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Applying the Working with Nature philosophy to navigation infrastructure projects

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In 2008, the World Association for Waterborne Transport Infrastructure (Pianc) published a position paper describing a Working with Nature (WwN) philosophy that aimed to change how the sector approaches navigation and port infrastructure projects. In 2018, Pianc published guidance on implementing WwN, an integrated approach that aligns new or existing infrastructure with natural processes. Pianc's guidance presents a six-step process to implement WwN that encourages consideration of site-specific ecosystem characteristics and WwN opportunities at early stages of project development, early stakeholder engagement and integration of WwN into the development of project objectives before design begins. By incorporating WwN applications during conception, design and early stages of development, the WwN approach provides the most promising opportunities to affect positive outcomes for the environment. This holistic understanding of ecosystem processes and socioeconomic interactions realises that environmental impacts can be minimised while concomitantly seeking opportunities to enhance ecosystem functions at various spatial and temporal scales. Project delivery thus goes beyond merely avoiding or compensating for negative project impacts and seeks multi-sector ecosystem and socioeconomic benefits. Applied in practice, and consistent with UN Sustainable Development Goals, WwN can increase habitat functionality, reduce energy associated with construction or maintenance, and enhance the short- and long-term delivery of ecosystem services. Projects consistent with the WwN philosophy therefore achieve their underlying engineering objectives, alongside various co-benefits, consistent with the environmental, societal and economic sustainability pillars.

Keywords: nature-based solutions; ports; UN SDG 13: Climate action; UN SDG 14: Life below water; UN SDG 15: Life on land; waterways & canals

1. Introduction

In 2008 (updated in 2011), the World Association for Waterborne Transport Infrastructure (Pianc) published a position paper describing a Working with Nature (WwN) philosophy (Pianc, 2008). This document posits that, by changing the way waterborne transport infrastructure projects are approached, WwN can maximise opportunities to work with natural processes to deliver environmental enhancements that go beyond the more conventional approach of avoiding or mitigating environmental impacts. By taking an integrated approach that develops a better understanding of the environment early in the project, 'win–win solutions' that optimise ecosystem, social and economic benefits can be achieved.

Building on the position paper, Pianc then published guidance on WwN for navigational infrastructure projects (Pianc, 2018). WwN seeks sustainable solutions by integrating consideration of natural processes, ecosystem functionality and meaningful stakeholder engagement to maximise benefits for both people and nature (Pianc, 2018). Navigation infrastructure projects typically undergo extensive upfront environmental and cultural impact evaluations to avoid, minimise or mitigate impacts. WwN goes beyond this by implementing project alternatives that integrate natural processes into project designs, benefitting both the project and the environment. Furthermore, consistent with United Nations (UN) sustainability approaches, WwN yields a more sustainable approach to project design, planning and management. It enables practitioners to not only meet regulatory requirements, but to design projects more holistically, integrating nature and natural processes into project planning.

This paper illustrates how WwN is being implemented in practice to achieve more sustainable outcomes for the navigation infrastructure sector. The objectives of this paper are to

- describe the six steps of the WwN approach, as outlined in Pianc's guidance (Pianc, 2018)
- describe how the approach contributes to sustainable navigation infrastructure, integrating engineering with natural processes, while being consistent with the UN Sustainable Development Goals (SDGs)
- present practical examples of how WwN has been implemented successfully, contributing to sustainable navigation infrastructure.

2. Background

For the purposes of this paper, the term 'sustainability' is discussed in the context of waterborne transport infrastructure. Consistent with the definition by Brundtland (1987), the International Association of Dredging Companies (IADC, 2023: p. 10) states

> Sustainability is achieved in the development of infrastructure by efficiently investing the resources needed to support the desired social, environmental, and economic services generated by infrastructure for the benefit of current and future generations

where 'infrastructure' refers to the diversity of structures, features and capabilities associated with waterborne transport.

The focus of this paper is on dredging and the beneficial use of the dredged material generated by activity needed to support the development and maintenance of navigation channels, ports, harbours, levees, breakwaters, as well as natural infrastructure features such as islands, dunes, salt marshes, and oyster and coral reefs. A focus of sustainability is on reusing and recycling materials to reduce energy consumption and waste. The beneficial use of dredged material falls squarely in this definition (Laboyrie *et al.*, 2018).

The Pianc (2014: p. 12) report on sustainable ports developed the following definition:

> A sustainable port is one in which the port authority together with port users, proactively and responsibly develops and operates, based on an economic green growth strategy, on the WwN philosophy and on stakeholder participation, starting from a long-term vision on the area in which it is located and from its privileged position within the logistic chain, thus assuring development that anticipates the needs of future generations, for their own benefit and the prosperity of the region that it serves.

