ANNEX 4 - Guidance Note on Adaptation to Climate Change for Navigation

August 2015
Water & Climate Adaptation Plan for the Sava River Basin

ANNEX 4 - Guidance Note on Adaptation to Climate Change for Navigation

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GUIDANCE NOTE ON ADAPTATION TO CLIMATE CHANGE
FOR THE SAVA RIVER BASIN – NAVIGATION

1 Background
This report provides guidance note for decision making on the adaptation needs related to inland navigation in the Sava River Basin (SRB). This guidance note is one of the components of the Water and Climate Adaptation Plan (WATCAP) being prepared by the Consultant for the International Sava River Basin Commission (ISRBC) under World Bank funding. It builds on the main WATCAP report (World Bank, 2013b), the report on the development of future climate scenarios (Vujadinovic and Vukovic, 2013) and on the report on development of the hydrologic model for the Sava River basin (World Bank, 2013a).

2 Present navigation conditions
Navigation on the Sava River is possible in the upstream direction from its confluence with Danube in Belgrade up to the town of Sisak, on total length of 586 km. The Sava River and its basin are presented in Figure 1. The tributaries of the Sava River are navigable on short reaches as shown in Table 1.

Source: International Commission for the Protection of the Danube River (ICPDR)

Figure 1: The Sava River basin overview map with major rivers.

1 COWI AS of Norway were contracted by the World Bank to undertake the development of the hydrologic model – World Bank Contract No - 7162102.
One of the principal objectives of the *Framework Agreement on the Sava River Basin* (FASRB) between the riparian countries in the Sava River Basin is a sustainable development of inland navigation on the Sava River (ISRBC, 2009b). Navigation is therefore one of the primary fields of activity of ISRBC. These activities also include preparation of the studies necessary for rehabilitation and development of the Sava River waterway, such as the *Feasibility Study and Project Documentation for the Rehabilitation and Development of the Transport and Navigation on the Sava River Waterway* (hereby ‘Feasibility study’), which deals with set of rules and requirements for the improvement of navigation safety, as well as with the re-establishment of the waterway marking system on the Sava River.

The Sava River is centrally located in the east-west and north-south Core Transportation Network for South East Europe (SEE) and could better complement the road and rail corridors as well as the European waterway corridor focusing on the Danube River. Transport on the Sava was around 9.5 million tons in 1982 and decreased to 5.7 million tons in 1990. The war of the early 1990s destroyed economic activities and the river (and port) infrastructure. For this reason, the cargo handled in the Serbian ports of the Sava in recent years was down to less than 25 thousand tons and in ports of BiH and Croatia to less than 1 million tons.

Clearly, action was needed to regenerate river navigation and to invigorate use of the Sava River as a sustainable, more environmentally friendly and energy efficient form of transportation. Recognizing the potential conflict between the development of inland waterway transport and EU WFD implementation, the ISRBC, together with the Danube Commission (DC) and ICPDR, was involved in the implementation of the *Joint Statement on Guiding Principles for the Development of Inland Navigation and Environmental Protection in the Danube River Basin*. This document was adopted in December 2007 (by the ICPDR, DC) and in January 2008 (by ISRBC). The ‘Joint Statement’ is a guiding document for development of the ‘Programme of Measures’ requested by EU WFD, for the maintenance of current inland navigation, and for planning and investments in future infrastructure and environmental protection projects.

Low performance of cargo transport in ports along the Sava River is a direct result of the current very poor status of the waterway. In addition, the waterway infrastructure suffers from aging, lack of maintenance and incompleteness. The actual classification of the Sava River from Belgrade to Sisak (586 km) is 50/50 class III and class IV.

The quality of the Sava River as a transport mode mostly depends on the availability of sufficient depth for navigation. In line with Sava Commission Classification (SCC) regulations, the Sava Commission applies two standards:

- Navigation must be possible with a reduced draft 95% of the time;
- Navigation with maximum draft must be possible 65% of the time.
According to the SCC, the fairway for class IV waterways should have a depth of 2.3 m, 95% of the time, and a depth of 3.3 m, 65% of the time. The width of the fairway for two-lane traffic should be 55 m in straight sections and 75 m in curves, measured along the river bed centre line of the curve. The design requirements for improving the Sava to a SCC Class Va waterway are almost similar to the design requirements for a SCC Class IV waterway. The differences are:

- The depth of the fairway is 2.4 m for SCC Class Va and 2.3 m for SCC Class IV (at low navigable water level).
- The width of the waterway in bends is 90 m for SCC Class Va instead of 75 m for SCC Class IV; and
- The horizontal clearance below bridges is 55 m for SCC Class Va and 45 m for Class IV.

