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Sustainable Management of the Navigability of Natural Rivers (PIANC WG 236)

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Abstract. The PIANC InCom/EnviCom Working Group 236 was established in early 2021 to develop PIANC guidelines for improving navigability conditions on natural or quasi-natural rivers, while maintaining morphological processes and natural river form and function. Its key objectives include: 1) development of guidelines to improve and maintain the navigability in natural rivers; 2) assess the sustainability of river training works designed to improve the navigability; 3) assess the sustainability of dynamic river management (monitoring and shifting of navigation aids to adapt the navigation channel to the river dynamics); 4) highlight the technical, operational, economic and environmental considerations for navigation in natural rivers compared to that in regulated rivers and canals; and 5) improve the understanding of the physical processes in natural rivers, developed with or without river training works. The developed guidance includes a planning framework for developing a navigability improvement masterplan for a natural or quasi-natural river system, and the integrated and adaptive management strategies that can be applied at a system scale. Specific interventions and measures have been identified to meet the dual goals of maintaining morphological river function and improving navigability conditions. These measures include dynamic charting; morphological dredging and disposal management; Temporary, Adaptable, and Flexible Training Structures (TAFTS); riverbed armoring and sediment nourishment; rock excavation; meander cutoffs and oxbow development; localized traditional river training structures; and channel closure structures. The impacts and strategies for mitigation associated with some of the measures are analyzed and discussed. Finally, the continual monitoring, management, and operational tools available for improving navigability in a morphologically active river system is presented. It is recognized that natural and quasi-natural rivers will typically be more fluvially active and dynamic than systems that have used traditional methods for navigability improvements including heavily trained rivers or systems with locks and dams. These unrestricted and unconfined river systems, therefore, will require new and innovative strategies to monitor the fluvial and geomorphic changes of the system in order to inform managers and navigators

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of the river. Case studies are presented that include the Madeira River (Brazil); Magdalena River (Colombia); Niger Delta (Nigeria); Yangtze River (China); the Brahmaputra-Jamuna River (India); and the Red River (Vietnam).

Keywords: Nature-based · Inland navigation · Management

1 Introduction

Inland Waterway Transport (IWT) include three types of waterway features: 1) rivers and estuaries, 2) lakes and reservoirs, and 3) canals. In the riverine systems, there are two possible situations: natural rivers and rivers that are regulated or trained by hydraulic infrastructure.

The primary application of the PIANC Working Group 236 lies within natural or quasi-natural river systems – systems that are not constrained or significantly impacted by dams or river training structures. The navigable natural rivers are often some of the "large" rivers of the world. Due to significant depths and widths of these large rivers, navigation opportunities are naturally present in these systems.

A natural river system exhibits two important characteristics – unregulated hydrology and unconstrained morphology. In other words, both the hydrology and the morphology of the system is "natural", and the river can freely respond to the environmental boundary conditions provided by the watershed. These are the systems that have not been subjected to significant engineering interventions. This unconstrainted and unregulated condition results in dynamic and natural river evolutionary processes within the riverine corridor that are increasingly valued from viewpoints of ecology and natural heritage. Therefore, understanding these system-specific natural river processes are important in developing recommendations for navigability improvement on these systems.

In many natural river systems, it is not technically feasible nor environmentally desirable to improve navigability through river training works. The only solution is then to assist the river in maintaining a navigable channel through specific actions – for example morphological dredging or adaptive management of the navigation channel itself.

It is within this context that the PIANC Working Group 236 was formed. The focus of the Working Group is on best practices that can be implemented within the natural system, which will maintain natural riverine processes following implementation. This approach results in innovative navigability improvement and management strategies while maintaining the natural river system behavior (see the lower right quadrant in Table 1).

