operation

## 5.1 Implementation of smaller instead of larger vessels

### 5.1.1 Description

Apart from propulsion and equipment the main dimensions prove to be the core parameters of ships. Length, beam and draught significantly influence the range of operation for instance in terms of navigable waterways (e.g. available water depths and lock dimensions), capacity depending on the water depth as well as cost structure and scale effects.

For decades there is an obvious trend to larger ship units on the river Rhine aiming at size effects (economies of scale) and favourable costs, above all for bulk and container transports. This trend comes along with continuously increasing draughts. Vessels like for example of the type Gustav Koenigs have an empty draught of 1.10 m and a max. draught of 2.50 m, while GMS type ships have an empty draught of 1.35 m and a max. draught of 3.50 m. Finally, the empty draught of JOWI-type vessels varies from already 1.60 m for the empty vessel to 3,5 m for the completely loaded vessel.

Favourable waterways enable high capacity utilisation rates (loading factors) and relatively low unit costs for large vessels. At low water levels however, large ships can only operate, if at all, partly loaded (i.e. with a low capacity utilisation or low loading factor, correspondingly), while smaller vessels often still navigate at quite good loading factors.

### 5.1.2 Expected effects

The question, whether larger or smaller vessels would be more advantageous as to cost structures and reliability, to a large extent depends on the available water depths and in particular their variation and expected future development. In the case of heavily decreasing water levels due to expected climate changes smaller vessels would be more advantageous compared to larger ones. Therefore, a possible adaptation measure would be the implementation of smaller instead of larger vessels.

However, if those vessels have to be kept in addition to larger ones, their cost advantages might be compensated or go into reverse. Eventually, this question requires a consideration of expected climate change and water level scenarios.

## 5.2 Upgrade of smaller vessels to continuous operation

### 5.2.1 Description

As already mentioned before, smaller vessels like the types Gustav Koenigs or Johann Welker are due to their lower draughts less sensitive to lower water levels than larger ships. In periods with extreme low water levels when large ships can no longer or, if at all, only operate in partly loaded condition, these vessels can often still run at acceptable capacity utilisation. In contrast to larger ships and because of their usually higher age and the lower capital being tied up these smaller vessels predominantly navigate in daytime or semi-continuous operation mode (operation mode A1 or A2, i.e. 14 or 18 h/d). If they could be upgraded to run in continuous mode (all day round, 24 h a day), this would generate another approach to reduce the fleet’s sensitivity to low water levels. Precondition however would be additional crew members to meet the additional operating time (see manning rules for the navigation on the Rhine /9/ and other inland waterways including the Danube /10/). It is assumed, that the existing accomodation could be adapted appropriately for the additional personnel.

### 5.2.2 Expected effects

The ship being allowed to operate 24 instead of 14 or 18 hours per day would be able to realize more turnovers and hence a higher transport capacity (+70 % compared to a 14 hours operation or +33 % in contrast to a 18 h operation) especially during unfavourable water conditions, when larger vessels are hardly able to operate at all.

Also in this case, besides the additional costs for personnel and retrofitting, this approach requires a consideration of expected climate change- and water level scenarios.

## 5.3 Implementation of coupled convoys

### 5.3.1 Description

Finally, a further approach would be to distribute the cargo to a coupled system consisting of a self propelled vessel and a coupled barge instead of keeping it aboard of one ship only.

### 5.3.2 Expected effects

A standard coupled system on the Rhine consisting of a large motor ship (GMS, 110 x 11.4 m) and a Europe II barge can operate already at a draught of about 1.35 m. This is the least draught of the coupled motor vessel abaft enabling safe navigation and manoeuvring. At this draught the payload of the coupled convoy is on average about 1000 tons.

If however only a GMS would be loaded with 1000 t, a draught of 1.85 m would result; by distributing the max. payload of a GMS (approx. 3000 t) to a coupled convoy the draught would decrease from 3.50 m to about 2.30 m. Therefore, a coupled convoy is less sensitive to lower water levels (at constant load capacity) than a self propelled cargo motor vessel.