The situation in the field is far from meeting the requirements for Class IV and Va waterways. The ISRBC aims at rehabilitation and development of the waterway, improving the Sava River between Belgrade and Sisak to minimum Class IV waterway and to Class Va on sectors where it is possible and feasible.

The current navigation conditions are poor and unfavourable mostly due to:

(i) limited draft over long periods,
(ii) limited width of the fairway, and
(iii) sharp river bends limiting the length and width of vessels and convoys.

The conclusion of the Feasibility Study and Project Documentation for the Rehabilitation and Development of Transport and Navigation on the Sava River Waterway is that Sava should be improved to Class Va. The Feasibility Study recognized that 21 stretches of the river require dredging and training works and 20 stretches require river bend improvements, three bridges have to be reconstructed, and marking systems has to be completed (between rkm 335 to rkm 150), with a total cost of about 86 million EUR.

According to the Feasibility Study, rehabilitation and improvement of the Sava River waterway seems to be a project with clear positive socio-economic effects. However, due to the fact that the project has environmental implications, there is a need to carry out environmental impact assessments (EIA) before decisions are made. This is required by the appropriate EU directives for qualifying the projects. According to the ISRBC, the Sava navigation project is implemented in two parts, i.e. on two sections: moving progressively upstream from the confluence with the Danube, these are sections from 0 to 211 rkm and from 211 to 594 rkm. The EIA study for the upper section has been completed. Given some concerns expressed by environmental NGOs, additional environmental considerations will be made in the framework of the detailed design of the waterway, which is currently under development. For the lower section the EIA study is being prepared in parallel with the development of the detailed design.

### 3 Climate change impact on navigation conditions

Inland navigation is under significant influence of the meteorological and hydrological conditions. Four phenomena were identified by Nilson et al. (2012) as the potential main causes of climate-related restrictions of inland navigation:

(i) low flows,
(ii) high flows,
(iii) river ice, and
(iv) visibility (fog).

The first two phenomena are the result of the hydrologic regime, which is driven mainly by precipitation, temperature and evapotranspiration. Ice formation is under influence of air and water temperatures, while the fog results from higher humidity during lower air temperatures. All these factors can directly or indirectly change the navigability of waterways. Changes in water level in rivers, ice formation and fog may affect the number of days per year that waterways can be used without restriction. Therefore, the consequences of climate change could have a crucial effect on inland navigation or even be a question of its fundamental existence (PIANC, 2008).

For inland navigation, water level is the hydrologic variable of utmost interest. This variable is closely related to flows and riverbed morphology at a given river section. However, the shape of the riverbed changes over time due to the sediment-related processes. As a consequence, water levels at a stream gauge cannot be compared over long periods of time. To overcome this issue, it is a common practice to analyse flow rates rather than the water levels.

Since the hydrologic regime, sediment transport and the riverbed morphology are closely related, all these processes and their inter-relation should be taken into account in the studies of climate change impacts on inland navigation. Changes in water level and velocity can lead to changes in sedimentation processes such as bank failure, local scour, and locations of aggradation and degradation (PIANC, 2008). Changes in sediment processes, in turn, require changes in channel maintenance activities, such as increased or decreased dredging. However, this chain is not easy to model and even more difficult to predict for future.

In a comprehensive study on the impacts of climate change on inland navigation (ECCONET; see Nilson et al., 2012), it was assumed that the riverbed would remain stable in the future. This also implicitly assumes a “perfect” sediment management that maintains the current morphology. In such a way, the effect of climate change is analysed separately. Nilson et al. (2012) also indicate that the influence of different sediment-management practices can be even larger than the influence of different future climate-forced hydrologic scenarios. The same assumption is also made in this study and the climate change impacts on navigation are analysed by neglecting the impacts of changes in river morphology.

The focus of this guidance note is on the Sava River waterway, since the navigation on the tributaries is possible only to the limited lengths (Table 1). The climate change impacts are therefore presented for locations of hydrologic stations along the Sava River. Although navigation is currently possible downstream from Sisak (including hydrologic stations: Crnac, Jasenovac, Mačkovac, Davor, Slavonski Brod, Županja and Sremska Mitrovica), two additional hydrologic stations upstream of Sisak are included in the analysis (Zagreb and Čatež) to support potential extension of the waterway. With the available data, it was possible to investigate the climate change impacts on navigation related to low flows, high flows and ice cover. There was no data to support an analysis of changes in visibility and their influence on navigation.

