PIANC Working Group 236
Sustainable Management of the Navigability of Natural Rivers

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PIANC Working Group 236: Sustainable Management of the Navigability of Natural Rivers

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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, river form, and function. A natural river system exhibits two important characteristics – 1) unregulated hydrology and 2) unconstrained morphology. The key objectives of the WG236 – Sustainable Management of the Navigability of Natural Rivers – 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 free-flowing 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 river system, and the integrated and adaptive management strategies that can be applied at a system scale. Specific interventions and measures have been identified that are analysed 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 armouring and sediment nourishment; rock excavation; meander cutoffs and oxbow development; localized traditional river training structures; and channel closure structures. The impacts and strategies for mitigating impacts associated with some of the measures are analysed and discussed. Finally, the continual monitoring, management, and operational tools available for improving navigability in a morphologically active river system are presented.

Keywords: Inland Navigation, waterways, sustainability, dynamic river management

Introduction

The primary application of the PIANC Working Group 236 lies within the development of guidance for improving navigability conditions of natural or quasi-natural river systems – systems that are not constrained or significantly impacted by dams or river training structures.

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 previously 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 riverine processes following implementation. This approach results in innovative navigability improvement and management strategies while maintaining the natural river system behaviour (see the lower right quadrant in Table 1).

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

<table>
<tr><td colspan="2"></td><td colspan="2">Existing System Conditions</td></tr>
<tr><td></td><td>River State</td><td>Regulated or constrained by Hydraulic Infrastructure</td><td>Natural or Quasi-Natural</td></tr>
<tr><td rowspan="2">Proposed System Conditions</td><td>Regulated or Constrained by Hydraulic Infrastructure</td><td>Resulting Guidance: Management and maintenance of existing systems that are controlled by hydraulic infrastructure</td><td>Resulting Guidance: Traditional methods of River Engineering</td></tr>
<tr><td>Natural or Quasi-Natural</td><td>Resulting Guidance: River Restoration of Systems that have been trained or significantly regulated.</td><td>Resulting Guidance: Innovative navigability improvements that maintain natural river system behaviour. Focus of WG 236.</td></tr>
</table>

Proposed Classification of Navigable Rivers

Inland Waterway Transport (IWT) consists of various connected features that form the navigation system. These components may include natural lakes, reservoirs, navigation locks, canals, estuaries, and rivers. Rivers are the single largest component of the world's inland waterway transport systems and various measures have been applied in the riverine systems to improve navigability. In some systems navigation improvement measures have significantly altered natural riverine processes. Other systems are significantly regulated to alter the magnitude or timing of a watershed's natural hydrology. Systems with pools or reservoirs may result in increased depths that extend distances far upstream and provide improvements for navigation draughts, but this also results in environmental trade-offs (for example impacts to fish passage). Still other systems have minimal or localized measures that improve a specific navigation bottleneck – for example rock excavation projects, side canals, or more commonly riverine dredging. Based on the wide range of existing systems, it is necessary to classify a river within the context of navigation.

The main components of the developed riverine navigation classification system include the extent of hydrologic regulation and morphologic confinement. Hydrologic regulation of rivers is managed through reservoir operations. These reservoirs can be located in-line with the navigation channel – which requires a navigation lock – or can be a feature that regulates inflow of the tributaries. Morphologic confinement consists of river training structures including groynes, revetments, or other features that may alter the lateral migration of a river. These training structures may impact (at least temporarily) the sediment budget of a river system. The extent, types, and combinations of these features within a fluvial system are the basis of the proposed classification system that is listed in Table 2. Classes ranging from A through E are assigned to various river types based on the condition of a river's hydrologic regulation or morphologic confinement.

Table 2 Classification System of Navigable Rivers

Class	Name	Description
A	Natural Rivers	Undeveloped or quasi-natural rivers with natural hydrology and unconfined morphology.
B	Trained Rivers	Open River systems with natural hydrology but laterally fixed in place by river training structures
C	Pooled Rivers	Rivers with navigation locks and dams
D	Regulated Rivers	Open rivers that have altered discharges due to reservoir operations
E	Highly Regulated Rivers	These include navigable rivers that have significant alternations to discharge (reservoir operations), level (locks and dams), and morphology (training works).