Simultaneously, this approach strengthens the flexibility of the system: In periods of favourable water depths this concepts allows for the transport of much higher cargo volumes than the GMS (5400 t compared to 3000 t (GMS) at a max. draught of 3.50 m in both cases) and thereby is able to meet the trend to larger ship units. With investments of 6.9 million € (pushed convoy) compared to approx. 6 million € for a GMS this flexibility can be realized with limited additional effort.

Besides, the changed number of crew members and a higher consumption are to be considered; their proportion is expected to change approximately to the same degree than the investments.

As the number of coupled convoys is continuously increasing since years, this development underlines the high flexibility combined with favourable costs this approach offers.

# 6. Logistics

## 6.1 Strategic alliances between IWT and railways

This chapter focuses on one specific type of adaptation: cooperation with other transport modes. Low water levels imply restrictions on the load capacity utilisation of inland waterway vessels. As a consequence, the transport costs per ton, and hence also the market price per ton transported will increase. This implies additional transportation costs for users of inland waterway transport services in times of low water levels. There might also be other effects which are harmful to the sector, such as increased levels of unreliability.

### 5.1.1 Description

Jonkeren /11/ indicates that the inland waterway transport market may be characterised as a competitive market with many enterprises demanding almost homogenous products to be transported and many suppliers (shippers) and unlimited entry, even in the short run. Due to the heterogeneity in demand concerning shipment size, different markets for different ship sizes exist at the same time. When water levels decrease, load factors will decrease and smaller ships might obtain more market share. Another possible effect is that other alternatives (modes) are considered by users of transport services. Road and railway transport may become suitable alternatives for freight forwarders and shippers. It could therefore be worthwhile for inland waterway operators to set up cooperation arrangements with transport service providers active in other modes of transport, that in cases of disruptions in inland waterway transport (e.g. extreme low water periods, ban of transport, accidents) alternatives can be offered to customers at reasonable prices. This will depend on capacities available and the extent to which the alternatives can provide a feasible alternative in the short run.

It is therefore required to study the feasibility of other modes as a (short term) substitute for inland waterways. This report does so by looking at two different sources of information. First, it will focus on desk research (literature) on price elasticities. Price elasticities indicate demand sensitivity. Clearly, when price elasticities are low, demand becomes more inelastic indicating that prices have less impact on demand. This suggests that alternatives are less attractive. Item 5.1.2 describes work on price elasticities. Item 5.1.3 provides the review of results from a survey under shipping companies which is the other part of this approach. After an accident in the beginning of 2011 at Sankt Goarshausen, navigation on the Rhine was heavily disturbed for over a month. NEA has conducted a survey amongst shippers to understand what the economic effects have been and whether alternative modes have been used. This incident might be considered as a situation with very low water which makes normal navigation not possible. It is interesting to know whether shippers have considered other options, have used other modes, or that they did not change behaviour. This gives an indication of cooperation with other modes and the possibility to reschedule freight shipments. It is tried to obtain cost information, which is needed within the overall framework of the assessment of adaptation measures.

### 5.1.2 Elasticities

Changes in prices will normally lead to changes in demand for goods or products. The extent of this behavioural response depends on the steepness or flatness of the demand curve. The sensitivity to price changes is expressed by economists in the concept of elasticity. The price elasticity of demand is defined as the percentage change in the quantity demanded divided by the percentage change in price. The elasticity concept is a dimensionless measure of the sensitivity of a dependent variable to changes in an independent variable. So the unit of measurement (be it euros or cents and meters or kilometers) of the variables does not make a difference. The elasticity value will be the same, regardless of how the variables are expressed, which is an advantage of the elasticity concept over other measures of sensitivity. It measures the responsiveness of demand to a change in price. An elasticity can be positive or negative. Price elasticities are usually negative. The dependent variable is called elastic with regard to the independent variable when the absolute value of the elasticity exceeds 1. In other cases, the dependent variable is inelastic, while a fixed 'dependent' variable is said to be perfectly inelastic. These elasticities do not indicate what happens with the decrease in demand. Also cross price elasticities exist, which indicates the responsiveness of the demand for alternatives.

