Guidelines for Sustainable Inland Waterways and Navigation
GUIDELINES FOR SUSTAINABLE INLAND WATERWAYS AND NAVIGATION

Report of Working Group 6
of the
ENVIRONMENTAL COMMISSION

INTERNATIONAL NAVIGATION ASSOCIATION

ASSOCIATION INTERNATIONALE DE NAVIGATION

2003
PIANC has Technical Commissions concerned with inland waterways and ports (InCom), coastal and ocean waterways (including ports and harbours) (MarCom), environmental aspects (EnviCom) and sport and recreational navigation (RecCom).

This report has been produced by an international Working Group convened by the Environmental Commission (EnviCom). Members of the Working Group represent several countries and are acknowledged experts in their profession.

The objective of this report is to provide information and recommendation on good practice. Conformity is not obligatory and engineering judgement should be used in its application, especially in special circumstances. This report should be seen as an expert guidance and state of the art on this particular subject. PIANC disclaims all responsibility in case this report should be presented as an official standard.

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ISBN 2-87223-137-4

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PREFACE

Rivers and their floodplains are among the most impacted ecosystems in the world. Energy production, freshwater transfer, agriculture, deforestation, pollution, urbanization, drainage, river regulation, and flood protection schemes can lead to ecological deterioration and the loss of important functions, which in turn could threaten future uses of these systems.

Navigation infrastructure and operations can also impact the ecological character and functions of waterways. Likewise, a degradation of waterway conditions from any of the above factors might adversely impact the suitability of that waterway for navigation uses. Navigation should ideally be undertaken in a fashion that is in consonance with the other needs of the waterway, including the full range of physical, chemical, and biological functions as well as the social constraints and requirements placed on the system.

Water resource systems that can satisfy, to the greatest extent possible, the changing demands placed on them over time, without degradation, can be called “sustainable.” Sustainability, as defined by PIANC (1996) and many other global organizations, means “meeting the needs of the present without compromising the ability of future generations to meet their own needs.”

To achieve sustainability, navigation development and operations must consider long-term impacts to the ecosystem. Navigation has the potential to offer a cleaner and more energy-efficient means of transportation than other alternatives; however, to address the challenge of integrating economic, environmental, and social aspects in terms of sustainable development, guidelines for sustainability must be developed and employed.

The Environmental Commission of PIANC established Working Group No. 6 to develop a document entitled “Guidelines for Sustainable Inland Waterways and Navigation.” This report presents the findings of the Working Group, which include a recommended procedure for both strategic and project planning based upon an assessment of the interactions among inland navigation, the ecosystems on which navigation is practiced, and the other potential users of those systems. The report is aimed primarily at mid-level managers involved in Inland Water Transport (IWT) planning and operations, but is also useful to a broader audience involved with navigation or water management. Attention is given to the audience in developing countries.
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TERMS OF REFERENCE

BACKGROUND

Economic development, navigation infrastructure needs, safety considerations, etc., can and should be in harmony with nature. In the case of river management for navigation infrastructure (river training, navigation, flood protection, coastal protection, etc.), decisions in the past were often based on specific costs and benefits, without consideration for environmental effects. The pressure to encroach on river floodplains has frequently implied inappropriate land use planning, with the result of reinforcement of physical defenses against the river. Development has led to many non-natural interfaces between land and water, marine and fluvial, which weaken the ecological infrastructure.

Today, a holistic approach to navigation infrastructure development, operations, and maintenance is being promoted, thus leading to sustainable development. While engineers in the past were primarily focused on design, construction, and maintenance in support of navigation, they now realize the importance of also integrating and optimizing other interests, particularly ecological sustainability.

OBJECTIVE

Such new strategies may have implications for shipping on navigable rivers. PIANC needs to deal with these sustainable navigation infrastructure issues. Expertise on a more holistic approach is becoming increasingly available. Therefore, the PIANC Environmental Commission, in collaboration with the Inland Navigation Commission, proposed a Working Group to focus primarily on the situation with regard to navigable rivers, estuaries, and coastal river deltas, and aims to describe:

- State-of-the-art river management.
- New, more holistic approaches in support of navigation infrastructure.
- How new approaches relate to navigation needs.
- Proposals for new engineering guidelines for sustainable river management and related navigation infrastructure planning.

TERMS TO BE INVESTIGATED

The report should describe important functions of the river and provide guidance on the practical aspects of river management with emphasis on the sustainable management of navigation infrastructure, including such topics as:

- Navigation (including vessel design)
- Description of a river
- Definition of terms
- River functions
- Primary, secondary, and additional uses
- Hydrology
- River morphology
- River ecology
- River training
- River infrastructure
- Land use planning
- Recreation
- Commercial fishing
- Landscaping
- Nature conservation
- Restoration
- Spatial and temporal dynamics

WORKING GROUP MEMBERSHIP

The chairperson should be experienced in river engineering and science and have up-to-date knowledge on sustainable river management issues. The members of the group should represent a wide range of disciplines of engineering, hydrology, morphology, navigation, ecology, biology, and land use planning. Members should represent InCom, MarCom, RecCom, and appropriate environmental interests.
SUMMARY

In the face of expanding economies and an increased demand for transport facilities throughout the world, Inland Water Transport (IWT) is often shown to be the preferred alternative from not only an economic standpoint, but also in terms of environmental conservation. However, in many countries, this alternative is contested in the name of environmentalism. This argument is fuelled by past errors whereby drastic river development schemes indeed had damaging consequences for the environment simply because insufficient precautions were taken. Moreover, in many cases, the main aim of the scheme was not river navigation, but one or another of the numerous uses that have been made of our rivers since time immemorial.

Current development methods include the necessary measures for reconciling the requirements of different uses. The overriding aim has become planning for the future with a strict regard for sustainable development. Within the context of these new methods, it is important that new projects be assessed taking into consideration the main natural functions of river systems; in other words, that they ensure maintenance of the key functions and ecological functions, including:

- Morphological processes (erosion, transport and sedimentation)
- Maintenance of hydrological balance (e.g., flood pulse)
- Maintenance of the sediment balance
- Provision of habitat (ecological continuum)
- Maintenance of biological and chemical processes (nutrient cycles)

Maintaining these processes does not mean that any change has to be prohibited, but rather that each process must be carefully examined, that "before" and "after" situations have to be accurately assessed and that all possible consequences must be appreciated and considered with respect to the economic or other benefits derived from project implementation. This overall assessment must be carried out not just at the local level, but also for the river basin as a whole. In other words, the assessment of waterway schemes (from the ecological, economic and social standpoints) should be carried out for the scheme as a whole, rather than for its individual components, considering all alternatives and taking into account river basin management objectives.

Navigation is a unique mode of transport with the potential to use a resource without long-term adverse consequences. Vessels can be adapted to the conditions of particular rivers, rather than the waterway adapted to common standards and designs. Measures to achieve needed depth, clearance, width, or velocity can be selected to minimize impacts upon important waterway functions. These measures can even be modified to provide environmental enhancements.

Financing institutions and governments need to ensure that the full environmental and social costs and the long-term effects of proposed waterway schemes are included in cost-benefit analyses. Affected parties must fully participate in the decision-making process regarding any waterway. This includes actively participating throughout the entire project cycle, from identification and preparation to implementation and evaluation. Therefore, a legal and institutional framework for civil society participation at the national and local levels must be established. Local participation in decision-making is, therefore, essential. Participation is not merely a set of formal requirements but also a cost-effective source of added value for long-term sustainable use of rivers as transportation ways.

Effective participation calls for full access to information, a time schedule appropriate to local social and cultural conditions and adequate resources. It also includes empowerment (i.e., capacity building by education and technical assistance) to enable citizens and organizations to assert their rights and interest in the process. Case studies presented in the Appendices illustrate lessons to be learned on different steps in the proposed procedure. It has to be stressed that these cases, like any other IWT project, stand on their own, with unique historical, political and financial backgrounds. Nevertheless, we hope that for future projects these guidelines will contribute to a sustainable development of IWT as an environmentally and economically feasible friendly mode of transport.

1.0 INTRODUCTION

Concerns related to the impact of some water resource uses led the United Nations to propose a new institutional framework for addressing water resources management in an integrated fashion. As part of Agenda 21, the U.N. proposed that water resource management be based on the concept of water being an integral part of an ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its use (United Nations, 1992). Maintenance of the quantity and quality of water and its role in the ecosystem over time through integrated water resource management is the central theme of sustainability.

Navigation is a water resource use of significant historical importance – social and economic development would not have been possible without navigation. The global population has passed 6 billion people and is forecast to grow to 8 to 10 billion people by 2050. Waterborne transport will be needed to meet the challenge of people and commodity movement in a safe, economic, and environmentally acceptable manner for the benefit of mankind. PIANC is
committed to upholding the concepts of sustainability and integrated management in the development and improvement of global waterborne transportation. Sustainable development of Inland Water Transport (IWT) requires the improvement or further development of navigation and its related infrastructure, while minimizing negative effects on waterway functions and maximizing environmental benefits.

Thus, the Environmental Commission of PIANC established Working Group No. 6 to develop ecological and engineering guidelines for sustainable development of inland navigation as related to navigation infrastructure. The fundamental basis for sustainability, as adopted in this guidance, is that proposed development or management actions should sustain those critical processes (termed functions) that are necessary for the continuance of waterway ecosystems. Because most users of these guidelines are unfamiliar with this perspective, these key functions are first described (Chapter 3). Requirements for inland navigation, especially those relevant for the interaction with the functions, are elaborated next (Chapter 4). With this knowledge in mind, Chapter 5 presents a framework that supports balanced decision-making regarding sustainable inland waterways and navigation. The procedure can be used to compare proposed alternatives, or to compare a selected alternative to a baseline condition. The procedure is flexible in nature, and can be applied to virtually any situation, within every socio-economic context.

2.0 BACKGROUND AND APPROACH

2.1 Need

Efficient freight transport systems play a critical and positive role in the economic life of industrialized countries and in the daily lives of their citizens. These countries realize the importance of the relation between good systems and services and their economy. However, while these transportation systems are essential to a modern society, and there are substantial economic benefits to be realized from them, there are also significant negative environmental impacts, including the loss of habitat and key functions due to the disruption of topography, use of energy and other resources, and noise and air pollution. Public concern regarding these negative impacts has increased – leading to the adoption of corresponding guidelines, acts and regulations in several countries.

Figure 2.1.1 Comparison of cargo capacity of a 1600-ton tank vessel (about 2000 hp) to trucks (about 250 hp) and train cars (about 5000 hp).

Figure 2.1.2 Transport distance of one ton of goods by truck, train, and vessel with a given amount of fuel. (Modified from Federal Ministry of Transport, Building and Housing, Germany)
Decisions concerning a choice of transportation mode have historically focused on economic issues. Unfortunately, the economic competition between various transport modes is often based on financial costs, and not economic costs. The latter approach leads to more objective conclusions, which is important for achieving sound strategic planning. Increasingly, consideration is also given to selecting the mode that best “fits” the environment and does not contribute to unnecessary increases in fuel use, noise, exhaust emissions, accidents, spill incidents and congestion. Waterborne transportation often best meets these needs, as illustrated in part by Figures 2.1.1 and 2.1.2. But, like other modes of transportation, waterborne transport has the potential to generate impacts that, over the long term, diminish the character of the environment and call into question the sustainability of both the environmental resource and the transportation practice (e.g. improper operations may damage the river banks by wave action).

The result of this concern over the impact of transportation systems on the environment must be reflected in how those systems are planned for the future. Transportation designers and environmentalists, both of whom recognize the interdependence between transportation systems and the environment, are increasingly concerned about maintaining an appropriate balance between the two. Environmental laws and other national and international regulations and conventions have now established a legal framework aimed at keeping transportation decisions consistent with sustainability goals. Technical and policy frameworks must also be established to ensure decisions that promote the sustainability of the transportation systems and the environment in which they are placed.

The framework for the assessment of sustainability presented within this report must be employed within the context of these existing EU requirements. For example, the sustainability framework could readily be adopted as a component of most Environmental Impact Assessments (EIAs). Ultimately, legal requirements should be modified, where necessary, to be consistent with the principles of conservation and sustainability discussed herein in order to ensure the continuance of navigation and the protection of the environment.

2.2 Approach

Sustainable development of IWT requires the improvement or development of navigation as well as its related infrastructure. Within this report, navigation is defined as the transport of commodities and persons by means of maneuverable waterborne craft (vessels, barges etc). Infrastructure is defined as the network of waterways and related facilities, terminals and services to accommodate transport. This report applies to several types of inland navigable waterways: natural waterways, such as flowing rivers without regulation structures; as well as regulated and artificial waterways, including canals and channels without discharge.

Water Framework Directive

A number of existing laws, treaties, etc., prescribe that certain practices and principles be employed in the development and management of waterways. A new and very important step has been made by the European Commission when the Water Framework Directive entered into force on December 22nd 2000 (WFD – reference number 2000/60/EC ). It must be translated into national law of the member states at the end of 2003. The WFD marks the outcome of a complete rethinking of water and water protection policy. The key elements, in the context of this report, are:

- Attainment or maintenance of “good ecological status” by a specific point in time.
- Water management on the basis of river basins.
- Close involvement of the public in planning and decision-making processes.

In the process of implementation, several definitions are required, which were left unspecified in the framework – for example, the question of how the definition “heavily modified water bodies” is to be applied to waterways and to what extent the required “good status” has to be achieved. In the EU, the WFD became a vital tool for sustainable development and it might thus affect maintenance and construction of the entire western European waterway system.
Waterways may include impressive systems of related infrastructure, such as locks and dams, navigation channels, and harbors; flood prevention and control structures, such as upstream dams, levees, and bank protection; and other ancillary features, such as hydropower generation sites. To sustain navigation, waterways must be safe and reliable, requiring certain physical characteristics related to depth, clearance, width, alignment, and velocity. These needs are elaborated in Chapter 4 of this document.

