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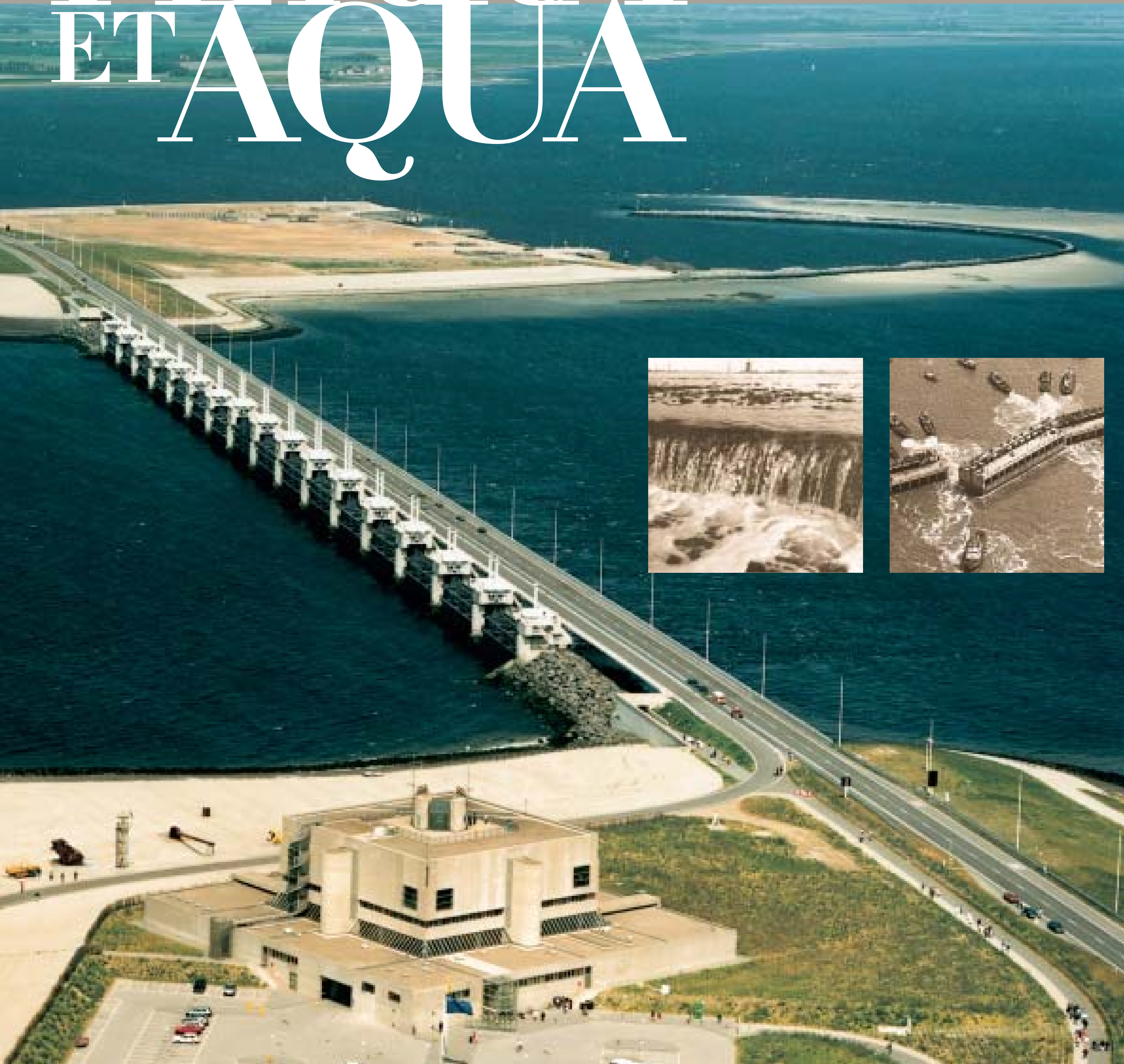
TERRA ET AQUA

International Association
of Dredging Companies



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Cover:

The Oosterschelde Storm-Surge Barrier is part of the Delta Project, a major infrastructure work to protect the Dutch coastline. Inserts: the flooding and the repairs 50 years ago.