Estimates of the price elasticity of demand for inland waterway transport are mainly found in North American literature /11/, /12/. Table 2.1 gives an overview of some yearly price elasticities (general transport costs) of demand for inland waterway transport and have a median value of about -1.0, which seems rather elastic.

| Paper | Estimated elasticity | Details |
|---|---|---|
| Yu and Fuller (2003) | Range between -0.5 and -0.2 | Grain transport, -0.5 for Mississippi river, -0.2 for Illinois river |
| Dager et al. (2005) | Range between -0.7 and -0.3 | Corn shipments on Mississippi and Illinois river |
| Oum (1979) | -0.7 | Intercity freight transport in Canada |
| Train and Wilson (2005) | Range between -1.4 and -0.7 | Revealed and stated preference data to analyse both mode and O/D changes as a result of an increase in barge rate for grain shipments |
| Henrickson and Wilson (2005) | Range between -1.9 and -1.4 | Concerns grain transport on Mississippi and accounts for spatial characteristics of the shippers |
| Beuthe et al., 2001 | Range between -10.0 and -0.2 | Estimated elasticities for 10 different commodities of cargo based on a multimodal network model of Belgian freight transport |
| Ecorys (2005) | Range between -0.4 and -1.0 | Distinguish between types of goods:<br>dry bulk (-0.4),<br>wet bulk (-0.6),<br>piece good (-0.9)<br>container transport (-1.0) |

*Table 11: Literature on price elasticities of demand in inland waterway transport*

There are clear arguments that demand might be less elastic for the following 3 reasons:

**1) Price of transport by barge is substantially lower compared to road and rail**

First, the price for transportation by inland navigation for most bulk goods is substantially lower than transport by another mode. This has the consequence that prices should rise substantially before other alternative transport modes become competitive. This indicates that modal split effects for this type of cargo transport are small. This is confirmed by an Ecorys (2005) study /12/, which finds an elasticity of - 0.4 for dry bulk transport. Also liquid bulk and piece goods transported by inland navigation have lower estimates.

A substantial parts of the amount of goods transported by inland waterway transport can be considered as 'captive markets' due to the heavy dependence of shippers for supply of goods by barge. Clear examples are the production of steel (supply of ores and coal by barge) and energy production (supply of coal to coal-fired electric power plants).

There is also a difference in distance since inland waterway transport becomes more competitive on longer distances, which implies that elasticities are generally higher on shorter distances.

**2) Required transport capacity is not available in road and rail transport**

A second argument is that ships carry large quantities of goods. Other modes of transport will not have the capacity to transport all cargo which is carried by inland waterway vessels. Especially in the short run (after an incident or disruption), immediate capacity will not be available which makes it difficult to shift cargo. For example the required spare capacity of trucks and drivers is not available as well as suitable locomotives and wagons, train drivers and train paths often need to be required on long time before the actual transport takes place. Moreover, due to this situation scarcity of capacity in road and rail transport will also result in higher freight prices on the spot market (short term markets). Low water periods can be predicted to a certain extent and will occur less unexpected, but still time is needed to coordinate and create capacity (if available at all). The period of low water is often too short and its duration not known beforehand to make modal shift strategies feasible.

**3) Transport costs are only a limited part of the overall production costs**

Thirdly, shippers have more options than considering alternative modes only as shippers aim to prevent their production processes from costly interruptions and costs of inland waterway transport are only a small part of total production costs. Harris (1997) mentions that for most low value goods, like coal and steel, inland waterway transport is about 2% of total production costs. Hence, accepting a temporally higher freight rate for inland navigation during low water periods is more cost efficient than having interruptions in the production process. So, in the long run demand will be more inelastic. In the short run, however, the demand may be more elastic because shippers are able to postpone transport and rely on their stocks.