The characterization of future climate and hydrologic regime for the selected locations on the Sava River is based on the results of hydrologic simulations of the Sava River basin with climate scenarios as described in the main WATCAP report. The baseline and future climate scenarios from five climate model chains were used (Table 2), all based on the A1B IPCC/SRES3 gas emission scenario. Climate scenarios were defined for three 30-year periods:

- 1961-1990 (past or baseline climate scenario),

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2 ECCONET – Effects of climate change on the inland waterway transport network, a FP7 project, www.ecconet.eu
3 Scenario from Special Report on Emissions Scenarios (SRES) from International Panel on Climate Change (IPCC) (IPCC, 2000).
• 2011-2040 (near future climate scenario), and
• 2041-2070 (distant future climate scenario).

Table 2: Global and regional climate model chains used in this impact study

<table>
<thead>
<tr>
<th>Short name</th>
<th>Institution</th>
<th>GCM</th>
<th>RCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM1</td>
<td>KNMI</td>
<td>ECHAM5r3</td>
<td>RACMO</td>
</tr>
<tr>
<td>CM2</td>
<td>MPI</td>
<td>ECHAM5r3</td>
<td>REMO</td>
</tr>
<tr>
<td>CM3</td>
<td>ETHZ</td>
<td>HadCM3Q0</td>
<td>CLM</td>
</tr>
<tr>
<td>CM4</td>
<td>METO</td>
<td>HadCM3Q0</td>
<td>HadRM3Q0</td>
</tr>
<tr>
<td>CM5</td>
<td>ICTP</td>
<td>ECHAM5r3</td>
<td>RegCM3</td>
</tr>
</tbody>
</table>

3.1 Low flows

Low flows result in reduced water depths and reduced widths of the fairway, and consequently in reduced draft of vessels and increased risk from grounding and collision of ships. Contrary to floods, which are usually considered as a short-term events, low flows can be long-lasting and therefore can impose significant restrictions to navigation.

The water management practices can have a significant effect on the low-flow statistics. This effect is difficult to quantify since some practices can work in direction of enhancing the flows (e.g. by releasing more water from reservoirs in the summer on account of storing water in the winter), while the others can contribute to further depletion of the basin reserves (e.g. greater withdrawal to meet increased user needs during summer).

The low flows are usually characterized by the annual minimum values of mean flows in a given number of days (e.g. minimum 7-day flow is the lowest average flow in any 7-day window during a year), or by the number of days in a year with flows below a certain threshold. The first measure gives an indication of the intensity of low flows and volume deficit, which are important for water use and water quality considerations. The second measure indicates the low flow frequency and is therefore more relevant for navigation and waterway management.

3.1.1 Characteristic low-flow thresholds

Low-flow thresholds for the Sava River are associated with target water depths that facilitate navigation with maximum draft and with a reduced draft. In this respect ISRBC applies two standards as given in section 2: navigation with maximum draft must be possible for 65% of time, and with a reduced draft for 95% of time. These requirements are related to discharges which are exceeded 65% and 95% of time during a year (denoted as Q65 and Q95 respectively), and are determined from the long-term flow duration curves for a given river cross section.

It should be noted that Q95 is closely related to the low navigable level, which is defined in the Decision 13/09 of ISRBC (ISRBC, 2009a) as the water level that corresponds to the flow having duration of 94%. Similarly, this Decision also specifies that each waterway class should guarantee safe navigation with maximum draught for a proper cargo vessel for 240 days per year, or 65% out of 365 days per year. The corresponding flow rate is then Q65.4

The characterization of future low flows in the Sava River is based on the results of hydrologic simulations on the Sava River basin with future climate scenarios. The results of hydrologic modelling with

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4 Decision 13/09 of ISRBC actually specifies the 60th percentile of the flow duration curve as the flow corresponding to duration of 240 days. This is probably specified having in mind a 360-days based flow duration curve developed from mean monthly flows. Since the flow duration curves used in this study are based on 365 daily flows, the 65th percentiles are used as those corresponding to duration of 240 days.
baseline and future climate scenarios were processed to assess the flow duration curves at all selected locations for three time frames.