To sustain their ecological character and environmental quality, waterways must also maintain their natural physical, chemical, and biological processes. These can be termed the “functions” of the ecosystem. In waterway ecosystems, there is a set of complex relations between numerous dependent variables that dictate the physical, biological, and chemical character of the environment. Changes to any one variable, whether induced by nature or as a result of man's activities, cause the system to respond and create changes in all other variables. The stream corridor, watershed, and landscape influence and are influenced by neighboring ecosystems; therefore, navigability and associated navigation infrastructure are intricately tied with ecological considerations.

For strategic planning and technical assessments, planners and managers often view waterways in terms of the uses they support, without explicit consideration for the long-term side effects of measures on other uses or waterway functions. Often, these side effects have to be mitigated or compensated by new and expensive measures (see fig 2.2.1). Decision-making on navigation projects should, therefore, consider the functional aspects of the waterway as well as the more traditional uses perspective. In this way, uses and functions can be considered as complementary.

This report proposes a consistent, yet flexible framework in which stream and riparian functions serve as the basis for evaluating these ecosystems, in addition to the uses that are involved in decision making already. The functional approach broadens the horizon for management from a species to an ecosystem level; from consideration of a specific site to consideration of the role of the site in the catchment, and from focusing on end products to focusing on the processes that created them.

2.3 Assessment of Navigation Projects

The general approach advocated in this document is to first formulate an understanding of the underlying processes (or functions) occurring on a waterway so that the physical and ecological limitations of the waterway can be understood and its potential for meeting project objectives established. The effects of proposed developments must be assessed within the market context and considered in relation to any operational or other limitations that may be beyond the study waterway. The aim should be to minimize changes to the river regime and, at the same time, facilitate an increased efficiency in IWT.

Figure 2.2.1 Water control structures necessary to ensure adequate discharge or sufficient hydropower generation may include features such as fish ladders as mitigation for impacts upon fish migration.
Vessel design and maneuvering character, for example, can play very significant parts in ensuring development of navigation while limiting the changes to the river regime.

Successful navigation projects are usually the result of carefully negotiating the best possible outcome for the project, given the prevailing knowledge of the ecosystem, project constraints, and the diverse interests of all stakeholders. Thus, success depends as much upon the process as it does upon the product. No one process will work effectively in all situations, so users of this document should be prepared to adapt the procedures recommended herein as required to fit the particular situation. Institutional reform and restructuring may be necessary to implement this sort of cooperation so that the planning and improvements are appropriate in practical, operational, social, economic, and environmental terms. This issue should be addressed by both government and by international development funding agencies.

2.4 Achieving Sustainability

An underlying premise of the guidelines presented in this document is that sustainability is most likely to be achieved by limiting ecosystem impacts. In other words, impacts to critical characteristics or processes are likely to compromise sustainability over the long term. Conversely, actions shown not to impact fundamental system characteristics or processes generally do not threaten sustainability. While this premise is applied herein to IWT, it could and should be applied equally when evaluating other modes of transport or other forms of development.

In this document, the fundamental characteristics and processes considered to be important are characterized as functions. Sustainability is easier to achieve by minimizing the impacts of proposed actions upon these functions, relative to the level at which they exist under natural conditions. Complete avoidance of impacts is seldom possible; therefore, the method outlined herein allows for mitigation to be considered in this evaluation.

The level of analytical detail necessary to determine if the optimization has been met will vary by project. In some cases, a simple qualitative analysis would ensure that no impacts on these basic functions are expected; thus, sustainability is not compromised. In other cases, detailed analyses similar to an environmental impact assessment should be conducted to characterize and to quantify the impacts to these basic functions. Regardless of the approach or level of analytical detail, the underlying hypothesis is that minimizing the impacts to key functions will help to achieve sustainability.

Figure 2.4.1 An illustration of the complexity of ecosystem interactions with related uses.
3.0 WATERWAY FUNCTIONS

3.1 Overview

Waterway ecosystems support a set of complex relations between variables that dictate the physical, biological and chemical character of the environment. Waterway development and management require a knowledge and awareness of the complex interactions among watershed and waterway processes, boundary sediments, bank and floodplain conditions, and ecological resources. The relations between waterway characteristics, social values and economics must also be recognized. Human activities, such as urbanization, infrastructure development, and channelization affect the waterway character and can adversely impact other uses. Many of the adverse consequences of development can be avoided through careful planning or can be mitigated through project features. Other consequences cannot be avoided, and the approval of the proposed development hinges on negotiating acceptable compensation. An increasing appreciation for the environmental value of stream systems has led to the development of new approaches to development that can be implemented with full appreciation for the environment while optimizing the use of the resource.

3.2 Waterway Ecosystems

Waterways are not only the base for inland navigation but are also complex natural ecosystems. An exception may be artificial canals, in which an associated ecosystem has been established. Most of the worldwide waterways are natural rivers and lakes that were extended or adapted to the requirements of navigation. But navigation is not the only reason for modification of these systems. Other uses and needs such as flood protection, land reclamation, water discharge, public and industrial wastewater discharge, irrigation, and mining of sediments have influenced water resource development. Most of these modifications were undertaken without consideration of the full range of implications to the ecosystem.

Waterways are large-scale natural systems in which physical and ecological processes interact dynamically on different levels in time and space. For proper planning, these processes, relevant scales, and interactions that occur among these processes must be understood. This introductory chapter gives a brief outline of the relevant aspects of waterways. Waterways include rivers, estuaries, canals, and lakes.

Rivers: The main physical processes operating in a river are the free discharge of water and sediment, and sometimes ice. River behavior depends on the geologic character of the valley, the river hydrodynamics, and the associated sedimentation and erosion processes. During periods of high discharge (e.g., during “monsoon” or ice-melt periods), the river system can be very dynamic with rapid morphologic changes. Large volumes of sediment may deposit on natural levees along the channel and in low-current areas, such as pools, swales and ridges, oxbow lakes, side channels, and marshes adjacent to the main channel.

River systems also support important biological and chemical processes. Tributaries supply minerals and nutrients to the system vital for biological activity. In turn, this biological activity produces oxygen and detritus, which provide nutrients for flora and fauna. Depending on the input of nutrients, the water quality and habitats, more or less complex ecosystems with different trophic levels can be found. A healthy system maintains its self-purification abilities.

As a consequence, every river system consists of a dynamic and wide variety of erosive and sedimentary environments of varying properties. In combination with hydraulic properties, such as water depth, current and turbulence, and biological and chemical processes, within every system a wide range of habitats can be found. Few species are adapted to the relatively high current velocities, coarse sediments, and dynamic bedforms of the riverbed. More species live along the shoals and in the channels between and along the banks and levees. A rich variety of flora and fauna is also found in the irregular floodplains, cut-off bends, and in side channels. Here, sediment and nutrients are deposited during high-water events. During subsequent events, these areas supply nutrients to downstream areas that are relatively calm and are important for spawning and feeding of migratory species. From a biological point of view, floodplains are very productive.

Within a natural river system, there is a dynamic balance among hydrodynamics, sediments, and ecology on different levels. Disturbance of this balance provokes a reaction on the appropriate spatial and time scale, which can be modeled by a rate law, using half-life values:

- During high-water events, large bedforms develop and are eroded after the next falling stage.
- A river bend cut-off increases river slope, generating upstream erosion for decades.
- Upstream river training works, reservoirs, and land use changes (deforestation) may change river regimes for centuries.
- Changes on the scale of continents or catchment areas are expected due to global warming: changes in precipitation, evaporation, land use and snow melt can significantly alter the hydrodynamic balance (e.g., by increasing the duration and frequency of extreme drought or flooding). In addition, sea level rise may influence river characteristics in the delta areas.
These changes in hydrodynamic balance - local, regional national, or international - generally affect the interaction with the groundwater system and terrestrial habitats adjacent to the river system.

**Estuaries:** Estuaries form the transition from river-dominated to coastal processes. The interaction of multi-directional tidal currents, wave action, and abundant sediment supply from riverine and coastal sources results in a dynamic environment. Wetland habitats such as shoals, mudflats, and mangroves are strongly influenced by salt content and nutrient supply. These areas are usually highly productive, but are also very susceptible to disturbance or destruction. Coastal areas attract many human activities like fishing, trade, and recreation. Dredging to maintain harbor entrance channels is a major activity.

**Lakes:** Lakes are natural or manmade freshwater reservoirs in which river discharges are temporarily stored. Often they are used as a waterway transport connection between the riverine inflow and outflow location, or between harbors along the lake boundaries. Characteristics include very low current velocities, but potentially high wind-wave action. Ecological productivity depends on the nutrient supply, turbidity, and water depth. Shallow areas, especially the boundaries, may be important wetlands. The stability of the water level (and thus water depth) depends on the riverine discharge regime, in combination with demands from other users; power supply, irrigation, drinking water.

**Canals:** Canals are manmade waterways, often accompanied by weirs and locks that regulate water levels and facilitate navigation or irrigation and drainage. Currents and stable water levels are absent. Natural banks are susceptible to wave action and other dynamic hydraulic effects caused by navigation. Canals are, therefore, often stabilized to prevent erosion. Recently more natural bank protection measures have been introduced, like shallow forelands, breaking the wave and stimulating the development of shallow-water habitats. Canals are often used for water management as well; e.g., discharge of water and effluents or supply of irrigation water.

Waterway systems often serve as corridors that connect locations or transfer nutrients or living material, such as spawning fish species. The length, width, vegetation composition and connectivity of riparian corridors are important characteristics in determining the type and degree of benefit. Alteration of the structure and nature of these pathways can alter the corridor functions and processes.

The structure and composition of the flora and fauna within the stream and stream corridor are ultimately controlled by the nature and frequency of disturbances within the valley. Disturbances can vary in space, time, frequency, magnitude, and duration. They need to be understood in terms of how they affect the form and function of the valley, its riparian zone, and the stream channel.

A sustainable system is resilient to disturbances (i.e., able to recover to its original condition). Prerequisites for recovery are dynamics, space, networks, spatial differentiation, and gradients. If these factors are available, the system can cope with natural variations (e.g., flora and fauna that are adapted to seasonal discharge fluctuations and a water transport system (vessel draft) that can overcome periods of low discharge). Fluctuations beyond these natural margins may endanger resilience; for example:

- Exceeding critical levels in critical periods (e.g., discharge distribution over bifurcations during extreme floods, resulting in new river patterns; water levels being too high or too low for floodplain inundation before the growing season, devastating crop yields).
- Loss of critical areas or connections in critical periods, such as natural armoring layers protecting the river bed for erosion during high-water events, prolonged periods of flooding or drought in habitats for migratory animals, shoals during low stages blocking navigation, and locks preventing migrating species from reaching their spawning grounds.

Because waterways are large-scale systems and corridors for fauna, flora, and human use, local disturbances can have large-scale consequences. The disappearance of a vital element may make the chain useless. Which element is vital depends on the functions and use of the waterway system, and should be established explicitly for every case. The variation and combination of waterway dynamics in space and time create a wide and dynamic diversity of habitats, which can potentially lead to a well-balanced aquatic community with habitats for all life cycles (spawning, rearing and feeding areas). This is the habitat function of a waterway system. This habitat function is closely related to the hydraulic balance, sediment continuity, and chemical and biological processes.

### 3.3 Functions

Waterways support and maintain basic functional components associated with either structure or processes. These functions relate to the physical, biological, and chemical nature of waterways but do not relate directly to their social nature, which is addressed later in the category of uses. The basic functions that waterways support can be divided into five categories:

- Evolution through morphologic processes.
- Maintenance of hydrologic balance.
- Continuity of sediment processes.
- Provision of habitat.
- Maintenance of chemical and biological processes.
Within each of these categories, several key components and processes have been identified (Table 3.3.1). It is important to note that not all functions will be of equal importance in different waterways, so interpretation of this framework will be required for each situation (see also Fischenich, 2002).

Each waterway system, reach, site, or riparian corridor should be evaluated to determine the relevant functions (i.e. which functions are currently limiting, are functioning inappropriately, or are acting as stressors, etc. to the system). These functions should then be emphasized in planning and management. In evaluating relevant functions, it is important to remain cognizant of the interrelated nature of the functions, namely that several functions have similar indicators and direct measures, and impacts to one are not necessarily independent of all others. This concept, and the value of it in terms of analysis efficiency, will be expanded upon later in the document.

### 3.4 Waterway Uses

The social and economic aspects of waterway ecosystems are addressed in this report as uses. Waterways provide for a wide variety of uses. With respect to *Uses*, the WG makes a distinction between using the system as a sink, a source (consumptive use) or a source (indifferent, non-consumptive). Table 3.4.1 lists common uses of waterways and how they affect or are affected by the primary functions. The uses are presented without respect to priority or value, which would and must vary with time and by region.

Table 3.4.1 demonstrates the considerable interrelation between the primary functions on a waterway and the common uses ascribed to the resource. A particular use can impact one or more functions, with consequent impacts upon other potential uses. Uses reflect public and private interests that often have a strong economic influence over management decisions. Uses are not consistent across political boundaries, change with public perception, and change with time. In contrast, functions have a scientific basis, can be measured using established ecological and hydrological methods, and do not change with public perception or political entities.