It might be concluded that empirical cross price elasticities for inland navigation are scarce. A study by Oum et al. /14/ presents cross price elasticities for inland navigation. An increase in prices of inland navigation mainly leads to more rail transport (+0.61 to +0.86). A shift to road transport is less obvious (-0.12 to 0.13). The negative value suggests that road transport is not only a substitute to inland navigation, but also a complement (part of the intermodal chain). Note that cross price elasticities very much depend on market specific circumstances and the level of aggregate data that is available to derive elasticties.

It follows from the desk research that the impact of water levels on transport prices are negative, and that increasing water levels, given negative price elasticities, will lead to more demand for inland transport. Jonkeren /11/ provides an overview of different price elasticities of demand from literature, and estimate an elasticity of -0.6 based on own data. In his analysis, periods with low water levels (such as 2003) lead to considerable welfare losses. This does not mean that in low water level periods and price increases alternative modes will benefit. Other responses are possible and plausible in the short run, such as accepting less payload and higher freight rates, more storekeeping, changing to usage of smaller ships and postponement of transport. Given the type of goods and the uncertainty in availability of capacity with other modes, a change to other modes is less feasible. The survey discussed in the next chapter will reveal whether this is practically true.

### 5.1.3 Survey among stakeholders

NEA has carried out a survey among stakeholders using the river Rhine for inland navigation, such as ship owners, shippers and freight forwarders, to assess the economic damage of the accident with a Rhine tanker (the MT "Waldhof"). For more than three weeks starting in January 2011, a capsized tanker carrying 2,400 tons of sulphuric acid blocked ship traffic on the Rhine, one of the busiest commercial arteries in Europe. The river was closed for commercial traffic from Mainz to Koblenz, leaving many ships waiting along the river unable to pass. There was much uncertainty about when the river would be open again for traffic. Companies waiting for their ships to pass have reported considerable losses up to €2000 a day.

It is very interesting to know whether companies have decided to use alternative modes instead of inland navigation due to this blockage of the Rhine. As part of a large study to assess economic damage, NEA has also included questions about considerations and practical use of road and railway transport which can be considered as most realistic alternatives for Rhine transport. The following questions have been asked to shipowners:

- Have you seriously considered (or really searched) alternative transport options due to the tanker incident?
- If no, why not?
- If yes, have you only considered or searched, or did you really use alternative options? When alternative modes have been used, what have been the costs?
- Do you consider future cooperation with road and/or railway companies to be better prepared for future accidents or low water periods?

We have made use of an Internet survey. All questions have been put on a website. NEA has kindly invited shipowners providing inland Rhine services to go to the website and answer a few questions with a clear explanation of purposes and privacy treatment of their answers. The website with questions has been online in June and July 2011, which is a few months after the incident but still sufficiently soon to remember the economic impact of the blockage.

### Results of survey

In the end, 74 shipowners have answered the questions. The table below shows the results on the above questioning.

| Questions | Answers |
|---|---|
| Seriously considered alternative transport? | Yes: 42% (N=31); No: 58% (N=43) |
| If not, why? | Uncertainty about duration (56%)<br>Too expensive (32%)<br>No capacity available (23%) |
| Yes (N=31): | |
| • We did consider but made no use in the end | 70% (N=22) |
| • We did change freight to other modes | Road 18% (N=6) and railways 21% (N=7) |
| • What have been the costs of using other modes | unclear |
| Do you consider future cooperation? | No: 93%, rest yes or do not know |

*Table 12: Questions and answers of survey*

The above table indicates that most shipowners did not seriously consider alternative modes during the time that the Rhine was blocked. This was mainly because of uncertainty: it was possible that ‘normal’ navigation would soon be possible. Although waiting involves additional costs, these costs are probably still smaller compared to shifting to another mode of transport.