Sustainability creates both present and future value across the three sustainability pillars. It is therefore relevant to strategic planning across the navigation infrastructure sector.

3. The WwN approach

WwN involves (*a*) project conception, planning, design and implementation, (*b*) ecosystem and performance monitoring and (*c*) adaptive management. Adaptive management recognises that navigation projects rely upon learning and adaptation to optimise project outcomes.

Pianc (2018) established a six-step approach (Figure 1) to implement WwN for navigational infrastructure projects. While focused on dredging, these same six steps can be applied to a broad range of engineering operations and decisions, facilitating greater focus on sustainability, circularity and nature.

3.1 Step 1: Establish project needs and objectives

All successful projects must have defined navigational objectives. Objectives traditionally centre on the required functions of the new development or project expansion as well as ongoing economic and operational requirements. WwN principles facilitate a wider view of objectives by involving broader environmental and community benefits. While project needs and objectives are initially defined during the initial stages of a project, a better understanding of the

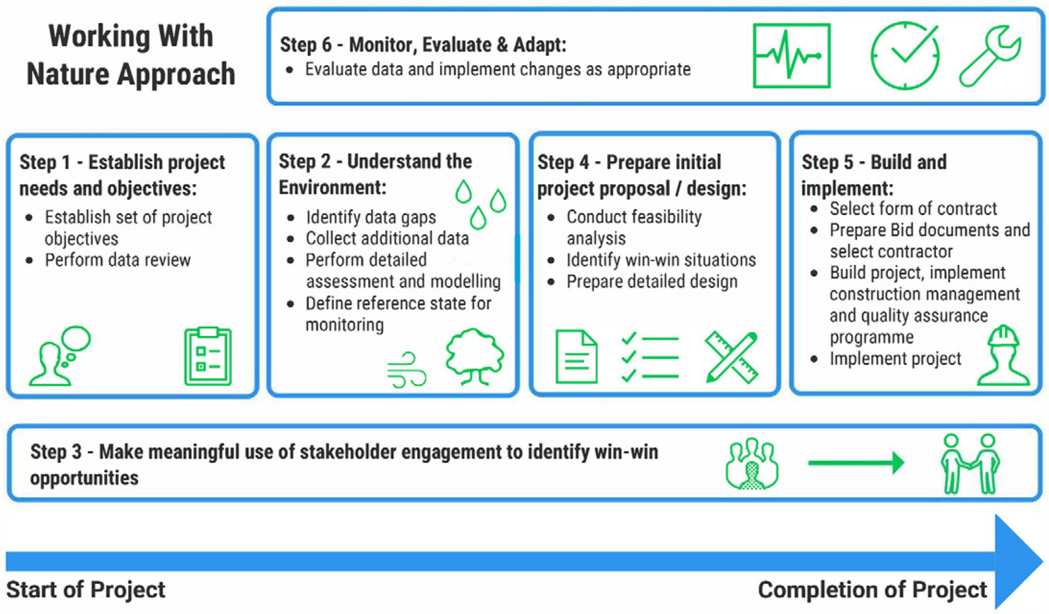

Figure 1. Six steps of the WwN approach (adapted from Pianc (2018))

environment is achieved, new nature-based opportunities may be identified, supporting the formulation of new objectives.

3.2 Step 2: Understand the environment

In the context of WwN, developing an understanding of the local environment before key project decisions are taken is a crucial element to success, extending beyond the standard environmental impact assessment approach. Understanding the physical processes operating and the biological environment (including ecosystem functions and services), as well as how these processes may be impacted by the changing climate, enables site owners and stakeholders to identify new opportunities for environmental protection and enhancement as the project evolves.

3.3 Step 3: Make meaningful use of stakeholder engagement to identify possible win–win opportunities

The WwN approach supports the UN SDGs: to achieve economic growth, social development and environmental sustainability. Stakeholder engagement is essential to identifying these goals on a project level. Stakeholder engagement seeks win–win solutions for the project sponsor and stakeholders alike, ideally building unanimity of support for the project as a measure of success. Stakeholder engagement should be thoughtfully included as an integral part of all steps of the WwN process and should be conducted in a collaborative environment (Figure 2).