The report recommends that both functions and uses be considered in planning and (political) decision-making. Advantages of considering functions in the decision process include:

- **Functional assessment will identify similarities and dissimilarities between stream reaches, watersheds, and stream classes, establishing reference conditions, prioritizing watersheds for preservation or restoration, and reducing uncertainties associated with natural variation in aquatic ecosystems.**

- **Based on functions, processes, and interactions, a functional assessment will target the cause of impairment, predict the short- and long-term effects on water and sediment quality and quantity, establish means of remediation or restoration that restore functionality, and identify success criteria.**

- **Assessment of functions provides the unique ability to address impairment caused by not only maximum loading but also aids in the identification of minimum requirements (e.g., importance of sediment transport on delta accretion and maintenance).**

- **A functional assessment based on direct measures and surrogates of those measures can be used to formulate hypotheses and identify research needs.**

<table>
<thead>
<tr>
<th>Morphologic Evolution</th>
<th>Hydrologic Balance</th>
<th>Sediment Continuity</th>
<th>Habitat Provision</th>
<th>Chemical and Biological Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream Evolution Processes</td>
<td>Surface Water Storage Processes (short &amp; long-term)</td>
<td>Full Sedimentation Processes</td>
<td>Biological Communities and Processes</td>
<td>Water and Soil Quality Processes</td>
</tr>
<tr>
<td>Energy Processes</td>
<td>Surface/Subsurface Water Exchange Processes</td>
<td>Substrate and Structural Processes</td>
<td>Necessary Habitats for all Life Cycles</td>
<td>Chemical Processes and Nutrient Cycles</td>
</tr>
<tr>
<td>Riparian Succession</td>
<td>Hydrodynamic Character</td>
<td>Quality and Quantity of Sediments</td>
<td>Trophic Structure and Pathways</td>
<td>Landscape Pathways and Processes</td>
</tr>
</tbody>
</table>
3.5 Criteria and Measurement of Functions and Uses

Criteria are variables, features, or attributes that allow for a reasonable and practical means of quantifying and understanding cause/response relations at and between the various scales present on aquatic systems - not a simple matter given the complexity of ecosystems. Processes operate across scales and thus define critical linkages (e.g. runoff generation, sediment load and transport, erosion/deposition, and vegetative interaction/succession). These processes are assessed in terms of the physical variables, features, and attributes that are manifested at the scales of watershed, reach, and site. Measurement of certain attributes allows quantification of the degree to which a particular function is achieved in an ecosystem. Measures can be ecological, economic, social, physical, or directly related to navigation. Fischenich (2002) describes common indicators and measures for river and riparian functions, and discusses how these can be applied to assess impacts.

<table>
<thead>
<tr>
<th>Uses</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morphologic Evolution</td>
</tr>
<tr>
<td>Sink</td>
<td>O</td>
</tr>
<tr>
<td>Cooling water</td>
<td>O</td>
</tr>
<tr>
<td>Drainage</td>
<td>I/O</td>
</tr>
<tr>
<td>Flood storage and attenuation</td>
<td>O</td>
</tr>
<tr>
<td>Wastewater</td>
<td>O</td>
</tr>
<tr>
<td>Aggregative withdrawal</td>
<td>I/O</td>
</tr>
<tr>
<td>Draining water</td>
<td>O</td>
</tr>
<tr>
<td>Fishing and hunting</td>
<td>-</td>
</tr>
<tr>
<td>Hydropower</td>
<td>I/O</td>
</tr>
<tr>
<td>Industrial water supply</td>
<td>I/O</td>
</tr>
<tr>
<td>Irrigation</td>
<td>I/O</td>
</tr>
<tr>
<td>Groundwater withdrawal</td>
<td>-</td>
</tr>
<tr>
<td>Riparian timber harvest</td>
<td>I/O</td>
</tr>
<tr>
<td>Non-consumptive</td>
<td>-</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>I/O</td>
</tr>
<tr>
<td>Ecosystem protection</td>
<td>I/O</td>
</tr>
<tr>
<td>House</td>
<td>I/O</td>
</tr>
<tr>
<td>Landscape feature</td>
<td>-</td>
</tr>
<tr>
<td>Recreational boating</td>
<td>I/O</td>
</tr>
<tr>
<td>Commercial transport (passengers, freight)</td>
<td>I/O</td>
</tr>
<tr>
<td>Navigation service</td>
<td>I/O</td>
</tr>
<tr>
<td>Non-boating recreation</td>
<td>O</td>
</tr>
<tr>
<td>Spatial corridor (e.g. utilities, transport)</td>
<td>I/O</td>
</tr>
</tbody>
</table>

Key:
- No Discernable Impact
I Use May Impact Indicated Function
O Use May Be Impacted By Indicated Function
4.0 INLAND NAVIGATION REQUIREMENTS RELATIVE TO FUNCTIONS

4.1 Introduction

Few waterways, whether natural or manmade, have been developed and maintained - or will be developed - with only IWT in mind. They usually serve multiple purposes such as agriculture (irrigation and drainage), drinking water supply, industrial process water (including cooling water), wastewater discharge (polluted or partly purified), fishing, recreation, hydropower generation, flood control, excavation of building materials (boulders, gravel, sand, clay), and more.

IWT development, therefore, has to start on a much broader footing than that of representing the immediate and restricted interests of water transport alone. In a way it complicates matters, because almost all decisions are multi-party decisions and involved decision-makers need a basic understanding of a wide field of disparate issues. For the development of an adequate set of rules and regulations, all users' claims must be well understood - IWT requirements for the development of a specific waterway differ from country to country, from region to region, and from continent to continent. At the same time IWT facilitates matters, because the cost of waterway development and maintenance can be shared. Two lessons from successful IWT projects around the world are that IWT is only economically viable if integrated with other uses to share the construction and maintenance costs; and it is imperative that a balance between economy and ecology be achieved.

In many parts of the world, IWT is the traditional means of inland communication and transport. It has been essential not only for the economic development of specific areas but also for the welfare of the people living in isolated communities and remote areas. Of late, IWT has come to be recognized as an energy-saving as well as cost-effective mode of transport, especially for low value bulk cargo. Container transport by inland barges has become a booming means of commodity flow, relieving land-based traffic. In many countries there is still a considerable potential for developing IWT as an alternative to other (dry) modes of transport and at lower costs. But IWT often remains unexplored or under-utilized because of a lack of management and operational skills and insufficient awareness of possibilities and techniques.

Although IWT is frequently more economical and environmentally friendly than other modes of transport, and thus relatively more sustainable, steps are often required to ensure sustainability. The design and operation of the IWT sector should be symbiotic with other waterway uses, and should seek to avoid, or at least minimize, impacts to the ecological functions identified in Chapter 3. Potential impacts vary, but are most often associated with fairway modifications, vessel operations, and collisions or spills. This chapter discusses the interaction of IWT with other uses and sectors, and provides guidelines to assist the design, construction, and operation of waterways in a manner that promotes ecological sustainability without compromising the inherent benefits of IWT.

4.2 Conservancy and management of navigable natural waterways

Natural waterway systems serve many human uses. Management for a single use, or directed only at short-sighted human aims, may cause considerable harm to the ecosystem. Management that preserves the natural functions of the system helps ensure that the social and economic considerations associated with other waterway users are addressed. As the different interests of the users do not always run parallel, sound management requires a clear insight into both the properties of the waterway in question and the importance for the region/country of all interests involved. Such multi-purpose management is easiest to realize if the direct responsibility of major users is laid in one hand as much as possible.

The responsible board should ensure that measures on behalf of navigation are not detrimental to other major users that are involved, or to the underlying functions of the system. Clashes between different users, e.g. IWT and irrigation, will be inevitable at one time or another. In this respect, the judgement of the board should be based upon good knowledge of hydrography as well as hydrology, and also ecology, of the river. This requires a good organization of the public sector authorities and a regular contact with Non-Government Organizations (NGOs) and independent research institutions.

Safe and efficient management of an IWT system includes not only river improvement and river conservancy, but it also includes guiding, control, and regulation of the traffic. When mechanically propelled vessels are introduced on a waterway where country craft already exist, it is of great importance to have official waterway regulations and services (patrol/control/supervision), especially during low stages, when only one lane of traffic is possible at limiting locations. Fairway regulations should address issues such as up- and downstream traffic, characteristics of various vessel types, speed limits and wave restrictions, vertical and horizontal clearances, rules for vessel equipment (including navigational aids), skill of crew, traffic rules and signs (including aids to navigation), pollution control, extra measures for the transport of hazardous goods, and (in the event that an IWT system develops well) additional rules for night navigation.
If an IWT network will be developed, a classification of the IWT system is recommended that fits medium- and long-term developments of waterway dimensions (cross-profile of channel, bend radius, minimum depth), vessel size and tonnage, vertical and horizontal clearance at bridges, and (if there are any) lock chambers. This will ease long-term planning of the development of infrastructure, will help to generate consistent political support, and will foster the sustainability of both the IWT and the waterway.

4.3 Hydraulic phenomena associated with navigation in confined waters

Hydraulic phenomena (such as return flow, water level drop, waves, underwater suction forces on banks and bottom, squat, trim, screw turbulence, etc.) can cause erosion of the bed and banks of the waterway, potentially leading to environmental degradation. Avoidance of these impacts requires limits on the size and speed of vessels in channels or canals, or channel modification to provide minimum dimension (wet cross profile), or stabilization of the bed or banks. Restrictions on speed and vessel movements may be preferred in favor of a minimum channel dimension. The latter may require expensive development and maintenance for the waterway and more significant environmental impacts. From an environmental point of view, vessels for regular commercial navigation on a specific stretch should preferably be adapted to the natural waterway, and not the reverse.

To permit overtaking and encountering maneuvers, and to minimize impacts from hydraulic phenomena around and under plying vessels, minimum cross-profile requirements with safety factors in depth and width are needed. The more critical the cross profile in a fairway (a high blockage ratio), the greater the annual maintenance cost and environmental impact. On the other hand, fairways designed with a low blockage ratio can adversely impact economic viability because ship dimensions (and thus effective tonnage) are restricted. To determine the optimum blockage ratio, non-technical factors such as the potential environmental impacts, the economic prospects and forecast of cargo flow, the origin-destination pattern of commodities, requirements of other users, anticipated vessel design, and alternatives for required water transport system on land must be considered. The waterway authority, other users, the ruling politicians, and funding entities such as the World Bank must be involved in the decision process.

4.4 Nautical management of an IWT route

Knowing the essentials of vessel interaction with the surrounding water, the first way to improve IWT is an

### Hydraulic Phenomena

A ship's maneuvering characteristics are determined by the design of rudder(s) and screw(s) and by the effective propulsion power on board; but they are also determined by factors such as draft, beam, length/beam ratio, squat and trim, wind effects, (cross) currents, and fluctuating keel clearance. Each vessel has its own operating speed under particular circumstances, so if strict regulations on overtaking do not exist, a random pattern of traffic behavior will result. This can degrade traffic safety, so a waterway authority may adopt strict traffic rules for safe operations, for environmental reasons, and for safeguarding the interests and claims of other users of a waterway.

Hydraulic phenomena largely determine the actual speed and ease of navigation of a vessel, and also the possibilities of overtaking and encountering. A return flow is caused by the displacement of water by the bow of the vessel and the simultaneous flow into the gap left behind the stern of the plying vessel, resulting in a continuous flow along and under the hull. The velocity of the return flow depends on the restrictions of the fairway in depth and width, the extent to which the hull blocks the wet cross-profile of the channel, and the vessel speed. The return flow (in the opposite direction of the ship's movement) can grow so strong at limiting stretches that excessive power is needed to maintain the ship's speed, reducing fuel economy and increasing scour, bank attack, environmental impact, and potential danger.

The return flow not only produces a depression of the water level around the vessel so that the ship moves in its own "trough," but also causes a longitudinal gradient by which the vessel trims at the stern. The water level depression (causing squat) and related trim considerably reduce the 'keel clearance.' To prevent the vessel from touching bottom at a limiting fairway stretch due to squat, a certain minimum keel clearance should be provided, which is usually expressed by a rule of thumb of h/d > 1.3, in which h equals the minimum depth of the fairway and d equals the maximum draft of the vessel at rest.

A moving ship generates various types of waves. As with squat, the extent to which waves occur is mainly dependent on the ship's speed, hull shape, and draft. A blocking ratio (the so-called Ff ratio, where F is the wet cross-profile of the channel and f is the wet cross-profile of the ship) of the channel is of secondary importance. Waves increase the vessel's resistance and, in combination with return currents and water level drop, attack the waterway banks and bed. The frequency of shipping traffic can significantly influence the extent of this impact. There are numerous designs of environmental protection works along waterways, in particular along canals with stable water level and no current. Also, for natural waterways with varying water levels and fluctuating currents, effective designs have been developed. Often, proper execution of these protection works requires adequate labor skill and special equipment.
optimal use and proper maintenance of the existing infrastructure. Good information and sound management of the waterway and vessels enhance economic efficiency and safety of an IWT system. After analyzing the existing system, the first step in improving an inland waterway is normally setting up a signaling system and patrol services.

Technical data on water levels, discharges, and other river characteristics are needed, and economic data on traffic and cargo flows will enable an optimum use of the existing waterway (system). Thereafter, more regular shipping implies a regulation of nautical conditions, which often means an increase of the least available depth (LAD). In developing countries, it often takes time to increase cargo flows. Therefore, economic justification requires that large capital investments be avoided. Low-cost construction methods and materials are the only way to keep investments low in this phase of a project.

An authority with its own patrol service is often required for traffic and river control. Patrol boats are needed for traffic supervision (in particular if hazardous goods are transported by ships), as aids to navigation, and for safeguarding the interests of other waterway users. Echo soundings should be made regularly in the channel and at limiting shoals; buoys, beacons, signs, and gauges must be maintained; and traffic control and announcement of LAD based on soundings and/or gauge readings on all the fairway stretches are necessary. These tasks often cannot be carried out by a single patrol crew, and it may be necessary to split tasks among two or more operating service vessels. When multiple support divisions are operating at the same time along a waterway, it is necessary to have a central office coordinate and control efforts. This central office should ideally serve as the location where data (such as water level readings, echo soundings, rainfall data in the catchment, LAD, forecasts, etc.) are collected, disseminated, and maintained.

Reliable LAD data and good maps are crucial for the operation and terminal handling of ships and for planning and management of the river and floodplain. Maps should be standardized by scale and legend, and preferably based on the use of only one chart datum or reduction level with which all gauge readings are compared. Such a reduction level should be related to a shipping-critical low water discharge so that anywhere along the river the reduction level is exceeded as an average during the same number of days per year (for instance, an LRL exceeding 95 percent of the year means that, on an average, the actual water level will be lower than the LRL only 18 days per year). It is important to make waterway maps available to other users, and to distribute nautical maps to sailors. These maps should be augmented with regular and special bulletins on issues such as new buoys, temporary obstructions in the fairway, etc. It is also helpful if the maps utilize aerial photographs, taken during low and high stages, as a base.