Table 1. Resulting guidance based on existing system conditions and future end state

		Existing System Conditions	
	River State	Regulated or constrained by Hydraulic Infrastructure	Natural or Quasi-Natural
Proposed System Conditions	Regulated or constrained by Hydraulic Infrastructure	*Resulting Guidance:* *Management and maintenance of existing systems that are controlled by hydraulic infrastructure.*	*Resulting Guidance:* *Traditional methods of river engineering.*
	Natural or Quasi-Natural	*Resulting Guidance:* *River restoration of systems that have been trained or significantly regulated.* ***Recommended for a future PIANC Working Group***	***Resulting Guidance:*** ***Innovative navigability improvements that maintain natural river system behavior. Focus of WG 236.***

2 Planning and Design Strategies to Improve Navigability in Natural Rivers

A planning process is first developed as a framework for the navigability improvement masterplan associated with a natural river system. This begins with developing an understanding of the natural processes followed by an integrated and adaptive management strategy at the system scale within the context of the dynamic morphology of the system. This requires specific steps and guidance for implementing a planning study on a natural river, which include data acquisition (hydrographic surveying, remote sensing, sediment data collection), geology and fluvial geomorphology studies, hydrology and hydraulic analysis, sediment transport analysis, economic analysis, and socio-environmental studies.

On a strategic level, navigability in a natural or quasi-natural river system can be improved either by means of classical and dedicated river engineering projects or by means of continuous improvement processes of the daily management of the river. Whereas river engineering projects have a defined project framework (set of river engineering measures, concrete timeline, defined project budget, planning and construction phase, acquisition of necessary permissions) the improvement of the daily river management is a continuous and more fluent task, which can be described by means of following the river management cycle (see Fig. 1).

This river management cycle displays the basic elements (planning and execution of works, monitoring, and evaluation of continuous information on fairway status) in the daily work of a river manager aiming at maintaining or improving navigability in a natural free river stretch.

The continuous improvement of these management elements is a dynamic process, which has to take into consideration the specific financial and human resources of the respective waterway authority, the specific annual discharge pattern of the considered

natural free river stretch, the morphological and ecological opportunities and limitations of the respective river system as well as the specific needs of the users of the fairway (navigation sector).

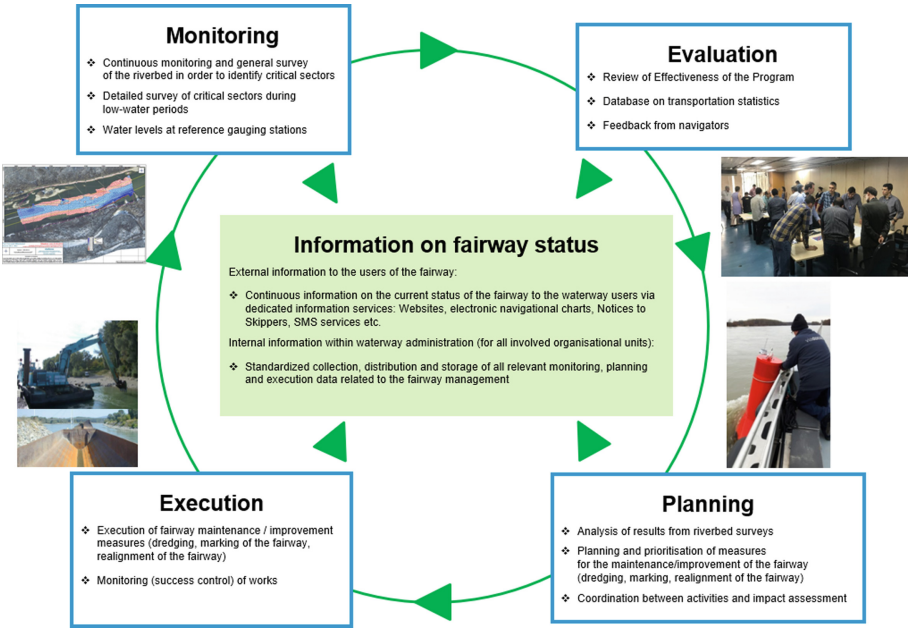

Fig. 1. The river management cycle

3 Interventions and Measures to Improve Navigability in Natural Rivers

Following the development of a masterplan, it is necessary to identify the measures that can be implemented to improve navigability in natural rivers given the system processes and constraints. Several interventions have been identified by the Working Group and are presented in the following sections.

3.1 Dynamic Fairway Management

Rivers that are highly dynamic, with high sediment transport loads and a very strong seasonal variation in water level and discharge, require an innovative approach to enable navigation. For these types of pristine rivers, it is not desirable, nor environmentally or economically justified to enhance navigation by providing structural interventions along the full stretch of the river. Moreover, on some free-flowing and braiding rivers, it is also not viable economically to establish and maintain one static channel. Therefore, because of their nature, this type of rivers can only be feasibly controlled by applying flexible, adaptable or dynamic management strategies. Dynamic

(Fairway) Management should be considered as an alternative solution to enable navigation in otherwise difficult to manage environments.