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International Association of Dredging Companies

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TERRA ET AQUA

Editorial

This issue of *Terra et Aqua* focusses on two major events in dredging history. Fifty years ago in the winter of 1953 the dikes in the southern part of The Netherlands broke as a result of a fatal storm. The damage was monumental with almost 2000 casualties. Through dedication and hard work, solutions were found in the form of the Delta Project, an extensive network of dikes for the protection of the population, which took another 30 years to achieve completely. The experience gained during these years paved the way for the expansion of the dredging industry and the major projects which have been constructed in the 1980s and '90s.

This year also marks the one hundredth anniversary of the signing of the Treaty with Panama in 1903 to dig a canal linking the Atlantic and Pacific oceans across the Isthmus – realising a dream that had existed since the 1500s. Remarkably the Panama connection continues to make history. Just a few years ago, the U.S. government returned the Canal to the government of Panama and a new "Panamanian" Panama Authority with extensive plans for expansion and updating is already taking action to modernise the canal.

These historical events bear witness to the significant role that dredging has played in our economic development and prosperity. But this is not only in the past. Infrastructural improvements are clearly part of our way of life and our future. As ships get larger, the needs of modern ports grow, and creative solutions to infrastructure projects remain in demand. The private dredging industry continues to meet the challenge for innovations.

One way in which IADC does this is by encouraging young people to conduct significant research by presenting them with an award which carries both financial remuneration and the right to publication in *Terra*. Recently we have expanded the reach of our awards to include worthy candidates, not only at conferences, but at other occasions as well. So in this issue we are happy to announce two IADC award winners.

Other events for 2003: the IADC Dredging Seminar will be held for the first time in Dubai; and the IADC website (www.iadc-dredging.com) has been thoroughly redesigned and upgraded with links to member companies and other sister organisations. We hope you will take a look.

Robert van Gelder
President, IADC Board of Directors

Kees d'Angremond

From Disaster to Delta Project: The Storm Flood of 1953

Abstract

Fifty years ago the Netherlands experienced the country's worse flooding in modern times. The United Kingdom and Belgium were also inundated, but in the Netherlands the loss of life, livestock and destruction of land was enormous.

Facing this disaster, the first order of business was to rescue as many people as possible. The second step was to repair the breaches in the dikes, and the third was to take measures to make sure that such a disaster would not occur again. This last step resulted in the formation of the Delta Committee which subsequently created a plan known as the Delta Project. By the late 1950s and early 1960s a plan was in place that eventually resulted in the construction of an extensive storm-surge barrier.

The research that was conducted in this context transformed hydraulic engineering, including dredging, from a vocational profession into a science-based profession and laid the way for many of the projects executed today. It as well as gave us the tools for coping with a possible sea level rise which is predicted for the 21st century. In addition, during the 30-year span in which the work was conducted, the subject of the environment emerged as a dominant issue and the Delta Project marks the new age in which environmental impact assessments must be an integral part of any construction plans. What started as a response to disaster, turned into a monumental engineering feat.

After working for Delft Hydraulics (1963-75), Kees d'Angremond went to Volker Stevin (1975-1987) and then, after a short break as director of the Port of Amsterdam, to Delft University of Technology (1989-2001), where during his distinguished career as Professor of Coastal Engineering, he served as Head of the Hydraulic & Offshore Engineering Section, Chairman of the Department of Hydraulic & Geotechnical Engineering, and Dean of the Faculty of Civil Engineering. He recently became Professor Emeritus and is presently an independent consultant working as an advisor for, amongst other organisations, the Hanoi Water Resources University. He is also Chairman of the Foundation for the National Dredging Museum in Sliedrecht, The Netherlands.