It is helpful to have well-known (in coordinates) and regularly marked fixed points on regular distances along the waterway, and to be able to execute proper technical measurements for any user, if needed. Positioning and communication are becoming easier with the application of Global Information System (GIS) systems and mobile phones. Reliable functioning of these applications requires additional equipment on shore. Radar navigation may be needed at night or during periods of low visibility. This requires special attention to buoys, beacons, and channel alignment; they must give a good radar echo at all stages and weather conditions. Shipping at night can also be made safer by using searchlights on ships and reflective tape or paint on buoys and beacons, or by installing navigation lights to mark the channel. Lighting can be difficult in remote regions (energy problems) or populated areas (theft is an important problem for all equipment installed along or on the banks). For small and stable channels, authorities can install beacons on shore, but in other cases floating buoys with a proper anchoring system (easily handled by the crew on board a service vessel) are recommended.

The buoyage system is one of the most important aids to navigation and can significantly reduce collisions and groundings associated with environmental hazards. The lateral buoyage system, indicating the channels, is generally preferred over the cardinal buoyage system, which indicates the dangers. It is generally best to install/anchor the buoys at the steep side of the channel and away from important environmental resources. Buoys on both sides of the fairway are only needed when it is very narrow or crowded. Great skill is required to mark a channel with a good and reliable buoy system, particularly for untrained and wild fairway stretches. The regular inspection, cleaning, and maintenance of all buoys, beacons, gauges, traffic signs, etc. is recommended.

Dredging is often required to maintain a safe and predictable channel. This must be done carefully and with due consideration to the environmental consequences of the dredging operations and the disposal of the dredged material. The PIANC documents “Management of Aquatic Disposal of Dredged Material” (PIANC 1999), the Supplemental Bulletin “Dredged Material Management Guide” (PIANC 1996) provide guidance on dredging and the environment.

4.5 Fairway improvement

Each waterway system has its own particular history, and previous development can profoundly affect the IWT sector. Vessel types, designs, and operations that are specific to a particular region or physical limitations of the waterway system may not be consistent with goods transported to a global market. The legacy of environmental impacts from former uses may present a barrier to modernization. Therefore, while there are uniform criteria to make a river navigable, each particular project typically requires an
adapted design for the vessels and fairway. Important factors are depth, width, currents, stretch (if there are locks), locking time, harbor and quay facilities at terminal sites along the stretch, and the regime of the river. The depth and width of the channel at low stages are important for the maximum beam, draught and length dimensions of the vessels or barge trains. When a modern IWT system is to be developed on a river already used by country craft with primitive equipment, there are three ways to tackle the problem:

- The vessel design is fully adapted to the already limiting location(s) of the fairway.
- After every flood season, some temporary channel improvement works are carried out; this offers more freedom for designing a vessel.
- Permanent control works are employed - offering the best possibilities for a vessel design.

The method chosen must be based on a careful assessment of the economic consequences of many aspects such as vessel design, management and labor problems, maintenance of fairway and fleet, dredging regularly the limiting shoals of the waterway, etc. Environmental requirements can determine the way(s) to be followed. Most cases involve a multi-purpose project, which requires at least a feasibility study and environmental impact study.

From a river engineering point of view, adapting the vessel design to the natural fairway is easiest and least expensive. In that case, extreme high- and low-water conditions are especially decisive for the vessel design. An assessment should determine if IWT is needed over 12 months a year, or whether it can temporarily be stopped during a drought or flood season. A minimum stockpiling capacity at the terminals during periods of stoppage may be required.

Because droughts typically last longer than floods, nautical activities in the dry season are frequently the limiting factor in vessel and fairway design from both an economic and ecological standpoint. These circumstances mandate a vessel design with as shallow a draught as possible. For modern vessel designs for services on shallow waters, a commercial limit may be a draught of about 1.25 m, requiring an LAD of about 1.5 m.

Self-propelled vessels normally have their maximum draught at stern, where the most vulnerable parts are situated (screws and rudders). When such a ship grounds, the physical and ecological damage can be considerable. Modern shallow-water vessel design, therefore, often favors the use of a push boat with barges. The draught of a fully laden barge is normally more than the draught of the push boat itself. When the laden formation hits the bottom during low stages, it will be the rough and simple laden barges that hit bottom, not the vulnerable push boat.

An optimum shallow-water barge formation design maximizes beam and length dimensions. This compensates for the small draught and makes it possible to carry economic quantities of cargo during the dry season. More draught of the push boat results in bigger screws and more powerful engines. Such a ship can ply the river longer during flood periods when the currents increase considerably. This has consequences for the storage capacities at terminals (stockpiling during the dry season or during flood periods).

Waterways are often altered or “improved” to enhance the safety and reliability of nautical prospects, or to better meet the needs of other users. These alterations, while often necessary, pose a risk of adverse ecological impacts and, thus, must be carefully studied. Permanent control works should be considered only when inland navigation has already proven to be a viable mode of transport. The costs of permanent river improvement works such as normalization and canalization are only justified if other interests are also highly involved.

Controlling the waterway for regular navigation may include stabilizing the main channel and closing secondary channels, improving the channel alignment (e.g. a uniform radius and width), widening the navigation channel, removing shoals or other navigation impediments, and incorporating structures designed to provide increased depth for shipping. At low stages, the main channel width and the LAD are the main factors for transporting cargo over a particular stretch of the river. At high stages, the main design criteria are vertical clearance at bridges, and the velocity field of the river.

**Inland Terminals**

*Much more can be said about the intricacies and the challenges of barging in the First World than in this overview. But many details are not relevant for specific circumstances elsewhere, since every waterway system and transport contract have their typical requirements and peculiarities. IWT is optimized by using vessels and operations specifically designed for that waterway and waterway system - not copied from elsewhere. But a universal lesson is that the layout and equipment at inland terminals is of crucial importance to successful IWT operations. Considerable effort can be invested in vessel design and waterway improvement. But as long as attention given to the functioning of terminals is inadequate, no IWT system will be profitable. For guidelines related to the optimization of inland terminals, readers are referred to other PIANC reports dealing with the subject.*
Lessons Learned

Lessons learned in other parts of the world can often be applied in the development or modernization of the IWT sector to enhance sustainability. Many technical innovations have improved the performance of IWT and effective management structures (public and private) have done the same. In Europe, wooden cargo vessels with sails completely disappeared in the late 1920s- in many Third World countries, this type of vessel is still operational. In Europe, the public sector does not participate in barge and fleet operations - in the Third World the public sector is often the only operating agent. In the United States and in Europe, the push barging concept has developed, but this is often not the best solution for the Third World. Competition with rail and road led to the design of self-propelled vessels for specific transport in Western Europe, a development not followed even in the United States, let alone the Third World. Physical fixed obstructions at bridges and locks have led to the development of retractable wheelhouses in Europe, but for mainly (wrongly interpreted) economic reasons, this example has not been followed elsewhere.

Specific industries in many countries have developed their own fleet and vessel designs. Lease contracts between a big industry and a specialized private sector barging company are becoming the norm in Europe. Particularly in the First World, specially equipped dumb barges, self-propelled vessels of various tonnages, and specialized tankers for liquids and chemicals have been designed and built not only for efficiency but to comply with strict(er) environmental considerations. These modern, self-propelled vessels and dumb barges operate rather successfully in terms of safety and economy, also because the waterways on which they serve are reliable and offer sufficient draught during lower discharges; their design is acceptable from an environmental point of view. This last example is typical of the successful cooperation between the public and private sector who are respectively involved in waterway management and barge operations, but strangely enough, this concept is not followed widely elsewhere so far.

Waterway alterations often start with non-permanent methods and shift gradually from semi-permanent towards permanent solutions. It might appear desirable to pursue a permanent solution as soon as possible in order to cut down the annual cost for the annually repeating non-permanent works. However, in the few rivers in the world where permanent works have been applied, this was generally carried out over a long period of time, often centuries. The main permanent structures, such as bank revetments, are generally made to protect high-cost infrastructure or provide flood protection - not for IWT alone; so justifying these expenses (both economic and environmental) in the name of IWT is not appropriate.

The three options mentioned earlier in this section can be applied to a less-developed water system. Due to scarcity of technical, economic, and environmental data, the phases of channel improvement, design, and further data collection often run parallel, rather than in a sequence. This leads to a situation where the work has to be done based on insufficient or unreliable data. This approach requires creativity and flexibility. In those circumstances adapting the vessel design to the waterway system would be preferable.

4.6 Shipping and other uses, in particular environment and flood control

Native settlements occur along natural waterways for many reasons including transportation, water resources, power, agriculture, etc. If shipping exists on a low-profile scale as ‘a remnant of the past,’ or when water-related recreation development occurs, and the waterway has navigation potential to meet realistic forecasts of a new and sound economic cargo flow of commodities suitable for IWT, some fundamental improvement of the navigability to modern standards of technology may be feasible. In such a case, it is clear that environmental, economic, and technical considerations must accommodate the existing and likely future uses, and that IWT development may be constrained by these other needs.

Rivers periodically flood and, as long as a floodplain shows limited occupancy, this will not lead to catastrophes. But where cultivated land becomes inundated during floods on a large scale, federal/central government involvement is imperative. There are examples in the world where federal/central intervention has finally led to a multidisciplinary development where water transport is only one of the users. But there are also striking examples where central involvement has led to a river system where no place has been left for IWT, to safeguard the interest of one or a limited number of other users; in particular, irrigation and hydropower. There are also examples where a fixed major dam (for flood control, hydropower or water supply, or for a combination of these users) initially cut off the possibility for migrating fish to reach their natural spawning areas in the headwaters and tributaries of a major river system. Building a bypassing lock for IWT (sometimes with additional facilities) mitigates this environmental disruption. So, thanks to the needs of inland shipping, an environmental problem was solved.
Endless varieties of engineering solutions are applied for preventing flood damages. In all cases, effective technical solutions are determined by the setup and described responsibilities of managing authorities and concerning legislation. Comprehensive approaches for resolving the economic (and environmental) losses and threats to public safety due to floods are continuously sought. When floodplain areas become over-exploited (e.g., the economic growth and demands are no longer in balance with the natural and ecological functions of the floodplain), the frequency and magnitudes of flood events will increase. But in general it can be concluded that effective flood-control management will improve the potential for IWT. Deep and stable uniform channels offer the maximum discharge capacity during the passage of floods; and depth is precisely what shipping needs, while a stable channel justifies capital investment in items such as terminals along its banks. Stabilized channels and banks, controlled runoff and secured economic developments in a river corridor stimulate inland navigation prospects. Human intervention with the purpose of stabilizing or deepening the main channel will generate adverse effects over the long term, however. The magnitude of these effects depends on geological and morphological character of the river stretch. To minimize this impact, suitable mitigation measures should be incorporated into the design.

Coping with the environmental problems as they develop along a river on a local, regional, and even global scale, requires not only technical and political solutions and enforcement, but also a change in man’s attitude towards nature and his environment, a socially accepted awareness of the long-term effects of human intervention in river ecosystems, and the time required to develop/restore the system.

Cooperation between different parties and countries is also needed (e.g. international regulations for the transport of dangerous goods (IMO) and safety (International Association of Lighthouse Authorities)). Along the river Rhine, for example, cooperation started in 1868 on navigation with the Mannheim Act, followed in 1986 on water quality, in 1995 on flood protection, cumulating in 2001 with integral water management on the catchment scale.

4.7 IWT design guidelines

The development and planning of a waterway system is a long-term process that requires the continuous (and preferably consistent) attention of politicians, managers, lawyers, environmentalists, economists, engineers, and others. No single manual can cover the broad field of interests involved in developing IWT and provide sufficient information and to-the-point guidelines for all concerned. Surabaya (1992) presented 14 matrices with suggestions to help analyze multidiscipline projects. Although each project has its own determining boundary conditions, and no concept that has proven successful elsewhere can be copied directly, we can learn from past mistakes and problems.

Table 4.7.1 lists several navigation needs and many of the common measures or alternatives to achieve these needs. The table compares the potential impacts of each alternative with respect to the need for minimizing and mitigating measures. In addition to the table, the following general advice is offered:

- Among economically viable alternatives, the one with the least net impact to the targeted system functions (inclusive of minimization and mitigation measures) is generally the most sustainable.
- Whenever possible, adapt vessels and operations to the waterway rather than the waterway to vessels and operations.
- Aids to navigation such as real-time data, communications systems, beacons, buoys and other signaling devices are often the most cost-effective and environmentally sustainable navigation improvements.
- Utilize, to the extent practical, existing infrastructure and design the IWT to be integral with other land-based transport modes.
- Maintain, where possible, floodplains and riparian corridors to serve a variety of ecological functions and limit potential damage to the navigation channel during high flow events.
- When modifications to the fairway are needed to sustain navigation, seek to maintain diversity by including features and conditions outside the navigation channel that replicate important habitats and refugia such as shoals, backwater areas, connected oxbows, and wetlands.
- Limit the armoring of the beds and banks to high-energy locations – use native vegetation and bioengineering techniques to stabilize other areas.
- Ensure that locks, dams, and barrages are designed to permit up- and downstream migration of aquatic organisms.
- Conduct operations in a manner that limits the potential introduction of non-native and invasive species of flora and fauna.
- Seek to minimize maintenance requirements – low-maintenance projects are generally more sustainable than those requiring significant intervention.
Table 4.7.1 Navigation needs, alternatives, and potential direct impacts to waterway functions

<table>
<thead>
<tr>
<th>Need</th>
<th>Alternative Measures</th>
<th>Potential Impact to Listed Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft</td>
<td>Adapt loaded vessel to available draft *1</td>
<td>o</td>
</tr>
<tr>
<td>Training by groins</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Bank protection</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>Armoring of riverbed</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Longitudinal dikes</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Barrages, dams and locks</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>Flow regulation</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Lateral canals</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>Dredging</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Clearance</td>
<td>Lowering the water level via waterway alteration</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Lowering the water level via hydrologic change</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Retractable wheelhouses</td>
<td>o</td>
</tr>
<tr>
<td></td>
<td>Rising of bridges or other obstructions</td>
<td>o</td>
</tr>
<tr>
<td>Width and bend curvature</td>
<td>Realignment and channelization</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Local flow control</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Operational restrictions (e.g. single lane traffic)</td>
<td>o</td>
</tr>
<tr>
<td></td>
<td>Adapt vessel design (e.g. less beam or length)</td>
<td>o</td>
</tr>
</tbody>
</table>

**KEY:** o - No significant impact; * - Possible impacts, readily minimized or mitigated; ■ - Impacts requiring mitigation likely
<table>
<thead>
<tr>
<th>Need</th>
<th>Alternative Measures</th>
<th>Potential Impact to Listed Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Velocity and Wave Control</strong></td>
<td>Breakwaters and jetties</td>
<td>✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Locks and Dams</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Adapt vessel design (freeboard)</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Operations (speed limits, stoppages)</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Refuge areas/harbors</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td><strong>Operational support</strong></td>
<td>Mooring facilities</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Terminal facilities</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Aids to Navigation</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Effective assistance during accidents</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Frequent and reliable lock and bridge operations</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Traffic Control</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Waste disposal</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Skilled crew</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Dry dock and maintenance facilities</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
<tr>
<td></td>
<td>Water intake and discharge</td>
<td>✶ ✶ ✶ ✶ ✶ ✶ ✶</td>
</tr>
</tbody>
</table>

**KEY:**  
- ✶ - No significant impact; ✶ ✶ - Possible impacts, readily minimized or mitigated; ✶ ✶ ✶ - Impacts requiring mitigation likely

1. Measures that increase traffic have several potential indirect impacts (e.g. increased erosion, introduction of non-native species, etc.). This table addresses direct impacts only.
5.0 SUSTAINABILITY ASSESSMENT PROCEDURE

This chapter outlines the way in which the foregoing information would be used to assess the sustainability of proposed navigation development, or changes to operations or maintenance. The procedure is general in nature and accommodates various types of projects and their associated levels of analytical detail. Example applications are presented in Appendix 2.