Many shipowners consider (or assume) a modal change as rather expensive. A final argument put forward by some respondents is the limited available capacity with other modes. These reasons might be perceptions, but they may also well be formed by experience.

A minority of 31 shipowners did seriously consider alternatives, of which 70% did not change in practice. Still, 13 (17.5% of total) have cooperated with other modes with almost equal shares for road and railway transport. In those cases it is very difficult for the respondents to assess the costs that have been involved. Hence, it is not possible to quantify this for the respective analysis. It also appears that future accidents or uncertainty caused by low water levels is not something that is seriously considered as a reason for more cooperation with other modes in order to be better prepared. A vast majority (93%) indicates that future cooperation is not considered.

# 7. Summary and conclusions

Three groups of adaptation measures to cope with the expected future climate changes and the corresponding developments of water levels on Rhine and Danube have been considered: technical, operational and logistical measures. The main characteristics of these measures and their impacts are summarised in the table below.

| | Measure | Primary effect | Comments and remarks |
|---|---|---|---|
| A1 | Lightweight structures, e.g. high tensile steel, SPS etc. | Reduction of own weight<br>➔ lower draught;<br>weight savings / payload gained: appr. 50-200t | Lightweight structures are relatively sensitive against damages; further research on technical solutions expected (beyond ECCONET) |
| A2 | Adjustable tunnel | Extension of navigability to lower water levels | Applicable only for a limited number of vessels (which are not yet equipped with tunnels) e.g. in combination with A1<br>(no stand-alone-solution) |
| A3 | Side blisters | Reduction of draught; payload gained at low water betw. 115 and 260t | Rather theoretical approach;<br>’handling’ difficult,<br>esp. (de-) coupling of blisters;<br>sensitive against damages |
| A4 | Flat hulls<br>(multiscrew vessels) | Considerable draught reduction of push boat from e.g. 1.7 to 1.4 m | Promising approach esp. for push boat technology, even though construction costs increase and propulsion efficiency decreases |
| B1 | Small instead of large vessels | Small vessels are less low water sensitive than large ones due to lower draughts | Favourable only in case of low water levels, but rel. high transport costs in case of favourable water levels, when ‘scale-effect’ (economies of scale) could not be realised due to small units |
| B2 | Upgrade of small, less sensitive vessels from daytime to continuous operation | Increase of performance of the smaller, less sensitive vessels in times of low water | Promising, as far as upgrading will succeed (adaptation of accommodation for enlarged crew) |
| B3 | Coupled convoys instead of single propelled vessels only | Distribution of load to both units<br>➔ Reduction of draught;<br>(or: increase of load capacity) | Promising approach; able to operate at moderate draught and also, to serve the trend to large units (scale effect) without increasing draught; high flexibility |
| C1 | Strategic alliances between IWT and other modes | Co-operation with other modes: shift of cargo to other modes in case of low water | Possibilities limited due to expected ‘barriers’ and capacity limits (rail: infrastr. and rolling stock) and high price level of road transport |

*Table 13: Overview and characteristics of adaptation measures*

### Interim conclusions

As regards fleet and transport systems it can be stated, that certain adaptation measures do exist. Especially flat hulls and multi screw vessels, respectively (for push boat technology) and coupling convoys are considered as promising approaches on a general level; the same refers to the upgrade of smaller, less low-water sensitive vessels to the continuous operation mode. Further approaches do exist and seem to be promising in certain cases like e.g. lighthull structures, or adjustable tunnels.

Nevertheless, further evaluations have to be carried out in order to investigate the relative advantageousness of these measures and their chances for implementation. Thereby, also the expected degree of climate change impacts has to be considered, accordingly: the more intensive the expected impacts are, the more (expensive and challenging) approaches are needed. As an interim conclusion a compensation of expected climate change impacts seems to be possible to a certain extent with fleet related strategies; in this context also the potentials of other measures like waterway adaptation, improved prediction methods and adaptations of production processes have to be envisaged.

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