Kees d'Angremond

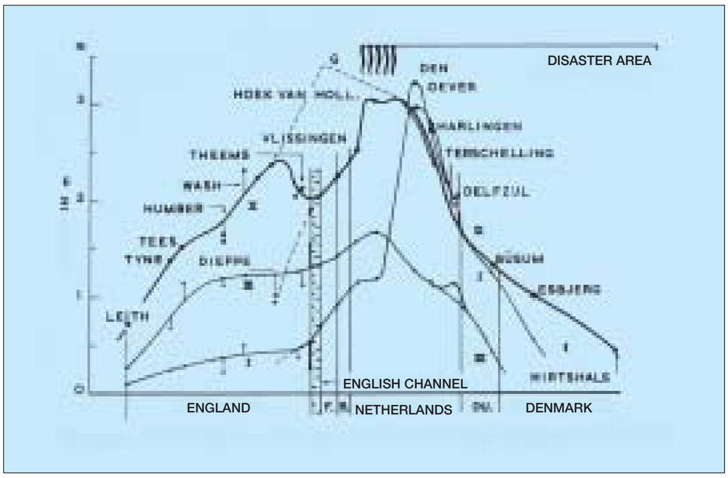
Introduction

On 1st February 1953, the coastlines of the southern North Sea were hit by a severe storm surge. Large parts of the United Kingdom, Belgium and the Netherlands were inundated. In the Netherlands alone, more than 1800 people drowned and 135,000 ha of land were flooded.

The first days after the event, the extent of the disaster was largely unknown. Rescue operations and initial repair activities took place in an improvised way. Thereafter, a more systematic approach was followed. The breaches in the dikes were all repaired before the end of the year. Already on February 18, the Delta Committee was established to advise the Government on measures to be taken to prevent such a disaster in the future. This Committee initiated projects of a to-then-unknown scale. The works became feasible as a result of an unprecedented research effort that lasted over 30 years and that turned the hydraulic engineering profession (including the dredging industry) from a largely vocational profession into a modern science-based enterprise. Without the experience gained during the execution of the Delta Project, many present-day projects would not have been feasible. As such, the disastrous flood of 1953 has provided us with the tools to cope with a potential sea level rise in the 21st century.

Figure 1. The path of the tidal wave into the southern North Sea with the times of high water (HW) indicated.

Figure 2. The surge resulting from the HW in the southern North Sea, going from left to right along the coast of the U.K. across the Channel to France, Belgium, The Netherlands, Germany and Denmark.



The Storm of 1953

From noon on 31st January 1953, a NW gale swept the water from the northern part of the North Sea (between Scotland and Norway) in a southerly direction towards the English Channel. Though part of the water was drained through the Channel, a major surge developed along the coasts of the UK, Belgium and the Netherlands. As a result of the wind direction and the coincidence of the surge with the astronomical tide, water levels exceeding any previously observed occurred in the early morning of Sunday, 1st February, 1953, specifically in the SW (Delta area) of the Netherlands. Conditions were worsened by the fact that the storm coincided with spring tide, though fortunately not the highest spring tide of the month.

The path of the disastrous tidal wave into the southern North Sea with the times of high water (HW) is indicated in Figure 1. The resulting surge (set-up above the astronomical HW) along the coast of the southern North Sea is given in Figure 2, starting at the left-hand side with the coast of the UK from N to S, then across the Channel, the French and Belgian coasts to the Netherlands, ending on the right-hand side in Denmark. The draining effect of the Channel can clearly be seen between the mouth of the River Thames and Flushing. Looking at this figure, it is no surprise that serious damage to the sea defenses occurred in the region where the surge reached levels of 3 m [1].

Flooding

The area that suffered the most direct hit was the Delta region, between Vlissingen and Hook of Holland. In total 187 km of sea defense was damaged, of which 48 km seriously. Most damage was caused by water flowing over the crest of the dikes and eroding the inner slope. Most breaches were found along the southern shores of the islands, where the freeboard of the dikes was less. (The dikes facing N and NW were designed higher so as to cope with wave run-up expected mainly from the NW.) Many deep polders were inundated to a depth of more than 5 m, most in the first night, but some later when sleeper dikes failed. In the meantime, the local people attempted to save their lives on roofs, in trees and on high spots. Others worked very hard to protect failing dikes and to repair breaches before they could grow into gullies. The Dutch journalist Cees Slager [2] has annotated numerous stories about the heroic efforts of the people in these first days.