Sustainable waterway development and management require balancing the different policy objectives for different water users with each other and with the bearing capacity of the natural system. Thus, explicit and quantitative objectives must be developed for every user, not only for IWT. These objectives must be translated into standards for the different functions, taking individual water system demands and natural conditions into account.

Knowledge of the crucial interactions between users and natural processes, spatial- and time-dependant scales, relevant thresholds, and critical boundaries is needed to compare different management options. The full scale of impacts upon the environment from both the water and land-based transportation infrastructure and operations must be considered. The impacts for each alternative are compared to identify the least damaging alternative and to evaluate whether the effects of measures are acceptable relative to the standards to be maintained.

The outcome of this evaluation depends on local waterway and user characteristics, their relative importance, their interactions, and the scope of the project to be undertaken. However, the process of evaluation can follow similar steps because the primary aim is to develop a sustainable project. This means an approach in which user demands (e.g., new navigation) and natural functions are balanced in such a way that future needs will not be compromised. The steps of the approach consist of identifying and prioritizing functions, themes, and users. The main steps in planning and implementing the project in a sustainable manner are to first avoid impacts and effects; second, to minimize; and finally, if both of these steps are not realized, mitigation or compensation.

5.1 Strategic Planning

Strategic planning for navigation involves defining the goals and means of achieving a long-term “vision” for a waterway and the associated infrastructure. The planning effort includes an assessment of the long-term social, economic, and environmental implications of management plans aimed at attaining the desired vision. Navigation, although paramount, is only one of many issues in strategic planning. The interaction of other issues and all uses of a waterway system must be considered in relation to the system functions.

A rational management strategy requires an understanding of relevant interactions within the system to be managed, and should be reflected in long-term policy papers that are revised every 5 to 10 years. Ideally, the manager needs quantitative information on the likely impact or efficiency of a proposed development or control scheme to objectively evaluate the available options. The result of those considerations should be a strategic management plan for river-specific navigation projects with the estimated effect that the plan will have upon the navigation sector, other users, and the waterway ecosystem. The IWT strategy is part of an overall transport strategy in the catchment, including the land modes such as road and rail. Because IWT prospects strongly depend on the opportunity to develop bulk transport (e.g., fertilizer, coal, liquids), any IWT strategy that neglects economic development policy will ultimately fail.

The concept of a “river contract” aims at committing interested groups (regional and federal government, municipalities, industry, agriculture, recreation and other water users) to jointly develop a program of action (a so-called “Management Plan”). This concept favors meeting and open discussion between groups with initially opposite interests. An example of strategic planning is provided in the case study of the River Rhône in France (see Appendix 2.3).

5.2 Project Planning / Process of Planning Navigation Projects

Individual projects are analyzed in detail within the context of the overall management plan. Figure 5.2.1 is an overview of the project assessment procedure. The effects of the planned operations in developing the river system should be investigated and assessed. The direct and indirect effects must be identified, described, and assessed for the following environmental factors (European Union Directive, EC 1985)):

- Humans, fauna, flora.
- Soil, water, air, climate, and landscape.
- Interaction between the factors mentioned above.
- Material assets and cultural heritage.

The developer must describe and assess different alternatives to realize the project objectives in light of these considerations. This approach is based on the identification of three items:
1) Priority functions (described in Section 3.3).

2) Environmental themes (IWT examples are waste discharge, accidental spills, sediment pollution, dredging, and dumping site effects).

3) Sectors (examples are agriculture, urbanization, industry, recreation, inland waterways transportation, and sub-sectors, for which trends are analyzed).

Steps in the approach are to identify and give a priority to functions and themes, and to focus on the most important aspects to address. If a proposed use has no impact on any of the key functions, sustainability is preserved. A simple qualitative assessment can be performed; it serves as a useful screening tool for potential alternatives related to any use, including navigation. In addition, the effects of different alternatives on the previously addressed functions can be compared.

Generally, the screening process will identify those functions that are likely to be impacted by a proposed activity and existing users with no mitigation measures at all. The next step would be to try to characterize and quantify the nature of those impacts, normally in an EIS. Issues relating to competing uses typically enter into the evaluation at this point.

A number of procedures could be developed using this general philosophy. The steps in Figure 5.2.2 outline one such procedure, and more details appear in Appendix 1. Users, however, are encouraged to adopt the general philosophies outlined in this document and develop procedures that meet the needs for a specific project. The goal is to identify alternatives or alternative/mitigation combinations that minimize impacts on the basic functions and, thus, increase the likelihood of long-term sustainability of the project.

Although the most important factors of a project can be identified during the planning phase, their significance in the construction and operation phases must still be determined.
With respect to navigation projects, these factors include morphological changes of natural rivers, influence of structures and navigation on river regime and morphology, ship-induced water movement and its interaction with banks and the associated biotope, and stability criteria for different protection methods including vegetation, etc. Measurement and monitoring sites have to be located in areas indicative of possible future relevant effects on other users or functions. Measurement and monitoring parameters and techniques should be accurate enough to distinguish between natural and project-related changes.

5.3 Methods of Estimating Environmental Costs

Economic assessment of the environment is a means of quantifying the effects of disturbance the functions by users of a waterway system, like pollution, noise, accidents, etc., on our surroundings. Environmental costs measured in monetary terms can be assessed jointly with the other economic costs and benefits for a specific project. The most widely used methods of estimating such costs around the world are as follows:

- **Effect On Production (EOP).** Consists of assessing the loss of a good in relation to its market price.
- **Preventative Expenditure (PE).** The costs of effects on the environment are considered equal to the costs of preventing its alteration.
- **Willingness to Pay (WTP).** The cost of changing the environment depends on what the inhabitants/users would accept to maintain and/or to restore it.
- **Willingness to Accept (WTA).** The cost of changing the environment depends on what the inhabitants/users are willing to accept as compensation for its loss.
- **Replacement Costs (RC).** The costs that will have to be paid to replace an environmental good are considered such as costs of an alternative location, replacement product costs, compensation costs, etc.
- **Human Capital (HC).** The economic costs of illnesses produced in human beings due to changes in the environment.
- **Property Value (PV).** Changes in the quality of the environment lead to changes in the value or “price” of a property.
- **Wage Differentials (WD).** Increases in health risks and discomfort increase the cost of employee wages.
- **Travel Cost Method (TCM).** A natural zone is valued in relation to the distance one must travel to reach another area of similar characteristics.

The economic methods on the preceding page are not "precise" in determining environmental costs. They can only help decision-makers by giving a range of results. To limit the range, several methods can be applied. Costs can be estimated in terms of the loss of use with the following steps:

1. Identify the functions affected.
2. Select the assessment method for each of the functions.
3. Determine the functions that can be quantified.
4. Quantify the sub-functions.
5. Aggregate the valuation of each function.

5.4 Monitoring and Adaptive Management

Development activities influence ecosystem structure and function to secure needed goods and services. Often the developer should investigate different alternatives in planning the project to get the same use or benefit. Those alternatives bring about other changes in both the natural and social components of the ecosystems in question, and in a ranking, the developer can choose the best alternative using the sustainability philosophy. These changes, of course, may occur rapidly or slowly. Therefore monitoring is required to minimize conflict by means of early identification and resolution.

1. **Adapt the early planning evaluations (reconnaissance and diagnosis) of the major ecosystems of the study area to serve as baseline studies for future monitoring as well.** Any data gathered need to be reduced and interpreted with a future monitoring activity in mind. This later monitoring effort need not be at the same intensity or detail of the baseline/reconnaissance studies. The early studies, however, should be compatible with the future monitoring effort.

2. **Include both biophysical (natural) and social components in any monitoring schedule.** Requirements include tracking change in the mix of goods and services and in the characteristics of structure and function. Together, these two sets of data will allow planners to focus on important changes early.

3. **Plan the monitoring schedule as a compromise between budget restrictions and the need for information.** A few good, complete records are better than many records that are poorly kept and incomplete. Budgets can be held in check by sampling, by undertaking "rapid" assessments, and by following key indicators.
4. Use remote sensing as a tool in monitoring. Remote sensing is particularly applicable to waterway monitoring because of its flexibility, wide range of application, and low cost compared to ground surveys. Remote sensing can include image assessment, hydrologic and hydraulic data gathering, and a variety of other tools that measure and monitor the system for key parameters.
REFERENCES


BfG - Federal Institute of Hydrology; 1997: Environmental Impact Assessment (EIA) of the Project “Securing the Kiel Canal (Section Rendsburg East) - KC-km 61.680 to KC-km 66.150”. BfG-Report-0788, Koblenz, Germany.


PIANC Permanent Committee for Developing Countries (1992); Guide to Inland Water Transport Development. 2nd Seminar on Ports and Inland Waterways, Surabaya, 2-7 March 1992, Bruxelles.

APPENDIX 1

STEPS IN EVALUATING NAVIGATION PROJECTS FOR SUSTAINABILITY

STEP 1: Identify objectives and alternatives (established with all stakeholders), and agree upon the reference situation

STEP 2: Describe the waterway system and functions at the appropriate scale

STEP 2a: Identify functions that are vital for the waterway system - both locally and regionally and describe their present situation (T0).
- Maintenance of hydrological balance
- Maintenance of sediment balance
- Maintenance of morphological processes (erosion, transport, and sedimentation)
- Maintenance of biological and chemical processes (nutrient cycles)
- Provision of necessary habitat

STEP 2b: Identify processes, parameters or species, periods, and locations that are vital for these functions. These can be qualitative or quantitative, depending on the nature of the project.

STEP 2c: Identify special criteria established by policy, regulation.

STEP 3: Are the waterway functions affected?

STEP 3a: Are these processes, parameters, periods, and locations affected by the project proposed?

STEP 3b: If yes: how, when, where, in what relative degree?

STEP 3c: Are these effects reversible? If not, what is the final effect?

STEP 3d: How can these effects be avoided, minimized, mitigated, or otherwise compensated? (Reference the River Waal case study)

STEP 3e: Are there other solutions in which natural functions (listed above) can be revitalized?

STEP 3f: If relevant information is needed, start inventories or measurement (see below).

STEP 4: Are other uses affected or affecting the waterway?

STEP 4a: What are the effects on other users?

STEP 4b: Are they acceptable compared to established or foreseeable standards?

STEP 4c: If not, how can effects be avoided, minimized, mitigated, or otherwise compensated?

STEP 4d: Are there other solutions in which navigation and other users both benefit?

STEP 4e: How are other users affecting the waterway, and how can this be dealt with?

STEP 5: Evaluate alternatives and select the most preferable solutions with respect to effects on functions, other uses, and life-cycle costs (NOTE: STEP 5 should be prepared and executed in close participation with relevant partners, sectors, and interest groups, in order to gain commitment for the execution of the plan by all parties involved).

STEP 5a: Determine criteria for functions and uses, as derived from Steps 1 – 3. “Reasonable” limits should be established for functional criteria to ensure the sustainability of ecological character, and that regulations, treaties, and other guidelines can further define criteria.

STEP 5b: Determine different weights of the criteria (if appropriate)

STEP 5c: Reformulate alternatives based upon assessments

STEP 5d: Evaluate alternatives, including mitigating measures and the “zero option”

STEP 5e: Select preferred alternative

STEP 6: Prepare the plan execution

STEP 6a: Define the measures to be taken, determine the planning and the organization

STEP 6b: Develop a communication plan to inform relevant parties of the progress (or lack of it)

STEP 6c: Develop a monitoring and reporting program

STEP 7: Monitoring and adaptive management

STEP 7a: Evaluate the objectives

STEP 7b: Evaluate the effects on the waterway system functions

STEP 7c: Evaluate the effects on the other uses

STEP 7d: Optimize performance through maintenance, modifications, or improvements, if needed.
APPENDIX 2

CASE STUDIES

A2.1 Case Study 1 - Securing the Kiel Canal (Section Rendsburg East) - KC-km 61,580 to KC-km 66,150 in Germany, Schleswig-Holstein (BfG-0788, 1995)

Context

The artificial waterway Kiel-Canal (known in Germany as the Nord-Ostsee-Kanal) runs for almost 100 km right through Schleswig-Holstein - from Brunsbüttel to Kiel-Holtenau - and links the North Sea with the Baltic. An average of 250 nautical miles and about 16 hours time will be saved by using the Kiel-Canal instead of the Skaw/Skagerrak route. During its building phases naval strategies were important - today the Kiel-Canal is the basis for the trade between the countries of the Baltic area with the rest of the world (location see fig. A2.1-2).