This classification system allows for a continuum between the classes. Few watersheds in the world exhibit truly natural river conditions due to construction of dams in the upland portion of the watershed, land use change, and other anthropogenic interventions. In some systems, the sediment budgets or hydrology have been modified due to engineering and development activities in the watershed, but the extent of the impacts may be limited and the system could be considered to be in a quasi-natural state. Therefore, Class A may be assigned to some rivers even though there are some quantified or observed changes in hydrology or morphology.

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

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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 Figure 1).

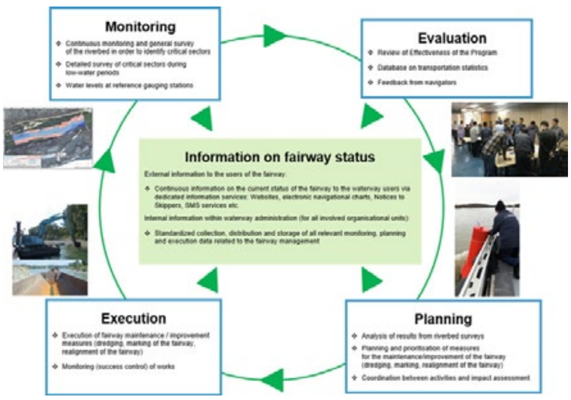

Figure 1 The river management cycle

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. This approach results in a dynamic masterplan which is updated at each iteration of the river management cycle.

Interventions and Measures to Improve Navigability in Natural Rivers
Following the development of a masterplan, it is necessary to identify or update the measures that can be implemented to improve navigability in natural rivers given the system processes and constraints.

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

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

Figure 2 Dynamic fairway management

A morphological dredging strategy combined with monitoring can be an effective solution for managing highly uncertain morphological development of river channels. Building on Dynamic Fairway Management (or Adaptive Management), the operational planning will anticipate the morphological developments. For example, by strategically selecting dredging locations, in combination with a good monitoring program, dredging could be applied to prevent the development of a bottleneck rather than just removing it.

Morphologic dredging is a <u>proactive</u> dredging strategy aimed to interpret morphological evolution and using dredging to positively influence this evolution. It also can be used in combination with limited structures. It differs from the <u>reactive</u> strategy of maintenance dredging associated with the dynamic fairway management, which generally updates the fairway following the observed morphological evolution.

Dredging remains the most effective means because it does not permanently fix the geometry of the river. It maintains the natural river behaviour and temporarily addresses a bottleneck of the system. Especially when the bottlenecks are temporary due to the propagation of sand waves, it is a solution that provides significant benefits to the navigation sector without a permanent change to the natural river characteristics. It is a flexible tool, but its effectiveness depends on the quality of trend analyses and forecasts of morphological changes.

As an alternative to dredging, some situations allow for other interventions to improve navigability while maintaining natural riverine processes. Temporary, Adaptable, and Flexible Training Structures (TAFTS) are also considered. These can be used at temporary bottlenecks and considered as an alternative to maintenance or morphological dredging.

The traditional usage of river training structures on natural rivers has largely focused on forcing a new, rigid organization on a system through robust, permanent structures for the singular goal of improved navigability. These rigid structures are optimized for a certain discharge and do not take account of the dynamics of natural river systems throughout the year. This philosophy has changed, as understanding has grown of what has been lost by applying a traditional methodology, and as re-imagining and re-framing of historic practices have presented ways to better align with the natural flexibility of untrained systems. Some examples of Temporary, Adaptable, and Flexible Training Structures include:

- Temporary placement of vessels or tetrapods for fairway channel constriction
- Low-cost deadwood structures allowed to fail or be rebuilt at low cost
- Base extensions and notching to increase or reduce constriction

These structures can be easily and inexpensively modified to adapt the lateral or longitudinal course of the fairway channel. Such temporary and flexible structures can also contribute to improve the ecological functions of the river and flood protection.

The aim of the structures would be to concentrate the flow during low-flow (dry) conditions. Within the limits of the structures, morphodynamic behaviour is still possible. The structures are to be envisaged in such a way that the river will self-maintain, avoiding or reducing the need for repetitive maintenance dredging as much as possible. During flood season, the structure should be submerged to allow for large river discharges.

If structures favouring scouring of one of the channels in a multi-channel system are to have a more lasting effect, they need to cover a larger area. An example is the application of roughness elements or "porcupines" in the Ayeyarwady River in Myanmar in a side channel with the purpose of improving navigability of the main channel (see Figure 3).