Only by the morning of 3rd February, a few days later, did the full scope of the disaster become clear.
The extent of the flooding is shown in Figure 3.
In total, 1835 people died, 200,000 cattle were lost and over 135,000 ha of fertile land were inundated.

The first task of the authorities was to bring the survivors to safety. In total, 72,000 people were evacuated. Thereafter, the systematic repair of the sea defenses was begun.

Repair of Damage

Many of the smaller breaches could be repaired with simple means such as sandbags and locally available materials (sand, clay, rubble and quarry stone). In some places, inland barges were used by sinking them in the current to block gaps in dikes. In this way, 75% of the flooded area was recovered by 1st April.

Some of the breaches, however, specifically in the dikes around the Island of Schouwen Duiveland, had grown into deep gullies by backward erosion owing to the in- and outgoing tidal currents (Figure 4). These gaps could not be closed by traditional means. Fortunately, some experience had been gained in 1945, when similar gaps in the dike around the Island of Walcheren had to be closed following the bombing by the RAF for the opening of the Port of Antwerp during World War II. At that time, several caissons constructed for the artificial port of Arromanches were used to block the gaps. The famous novel by Den Doolaard gives an accurate account of the earlier experience [3]. Some of these Phoenix caissons were still available in the UK in 1953. They were towed to the Netherlands, and along

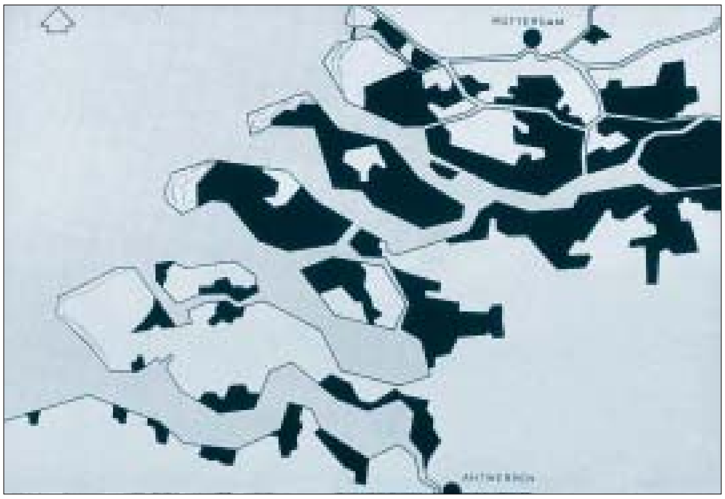


Figure 3. Areas of flooding in The Netherlands,1953.

with locally constructed smaller size caissons, they were used to block the final two gaps in Schelphoek and Ouwerkerk. Figure 5 gives an impression of the scale of these repair works. The last gap at Ouwerkerk was closed on November 6 and all flooded land was dry on 1st January 1954, less than a year after the flooding.

The Disaster in Hindsight

In hindsight, it is amazing that the storm of 1st February 1953 could have such a disastrous effect.

Figure 4. In some cases the streaming water through the breaches in the dikes caused deep gullies and waterfalls to form, which were difficult to close.

Figure 5. Caissons being used to close the gap at Ouwerkerk. The extent of the repair work was enormous.

As early as 1939, an engineer from Rijkswaterstaat (the Dutch Ministry of Waterways and Public Works) P.J. Wemelsfelder published an article in *De Ingenieur* [4] in which he indicated that the occurrence of extreme water levels along the Dutch coast followed a logarithmic probability distribution. On the basis of this work, he indicated that the crest levels of many dikes, in particular in the SW part of the country, were too low. Afterwards, it could be derived that the water level that caused the 1953 disaster had a probability of exceedance of about 3*10-3 per annum, or on the average, only once in 300 years.

Though the damage was extensive, it could have been much worse. A breach in the river dike between Rotterdam and Gouda was prevented by a major effort in the early morning of 1st February, probably thanks to the fact that HW occurred here close to sunrise. If this dike had failed, the densely inhabited (and well-developed) area between Rotterdam, The Hague and Amsterdam would have been flooded as well.