There were repeated plans from the 16th century onwards to dig a waterway connecting the North Sea with the Baltic area. On 3rd June 1887 Kaiser Wilhelm I laid the foundation stone of the ‘North Sea-Baltic Canal.’ On 21st June 1895, after 8 years of work and at a cost of 156 million marks, Kaiser Wilhelm II opened the ‘Kaiser-Wilhelm-Kanal’, as the North Sea-Baltic Canal was called until 1948. From 1907 to 1914 was the first time necessary to carry out construction work to widen the canal at a cost of an additional 242 million marks to adapt the canal conditions to the navigation requirements. Since 1962, additional extensions have had to be carried out because of increasing traffic and vessel draught, causing erosion on the embankments. With an investment program of about 1 billion German marks, the ‘program to secure the Kiel Canal’ was started.

The enlargements are shown schematically in Figure A2.1-2.

Fig. A2.1-1: Location of the Kiel Canal between the Elbe River and the Baltic Sea
The present dimensions of the canal are 98,637 km in length, 162 m wide at the waterline (partly 102.5 m), and 90 m wide at the bottom (partly 44 m). Water depth is 11 m and there are two pairs of locks (old ones 1895, new ones 1914) at each end of the canal. The canal is well-organized by comprehensive traffic regulations (e.g. speed limit and a traffic securing system, which will be improved continuously). The maximum speed for vessels with a draught of more than 8.5 m is 6.5 knots and for all others 8.1 knots (reducing wave impact, return current). Maximum dimensions of vessels passing through the Kiel Canal are as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Total cargo in tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>47,922,302</td>
</tr>
<tr>
<td>1997</td>
<td>49,257,439</td>
</tr>
<tr>
<td>1998</td>
<td>48,655,707</td>
</tr>
</tbody>
</table>

Excluding small boats, an average of 105 ships per day used the canal in 2001. The table below shows the total cargo of ships that passed through the Kiel Canal from 1996 to 2001:

<table>
<thead>
<tr>
<th>Year</th>
<th>Total cargo in tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>45,988,623</td>
</tr>
<tr>
<td>2000</td>
<td>57,861,599</td>
</tr>
<tr>
<td>2001</td>
<td>62,471,257</td>
</tr>
</tbody>
</table>

The Kiel-Canal is not only used as a waterway for commercial and recreational navigation, but also as a runoff opportunity of the catchment area. The runoff management is necessary to keep a constant water level and takes place at both sides of the canal, but mainly in Brunsbüttel towards the Elbe River and the North Sea. In situations with high water levels (e.g. storm surge tide) in the North Sea and strongly west wind the drainage takes place through a drainage canal in Kiel to the Baltic Sea. Because of the lockages, the salt and brackish waters of the Lower Elbe River/North Sea (as well as the Baltic Sea) flow into the canal, so that the salinity conditions are very different in the longitudinal direction, from brackish to freshwater milieu, determining the environmental conditions as well.

**Objective**

(Steps 1 - 4, Figure 5.2.2 and Appendix 1)

Since the early 1950's, ship traffic on the Kiel Canal has significantly increased. The number of annual passages nearly doubled between 1950 and 1960. Since then, the number of ships has decreased; however, ship size and the quantity of shipped goods rose until 1985, and have since remained at this high level.

This change to larger ships (partly ocean navigation) has impacted the canal bed. Examination of data collected between 1962 and 1966 shows that erosion of underwater slopes increased because larger ships produce higher return current velocities. This increased pressure has eroded the banks over long reaches, endangering the stability, a process still going on in those parts of the canal that have not yet been protected. The original bank slope has become steeper by this erosion, and reinforcement structures are difficult to anchor. At some places, there are undermined vertical ruptures several meters long, causing landslides that endanger the security of ship traffic and structures on the canal banks.

The loose material from the slopes that is deposited on the canal bed must be dredged regularly to maintain project depths. In the period 1955 to 1965, twice as much soil was dredged from the canal as in the preceding 40 years, amounting to 0.3 to 0.5 million cubic meters.

Since 1965, the "Sicherungsprogramm NOK." (Program to secure the Kiel-Canal) has been executed to stabilize the canal embankments over a total reach of 65 kilometers (Kiel-Canal kilometers (KC-km) 5.0 to 79.2). The Rendsburg-East reach (about 5 km long) was the last part of this program.

**Problems and Solutions (Steps 1, 5, and 6, Figure 5.2.2 and Appendix 1)**

A zero-option (non-development alternative) was out of the question, because the risks remain. There were three basic alternatives for securing the embankments (e.g. for the Rendsburg-East reach):
1. Reconstruct and reinforce the damaged embankment, maintaining the present canal cross section.

2. Stabilize the embankments with sheet piling, maintaining the present channel.

3. Widen the canal cross section by setting back the banks.

Comprehensive investigations have proved that Alternative 3 is the best solution to secure the canal bed. The eroding forces resulting from the wake of passing ships will be reduced to such an extent that the embankments will be less threatened. Moreover, enlarging the canal cross section will reduce the risk of hydraulic phenomena (waves, return current) as well as ship accidents and thereby increase traffic safety.

Alternatives 1 and 2 do not offer these advantages and have several additional disadvantages. The protective effects of such stabilization or reinforcement measures cannot be calculated. These alternatives would be twice as expensive as Alternative 3.

To accomplish Alternative 3, approximately 554,000 m³ of material both from above (dry spoil) and from below the water level (wet spoil) had to be dredged to extend the canal profile. The extension had mainly taken place only on the south bank in the western area, while East of the "Hochbrücke" (railway bridge Rendsburg), enlargement of both banks was necessary.

The dredged material could not be translocated within the canal bed, but rather had to be deposited on land. The sites at Osterrönfeld and Hochfeld (both situated in the extension work area) received the dry spoil. The wet spoil was transported to Flemhude for plan-approved disposal. As much of the dredged material as possible should be used as building material in the reconstruction of the canal. Humus soils removed should be used to cover the new embankments. To accelerate the recolonization of the underwater slopes, the old rock-fill should be used again and stored in an aquatic environment during the construction phase. All supply buildings and premises for the extension work should be placed in less ecologically sensitive areas. The work should largely be carried out from working floats, wherever feasible, to prevent soil compacting and to minimize the area needed for dirt roads in the riparian zone.

Suitable equipment should be used to reduce the emission of noise and dust. The main activities should take place in late summer, autumn, and winter to minimize the stress on fauna during their biologically active phase (i.e., during spring and summer). With respect to recreational uses, pedestrian and cyclist green space should be directed away from any sensitive areas and re-marked.

Evaluation (Steps 6 and 7, Figure 5.2.2 and Appendix 1)

The executed EIS showed no impacts on the geology, groundwater quality, local climate, and water levels. Impacts on the groundwater level, the surface waters (hydrology and water quality), fish fauna, recreation, housing, and preservation of historical monuments were "insignificant." However, the study found "significant impacts" for the following environmental sectors: soil, vegetation, fauna and landscape, air quality, recreational use, though the last two will be restricted to the period of construction. Slight improvements (i.e., "irrelevant positive" effects) are predicted with respect to aquatic (bottom) sediments. Within a landscape plan the experts propose compensation and substitution measures for these environmental sectors.

Among other things, the loss of soils should be compensated at suitable places in the surrounding area. Regarding the fauna, the surface should be restored to such an extent that the original species can return. Under this aspect especially the newly structured bed of the Wehrau brook (tributary) should be used as compensation for lost habitats. In view of the partial destruction of the landscape, a suggestion was made to revegetate existing woodlands, "knicks" (hedgerows), etc., and use only plants typical of the region. Disposal sites should be shaped and revegetated to fit into the existing landscape.

Conclusion

Since the security program was started in 1965, the Kiel-Canal was enlarged to secure the canal structure. The section Rendsburg East was the last part of the program. The case study shows that strategic planning needs have to be looked at in the future to ensure that specific project planning procedures have been carried out. With a thorough impact analysis of functions and uses, IWT could be improved in a sustainable way.

More details about the Kiel-Canal (with updates to the present) can be found at the following Internet addresses:

http://www.kiel-kanal.org/english.htm
http://www.wsd-nord.de/wsa-ki/startwsa.htm
http://www.hamburg.baw.de/wwss/NEU_NOK/wwwnok-en.htm
A2.2 - Case Study 2: Improving Navigability on the River Waal (The Netherlands)

Context

As the lower part of the River Rhine, the River Waal is the most important Dutch river. In addition, it is also the most important European inland transportation route, connecting the Port of Rotterdam and the German “hinterland.” The international transport volume is about 160 million tons per year, consisting of bulk cargo in push tow barges, chemicals, liquids, and even vehicles. Shipment of containers is growing at a particularly rapid pace. Without navigation, this transport volume needs an equivalent of 8 million trucks.

With the Mannheim Act (1868), the Rhine countries transferred the power of legislation for several subjects pertaining to traffic and carriage of goods to the CCR (Central Commission for shipping on the Rhine). In this way, the CCR has guaranteed economic freedom of transport and safety of navigation on this major IWT route for almost 150 years. In fact, without the CCR, IWT development along the Rhine would probably have been less prosperous, or may have vanished because of competition with major road and rail connections parallel to the Rhine.

The River Rhine is also very important for other uses. About 20 million people depend on the river as a supply of fresh water. In addition, large areas use Rhine water for agricultural purpose and to prevent salt water intrusion. Dams along Swiss and German upstream tributaries produce hydropower. The river, with its related tributaries, lakes, and floodplains, has many ecological values. Large areas are designated as nature preservation areas, and are part of regional, national, or international ecological networks. Recreation has developed along and in the river on an international scale.

Within this context, the Dutch navigation policy guarantees smooth and safe inland water transport along this river by:

- Obtaining a minimum depth of 2.80 m with a width of 170 m at ALR (Agreed Low River level, with an exceedance frequency of 95 percent per year). Under these conditions, three-lane traffic, including six-barge push tows, is possible from Rotterdam to Germany.

- Supervising traffic between 6 and 22 h. using vessels and traffic control centers onshore and a daily message service on water levels and depth restrictions.

For the same river, policy goals regarding other uses exist as well, e.g.:

- Riverbed should be of the appropriate size and slope to discharge ice, sediment, and water (maximum water discharge of 16.000 m³/s).

- Riverbed should be stable to prevent the occurrence of higher flood levels or lower groundwater levels (the normalization of the navigation channel by groin fields in the second half of the 19th century, combined with sand extraction, resulted in bed erosion of about 2 to 3 m.)

- Water and sediment quality complying with (inter)national /European standards.

- The river, its banks, and floodplains are important (wetland) habitats for natural flora and fauna. They connect other chains of the (inter)national habitat framework. This demands (more) room for natural processes of water and sediment transport.

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1 Average discharge: 2200m³/s, average sediment transport: 400.000 m³/y
Taking these other policy goals into account, it is a large challenge to accommodate the anticipated growth of inland transport to about 220 million tons per year. During the 1980’s, a policy analysis was performed, aimed at finding a way to increase the transport volume within the context of preserving or increasing natural values of the river system. It was concluded that this could be achieved by a combination of dedicated measures in the navigation channel itself: optimizing the cross section in river bends and using another maintenance dredging strategy in the straight stretches. In addition, local traffic control and harbours for overnight stay improve safety. In this way, large-scale measures affecting the riverbanks and floodplains, like bend cut-offs, could be avoided and the natural character and landscape of the river (the habitat function) could be preserved or locally restored.

River bend measures include localized armoured layers in the outer bend of the navigation channel (Nijmegen, 1987, Sint Andries, 1999) and bendway weirs (Erlecom, 1994). These measures increase the hydraulic roughness in the outer bend, enforcing the currents inward. Increased sediment transport capacity in the inner bend results in degradation and increased water depth there. In all cases, the navigation width increased by 25 to 50 m. However, this improvement was in all cases accompanied by the development of a sandy shoal downstream in the inner bend. Local maintenance efforts therefore remain necessary.

Along the straight stretches, the usual maintenance dredging strategy consisted of an annual campaign in which the demanded profile was dredged in a downstream way during the summer season. In this way, depth restrictions prevailed until they were reached by the campaign. By the time the campaign was finished, or at some point during the campaign, natural bed level restoration in combination with low water levels generated new depth restrictions, decreasing the effectiveness of these campaigns.

As part of a new dredging strategy, since autumn 1999 dredging is concentrated only to the depth restriction areas. In this way, navigation depth is immediately increased. The first results indicate an increase of navigation depth of a few dm. since June 2000. At first the dredged material was dumped in the deeper parts of the river (outer bends or the erosion pits attached to the groin tips). However, high current velocities there erode the dumped sediments quickly, resulting in unpredictable sedimentation patterns. A more promising strategy is to dump the dredged material upstream of the inner bend, where currents are more weak and directed inward.

Measures to optimize the navigability of the River Waal are part of a 10-year program that will cost approximately 250 million Euro. The execution of these measures is accompanied by a program that will monitor the effects on river dynamics and navigability.

The River Rhône has been used for centuries for shipping and power generation, and both the economy and urban life in the valley are structured around it. During the 18th and 19th centuries, a number of developments were carried out, first to stabilize the bed by building embankments, and then to concentrate the current and maintain depths using a system of longitudinal dikes and groins. Finally, in the 20th century, the river was completely harnessed by building some 15 “major development schemes,” each consisting of a dam, a hydropower plant, and a diversion canal with locks, with the three-fold aim of developing electricity, shipping, and irrigated agriculture. These works were performed by the “Compagnie Nationale du Rhône” (CNR), a company specially created for this purpose.

The Rhône has now been completely confined, flowing for part of its length in man-made channels. Although it has been closed off to migratory fish, it provides a quarter of all the hydropower generated in France, drains a major industrial valley, is witnessing expanding shipping, and provides water to a large number of people. The Rhône catchment area is one of France’s largest river basins.