Changes in flows exceeded 65% and 95% of time during a year (Q65 and Q95), taken as the corresponding percentiles from the long-term flow duration curves for each time frame are shown in Figure 2 and Figure 3. The mean values of the results from the ensemble of five climate models indicate that virtually no change of Q65 and Q95 would occur in the near future, while a modest decrease could be expected in the distant future. This change in the distant future is more significant downstream of Sisak (i.e. the Crnac station), with the largest decrease of 6% for Q65 and 11% for Q95 at the most downstream part at Županja and Sremska Mitrovica.

Figure 2: Change in Q65 (flows of 65% duration) in near future (left) and distant future (right).

Figure 3: The mean values of the results from the ensemble of five climate models indicate that virtually no change of Q65 and Q95 would occur in the near future, while a modest decrease could be expected in the distant future. This change in the distant future is more significant downstream of Sisak (i.e. the Crnac station), with the largest decrease of 6% for Q65 and 11% for Q95 at the most downstream part at Županja and Sremska Mitrovica.
In regard to somewhat higher uncertainty in some of the results (Q65 in the distant future and Q95 in the near future), it should be noted that the results related to low flows should be taken with caution, since the applied climate and hydrologic models were not calibrated in this study to reproduce extreme flows, but rather mean flows and runoff volumes. However, the results obtained are in accordance with the general conclusions from the Strategy on Adaptation to Climate Change for the Danube River Basin (ICPDR, 2013), where the alpine areas of the Danube River Basin have either no clear trend or a slight improvement of the mean annual low flow and drought situations. Furthermore, it should be noted that the future low flow regime depend on changes in water use, which could impair or improve the general trend.

### 3.1.2 Number of days with flows below the threshold

Two characteristic flows for navigation on the Sava River, Q65 and Q95 (defined as the 65th and 95th percentile of the flow duration curves), reflect the standards that navigation must be possible with a maximum draft for 65% of time during a year and for 95% of time with a reduced draft. We consider here Q65 and Q95 for the period 1961-1990 (denoted Q65_base and Q95_base) at selected stations as a threshold of flows that are not exceeded for 128 and 18 days per year, respectively (on average over 30 years). The measure of low flows is then the number of days below Q65_base and Q95_base, which allows an assessment of the impact of low flows on navigation. The values of Q65_base and Q95_base are determined from the hydrologic simulations with the input from the climate models for the period 1961-1990. To verify the results from climate models, the simulated and the observed distributions of the annual number of days below Q65_base and Q95_base (denoted n65 and n95) were compared and a satisfactory agreement was found (Figure 4 and Figure 5).
Figure 4: Annual number of days with flows below the Q65 threshold for 1961-1990 – comparison of distributions from the observed data and from hydrologic simulations with baseline climate scenarios for two hydrologic stations.

Figure 5: Annual number of days with flows below the Q95 threshold for 1961-1990 – comparison of distributions from the observed data and from hydrologic simulations with baseline climate scenarios for two hydrologic stations.

The change in the number of days below Q65_base and Q95_base was evaluated from hydrologic simulations for 2011-2040 and 2041-2070. Figure 6 and Figure 7 present the mean change from the ensemble of five models. The results lead to similar conclusions as those for low flows given in section 3.1.1. The number of days n65 and n95 is likely to increase very little in the near future (on average 3 days for n65 and 2 days for n95), but a significant increase could be expected in the distant future downstream of Sisak, i.e. the Cmac station (on average 13 days for n65 and 8 days for n95).
3.2 High flows

High flows can lead to restriction or suspension of navigation. The thresholds for the restrictions or suspension are usually regulated by competent authorities. These thresholds are related to water levels and consequently to flows of low frequency of occurrence.

As in the case of low flows, high flows are influenced not only by meteorological conditions but also by the water management activities such as river training or introduction of storage facilities. It will be assumed here that the effect of water management practice is the same as in the reference period, so that only the climate change effects are evaluated.

3.2.1 Characteristic high flow thresholds

According to ISRBC (2010), navigation on the Sava River is prohibited when the water stage at specified gauges exceeds given thresholds. These rules apply to the Sava mouth sector and the Upper...
Sava sector (Table 3). Although there is no information about the frequency or percent duration of the stages shown in Table 3, for the Jasenovac gauge it is estimated that the specified stage corresponds to flow rate of 2270 m³/s, which in turn is estimated to have duration of 0.5% from the long-term flow duration curve. On the other hand, ISRBC Decision 13/09 (ISRBC, 2009) describes high navigable level as the water level that corresponds to the flow having duration of 1%, which is used to define vertical clearance under the bridges or power lines/cables.