For highly-dynamic, fluvial rivers, like the Ayeyarwady and the Jamuna, where Inland Water Transport (IWT) is highly restricted by the available water depth and as a result IWT is yet to be developed, the only cost-effective method to develop the navigation channel is to use Dynamic Fairway Management techniques including (see Fig. 2):

- Hydrographic surveying and (electronic) chart updating,
- Aids to Navigation and their repositioning.
- Dredging to eliminate remaining navigation constraints.



Fig. 2. Dynamic (fairway) management

3.2 Navigability Forecasts and Alerts

Navigation charts need to be updated regularly when the river bed changes. This regular updating can be enhanced by making use of the echosounder data of the vessels that are plying the river. This is the background of the CoVadem initiative (www.covadem.com) which gathers and combines echosounder data from a large set of inland vessels. Currently, over 250 Dutch ships participate by measuring, logging and exporting data from every river and canal where they sail in the Netherlands, Belgium, Germany and Switzerland. During their trips, they continuously measure underkeel clearance using conventional echosounder equipment as well as location using a GPS meter. Underkeel clearances are translated into water depths by correcting for draught, squat and trim. The draught is taken from the logged loading gauge just before a trip starts. The squat and trim are calculated using an empirical model. The results are made available in the form of an operational water depth chart for 600 km of the Rhine in Germany and the Netherlands. This chart is constructed in two steps. First, measured water depth data are used to derive an up-to-date river bed topography. Second, this topography is combined with hydrological predictions of present and near-future water

levels. The resulting operational chart helps to maximize loading capacity, to reduce fuel consumption by sailing more efficiently, to guarantee a reliable estimated time of arrival (ETA), and to plan survey and dredging operations (Van der Mark and Lemans 2020). The challenge is to develop similar forecast systems for natural and quasi-natural rivers (Fig. 3).



Fig. 3. Up-to-date water depth chart from CoVadem (www.covadem.com)

3.3 Morphological Dredging and Disposal Management

Morphological dredging also called smart dredging makes it possible to perpetuate the measurer's management of the river to maintain or improve the navigability based mainly on continuously monitoring and prediction of the morphological evolution of the river. The morphological dredging effectiveness relies on good understanding of the morphological evolution of the hydrofluvial system and on following the principles of working with nature.

3.4 Removal of Obstacles in the Navigation Fairway (Rock Excavation, Clearing of Snags and Obstructions)

For some natural channels, the presence of rock will serve as the limit for available channel depth in the navigation fairway under low-water conditions. This rock may present an unavoidable obstacle if there are constraints to the fairway location (i.e. the channel cannot be re-aligned such that the rock does not pose an obstacle). In this case, the governing entity is posed with a choice: pursue rock removal, or exhaust channel limitation options (first light-loading, and eventually channel closure). This is driven by the economics of the rock removal (the volume needing removal and the cost per volume unit) vs. the cost to shipping of reduced channel efficiency or routing to another means of transportation. To determine the economics of rock removal, the volume needing removal and the competency of the material must be determined. The removal volumes is determined with extensive multibeam surveying, as sediment transport often

covers rock features. The volume needing removal can vary tremendously, as at some locations, only rock pinnacles or minor patches infringe on the desired low water navigation channel geometry, whereas other locations have rock infringe on that geometry for considerable height for entire reaches. The competency of the rock drives decisions on the removal methodology, as more competent rock requires more extreme removal measures, elongating the schedule and increasing environmental permitting requirements. Soft or loose rock can be removed via excavator. Harder rock will require more intensive means, such as a hydraulic hammer, rock grinder, or explosives. Geologists should be consulted to discuss the appropriate means of removal. Some of these alternatives (e.g. hydraulic hammers) come in different sizes with different rates and capabilities to break up rock. Specialized equipment such as a hydraulic hammer or grinder head for excavator will be expensive. However, this expense may be competitive with blasting when factoring in production rates, the cost of channel closures due to safety, and the increased environmental monitoring and mitigation measures that may be required.