At the outset, river ecology concerns focused on water quality. In light of the disastrous results of assessments carried out on many rivers in France, an initial reorganization of nation-wide water policy began in 1964 with the creation of basin authorities. France was broken down into six regions corresponding to the major river basins. The “Rhône Mediterranean Corsica” region basically corresponds to the Rhône river basin. A basin committee was set up in each region to represent all the interests concerned with water, with the authority to set charges for water use in order to finance operations of common interest, mainly sewerage and wastewater treatment. In addition, in 1992, a new law was passed with the following objectives:

- To preserve the aquatic ecosystems of protected sites and wetlands.
- To prevent all pollution and restore the quality of surface, ground, and sea-water within territorial boundaries.
- To enhance the protection of water resources.
- To promote water as an economic resource and to allocate the use thereof.
• To satisfy or reconcile, for different uses, activities or works, the following requirements:
  - Public health, civil security, and the provision of drinking water to residents;
  - Maintenance of a freely flowing river and prevention of flooding;
  - Agriculture, sea fishing, freshwater fishing, industry, power generation, transport, tourism, leisure activities and water sports, as well as any other legally performed human activity.

To fulfill these aims, the law notably states that: “For each basin, one or more water management and development master plans (using the French abbreviation SDAGE) shall define the main lines of sound water resources management as stipulated in article 1.”

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This was the basis used to draw up an SDAGE for the Rhône Mediterranean Corsica basin. This process took three years, between 1994 and 1996. The document has been operational since early 1997. As stipulated by law, the administrations are obliged to comply with it and it provides a frame of reference for all the other operators. The following objectives were defined for the River Rhône itself:

- Recovering a fast-flowing river on the sections that can still be shaped.
- Over the entire length of the river, restoring a high ecological quality, in both chemical and physical terms:
  - Water that will support aquatic life and is compatible with all current and potential uses, by halving discharges of oxidizable and ammonia-containing pollution, and achieving similar reductions in toxic discharges.
  - Allowing fish to migrate, whether they are diadromous or live only in fresh water.
- Protecting the river from risks of accidental pollution that would ruin everything that has been achieved to date.

In parallel, the SDAGE defines the following objectives for shipping:

- Ensuring that the development of commercial shipping remains compatible with the objectives of restoring the river’s ecological potential.
- Assessing the environmental impacts of increasing traffic (sediment resuspension, wave wash, etc.).
- Assessing the risks of chronic or accidental pollution.
- Defining a pleasure boating development policy, with regard to development schemes, waste water management, etc.

These points have since been included in development programs drawn up by the agencies concerned, notably the Compagnie Nationale du Rhône.

Results

There is no need for a special program to attain objectives regarding water quality, because until now, they have formed part of the national pollution reduction policy brought into force by European directives covering drainage and treatment installations, which is producing results very similar to those stipulated by the SDAGE.
However, the other objectives set for the Rhône were not implemented until 1998 and 1999, when an action plan was set up by a steering committee bringing together all the players concerned. The committee decided to focus its strategy on two major themes:

• Rehabilitating bypassed stretches of the Rhône and their associated habitats.

• Restoring migration routes used by breeding fish.

Rehabilitating bypassed stretches of the Rhône and their associated habitats

The reach of the river that has been developed is now so far removed from its natural course that it cannot be returned to it. However, entire sections have been bypassed by a side canal and have kept their original appearance, with the exception of the discharge diverted into the canal. This is also the case with the old river arms, sections only filled with water when the river is in flood, the “lones.” Redistributing the water and reorganizing water supplies to all these arms, could be a means of restoring the ecological potential and natural functions that have been lost. A detailed assessment of these different habitats was carried out, and about 50 percent of the surface area around the river was found to still offer interesting potential.

Initial efforts were concentrated on measuring the “compensation water,” which is the guaranteed discharge on the old river when most of the discharge is diverted into an artificial canal to generate electricity. This discharge is no more than 10 to 20 m$^3$/second of a total discharge of 1000 to 2000 m$^3$/s. On the Rhône, there are 16 bypass reaches over its total length of 161 km. The first 10-km section to be measured was Pierre Bénite, south of Lyon. After numerous discussions, it was decided to increase the compensation water from 10 m$^3$/s to 100 m$^3$/s by building a micro-power plant to turbine this discharge at its point of departure. The entire stretch was also redeveloped; the abandoned channels and lones were re-dug and footpaths were created to open them up to riverside residents. The total cost of the project was about FF100m.

Three more sections are currently being studied, while various works are being carried out on several “associated habitats” (i.e., the abandoned arms and wetlands of ecological interest). In each case, ideally, the local authorities (towns or communes) will take charge of maintaining these areas because they are in the best position to do so.

Restoring migration routes used by breeding fish

One of the major consequences of developing the river was closing it off to fish, especially those migrating upstream from the sea. Some 49 obstacles to movements up- and downstream were counted, plus 82 obstacles blocking access to the Rhône tributaries. Overcoming these obstacles must be made a priority. Work over the next ten years is expected to cost some FF100m and has been initiated to:

• Organize a means of allowing shad to swim up to the River Ardèche (i.e., 150 km from the river mouth). These fragile fish will be allowed to pass obstacles using the shipping locks.

• Build fish passes on some dams, selected in order of priority.

Other operations

Other actions have been undertaken in addition to the main operations. These include:

• Rehabilitating the banks and embankments and blending them in with their environment, by replanting them instead of using rockfill.

• Managing trees and plants growing along the banks.

• Protecting animal life (beavers, otters).

These actions are being carried out directly by the Compagnie Nationale du Rhône.

A2.4 Case Study 4 - Eliminating a Bottleneck on the German Danube

Context

The Rhine-Main-Danube Waterway stretches over 3500 km from Rotterdam along the North Sea coast in the Netherlands to Constanza in Rumania on the Black Sea. There is only one bottleneck left in Germany on this truly European waterway: the Danube between Straubing and Vilshofen – 69 km of free-flowing river (Figure A2.4-1).

On the regulated reaches of Rivers Main and Danube, ships can operate a minimal draft of 2.7 m even at low water after finishing the current river training project of the Main. Between Straubing and Vilshofen, however, 2.7 m are reached on average only during one third of a year. As water levels are very difficult to predict and as they change very quickly (unlike the river Rhine with the lake of Konstanz, the Danube has not such a big balancing reservoir), vessels often have to wait for higher water levels or partly unload. Further limitations to navigation between Straubing and Vilshofen are the width of the channel and the radii of the curves. Nevertheless the annual transport volume rose from less than 2 Mio tons in 1992 to more than 8 Mio tons today.
For almost three decades, solutions to these problems have been discussed without actually implementing any of them. Initially, only technical solutions with locks and barrages had been discussed. These were limited to the number and position of locks/barrages. River training methods could not guarantee the required channel depth. Nature conservation groups claimed that the effects of these solutions on ecologically sensitive areas such as the area around the mouth of the Isar and the so-called Staatschaufen–oxbow had not been considered sufficiently. In 1996 it was decided to study thoroughly the pros and cons of river training methods as opposed to building dams – therefore no minimal draft was set. In June 2001, the results of this study (which covered technical/hydraulic, ecological and economic aspects) were presented in a final report. It named the possible solutions by capital letters - solution “A” being the least obtrusive (without dams) and solution “D2” being the one with the most (three) dams. The report does not recommend which solution to take, but lists the costs and benefits of the various options.

Objectives

The aim of analyzing river training methods was to find out the maximum draft that could be achieved with river training methods other than dams. Conditions were defined as to what kind of vessels should be able to pass. The river should allow all current vessel types and also push-tow units with two barges (alternatives “A” and “C”) and four barges (alternatives “B” and “D”) (length = 185 m, width = 11.4/22.8m) (in curves with four barges generally only as one-way-traffic). A suitable average ship speed going upstream would be about 6 km/h (ground-speed). Restrictions concerning the encountering of vessels were accepted, if the related waiting times were economically acceptable.

A detailed ecological analysis was carried out in parallel and could thus take into account only roughly the results of the hydraulic and technical analysis. It still led to limitations of water level changes (no more than +/- 0.3m) for all discharge situations compared with the “original” situation. With regard to flood protection, considerably raised water levels at HQ(50) were unacceptable (demand for “high-water neutrality”).

Problems and Solutions

Reliable navigation conditions require a sufficiently high, mostly constant water level; changes of the river bathymetry due to bed load transport and fast flow velocities should be avoided. In contrast, ecological interests require varying velocities and natural irregularities of the riverbed and its banks. Maintenance of the existing forests and meadows require water level fluctuations. These aims obviously conflict with navigational interests.

For the economic use of waterways, the channel depth is important - in contrast shipping safety requires large channel widths and a fine-grained riverbed to avoid damage to rudders and ship’s propellers when touching (accidentally) the ground. Thus economic aspects and shipping safety lead to differing requirement such as bed sediment size.
Flood protection requires large discharge capacities and a minimum of bank and floodplain vegetation, which contradicts with river training structures, in particular groins, for better fairway depth and ecological requirements. Earlier river training measures caused erosion, so counteractive measures must be taken. This can cause conflicts with navigation and ecological interests.

These few points show that the various aspects of waterway use have to be regarded as a whole. It is absolutely essential to consider the system and its uses in its entirety, in order to achieve optimal solutions. The study focused first on alternatives “A” and “B.” “A” included optimizing the existing conditions: improvement of existing structures (groins, longitudinal walls) and the filling of areas greater than project depth while maintaining, but not enlarging, the existing channel width. Technically and scientifically the most interesting alternative was solution B, which aimed at going to the limits of river training methods (narrowing the hydraulically effective cross section and enlarging the effective roughness of the river: groins, longitudinal dikes, and refill of deeper parts (outer bends), bend scouring leading to a partially horizontal bed, stabilization by sediment management...) while keeping up a free-flowing river and also achieving larger widths to allow traffic of larger units. Alternatives “C,” “D1,” and “D2” (map B) included one or more dams, with “C” seeming to be a good compromise between solutions “A” and “D.”

Bed protection in the context of scour filings and bends experienced some stability problems because of local peaks due to propeller wash and the effects of stones when thrown/sucked at the propeller. Therefore, a 1:1 experiment was conducted in the navigation channel with normal traffic running. Over a 600-m reach of the riverbed covered with stones, ships loaded to different drafts were measured. The cost of this experiment alone was approximately €2-3 Mio.

Evaluation

Ecological evaluation

The area along the Danube between Straubing and Vilshofen is considered of high ecological value. There are several protected areas (some of them nominated to the EU as a part of the EU-wide Natura 2000 network under the Fauna Flora Habitat-directive (92/43/EC)). Public awareness regarding the future ecological quality of this area is high. The evaluation of ecological aspects was therefore most important, especially for the public acceptance of either solution to be chosen by the authorities.

The study analyzed the relevant ecological changes resulting from river development options in an area that is 50 km long and 100 km² large. Results are available on the Internet at www.do-gis.de. All in all, it takes 30 CD-ROM’s to store the volume of data collected in that exercise. On 81 1:5000 - scale maps, these data were merged for the project area. An accurate digital three-dimensional model of the area with a vertical accuracy of about 10 cm was used to get results with high precision. A geographic information system was developed. Human interests such as scenery, recreation, water-resource management, and cultural values were also considered.

Cost-benefit analysis

The estimated costs of the alternatives - river training and flood protection – ranged from € 400 Mio (“A”) to € 800 Mio (“D2”). The cost-benefit analysis considered the prognosis for a large variety of aspects, such as economic development in the region and on the Rhine-Main-Danube Waterway in general, the modal split, the structure of the Danube fleet, the transport costs (transport capacities, waiting times, reliability...), effects on employment and on tourism, reduction of CO₂, reduction of accidents, costs of construction and operation/maintenance. The reduction of transport costs by 70-79 percent was the largest benefit. There was no monetary evaluation of the ecological/environmental effects – discussions about this are still going on at the moment in Germany.

Conclusions

After more than 30 years of planning and 10 years of evaluation followed by an extensive study that took more than 5 years and € 15 Mio to complete, a decision is still pending. Stakeholder and public participation was difficult in such a large area (more than 100 km² and around 100,000 inhabitants). Participation at congresses of nature conservation groups, production of leaflets, setting up of Web sites, discussions on TV, information tours, building an information center (which included stakeholders such as nature conservation groups and shipping companies, harbours, etc.), videos with explanations of the research, computer simulations of the alternatives and results, and instructing engineers on how to communicate effectively became important issues – but only years after the project start.

Politics will have to balance the results of the ecological and economic evaluation. The decision will depend on the courage and the ability of those in charge to take a long-term view and stand up for their decision, despite criticism.

http://www.do-gis.de
http://www.wsv.de/Aktuelles/Projekte/Donauausbau/Donauausbau.html
http://www.baw.de/W/pub.htm
Figure A2.4-2 Alternatives C, D1, and D2.
A2.5 Case Study 5 - Balancing the Environment and Development on the Paraná-Paraguay Waterway in South America

Context

At the end of the 1980’s and beginning of the 1990’s, the Paraná and Paraguay Rivers in South America were navigated with conventional equipment. River pilots with knowledge of the river applied their own habits and customs. Navigation time downriver from Corumbá (Brazil) to Rosario (Argentina) was around 20 days and a round trip took approximately 50 days.

At the beginning of the 1990’s, regulations began to be drafted after signing the River Transport Agreement for the Paraguay-Paraná Waterway (Acuerdo de Transporte Fluvial por la Hidrovía Paraguay-Paraná). The first studies were also undertaken within the aims and scope of the agreement. The Paraguay-Paraná Waterway, or Hidrovía, comprises 3,442 km of these rivers. The Waterway was defined as a natural navigable waterway traditionally used by the five countries of the Plata Basin. The objectives of the actions carried out by the Intergovernmental Committee on the Waterway (Comité intergubernamental de la Hidrovía) are to promote the rational and ordered use of river navigation within the river’s natural conditions and improve the safety and river-worthiness of the river vessels used in a co-ordinated manner among the five countries. To this effect, a Technical Coordination Commission (Comisión de Coordinación Técnica - CCT) was set up in addition to specific Technical Groups. The former is made up of engineers and environmental specialists from the countries involved in the Improvement Program based on the traditional methods of dredging, signalling, and placing buoys.