Figure 3 Channel suppression using porcupines in Ayeyarwady River, Myanmar

In addition, the re-use of large woody debris is an element of the Madeira River masterplan in Brazil for improving navigation. Currently, wood jams at riverine ports create a nuisance and a significant amount of resources are used to remove the wood accumulation (Creech et al. 2021; Suedel et al. 2021). In addition, navigation at a location downstream of the riverine port is hindered due to low water at a channel split around an island. Although the side-channel is experiencing deposition, there is an opportunity to accelerate the deposition by placing the nuisance wood at the ports in the side channel and anchoring in portions to further promote deposition (see Figure 4).

Figure 4 Beneficial reuse of woody debris on the Madeira River.

Monitoring and Evaluation of the River Management Cycle

Monitoring is the targeted observation of natural or induced processes and thus an essential basis for evaluation with regard to the achievement of defined goals. Monitoring is a core element for the ongoing maintenance of a waterway and could be, at least to some extent, mandatory by law, e. g. for ensuring compliance with environmental regulations.

Monitoring and evaluation can be divided into an operational level and a strategic level. For the navigability of free-flowing rivers, both levels are relevant and are linked to the short to medium (daily to monthly: operational) as well as the medium to large (monthly to annually or even decadal: strategic) temporal scales. On the other hand, monitoring and evaluation in terms of river management is located on the strategic, i.e. medium to large temporal scales. In some cases, monitoring also provides data required as input by navigation assistance tools or management tools. The collection of data for research and development does not fall into any of previous categories, but provides longer-term profit for waterway and navigation through improved methods and a deeper understanding of the riverine processes.

In case of mandatory monitoring, the data and the scope of the monitoring must often be coordinated with the responsible bodies. Because, in principle, the number and variety of potentially important and relevant parameters that can be monitored on rivers is very large. Level of effort, feasibility, and benefits of data collection must always be weighed when implementing efficient monitoring and assessment systems that cover large spatial and temporal scales in dynamic systems such as large free-flowing rivers. As a rule of thumb, it is often more effective to collect a small number of selected parameters in a meaningful way over space and time than to collect a large amount of data in an insufficient extent and low quality.

Natural, free-flowing rivers are waterways that serve as valuable habitats, and provide a variety of other ecosystem services, such as flood control, water supply, or recreation. Therefore, any change to the system at a strategic level requires comparison of before and after conditions with the goal of identifying and separating intended and unintended impacts. In terms of such a before-and-after view, the following objectives of strategic-level monitoring are essential:

- Development of an understanding of fluvial processes in the river in order to support river (basin) management, or more specific, for example, sediment management, ecological development or adaptation to climate change
- Monitoring the success of measures implemented in terms of efficiency and, also, knowledge enhancement

Based on previously defined objectives and agreed parameters and methods for monitoring the success of measures, the following individual aspects of a monitoring and the associated evaluation are to be distinguished (DWA-M525, 2012):

- Have the intended goals been achieved? Does the process still support the projected outcomes?
- Can the expected effects of the measures be observed?
- Is there a causal and evident relationship between a) measures implemented and b) effects and achievement of objectives?
- Are the costs within the expected range and what is the cost-benefit-ratio?

Clearly, a well-designed and consistently implemented operational monitoring program is an important foundation for a both large-scale and long-term success. The elements of monitoring serve both aforementioned objectives, understanding fluvial processes and assessing effects and success of measures.

One of the most foundational data sets for this purpose consists in bathymetrical data, preferably carried under a wide range of flow conditions. Often, this does not require any additional measurement campaigns beside what is already collected at the operational level. By comparing two or more soundings vertical changes in the riverbed, areas subject to very intensive morphodynamics can be identified. Sounding data obtained over period of several years or even decades provide information of long-term erosive & accumulative processes. The so called “morphological space”, addresses short- to medium-term dynamics and represents the maximum bed level change between a single point of the riverbed, calculated by the difference of the maximum and minimum bed level height. Due to better handling the 90% percentile (M90) of the morphological space is computed for any desired reference area (see Figure 5) or along a longitudinal profile, e.g. over numerous subsections of the fairway. The size of the subsections should be determined in a way that they are large enough for the computational cost and calculation time being acceptable but small enough to detect local trends.