The Delta Committee: Long-term Solutions

Given the magnitude of the disaster and the economic consequences, it is no surprise that the Government wanted answers to various questions, of which the most important were:

- which storm surge levels could be expected along the Dutch coast; and
- is the safety against flooding along the Dutch coast sufficient, and if not, what measures should be taken.

In order to answer these questions, the Delta Committee was formed on 18th February 1953, just two and a half weeks after the disaster. It took the Committee almost 8 years to complete its task.
The final report covers six volumes, most of them the result of comprehensive research by a multi-disciplinary team of experts. Five interim reports were published to enable the Government to make an early start with the most urgent works [5].

The final report of the Delta Committee is a landmark in coastal engineering design. For the first time, the required safety level was based on a comparison between the economic damage owing to failure of seawalls and the cost of strengthening the coastal defense works. It was established that the sea defenses around the most densely populated part of the country should be able to withstand surge levels with a probability of exceedance of 10-4 per year (average once in 10,000 years).

To achieve this kind of safety, a major renovation programme for the existing dikes needed to be carried out. The Committee indicated, however, that it would be an advantage to close the estuaries in the SW part of the country instead of raising the crest of many dikes around the existing islands. Before the Committee arrived at this conclusion, due attention was paid to secondary advantages and disadvantages, such as salt intrusion, enhancement of land transportation and inland navigation, recreation, and social and environmental issues. The proposals of the Committee became known as the Delta Project.

Although the final report did not appear until after 1960, several interim reports formed the basis for the legislation comprising the closure of the inlets in the SW part of the country. The Delta Law passed through the Dutch Parliament (Tweede Kamer) on November 5, 1957, and was published on May 8, 1958.

Delta Project

In concrete terms, the Committee recommended the closure of the primary inlets (from N to S) Haringvliet, Brouwershavense Gat, Oosterschelde (Eastern Scheldt) and Veerse Gat. The latter closure had already been mentioned in an interim report. Since there would be a considerable time gap between closures of the inlets, secondary dams would have to be built to avoid shortcuts through the channels at the upstream end. This required secondary dams in the Volkerak, Grevelingen and Zandkreek. The closure dam in the Haringvliet had to be equipped with a discharge sluice of sufficient capacity to cope with the discharge of the River Rhine. Remaining dikes that would not be protected by the closure works were to be strengthened to the required level.