3.4 Step 4: Prepare initial project proposal/design to benefit navigation and nature

The design stage makes WwN operational. A multi-disciplinary design team should bring different perspectives to ensure that all parts work together in balance. The preparation of an initial project proposal to benefit navigation and nature is followed by design, where opportunities to work with nature are explicitly demonstrated and incorporated into the project. Ideally, WwN concepts will have been introduced early, during conceptual and feasibility assessment stages, to identify and compare options, costs and expected outcomes. In WwN, by avoiding and minimising negative environmental impacts during design, mitigation and compensation requirements also are minimised. This aligns with environmental directives that require projects to demonstrate avoidance and minimisation of environmental impacts during design, and compensation for impacts that cannot be avoided.

3.5 Step 5: Build and implement

During project implementation, the following need to be considered in a WwN context: contract structuring; early contractor involvement; construction planning; choice of construction methods/materials/equipment. Collaboration with construction contractors will help the project design team better understand what may or may not be feasible during the implementation stages. This approach can also identify and define appropriate contractual arrangements allowing innovation in the project execution, and potentially creating added value for both the project and the environment. The construction process can also benefit from WwN by minimising negative environmental impacts, reducing energy and resources, and creating a safe work environment during construction.

3.6 Step 6: Monitor, evaluate and adapt

Monitoring is recommended during multiple project phases. WwN is a continuous process that requires monitoring and adaptation, including corrective actions where appropriate. Monitoring,

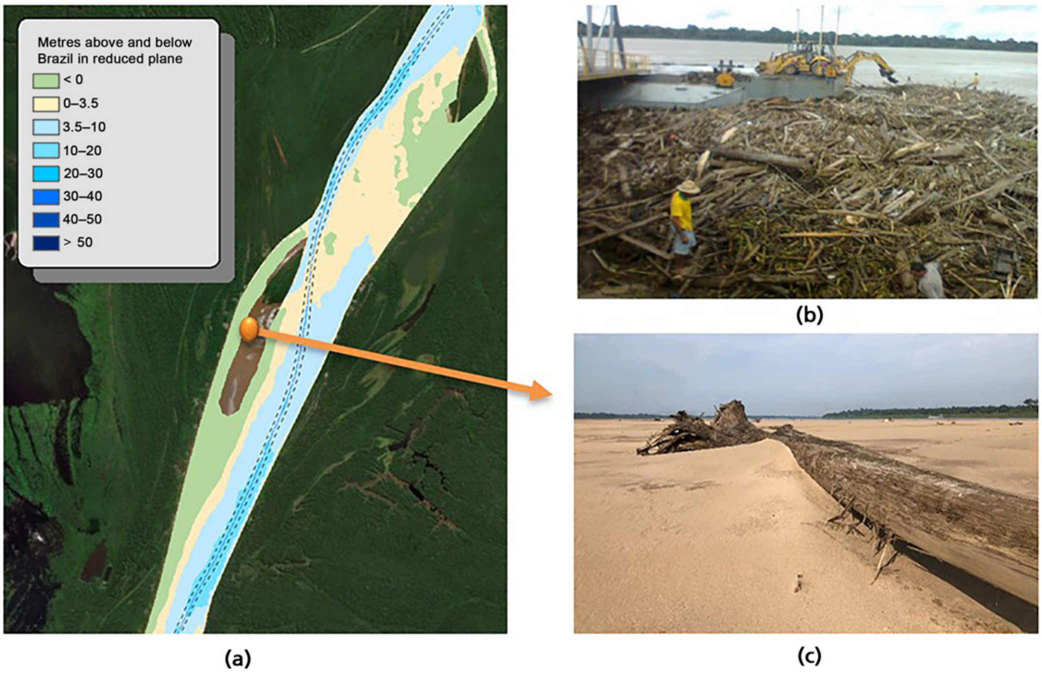

Figure 2. The use of large woody debris is an element of the Madeira River stakeholder-driven master planning process in Brazil for improving navigation. Currently, wood jams at riverine ports create a nuisance (b) and substantial resources are used to remove accumulated wood (Creech *et al.*, 2021; Suedel *et al.*, 2022). 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 experiences deposition, there is an opportunity to accelerate deposition by strategically placing and anchoring the nuisance wood in the side channel to improve navigation in the main channel ((a) and (c)). Wood naturally accumulates in the side channel and represents a WwN opportunity to improve navigation in this free-flowing river (photo credits: Calvin Creech)

evaluation and adaptation assess progress against the stated environmental objectives. Pre-project, baseline conditions along with the project objectives (including as refined during design) are needed to develop metrics to track progress on whether the project has met or will meet WwN objectives as planned. Monitoring also helps identify new actions or measures that may be required, should deviations from project objectives become necessary (Figure 3).