<table>
<thead>
<tr>
<th>Sector</th>
<th>From rkm</th>
<th>To rkm</th>
<th>Water stage (in cm) at specified gauge above which navigation is prohibited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sava mouth</td>
<td>0</td>
<td>11</td>
<td>600 at Belgrade</td>
</tr>
<tr>
<td>Upper Sava</td>
<td>550</td>
<td>594</td>
<td>710 at Crnac</td>
</tr>
<tr>
<td>Kupa</td>
<td>514</td>
<td>550</td>
<td>820 at Jasenovac</td>
</tr>
</tbody>
</table>

To analyse the effect of climate change of the number of days per year with restrictions related to high flows, two thresholds are considered as the indicators of high flows related to navigation. These are the flows assessed from the long-term flow duration curves for duration of 1% and 3%, i.e. the flows exceeded on 1% and 3% of time during a year (we denote these thresholds Q1 and Q3). The first threshold, Q1, is taken into consideration since it is used by the ISRBC Decision 13/09 to define the high navigable water level above which navigation is considered impossible. The second threshold, Q3, has been used in the study for the Rhine River (Nilson et al, 2012) as a compromise between different thresholds set by different authorities, and it is also used in this study for comparative purposes.

Changes in Q1 and Q3 under influence of climate change are estimated by taking the corresponding percentiles from the long-term flow duration curves for the baseline (1961-1990) and two future time windows (2011-2040 and 2041-2070). The flow duration curves are derived from hydrologic simulations with five climate scenarios. The results are shown in Figure 8 for Q1 and in Figure 9 for Q3, and reveal a lack of significant tendencies in these indicators. The near future period exhibits an interesting sequence of changes in both Q1 and Q3 along the Sava River where a weak increase in the upper parts gradually turns into a weak decrease at the downstream end. However, the magnitude of change (up to 3.4% in near future and up to 6.3% in distant future) is probably smaller than the magnitude of the overall uncertainties in the modelling chain and a firm conclusion on this is not possible. These results are generally in accordance with the conclusions of ICPDR (2012, 2013) that there is no clear tendency in the development of future flood events for the Danube River Basin.
3.2.2   Number of days with flows above the threshold
In order to investigate the number of days with high flows, thresholds Q1_base and Q3_base as Q1 and Q3 are evaluated for the period 1961-1990 at selected stations and used as the threshold flows that are exceeded for 3.65 and 11 days per year, respectively (on average over 30 years). Similarly to the low flow thresholds Q65_base and Q95_base, the simulated and the observed distributions of the annual number of days above Q1_base and Q3_base (denoted n1 and n3) in the baseline period were compared in order to verify the results of hydrologic simulations from climate models. Figure 10 and Figure 11 show that the agreement of these distributions is satisfactory.
Output from hydrologic simulations for 2011-2040 and 2041-2070 is used to assess the change in the number of days above $Q_{1\_base}$ and $Q_{3\_base}$. Mean change from the ensemble of five models is shown in Figure 12 and Figure 13 for two time frames. Conclusions that can be drawn from these graphs are similar to those for high flows from the flow duration curves given in section 3.2.1. The numbers $n_1$ and $n_3$ of days with flows above $Q_{1\_base}$ and $Q_{3\_base}$ are not likely to change significantly in both the near and distant future (on average for less than 1 day). All graphs show the same tendency as the characteristic high flows in the previous section, and that is a slight increase of the number of days in the upper part of the Sava River and a slight decrease in the lower part. This change in the number of days with high flows is gradual in downstream direction in the same manner as the corresponding flows. However, this conclusion might not be valid since this change is very small and is most probably within the uncertainty limits of the hydro-climatic modelling outputs.

It can therefore be concluded that the climate change impact on high flows would not have additional implications on the navigation sector in terms of the number of days in which navigation would be restricted or suspended compared to the current conditions. Similarly, the study by Nilson et al. (2012) came to a conclusion that there is currently no clear picture of the future development in the number of days with restricted navigation due to high flows (above $Q_3$) in the upper Danube region, while there is no comparative results for the lower Danube region.
3.3 Ice

River ice has the potential to damage the ships and thus is a major cause for suspended navigation during the days with ice cover on the rivers. Ice development is conditioned by continuous low air temperatures over several days in combination with low flow velocities. In addition, discharges from the power plants and industry have an impact on water temperature and chemical composition and can therefore play a role in ice formation.