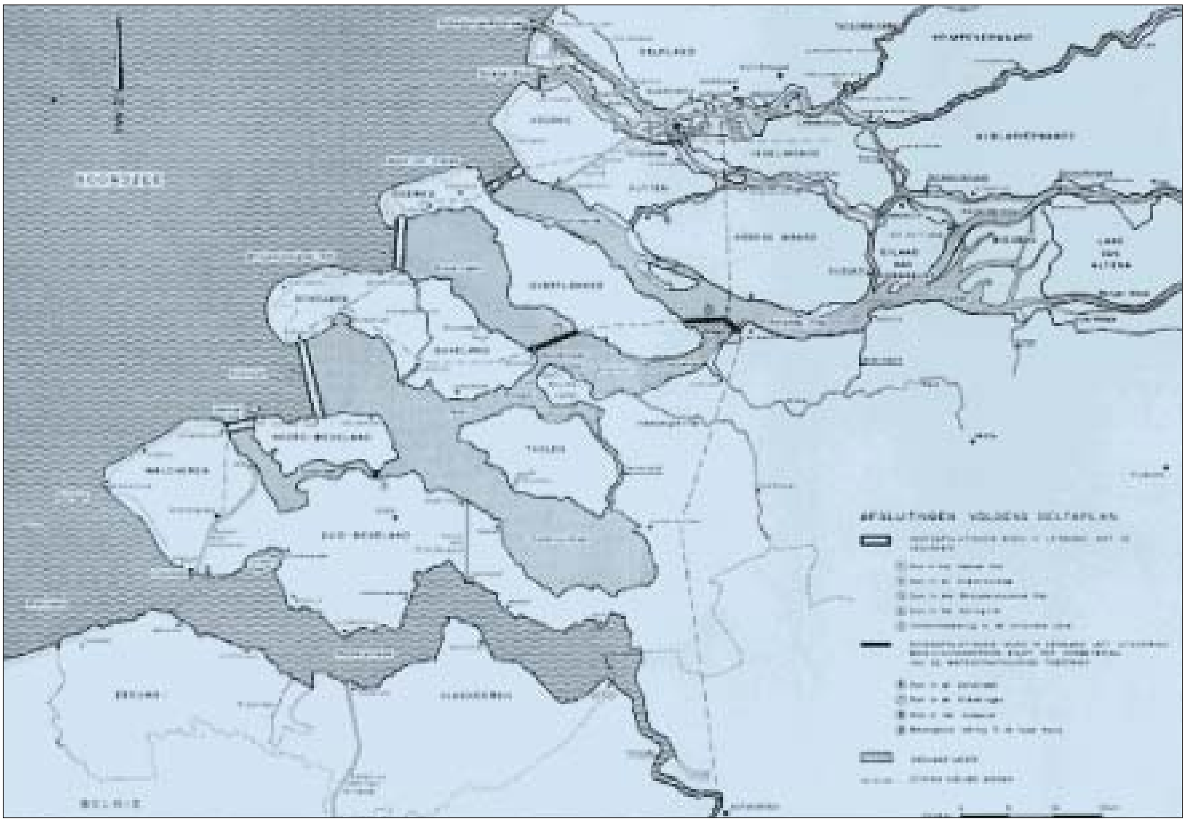
The report also pays attention to the possibilities of improved management of the fresh water resources in the SW part of the country. Control of the Haringvliet sluices would give the possibility to increase the discharge via the Rotterdam Waterway, reducing the salt intrusion caused by the continuous deepening of this channel for navigational purposes. A network of inlet sluices was designed to flush the reservoirs of Grevelingen and Oosterschelde with fresh (Rhine) water. Last but not least, new lock complexes in the Volkerak Dam and at the Kreekrak would facilitate the inland fairway from Rotterdam to Antwerp, honouring an already long overdue commitment to Belgium.

The report then discusses the technical feasibility of the works. A comprehensive comparison was made with similar earlier works. It was concluded that the works would be feasible, but that they so greatly exceeded the existing experience that only a phased approach could be successful, starting with the smaller inlets, and gradually tackling the larger inlets, based on experience gained during the project itself.

Finally, the Committee stressed the need to apply new technology and to carry out research by using all modern means.

The works proposed by the Delta Committee have been indicated in Figure 6. The suggested time schedule anticipated a construction period of 25 years is given in Figure 7. Three major works determined the total time schedule: the closings of Veerse Gat, Brouwershavense Gat and Oosterschelde. Other elements, such as the closure of the Grevelingen, the Volkerak and the Haringvliet, had to be fitted in between.

Figure 6. Delta area with major works.



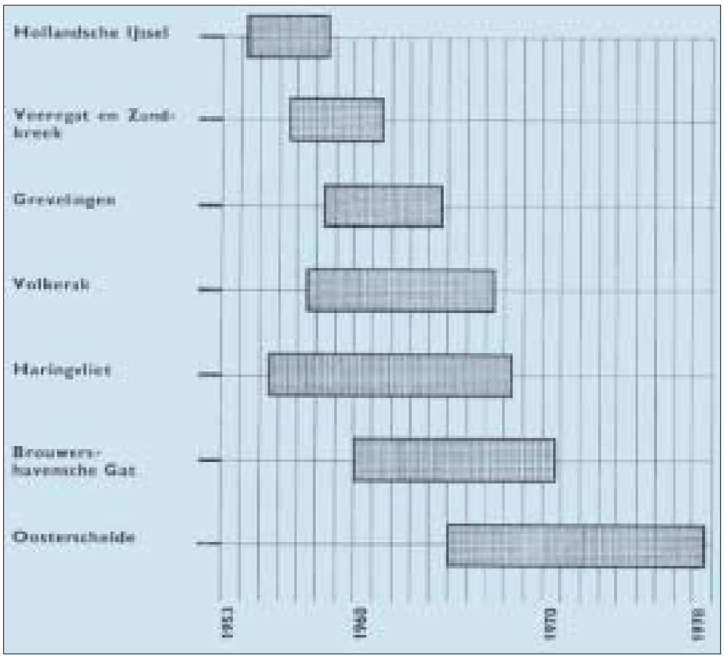


Figure 7. Time schedule of construction at the Delta Works.