4. WwN and sustainability

There are numerous ways in which WwN can be implemented, from altering the surface or texture of submerged structures and thus creating or expanding aquatic habitats, benefiting from natural hydro-morphological processes for fairway conditions, to using natural systems such as islands, marshlands and mangroves, to protecting nearshore environments from the severe storm events expected to become more frequent with climate change (Bridges *et al.*, 2015, 2021; Dolatowski *et al.*, 2024; Pianc, 2008, 2018; Suedel *et al.*, 2022).

The issue of sustainability is even more pertinent considering that the world's population and economic growth require increased infrastructure expansion and upscaling, even as the climate changes (Dolatowski *et al.*, 2024; Suedel *et al.*, 2022). This places continuous and rising pressures on the natural environment, ranging from local habitat loss to the transformation of regional ecosystems (Coverdale *et al.*, 2013; He and Silliman, 2019). Such challenges require creative solutions to develop infrastructure in the context of natural ecosystems that are already under pressure.

WwN can inform the delivery of environmental protections and enhancements while enabling economic development, reducing delays and leveraging opportunities to provide local communities with valuable amenities, recreational resources and improved landscape habitats.

Pianc has committed to achieving its mission sustainably, consistent with the UN SDGs. In addition to launching the WwN philosophy in 2008, Pianc's overarching goal is to support navigation infrastructure development in a manner that is mutually beneficial to economic, social and environmental interests (Pianc, 2018, 2023a). Working with, rather than against, natural processes can result in more cost-effective and sustainable solutions. Using natural infrastructure and natural processes combined with, or even instead of, conventional hard infrastructure can offer viable, cost-effective, long-term benefits (Bridges *et al.*, 2015, 2021; Gittman *et al.*, 2014; Huynh *et al.*, 2024; Ruswick *et al.*, 2022; Tritinger *et al.*, 2024). Thus, WwN can be a strategic enabler to achieving sustainable port and navigation development.

In 2015, the UN released its 17 SDGs, a call for action to promote prosperity while protecting the environment, as part of its 2030 Agenda for Sustainable Development (UN, 2024). While the 17 SDGs are necessarily broad, they are underpinned by 169 more

Figure 3. In the bird's foot delta region of the lower Mississippi River, the USACE New Orleans District is implementing WwN through the strategic placement of dredged material in Baptiste Collette Bayou. Current state-of-the-practice and management adaptations derived from lessons learned include the intentional smothering of plant overgrowth and the creation of tidal flats. As an example of this best practice, Gunn Island in May 2021 (a) immediately after placement to smother plant growth and before breeding by coastal birds had begun, and then later in July 2021 (b) showing dominant growth of Phragmites during the 2021 bird breeding season. This project exemplifies how projects can strike a balance between engineering for navigation infrastructure needs and creating/enhancing critical habitat for coastal seabirds and shorebirds (Tritinger *et al*., 2024). (Photo credits: (a) Michael Guilfoyle; (b) Jake Jung, both USACE ERDC)

specific targets, many of which are directly applicable to Pianc's organisational goals and initiatives. Overall, the SDGs serve as a blueprint for Pianc to achieve a more sustainable future.

Shortly after Pianc published its 2008 position paper on WwN (Pianc, 2008), the Building with Nature (BwN) (Bouw and van Eekelen, 2020; De Vriend and van Koningsveld, 2012) and Engineering With Nature (EWN®) (Bridges *et al*., 2014; King *et al*., 2020) initiatives were established to implement the WwN philosophy in practice. These initiatives promote resilient and sustainable development by leveraging ecosystems, natural resources and nature's energy to achieve navigation projects that benefit both society and the environment, and are thus consistent with UN SDGs, especially SDG 14 (Life below water) and SDG 15 (Life on land).

In addition to the Pianc (2018) WwN report, Pianc working groups (WGs) have also published other reports that provide guidelines for sustainably implementing the WwN philosophy in practice. These include WG 150 (Pianc, 2014), documenting the advantages of implementing a green port philosophy and the application of this philosophy to ports worldwide, and WG 148 (Pianc, 2023b), which focuses on WwN opportunities in the recreational navigation sector. Pianc also set up a Permanent Task Group on Climate Change (PTGCC), which supports Pianc's sustainability efforts by ensuring climate change challenges are integrated into all other navigation infrastructure activities, consistent with SDG 13 (Climate action) (Pianc, 2020). As part of this ongoing commitment, the PTGCC just launched a new WG that will investigate how the navigation sector can contribute to 'blue carbon'.