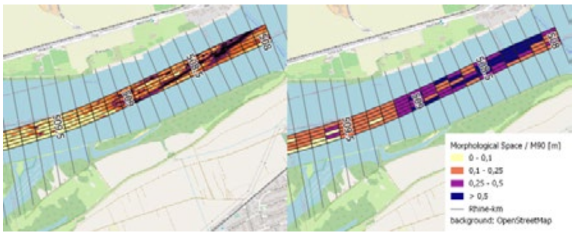

Figure 5 Morphological Space (left side) and resulting M90-parameter (right-side) for each grid cell (100 m x 24 m) based on six spatial datasets, river Rhine in Germany (km 508 to 510) (Reich & Winterscheid, 2022)

It is important to critically analyse the effectiveness and performance of the implemented measures aimed at ensuring and enhancing navigability in river systems. Maintaining navigability is the goal of the program, and the term "maintenance" in this context encompasses all actions that must be undertaken during the operational phase of a river system to uphold navigability standards. This encompasses various facets, including structural, managerial, institutional, technical, human, and economic aspects.

Several tools are integral to the process of ensuring navigability and continuous improvement, which depend on a combination of factors. These include structural measures, morphological dredging, programmed inspections and their frequency, marking, technical and technological resources, the efficiency of hydrographic services, human resources and their qualifications, and financial resources allocated to river management. Additionally, institutional measures play a crucial role in this complex ecosystem.

To ensure the efficacy of measures taken to improve navigability, certain criteria must be met:

- **Alignment with Public Expectations:** The targets set for navigability improvements must align with the expectations of the public. It is essential to ensure that the measures undertaken are responsive to the needs and desires of the users and stakeholders.
- **Satisfaction of Expectations:** The actions taken must satisfy the expectations of the stakeholders and users. This entails delivering on the promises made and achieving the desired outcomes.
- **Efficiency:** Efficient methods and processes should be employed in implementing the measures. It is important to make the best use of available resources, including time, money, and manpower.
- **Relevance to Targets:** The methods used must directly relate to the predetermined targets. The chosen strategies should be well-suited to the specific goals of enhancing navigability and addressing any identified issues.

In order to gauge the quality and effectiveness of the various tools and measures in place, a set of performance indicators is crucial. These indicators, such as efficiency, relevance, expectation, and satisfaction, can be used to assess the performance of different tools. For instance, performance indicators can encompass aspects such as the adherence to navigability requirements, the evolution of sills' characteristics during the hydrological cycle, the annual duration of navigation, and the proactive management of interventions.

Asset performance is an essential component of navigability maintenance. To ensure that assets meet the defined levels of service, inspections play a critical role in monitoring their performance over time. Regular inspections and assessments help identify areas where assets may be falling short of expectations and guide corrective actions.

Summary and Conclusions

This report was established to develop 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:

- development of guidelines to improve and maintain the navigability in natural rivers
- assess the sustainability of river training works designed to improve the navigability
- assess the sustainability of dynamic river management such as monitoring and using of navigation aids to adapt the navigation channel to the river dynamics
- highlight the technical, operational, economic and environmental considerations for navigation in natural rivers compared to that in regulated rivers and canals
- improve the understanding of the physical processes in natural rivers, developed with or without river training works.

The guidance in this Working Group report includes a planning framework for developing a navigability improvement masterplan for a natural or quasi-natural river system, and 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 armouring and sediment nourishment, rock excavation, meander cut-offs and oxbow development, localized traditional river training structure and channel closure structures.

The impacts and strategies for mitigation associated with some of the measures are analysed and discussed. Finally, the continual monitoring, management and operational tools available for improving navigability in a morphologically active river system are a critical component to the success of implementing a dynamic river management approach.

References

[1] Creech, C.T., Amorim, R.S., Lauth, T.J., & Osório, A.L.N.A. (2021). Development of a sustainable waterway masterplan on an Amazon mega-river: The Madeira River, Brazil. Journal of Waterway, Port, Coastal, and Ocean Engineering, 147, 05021007. 1943-5460.0000654

[2] DWA-M 525 (2023) - Sedimentmanagement in Fließgewässern - Grundlagen, Methoden, Fallbeispiele - November 2012; fachlich auf Aktualität geprüft.

[3] Reich, J., Winterscheid, A. (2022). A concept for analyzing the vertical dynamics of the riv-erbed along waterways. IAHR World Congress 2022, Konferenzband (in Druck)

[4] Suedel, B.C., Amorim, R.S., Lauth, T.J., and Creech, C.T. (2021). Nature-based solutions for improving navigation reliability on the Madeira River, Brazil. Integrated Environmental Assessment and Management — Volume 18, Number 1—pp. 115–122.

[5] Van der Mark C, Lemans M (2020) Operational 2D water depth prediction using echo sounder data of inland ships. River Flow 2020. CRC Press