Management

For the management of the Delta Project, a separate entity the Deltadienst within Rijkswaterstaat was formed: Within this department, units were established for the design and supervision of the works, and for the research that had to be carried out to make the works feasible. For many years, the "Waterloopkundige Afdeling" (Hydraulic Department) guided the long-term research, varying from field observations to all kinds of model tests and calculations. This Department formed the liaison between research and practical engineering for over 25 years.

The sequence of the works was partly designed to create a learning curve. Since it would be necessary to develop and test new techniques, a variety of working methods was used to provide experience and to make the appropriate choices for the most difficult closure – the Eastern Scheldt. A good insight in the execution of the works can be obtained from the series *Driemaandelijkse Berichten Deltawerken* edited by the "Deltadienst"[6].

In this way, in 1969, the formal decision to close the Oosterschelde could be taken. After careful consideration, the decision was taken to use the technique of gradual vertical closure by cable car. This method was preferred to the use of caissons to avoid the inherent risks of placing the caissons. The works on the Oosterschelde started with the construction of work harbours and dam sections over the shoals. A huge factory was constructed for pre-fabricated geotextile mats to be used as scour protection. The works were well under-way, but in the public opinion there was a growing concern about the environmental effects of the large stagnant water basins. The potential loss of the oyster beds near Yerseke also continued to cause concern. Closure of the Oosterschelde even became an issue in the parliamentary elections of 1973. After the formation of a new coalition cabinet, it was decided to re-consider the continuation of the Delta Project.

Environmental Concerns

After ample consideration, a compromise was achieved: instead of completely closing the Oosterschelde Estuary, a storm-surge barrier would be constructed in the mouth. During normal tidal conditions this barrier would reduce the tidal amplitude to a level that was considered adequate for the oyster cultures. During storms the barrier could be closed to provide the desired safety. In the upper reaches of the estuary, some compartment dams would be built to separate the Rhine-Scheldt canal from the now tidal Oosterschelde, and to reduce high current velocities in the Krammer. Although the new plan was far more costly than the old one, the idea was received favorably. This marked the dawn of a new age in which environmental impact assessments would become an integral part of any construction and dredging projects.

Enhanced Role for Construction Industry

Preparation of the new design was not a task of Rijkswaterstaat alone; a design team was established with strong participation of the contractor. During the design phase, serious problems were encountered that forced the designers to a make radical change several times. First, the idea of using the caissons was abandoned to make place for a design with piers cast in situ and a foundation deep in the Pleistocene deposits, with the aid of cellular rings. Construction of the piers and their foundation would take place in separate steel cofferdams. This idea was also abandoned, and eventually the choice fell on pre-fabricated concrete piers that would be placed on mattresses consisting of a granular filter (Figure 8).

In between the piers, a sill was to be constructed consisting of a sill beam and heavy quarry stone. The sill beam would be the lower support for the steel gates that would move in between the piers. In total, 66 piers had to be placed with a heart-to-heart distance of 45 m, distributed over 3 main channels, thus forming 63 openings. The soil, consisting of loosely packed, fine sand had to be densified before the foundation mattresses could be placed. Accuracy was essential while working under extremely difficult conditions in

Figure 9. One of the spin-offs of the Delta Project: discharge caissons at the Oosterschelde, being built in 1976.

water depths up to 35 m and current velocities of over 4 m/s.

Part of the already completed works had to be demolished including part of the scour protection and the piles for the cableway. Therefore the conditions set by the Government with respect to cost and time of completion could not be met. The barrier was completed in 1986 instead of 1985, and the budget was also exceeded even after correction for inflation. This could not be a real surprise since the original idea was abandoned to carefully build up experience during construction working from smaller to larger closures. The work methods required for the Oosterschelde barrier were a completely new challenge to the engineering community.