5. Case studies

The following sections present two comprehensive case studies that exemplify how the six-step WwN approach is implemented in practice. Each example reflects meaningful collaboration among relevant stakeholders including navigation project owners, government agencies, non-governmental organisations, academia and the public to promote projects that restore or create ecological habitat, encourage the beneficial use of dredged material, reduce energy consumption and promote carbon dioxide sequestration. Both projects integrate project features and components that are consistent with the UN SDGs (Table 1). The two case studies represent completed projects at the field scale, demonstrating the practical civil engineering application of WwN with attention to stakeholder engagement and environmental conservation.

6. Case study 1: River island creation, Atchafalaya River, Louisiana, USA

The Horseshoe Bend project on the lower Atchafalaya River exemplifies WwN through the innovative placement of dredged material to form a riverine island. For 12 years, beginning in 2002, sediment dredged from Horseshoe Bend in an open river area was strategically placed. Placing 0.4–1.5 million m^3 of dredged sediment every 1–3 years contributed to the island's growth and eventually to the establishment of a 35 ha riverine island (Figure 4) (Berkowitz *et al*., 2017; Suedel *et al*., 2014, 2015). By 2015, the island was fully formed. The project's objective then refocused on

Table 1. The association of the two project case studies presented with select UN SDGs (✓ indicates a meaningful association)

Case Study	SDG 3 Good Health and Well-being	SDG 6 Clean Water and Sanitation	SDG 8 Decent Work and Economic Growth	SDG 9 Industry, Innovation, and Infrastructure	SDG 11 Sustainable Cities and Communities	SDG 13 Climate Action	SDG 14 Life Below Water	SDG 15 Life on Land
1. Horseshoe Bend Island, Atchafalaya River, Louisiana, USA	✓	✓	✓	✓	✓	✓	✓	✓
2. Port 2000 Le Havre and Seine Estuary, France	✓	✓	✓	✓	✓	✓	✓	✓

(a) (b)

Figure 4. Satellite imagery showing the evolution of Horseshoe Bend Island from December 2013 (a) to January 2024 (b). The small light-coloured land features immediately upstream of the island in both images are remnants of recently placed dredged material. The river continues to shape the island through natural processes (images from USACE New Orleans District)

performing studies to identify and quantify to the extent possible the various climate change, navigation, environmental and economic benefits being realised for enhancing the coastal Louisiana landscape. Leveraging nature's energy to relocate dredged sediment led to higher quality habitat than otherwise would be present using more conventional placement practices. This project demonstrates how strategically placed dredged material can be shaped by natural riverine processes rather than being rigidly confined between containment dykes.

The following narrative describes how the Horseshoe Bend Atchafalaya River project followed the WwN approach.

6.1 Step 1: Establish project needs and objectives

Throughout the 1990s, material dredged from the federal navigation channel at Horseshoe Bend was placed at adjacent wetland development sites located along the river's banks, but these placement sites filled to capacity. Anticipating future channel maintenance requirements, the US Army Corps of Engineers (USACE) New Orleans District evaluated an innovative placement alternative whereby dredged material was mounded at mid-river open water placement sites, within a 142 ha area, immediately adjacent to the navigation channel and upriver of a small, naturally forming island. This alternative was selected as a demonstration to evaluate the efficacy of mid-river sediment placement while limiting shoaling downriver of the designated area (Suedel *et al*., 2014, 2015).

6.2 Step 2: Understand the environment

To improve understanding of the processes contributing to the island's formation over a 12-year period to 2014, the USACE conducted hydrology studies investigating the transport of the mounded material onto the island. Information including mapping the floral and faunal composition of the island was also collected to document and quantify environmental and other benefits (Berkowitz *et al*., 2015). A multi-factor ecosystem assessment was undertaken, which included an evaluation of landscape geomorphology, ecosystem classification, floral, avian and aquatic invertebrate communities, soil and biogeochemical activity, and hydrodynamic and sediment modelling (Berkowitz *et al*., 2017). High-resolution images were obtained to document the island's growth over time (Figure 4). Overall, the multi-factor approach provided a comprehensive ecosystem-level analysis of a diverse series of ecosystem components and functions.

6.3 Step 3: Make meaningful use of stakeholder engagement to identify possible win–win opportunities

Before the mid-river placements began, the project team consulted with State of Louisiana and federal environmental agencies to obtain feedback on the proposed innovative sediment placement approach as a more sustainable alternative compared with filling in wetlands or disposing of the material offshore in Atchafalaya Bay. Support was provided by the US Fish and Wildlife Service, who provided visual inspections of the island, and the Port of Morgan City, who provided commercial vessel data used for quantifying the navigation benefits associated with the project.