The water temperature in navigable river sections depends on the air temperature. Since an increase in the annual mean air temperature of approximately 0.25 °C per decade is expected on average within the SRB, it can be assumed that the water temperature in rivers will rise by a similar amount. With the rise of water temperature, especially in winter, freezing of rivers would occur less often. However, detailed studies and projections of ice occurrence for inland waterways are missing so far (PIANC, 2008; Nilson, 2012).
To investigate changes in the possibility for ice formation in the future, Nilson et al. (2012) use the sum of temperatures below 0°C between November and March. This proxy variable is usually applied as an indicator of the severity of a winter season and of a potential for ice formation on standing water bodies (e.g., lakes). The same indicator is used in this study. Air temperature data from meteorological stations located near the Sava River (Zagreb, Sisak, Slavonski Brod, Gradište/Županja, Sremška Mitrovica and Beograd) are used from five climate model outputs for the baseline period (1961-1990) and two future time frames (2011-2040 and 2041-2070). The cumulative negative daily temperatures in the winter season are presented in Figure 14. Since the climate models used in this study predict a significant increase in both mean annual and mean winter (December-January) temperatures, it is not surprising that the same is valid for the annual sums of negative temperatures from November to March. The graphs in Figure 14 show that all climate models predict a reduced potential for ice formation along the whole navigable part of the Sava River. This, of course, would have a beneficial impact for inland navigation since the number of days per year with navigation suspended due to ice is expected to decrease.

However, the PIANC (2008) study warns that although the climate trends indicate shorter periods of ice cover, a high degree of variability in local climatic conditions is still expected to cause ice impacts to inland navigation. Warmer early winter air temperatures, followed by a rapid decrease in air temperature, can result in thicker or rougher than normal ice cover formation or freeze up jamming. While reducing the period of ice cover, earlier break up can coincide with higher than normal ice strength, resulting in midwinter ice jams that freeze in place or jams that occur in different locations than expected.
4 Adaptation measures

The climate induced changes in the hydrologic regime can have a range of impacts related to navigation. The hydrologic regime directly affects the river morphology, including water widths and depths, flow gradient, flow velocities, sediment supply and transport, etc. The hydrologic regime therefore indirectly affects the fairway parameters and its availability for navigation. The hydrologic regime also influences the effectiveness of the existing waterway infrastructure (groynes, rip-rap, training walls), which serves to establish the fairway. These three factors and their interconnection have crucial effect on navigation (Figure 15).

Figure 14: Change in the sums of negative daily temperature in the November-March season at meteorological stations along the Sava River as an indicator of the potential for ice formation (horizontal bars indicate average values for 30 years from different climate models).

The previous section discusses the hydro-climatic drivers and their impact on navigation. It has been shown that the most important impact is related to decreasing low flows, which is not very pronounced in the near future 2011-2040, but seems significant in the distant future 2041-2070. While there is no clear indication that there would be a significant change in the share of days with extremely high flows...
that would limit or suspend navigation, it has been shown that the projected increase in future temperatures can lead to later ice formation and shorter ice cover duration. Therefore, this will have a positive effect on the length of the navigable period.

With more pronounced low flows and droughts in the future, decreased water levels and velocities and change in sedimentation would affect not only the river morphology but also the waterway infrastructure, transport operations and the vessels. An increased number of days with flows (and consequently water levels) below the navigation standards can lead to more frequent navigation with reduced draft and consequently reduced cargo loads and increased costs. This can also impair the supply chain of goods by shipping, therefore also potentially affecting the production processes.

Therefore, the adaptation measures for navigation should include the measures that would primarily be related to providing better navigation in the low flow conditions adaptation of the waterway infrastructure. This should also be accompanied by the adaptation of transport operation and vessels, including improvement of the hydrological prediction that could also contribute to better planning and more effective transport.

The following two subsections summarize possible responses to climate change impacts on inland navigation related to waterway infrastructure and waterway transport operations, and is based on adaptation measures recommended by PIANC (2008), Ubbels et al. (2012) and ICPDR (2013). Table 4 lists possible responses of navigation infrastructure and operation to climate change impacts. The third subsection list gives an overview of measures according to ICPDR (2013) and provides other possible adaptation approaches.