Once the feasibility and the economics of rock removal have been determined, a detailed coordination plan is required to manage the removal activities, surveying for quality control or quality assurance on successful removal and removal quantities, and environmental monitoring. This plan needs to be highly flexible, as removal activities often have a high dependence on river stage at the removal location. The quality control or quality assurance process establishes needs to be capable of quick confirmation, as sediment transport into the site will obscure cleared rock sites with mobile material. Thus, breaking a removal site down into smaller units that can be surveyed and analyzed quickly is recommended.

3.5 Temporary, Adaptable, and Flexible Training Structures (TAFTS)

The traditional usage of training structures on untrained rivers has largely focused on forcing a new, rigid organization on a system through robust, permanent structures for the singular goal of navigability. These rigid structures are optimized for a certain discharge, not taking account the dynamics of natural or quasi-natural river systems throughout the year. This philosophy has changed, as understanding of what was lost through the traditional methodology has grown, and re-imagining and re-framing of historic practices have presented ways to better align with the natural flexibility of untrained systems. This section seeks to highlight temporary, adaptable, and flexible structures such as:

- Temporary placement of vessels or jacks for channel constriction
- Low-cost woody debris structures allowed to fail
- Base extensions and notching to increase or reduce constriction

These structures can be altered easily and at low cost to adjust for the lateral or longitudinal migration of the channel. Such temporary and flexible structures can also contribute to improve the ecological functions of the river and flood protection.

3.6 Armouring and Sediment Nourishment

Improving the navigability of a river possibly comes along with managing the sediment transport capacity. In erosive environments, in combination with a bedload deficit, e.g., downstream of dams or induced by extensive mining, this can result in progressing riverbed incision. An erosive system cannot only worsen river ecosystems, but also deteriorate navigability conditions, e.g., by destabilizing buildings along the river, exacerbating the access to harbors and non-fluvial parts of the IWT network, or revealing obstacles like rocks. Therefore, methods are necessary to prevent these effects and to control a degrading system by stabilizing the riverbed.

Riverbed stabilization can be accomplished by many different interventions and measures whereby three different approaches can be mentioned: Riverbed armouring aims for increasing the particle erosion resistance of the riverbed. Sediment nourishment tends to raise the sediment supply. The third approach focuses on interventions decreasing the capacity of the flow to transport sediment (expressed by flow velocity, bed shear stress or stream power).

The objective of this section is to provide a flexible and dynamic tool as part of a river basin wide sediment management strategy. If properly designed, it can also promote natural river morphology and have positive effects on environmental conditions such as habitat diversity. For this purpose, riverbed armouring and sediment nourishment are suitable methods, while the former acts locally and the latter also has impact on downstream river reaches.

Riverbed armouring as a method describes the adding of coarse material to the riverbed to control ongoing erosion by increasing the erosion resistance of the upper bed layer. In contrast to sediment nourishment, the added sediments are intended to remain in place and form an armour layer rather than be transported. This procedure can be considered as a direct method to stabilize the river bed. It is suitable for locations with locally high bed shear stresses and high transport capacity in combination with low particle erosion resistances.

The stability of riverbed armouring depends on the type of riverbed armouring, in particular its grain size. If the riverbed armouring is much coarser than the existing riverbed, this may result in a completely immobile armour layer. Although this may be efficient, it is also a risk in the long term due to resulting sediment starvation downstream. Likewise, in dynamic natural or quasi-natural rivers, the relative position of the armour layer within the river may change over time. For example, an armour layer placed in an outer bend may end in the inner bend after meander migration. Also, in case of overall riverbed degradation, the armour layer may form an obstacle for navigation on the long term (examples in the Rhine). Riverbed armouring should therefore be applied with care and with knowledge about the long-term development of the river.

3.7 River Training Works

River works for regulation of the low-water bed may include the construction of bank revetments, longitudinal dikes, and groynes or spur-dikes. There are a great variety of these structures, in type and dimensions as well as in the materials of construction. These types of structures include:

- Spur dikes
- Bottom vanes
- Longitudinal dikes with or without transverse dikes
- Revetments (Fig. 4).