The investment in port infrastructure and equipment and cargo traffic was increased due to the new legal framework. Steel barges and high-powered tugboats capable of thrusting convoys of up to 30 barges or more and equipped with instruments of the latest technology were incorporated. Pilots and crews were trained and familiarized with modern equipment. The improvement of safety standards in maneuvers and navigation reduced navigation time downriver from Corumbá to Rosario from 20 to 12 days. Return trip times were also reduced from 50 to 30 days. In addition, transport costs were reduced (up to 50 percent, depending on the product).

The regularity and continuity of greater cargo capacity on the waterway allowed for better embarkation planning and facilitated export operations. It also enabled long-term cargo contracts to be established, therefore improving the overall context as well as access to exportable products to the different world markets. The areas of cultivated land were promoted, as were production volumes due to the widening of productive frontiers.

General cargo transport and bulk transport evolved in a similar fashion. Feeder services were increased and new river transport moving equipment was incorporated to satisfy the demand for general cargo (containers, automobiles, machinery, etc.). The services of this modern equipment cover the river ports within a 1,630-km section from Buenos Aires to Asunción. A return trip now takes approximately 7 days; 4-1/2 days upriver (108 hours) and 2-1/2 days downriver (60 hours). This equipment has a thrust of 3,000 HP. The vessels measure 76 metres in breadth and 23 metres in registered length with a cargo capacity of up to 240 containers. The same equipment is to be incorporated to cover 1,140 km from Asunción to Corumbá, coordinating integrated logistics on both sections along 2,700 km for the transport of general cargo from Buenos Aires and vice versa.

Objectives and Problems

While navigation has been improved in the lower reaches, the ultimate plan for the Hidrovía is to provide 24-hour, all-season navigation from Uruguay's port of Nueva Palmira to the state of Mato Grosso in Brazil's western interior, ending in the Brazilian city of Caceres in the environmentally sensitive Pantanal wetland. The project is considered to have extremely positive effects for the landlocked Latin American countries, Bolivia and Paraguay, who are now reliant on expensive overland transport. This is a way to exploit the potential of the world's largest estuary, the La Plata River and to promote the development of the region by reducing the cost of transport and improving links with commercial centers.
The infrastructure requirements of the plan include substantial dredging, channel stabilization, and realignment, and the excavation of more than 100 rock outcrops in the riverbed to allow freighters and large barge trains to travel upriver with greater draft during the dry season. It will also require the straightening of bendways along the Paraguay river, dredging of 86.6 million cubic meters of sediment, and creating 32 dikes to increase the volume of the water. Future investments would also include the construction of riverside ports and other spin-off industries.

The project would be beneficial to 17 million people living in the region but it will affect the rich environmental setting of the Pantanal and its unique biological richness. The problems that the project implicates are fundamentally grouped in three sets of issues: biological changes in species and ecosystems; social changes surrounding populations; and changes in water and the accompanying problems of overexpansion in riverfront communities. Experts have questioned the economic worth of the project and are measuring the eventual environmental effects that it could have in the area. In this respect the project presents its biggest risks: it would drain vital wetlands and significantly impact ecosystems up and down the course of the waterway.

The greatest concerns have related to the dredging and channelization options for the segment of the Paraguay River downstream of the Pantanal. Removal of the rock outcrops and the other proposed changes would decrease backwater—lowering the water surface and adjacent groundwater by about 0.25 meters in the dry season. This hydrologic change would profoundly impact the Pantanal, and some experts estimate that as much as half the wetland could be lost. Additional land conversion for soybean production, introduction of invasive species, increased flooding, and displacement of indigenous populations are also significant concerns. Many NGOs have argued strenuously against developments in the upper portions of the waterway.

### Evaluation and Conclusions

Several important improvements to the system have been realized, and others remain on hold pending further assessment and funding. Proposed dredging and channel rectification in the upper reaches have been put on hold by the principal funding agencies. Instead, navigation improvements in this reach will focus on aids to navigation and efforts to develop vessels tailored to this reach of the river system. The increase in tonnage (not including transport in overseas vessels) of cargo transported by the thrust navigation system is shown in the table below for 1992 to 1998.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>UPRIVER (ton)</th>
<th>DOWNRIVER (ton)</th>
<th>TOTAL (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>812.250</td>
<td>1.328.273</td>
<td>2.140.523</td>
</tr>
<tr>
<td>1998</td>
<td>1.612.000</td>
<td>10.210.000</td>
<td>11.822.000</td>
</tr>
</tbody>
</table>

% INCREASE 1992-1998: 98.47% for Upriver, 689% for Downriver, and 450% for Total.

Eleven regulations have been approved:

- Single regulations for the transport of merchandise on the deck of waterway vessels.
- Single regulations on the placing of buoys.
- Single regulations on infringements and fines.
- Regulations on the prevention of collisions.
- Regulations to determine the tonnage of the Paraguay-Paraná Waterway vessels.
- Single regulations on the size of waterway convoys.
- Regulations on the recognition, inspection, and safety certification of waterway vessels.
- Communications plan for navigation safety on the Paraguay-Paraná Waterway.
- Single scheme of the allocation of freeboard and stability.
- Common requirements document for the registration of vessels.
- Uniform glossary of the Paraguay-Paraná Waterway port services.

The Technical Groups from the five countries reached agreement on the Environmental Management Plan (Plan de Gestión Ambiental - PGA). The Plan contemplates monitoring and environmental impact control actions in each country. The Technical Groups also agreed on the Integrated Action Plan (Plan de Acción Integrado – PAI) whose aim is to have guidelines available for the countries and allow for monitoring and coordinating actions from an integrated and systematic perspective within each of the sections that make up the waterway. Both agreements were approved in a Head of Delegations Meeting attended by the five countries held in Santa Cruz de la Sierra on 28 May 1999.
It should be noted that Argentina has taken on the commitment (within the framework of the PAI) to maintain navigation at 10 feet, and to provide for signalling and navigation information in the sections between Puerto de Santa Fe and the north. The Regulations of the Consultative Forum on the Waterway have been approved. This instrument will allow the Civil Society to participate in the decisions affecting the program’s development.

It was decided to start work on the “Information System of the Paraná-Paraguay Waterway Programme” at the meeting held in Santa Cruz de la Sierra on April 8 and 9, 1999. The said agreement along the Latin American Association on Integration (Asociación Latinoamericana de Integración) will put forward proposals on the design of a database in order to gather information on the waterway as well as the signalling system, navigability by sections, shipping operations, trade, the interchange of goods and services through the waterway, and other matters related to waterway use.

The Waterway Program, developed at the end of the 1980’s, came about in conjunction with MERCOSUR and the profound economic changes in Argentina. This is particularly true for river and maritime transport, port deregulation (Law 24,093 18/4/93), the privatization (from 1/05/95) of river way maintenance and signalling on the lower Paraná River to allow for daytime and nighttime navigation for overseas vessels with draughts of 22 feet from Santa Fé (km 585) to San Martín (km 460) and vessels with draughts of 32 feet from the latter port to the ocean. These are projected to be increased to 28 and 36 feet, respectively. The investment needed to carry out maintenance operations from Santa Fé (km 584) to Argentina, including the sections shared with the Republic of Paraguay, are projected by means of reaching agreements and coordinating with said country.

In this way, the waterway ports are becoming a stable access point to the Atlantic Ocean and contributing to the development of two-ocean corridors (east-west) as well as roads and railway lines through Chile to the Pacific Ocean and vice versa. These support north-south river and maritime transport as well as transport to and from the center of South America.

A2.6 Case Study 6 - Environmental Remediation of the Upper Mississippi and Missouri River Systems in the United States

Context

The Upper Mississippi River System (UMRS), as defined by Public Law 99-662, includes the commercially navigable reaches of six Midwest rivers (See Figure A2.6-1). The U.S. Army Corps of Engineers is responsible for building, operating, and maintaining channel training structures (i.e., revetments, wing dams, closing dams); locks and dams; and dredging on the UMRS. These activities provide a continuous and permanent 9-ft (2.7-m) channel through which barges move between such cities as St. Louis, Missouri; Minneapolis-St. Paul, Minnesota; Chicago, Illinois; Memphis, Tennessee; and New Orleans, Louisiana. The driving need for commercial barge traffic on the UMRS is to move Midwest grain to international markets. Upstream transport of coal, petroleum, and fertilizer takes advantage of the bulk transport capacity presented by returning barges. Occasional reference is made in this appendix to the Upper Mississippi River (UMR) without the word "system" attached. The UMR is the upper portion of the Mississippi River, not including tributary rivers.

The Missouri River basin, shown in yellow in Figure A2.6.1, encompasses more than 500,000 square miles and is more than 2,300 miles long. In the 1950s, the Corps of Engineers constructed six mainstem dams on the upper portion of the Missouri River. These dams were intended to reduce flood damages, enhance navigation, generate hydroelectric power, and store water for irrigation. Reservoir releases are scheduled to provide sufficient discharge to maintain navigation between Sioux City, IA and St. Louis, MO for eight months of the year. This 735-mile channelized stretch provides a 9-ft-deep navigation channel maintained not by dredging, but by navigation structures that constrain the width of the channel.

Objectives/Aims

The Mississippi and Missouri Rivers and their tributaries have tremendous national historic significance. There is a growing recognition that economic value to the people of
the region is dependent on a healthy environment, and that future coordinated and comprehensive land use and water management are critical to continued clean and productive use of the rivers.

Changes in social preferences since the construction of the Missouri and UMRS projects have resulted in a new mix of stakeholders on the rivers. Many of these new uses revolve around recreation and environmental considerations.

Studies are under way to compile and evaluate existing data; inventory and identify problem flooding areas; forecast future changes in land cover and land use; apply hydrologic, hydrodynamic, and water quality models to quantify watershed hydrology and materials transport and fate processes for existing conditions; identify soil loss, nutrient source, and water quality problem areas; examine alternatives to protect and restore wetland and river habitats; and identify a set of watershed and water quality management alternatives. The aim is to investigate changes to the system's character and operations that reflect the current uses and that restore the ecological character of the rivers and floodplains.

Problems/Solutions

River modifications, control projects, and floodplain development have had wide-ranging effects on the natural processes—particularly hydrology—that drive and maintain the floodplain ecosystem. Sixty-six percent of the nearly 1,200,000 acres in the Upper Mississippi River floodplain are now used for crop and pasture land. These agricultural lands are isolated from the normal floodplain function by extensive levee systems. Although lock and dam construction originally created a significant increase in and diversity of habitat for fish and wildlife, sedimentation has since resulted in serious degradation. Present erosion rates in the basin exceed the rate of soil formation, resulting in a net increase of sediments entering the Mississippi River. The sediments fill in backwater areas and increase turbidity, carry excessive nutrients into the aquatic ecosystem, and bring in pesticides and other toxic chemicals. Continued sedimentation will degrade the quality of the habitat, reduce diversity, and result in a gradual aggradation of backwaters, leading to their transformation from aquatic to terrestrial habitat. The Mississippi River backwaters that presently produce fish, wildlife, plants, and nursery habitats may be lost to sedimentation and eutrophication within the next 50 to 100 years. Environmentalists have warned that planned expansions of locks and dams on the Upper Mississippi River would further degrade the river’s already damaged ecosystems, threatening river species and migratory birds that rely on the more than 200,000 acres of wildlife refuges along the river’s length.

Operation of the Missouri River projects has led to loss of 300 million acres of natural riverine and floodplain habitat. Sediment transport has been reduced from 142 million tons of sediment per year to roughly 4 million tons per year. Floodwaters storage has significantly reduced the amplitude and frequency of high flows. Cottonwood reproduction has largely ceased, and benthic invertebrates production has dropped 70 percent. Of 67 native fish species living along the mainstem river, 51 are now listed as rare, uncommon, and/or decreasing across all or part of their ranges. Four species, the pallid sturgeon, interior least tern, piping plover, and bald eagle are listed as endangered or threatened. Current river operations, as well as the continued maintenance of the bank stabilization and navigation project, are expected to perpetuate habitat loss, nest failure, reduction in forage base, reduction of spawning cues, and overall reductions in the reproductive success of the species.

The U.S. Army Corps of Engineers is actively involved in efforts to modify operations on these systems. Actions to date have included the restoration of oxbows and backwater areas, floodplains and wetland restoration, riparian restoration, and modifications to river training structures in order to improve habitat. Changes to reservoir operations are being assessed to optimize system performance with respect to current and anticipated uses as well as to better mimic historic hydrodynamic conditions on the rivers. Alterations to navigation infrastructure and operations are being implemented on a case-by-case basis while an integrated program is developed. Other federal and state programs are aimed at altering damaging land use practices in the watersheds and on tributaries.

Evaluation and Conclusion

The restoration actions completed to date have been very successful in terms of restoring lost or declining habitats and in assisting with recovery efforts for impacted flora and fauna. However, agreement upon the course of action for more comprehensive restoration and management has remained elusive. The magnitude of the impact and the continued need for flood control, hydropower, irrigation, and navigation on these systems essentially guarantee that the full recovery of the historic conditions of these systems will not be possible. No Missouri River management issue has polarized the river's stakeholders as much as the debate over the provision of flows and channel depths for navigation. Navigation on the river is controversial in part because of economics. While recreation in this reach generates an estimated $70 million annually, barge traffic is valued at only $7 million.
The ultimate decision regarding the proper balance between navigation and other river uses is a public-policy issue. Current management protocols for operating the river systems represent an accretion of federal laws, congressional committee language, appropriations instructions, and organizational interpretations that have been enacted or developed over the past century and confuse and compound the management structure. Independent organizations, such as the National Research Council, that have reviewed these projects have argued that an adaptive management approach should be adopted and that incremental changes in navigation and the river channel should be considered. They have recommended that Congress give the Corps of Engineers authority to provide navigation services on a segment-by-segment basis based on the benefits derived in each segment of the river.