Table 4: Possible responses of inland navigation to climate change impacts (source: PIANC, 2008)

<table>
<thead>
<tr>
<th>Area of intervention</th>
<th>Response (measures)</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterway design and maintenance</td>
<td>Creation of water storage facilities</td>
<td>(Upstream) reservoirs needed for flood mitigation could also be used to improve navigation</td>
</tr>
<tr>
<td>Waterway design and maintenance</td>
<td>Deepening of channels instead of widening</td>
<td></td>
</tr>
<tr>
<td>Waterway operation</td>
<td>Managing water flow</td>
<td>Store water in times of high water flow, release water in times of low flow</td>
</tr>
<tr>
<td>Waterway operation</td>
<td>Improving forecast of water level</td>
<td>Better information, further ahead, could optimise the use of vessel capacity for given conditions, and reduce uncertainty margins</td>
</tr>
<tr>
<td>Waterway operation</td>
<td>Improved queuing procedures</td>
<td>Decision support systems and automation of queuing could help to overcome capacity restrictions of waterway infrastructure</td>
</tr>
<tr>
<td>Waterway operation</td>
<td>Implementation of River Information Services (RIS)</td>
<td>RIS in general support safe and efficient navigation</td>
</tr>
<tr>
<td>Waterway operation</td>
<td>Providing up-to-date electronic charts of fairway with water depth information</td>
<td>Better information to optimise use of vessels in given conditions, and reduce uncertainty margins</td>
</tr>
<tr>
<td>Transport management</td>
<td>Chartering of additional vessels</td>
<td></td>
</tr>
<tr>
<td>Transport management</td>
<td>Increasing daily operation times of vessels</td>
<td></td>
</tr>
<tr>
<td>Transport management</td>
<td>Cooperation with other modes of transport</td>
<td>Contractual arrangements with road and rail transport can be made for times of reduced navigability</td>
</tr>
<tr>
<td>Transport management</td>
<td>Increased storage of goods</td>
<td></td>
</tr>
<tr>
<td>Vessel operation</td>
<td>Employing sophisticated Inland ECDIS (Electronic chart display and information system)</td>
<td>Provision of necessary and always up-to-date information, better to utilize given navigation possibilities</td>
</tr>
<tr>
<td>Vessel design</td>
<td>Reduction of weight</td>
<td>Using alternative design or materials, installing lighter equipment</td>
</tr>
<tr>
<td>Vessel design</td>
<td>Increasing width</td>
<td>Wider vessels need less draught</td>
</tr>
</tbody>
</table>
4.1 Waterway infrastructure

Adaptation of the waterway infrastructure can be directed toward maintaining navigable water levels, including the measures related to waterway maintenance and river engineering works.

Climate change impacts on water levels in waterway can be mitigated through operational flow control, or by waterway and fairway maintenance.

Enhancement of low flow situations by flow control can be accomplished by water control facilities, either existing or new ones, intended for flood mitigation and which could also be used to improve low flow situations. However, in operational management of water control facilities, navigation is competing with other water users such as domestic water supply, industrial and agricultural demand, and ecosystem requirements. Therefore, operational changes to water control would require legal and environmental analyses prior to introduction of such a measure.

The central element of the waterway infrastructure is the fairway, which is established by means of the structures such as groynes, training walls and rip-rap, and maintained by means of dredging, bank stabilisation and other maintenance measures. Adaptation of maintenance measures should be toward better exploitation of the fairway (e.g. fairway within fairway; Simoner et al., 2012), and toward modification of the existing or construction of new structures, and monitoring of their effectiveness under changing conditions. Changes to existing maintenance practices such as channel and bank stabilization and dredging, will also require environmental impact analyses before proceeding. Costs and effects of these measures would differ and depend on length and morphology of a river section and the number of structures needed to construct or modify.

For the Sava River it is currently difficult to estimate the level of river engineering works that are necessary to achieve the waterway standards given by ISRBC (see section 2) and to separate this from the works needed specifically as a response to climate change.

For the Danube River, the study by Simoner et al. (2012) focuses on maintenance of waterways, thereby implicitly implying that large infrastructure works such as dams and reservoirs are not seriously considered as being feasible or necessary for climate change adaptation.

4.2 Waterway transport operations and vessels

Possible responses of the inland navigation sectors to the impact of low water levels are already known and often applied (PIANC, 2008). Changes in transport management and operation of the vessels are short-term responses addressing situations in which navigation is inhibited for a short period of time. Low water levels require either light loading of current vessels, or use of vessels with reduced draft. If navigation conditions are altered over longer periods of time, adaptation of the fleet and new vessels of different design seem to be inevitable.