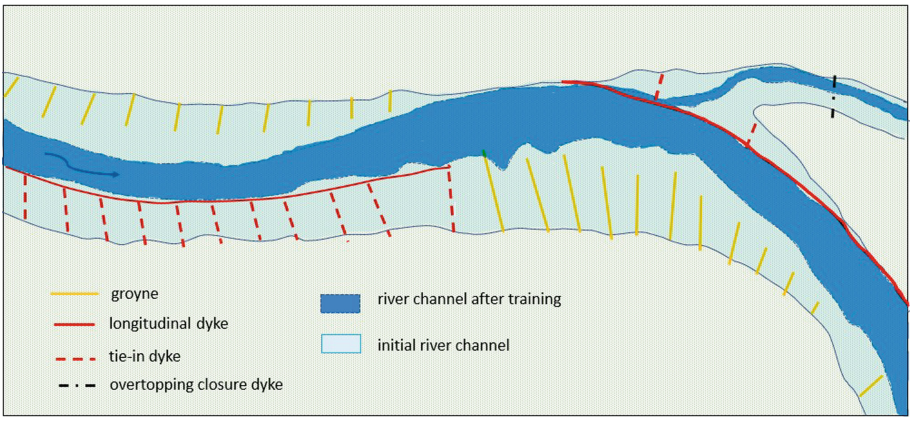

Fig. 4. Various types of river training structures

4 Future Work

4.1 Impacts and Mitigation of Navigability Improvement Interventions

The impacts and mitigation of navigability improvements will then described in the Working Group Report. Here the focus will be on river training works as they have the largest impacts. Nonetheless, impacts associated with other measures will be included too, as applicable. These impacts include mitigation of bank erosion processes as well as sediment nourishment. The impacts on reaches of the river that have been adapted by river training structures are necessary to analyze within the context of navigation safety. The Working Group also will include descriptions of potential impacts from river training structures (or other physical navigability improvement measures) to other areas including flood risk and ecosystem resources. This section will also include potential measures to mitigate against these impacts and discuss the long-term navigability of the system following the implementation of these measures.

4.2 Monitoring, Management, and Operations Tools

Reasoned work planning methods may be described in a cycle leading to continuous navigability quality improvement, the service offered to users and any economic, environmental or other objective that has been clearly identified and defined.

These tools are dependent on structural measures, management, institutional, technical, human and economic resources, such as:

- structural measures (river training works, bank protection, …)
- morphological dredging
- programmed inspections and frequency
- marking
- technical and technological resources (hydrographic boats, measuring equipment, …)
- efficiency of the hydrographic service (management and informatics resources, …)
- human resources and their qualification
- financial resources devoted to the management of the river
- institutional measures

Consequently, it is important to have a set of indicators - efficiency, pertinence, expectation, satisfaction – (i.e. respect of the navigability requirements, evolution of the river during the hydrological cycle, annual duration of navigation, proactive intervention management) to judge the quality of each of these tools and to consider possible actions to improve them.

For example, the following considerations are included:

- critical analysis of information collected from pilots regarding problems, alerts or accidents due to navigability failures
- improvement of corrective interventions on local structural measures, morphological dredging (i.e. optimisation of trends analyses based on data base) and marking management
- improvement of protocol field measurements, data analysis and integration of new technology
- improvement of the activities of a hydrographic service (i.e. informatics resources and continuous training of the personnel
- where asset performance relates to the ability of the assets to meet target levels of service, inspections allow the monitoring of that performance with time.

4.3 Summary and Conclusions

The current version of the Working Group 236 report is the first compiled document containing all the contributions of the WG's members. It is a working document allowing the Working Group to continue its work according to the ToR.

The Working Group will conduct the following recommendations:

1. Gather information under the different themes listed in "Monitoring, Evaluation, Planning and Execution" in order to concatenate and issue specific recommendations for them.
2. Gather relevant information specific to the sustainability of the effects of measures to improve navigability and their technical and socio-environmental impacts.
3. There are three specific recommendations that are being advanced by the working Group for inclusion in the PIANC WG 236 Report. These include:

a. Establish or create a hydrography service (institutional aspects, human resources, innovations technologies, financial aspects, etc.). It is an important point to guarantee continuously monitoring.
b. Operations and Maintenance of the Aids to Navigation
c. Continuous training of the staff (local and/or outside training)

Reference

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