6.4 Step 4: Prepare initial project proposal/design to benefit navigation and nature

Previous studies provided limited qualitative documentation of the flora, fauna and geomorphology of the created island. To improve understanding of the island's value, the EWN programme funded a study to demonstrate how WwN could be implemented (Berkowitz *et al*., 2015, 2017). Upon approval, the project proceeded towards design, involving the means and methods for the placement of dredged material in the river and identifying targeted locations for material placement.

6.5 Step 5: Build and implement

The project used natural processes, thereby reducing demands on limited operations and maintenance resources, minimising the project's environmental footprint and enhancing the quality of its benefits. Multiple economic benefits were documented (Foran *et al*., 2018). The enlarged island reduced the cross-sectional area of the river at this location, increasing the river's flow through the navigation channel sufficient to reduce shoaling and therefore maintenance dredging requirements. The island's formation greatly contributed to the decision to re-route the navigational channel, which is now 1.13 km (0.7 nautical miles) shorter, has fewer turns and reduced sedimentation (Foran *et al*., 2018). The straighter route combined with reduced shoaling is resulting in a safer and more reliable navigation channel that requires less dredging. Project costs were reduced compared with conventional disposal approaches that involved hauling dredged material over long distances. Intentionally aligning natural processes in the river with engineering processes by strategically mounding dredged material is achieving tangible environmental, social and economic benefits consistent with several SDGs (Table 1).

6.6 Step 6: Monitor, evaluate and adapt

The project objective to demonstrate how dredged material can be used beneficially to nourish a naturally forming river island was successfully met. Evaluation of the biology, ecology, geomorphology, hydrodynamics and sediment transport highlighted the effectiveness of this project to restore, create, enhance and protect the coastal Louisiana landscape (Berkowitz *et al*., 2017). Wetland classification and analysis of geomorphic features demonstrated that Horseshoe Bend Island provides a variety of habitat types (Figure 5) and supports complex communities of vegetation, invertebrates, soil microbes and higher organisms, including a large wading bird rookery. The island provides approximately 6.0 ha of new emergent habitat and 7.7 ha of aquatic bed habitat. The island supports 81 plant species and 23 animal species, including nine species of wading birds (Berkowitz *et al*., 2017). More than 85% of plant species observed on the island are native and invertebrate abundance and diversity is well supported. The island's soils sequester nutrients and perform water quality functions comparable to natural wetlands in the region (Berkowitz *et al*., 2017). Periodic dredged material placements continue to the present day.

Figure 5. Airboats are required to access Horseshoe Bend Island due to its remote location and shallow water features. Habitat types shown in the photo are aquatic beds (foreground), emergent (centre), scrub–shrub and forested (background and far right) (photo credit: Burton Suedel)

Environmental and habitat improvement, nutrient sequestration, climate regulation and navigation support services that were assessed after the island's development realised multiple, quantifiable ecosystem service benefits (Foran *et al*., 2018), consistent with several SDGs, ranging from the creation of emergent wildlife habitat and enhanced recreational opportunities to improved navigation and reduced sediment dredging and dredged material transport. Horseshoe Bend Island therefore exemplifies what can be achieved by applying the WwN principles to navigational infrastructure projects.

7. Case study 2: Port 2000 Le Havre and Seine estuary, France

Experiences gained during the development of the Port 2000 project in the late 1990s were instrumental in setting the foundations for the original 2008 Pianc WwN position paper. The Port 2000 project commenced in the late 1990s, and a key objective from the outset was to fully integrate both the needs of the natural environment of the Seine estuary and the ideas emanating from the stakeholder engagements with the needs of the project. Later phases of the port development (completed in 2022) then applied the WwN approach (Pianc, 2018; Revue Travaux, 2006).

From the outset, the Port 2000 vision to accommodate large container ships included the environmental rehabilitation of the Seine estuary. After environmental, technical and economic studies were completed in the late 1990s, construction commenced in 2001 with the building of a 5 km breakwater and 1400 m of quays. Commercial operations began in April 2006. After two additional phases of quay construction, finished in 2022, the port now offers 4200 m of quays for vessels of 16 m+ draught. New direct access for river barges will commence in 2024.

Dredging supporting Port 2000 has created more than 100 ha of new mudflats, a channel dedicated to the environment near the Normandy Bridge (Figure 6), new bird resting areas and ongoing improvements in wetland connectivity. The creation of mudflats at a large scale is associated with several UN SDGs, as they contribute to nutrient purification, carbon dioxide sequestration, water purification, biodiversity and flood risk reduction. The following sections describe how WwN continues to be followed more than 30 years later.