The following measures related to the vessel design were identified by Ubbels et al. (2012) related to technical changes, operation of the fleet and logistic solutions:

- Vessel design adjustments for reduction of draught: reduction of own weight of vessels, adjustable tunnel (applicable only for a limited number of vessels) to extend navigability to lower water levels, side blisters, flat hulls;
- Operation of fleet: smaller instead of large vessels for low flow conditions; upgrade of small (less sensitive) vessels from daytime to continuous operation; coupled convoys instead of single propelled vessels;
• Strategic alliances of inland water transport and other modes: shift of cargo to other modes in case of low flows (optimal solutions to be found, taking into consideration limited capacity of other modes and higher costs).

Better hydrologic forecasting and extension of the forecast lead time could optimise the use of vessel capacity for given conditions and reduce uncertainty margins.

Navigation system operation may benefit from increased use of automation, queuing procedures and the application of River Information Services (PIANC, 2008). Decision support systems and automation of queuing could help to overcome capacity restrictions of waterway infrastructure. Increased data sharing regarding unexpected hazardous conditions or conditions requiring restrictions, and lessons learned from response successes and failures, should also improve system operation in the face of climate changes.

4.3 Overview of measures

This overview of measures has been made according to ICPDR (2013).

4.3.1 Preparing for adaptation

Preparation for adaptation concerning river navigation involves better monitoring, research and forecasting including:

• Better monitoring of water levels.
• Initiating research programmes with the view to develop reliable adaptation strategies and measures for shipping and the waterway network.
• A more detailed and scientifically-sound assessment is required for deepening traffic routes.
• Research into a River Information System to enable improved seasonal discharge predictions;
• Improvement of methods in forecasting water levels.

4.3.2 General measures

General adaptation measures for river navigation include:

• Promoting river transport on Sava will enhance the competitiveness of river transport relative to other modes of transportation.
• Reducing environmental impacts.
• Providing sufficient water depth in times of low water flow.

4.3.3 Ecosystem based measures

Ecological adaptation measures to be aware of include:

• The need to combine any increased water storage to support navigation infrastructure with habitat creation initiatives.
• Adequate silt and sediment management planning to offset any potential new dredging requirements by identifying measures, such as buffer strips, which aim to prevent additional sediment (and associated nutrients, pesticides, etc.) entering the watercourse.
• Establishment of a sustainable, environmentally sound and inter-country coordinated approach in ship waste management along the Sava by (1) elaborating national ship waste management concepts, (2) implementing pilot actions and (3) developing a financing model for the operating system based on the polluter-pays principle.
• Identification of environmentally sustainable solutions for improved navigability in order to eliminate existing navigation bottlenecks taking into account likely impacts of climate change, the preservation of functioning ecosystems and planning guidelines.
• Definition of navigation fairway conditions according to ecological needs.

4.3.4 Management measures
Measures to improve river navigation relating to climate change adaptation include:

• Investment in better education for the Sava navigation sector
• Better reservoir management in low-flow cases
• Support transport on waterways by shifting from other transport modes that are potentially more harmful to the climate, such as road transport
• Offer competitive alternatives in the ‘door-to-door’ logistical chain
• Increasing the share of river transport in the total transport of goods by increasing the use of inland waterways and railroad transport
• Avoidance of redundant transportation, changes in industrial production leading to lower transport requirements or shifting transport towards the season with high river discharges, if possible, this could reduce the pressure on the navigation sector during months of low water flows

4.3.5 Technological measures
Technological climate adaptation measures include:

• Adaptation / creation / modernisation of infrastructure
  - Adaptation / modernisation of river infrastructure to optimise the average speed and fluidity of traffic.
  - Make improvements to the existing ports
• Low flow measures
  - Support the container shipping with shallow draft vessels
  - Buffering water level fluctuations by damming
• Modernisation of the fleet by:
  - Innovation, dedicated fleet modernisation and optimised waste management measures, in order to improve environmental and economic performance of Sava navigation
  - Establishment of a common approach for the modernisation of inland vessels.
  - Technological developments in terms of innovative vessels, engines and optimised fuel consumption.

4.3.6 Policy Approaches
Policy issues concerning river navigation include:

• Providing a balanced framework for fair competition among ports.
• Gradual development of shipping on interior waterways through upgrading and expansion of port infrastructure.
5 References

4. ISRBC (2009a) Decision 13/09 on adoption of Amendments to the decision 26/06 on adoption of the detailed parameters for waterway classification on the Sava River, International Sava River Basin Commission, Zagreb, Croatia (available at http://www.savacommission.org)