7.1 Step 1: Establish project needs and objectives

The port of Le Havre is at the mouth of the Seine River, at the entrance of the English Channel and is a natural gateway to Paris and northwestern Europe. The Port 2000 vision was to reinforce Le Havre as a major entrance to Europe for all sizes of container ships arriving from Asia or the Americas, by accommodating long-term growth of container traffic and the increasing size of ships. Located at the mouth of the estuary, wave action made it difficult for river barges to have direct access to the port, and barges have had to dock at a multi-modal terminal with containers transferred by rail. Among the Port 2000 improvements, there is nonetheless a growing demand for direct barge access to maritime quays. This need required multiple stakeholder meetings to resolve port expansion requirements to support barge access. During public hearings, stakeholders noted the need to restore the estuarine environment to support birds and fish nurseries. From these discussions, the WwN objectives were developed, focusing on wetland restoration and creation in the Seine (Morin *et al*., 2010).

Figure 6. Seine estuary showing environmental development around Normandy Bridge with Port 2000 in the background (photo credit: Paul Scherrer)

7.2 Step 2: Understand the environment

During the project's initial development, global environmental studies included field measurements and physical and mathematical modelling to understand hydrodynamics and sediment transport. Biological studies investigated fish, fish nurseries, use of the estuary by birds (permanent and migratory), amphibians and plants. To develop a holistic understanding of the estuary, studies were performed over a large area of the river, outside and upstream of the port (GIP Seine-Aval, 2022a; Lestel *et al.*, 2021).

7.3 Step 3: Make meaningful use of stakeholder engagement to identify possible win–win opportunities

The Port Authority engaged stakeholders at an early stage to facilitate dialogue, achieve mutual understanding and gain public trust. This approach avoided future project delays associated with public concerns. There were many informal discussions with multiple stakeholders before official public hearings for Port 2000 in 1997 (CNDP, 2024a) and in 2017 (CNDP, 2024b). This engagement continued through all phases of work. Specific attention was given to fishermen's interests. At the beginning, fishing associations opposed the project due to concerns about impacts on fish nurseries and reduced fishing opportunities.

Study results were shared continuously, building trust with stakeholders. During construction, before any recent activity, meetings were held with anglers, port engineers and contractors to help protect fisheries and the environment to the maximum extent practicable. For barge access, discussions with stakeholders led to abandoning the lock option at the far end of the Port 2000 basin, in favour of access between the two port entrances with a breakwater protecting against wave action (Figure 7).

7.4 Step 4: Prepare initial project proposal/design to benefit navigation and nature

The use of physical and mathematical models developed for the port design made it possible to identify opportunities to minimise excessive sediment transport, optimise habitat creation and maximise habitat stability (e.g. GIP Seine-Aval, 2022b). This led to triple-win approaches that benefited Port 2000 economics, public perception and the environment. The necessity of a bird island emerged from stakeholders during public hearings. An island was designed and constructed south of the estuary, using dredged material from Port 2000 to form the island. The island offers resting habitat for thousands of birds annually (Figure 8). With WwN, by avoiding and minimising most of the negative environmental impacts, mitigation and compensation requirements were also minimised during design.

During public hearings held in 2017, stakeholders identified the need to continue restoring the estuary to create more bird habitat and fish nurseries. These discussions led to the decision to lower approximately 1000 m of Seine calibration dykes (i.e. the longitudinal dykes separating the northern part with humid prairies from the central part with a navigation channel to Rouen) to restore lateral continuity of water flow and habitat. This future project will be completed at four locations at the mouth of several small coastal rivers, upstream of the Normandy Bridge.

Figure 7. Aerial artistic view showing future protective breakwater (foreground and right) permitting safe and direct barge access (photo credit: Haropa Port)

Figure 8. Nature-based bird island built from dredged material as part of Port 2000 operation (photo credit: Haropa Port and Paul Scherrer)

7.5 Step 5: Build and implement

Construction of the project considered environmental impacts, with measures established to minimise those impacts. Contractors were required to use mathematical models to phase dredging and breakwater construction to identify progressive solutions, thus minimising peaks of current velocities and sediment transport. The building of a groin for the new mudflat and environmental channel explicitly allowed adaptations to the design during construction, using natural sedimentation processes.

7.6 Step 6: Monitor, evaluate and adapt

The Port Authority established a multi-year monitoring programme that extends from Tancarville Bridge to the sea. Monitoring objectives were defined by an independent scientific committee active in the Seine estuary and officially approved by the local state government (Préfet de Région). Ongoing monitoring includes assessments of wildlife such as fish, birds and amphibians, as well as sediment and water quality. The Port Authority continues to share the monitoring results with stakeholders. Beyond stakeholder meetings, which are still ongoing, the Port of Le Havre shares results of surveys with the scientific programme Seine Aval (GIP Seine-Aval, 2022c) and contributes to the management of the nature reserve of the Seine estuary.

8. Conclusions

With the launch of the WwN philosophy in 2008 (Pianc, 2008) and the later publication of WwN guidance (Pianc, 2018), Pianc has developed tools to help the navigation infrastructure sector advance sustainability in the face of a changing climate. WwN strives to go beyond conventional approaches to mitigate or minimise environmental impacts by generating a holistic understanding of ecosystem processes, thereby enabling the identification of opportunities to enhance environmental and other co-benefits. An integrated six-step approach to WwN seeks to use natural processes to deliver navigation infrastructure project objectives more sustainably, achieving engineering objectives alongside environmental, economic and social benefits, consistent with the UN SDGs.

The Pianc guidance (Pianc, 2018) presents a six-step process to implement WwN

- establish project needs
- understand the environment
- engage stakeholders
- integrate nature into the project design
- build and implement
- monitor.

This approach encourages consideration of site-specific ecosystem characteristics and WwN opportunities at early stages of project development, thereby integrating WwN into the development of project objectives before design begins. By incorporating WwN applications during conception, design and early stages of development, the WwN approach provides the most promising opportunities to effect positive outcomes for the environment.

WwN contributes to the UN SDGs by informing the delivery of better environmental protections and enhancements while promoting economic development, reducing delays and leveraging opportunities to provide local communities with highly sought amenity areas, recreational resources and improved landscape habitats (Pianc, 2018). WwN is meaningfully aligned with SDG 14 (Life below water) and SDG 15 (Life on land). World population growth and increased infrastructure expansion place continuous and rising pressures on the natural environment. Environmental challenges ranging from local habitat loss and the transformation of regional ecosystems to global climate change require increasingly creative solutions that develop infrastructure in the context of natural ecosystems, so that both may be managed effectively. Pianc's WwN approach and the USACE's EWN initiative actively promote integrating nature into navigation infrastructure projects.

Two comprehensive case studies were used to exemplify how WwN can be implemented successfully across diverse geographic regions. In the USA, the Horseshoe Bend project used a river's natural processes and strategic sediment placement to create an unconfined river island. The 35 ha island consists of four distinct habitat types supporting complex communities of vegetation, invertebrates, soil microbes and higher organisms such as birds. Horseshoe Bend Island contains a wide variety of vegetation, including more than 85% of native species. The approach applied at Horseshoe Bend Island resulted in landform characteristics that support a large, successful wading bird rookery and invertebrate abundance and diversity consistent with emergent aquatic bed landforms enabled by the strategic placement of dredged materials. In Europe, Port 2000 restored over a hundred hectares of mudflats that support bird resting areas for thousands of birds. Other coastal ecosystem functions that were enhanced by the project include wetland connectivity, nutrient purification, carbon dioxide sequestration, water purification, biodiversity and flood risk reduction. In South America, natural materials such as large woody debris are being used in the Madeira River to naturally shape the river and regulate flows in ways that improve navigation safety, while removing debris from areas where freely flowing waters are obstructed (Figure 2) (Creech *et al*., 2021). To underscore the growing importance of maintaining morphological river function while improving navigability conditions of the world's few remaining natural rivers, Pianc recently published guidance for developing masterplans for improving the navigability of natural river systems and integrating adaptive management strategies applicable at a system scale (Pianc, 2024).

Collectively, these case studies show how a stakeholder-driven approach like WwN can be integrated into navigation infrastructure projects cost-effectively and in ways that benefit people and nature. WwN and the enabling BwN and EWN initiatives, provide the navigation sector with important tools to contribute to sustainable development now and into the future. The case studies presented here demonstrate the multiple economic, social and environmental benefits of navigation infrastructure projects and contribute to a more complete understanding of how the WwN approach can be applied in practice. To this end, the USACE and others are integrating the WwN approach into other navigation projects worldwide, contributing to a more sustainable navigation sector. In the meantime, Pianc is monitoring and learning lessons from good practice with the more general implementation of nature-based solutions internationally. The future evolution of the WwN approach will therefore need to consider and build on lessons learned in respect of, among others, scaling up, securing finance, ensuring more effective partnership and developing solutions that are designed to be adaptive to accommodate uncertainty as the climate changes.

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