Figure 8. Concrete piers at the Oosterschelde works.

Innovations and Spin-offs

The emphasis on research and innovation was not restricted to only Government Agencies.
Private enterprise, including the dredging industry, was challenged and sometimes urged to participate in this process. As such, the Delta Project has contributed significantly to the evolution of the hydraulic engineering profession in general and the dredging industry in particular from a vocational profession into a modern science-based industry.

With so much emphasis on innovation, there must have been a tremendous spin-off. At present, it is difficult to recognise the origin of present-day working methods. Nevertheless an attempt has been made to list at least some of the achievements including:

- Quantitative insight in scour
- Extensive study of wave impact forces
- Large-scale application of geotextile and asphalt mats for scour protection
- Closure of tidal channels by dumping material from cable cars
- Application of geocontainers
- Use of discharge caissons (Figure 9)
- Large-scale use of asphalt and sand asphalt for slope protection instead of labour-intensive stone revetments
- High capacity dredging of sand;
- Extensive use of pre-stressed concrete in the marine environment
- Compaction of sand by vibration to a depth of NAP –60 m
- Placement of foundation mattresses consisting of 3 layers of granular material

Figure 10. Aerial view of the completed Oosterschelde Storm-Surge Barrier.

- Lifting and accurate positioning of extremely heavy elements in water depth of 35 m and velocities up to 4m/s
- Closing tidal channels with sand only
- Development of probabilistic design methods
- Technology of granular filters
- Accuracy of dredging and providing foundation layers for caissons.

The Delta Project in Hindsight

The Delta Project was originally designed in a period when awareness of the environment and of the ecological effects of civil engineering works scarcely existed. Moreover, the decisions to carry out the project were taken in an emotional context immediately after a major disaster that took over 1800 lives. It is therefore not surprising that during the execution of the project priorities changed. The growing level of prosperity and the growing attention for the quality of life strengthened the concern for the environments.

Conclusions

Looking back 50 years, it is clear the Delta Project has certainly been very effective in reducing the risk of inundation. With the growing concern about the rise in sea level, this aspect is gaining emphasis.
Also, the side effects of the project have been positive for the economic and social development of the region, including the opportunities for tourism and recreation. This is due not only to the better wet and dry traffic infrastructure, but also to the creation of the water basins. The effect on the national water management must be rated as positive. With the aid of the Haringvliet Sluice it has become possible to control the Rhine discharge, to reduce salt intrusion, and to safeguard drinking water resources.

It is perhaps some small solace to those who lived through the disaster and grief of the storm flood of 1953, that without it and the Delta Project as its logical consequence, hydraulic engineering and dredging would not have advanced as dramatically as they have, preventing similar disasters since and providing us with solutions for the impending problems of the 21st century.

References

1. **Rijkswaterstaat (1961).**
   "Verslag over de stormvloed 1953", Staatsdrukkerij- en Uitgeversbedrijf, 's-Gravenhage, the Netherlands (In Dutch with English Summary).

2. **Slager, K. (1992).**
   "De ramp : een reconstructie" ISBN 90-72-138-24-4, De Koperen Tuin, Goes, the Netherlands (In Dutch).

3. **Doolaard, A. Den, (1947).**
   "Het Verjaagde Water", Querido, geannoteerde heruitgave 2001, Delft University Press ISBN 90-407-2224-2 (In Dutch).

3a. **Doolaard, A. Den, (1948).**
   "Roll Back the Sea" (translation of [3]), Simon and Schuster, New York.

4. **Wemelsfelder, P.J. (1939).**
   "Wetmatigheden in het optreden van stormvloeden", *De Ingenieur nr. 33* (In Dutch).

5. **Deltacommissie (1960).**
   Eindverslag en Interimadviezen, 6 Volumes, Staatsdrukkerij- en Uitgeversbedrijf, The Hague, The Netherlands (In Dutch with English Summary)

6. **Deltadienst (ed.), (1957-1988).**
   Driemaandelijks Bericht Deltawerken, 124 Volumes, Staatsdrukkerij, The Hague, The Netherlands (In Dutch with English Summaries).

Special IADC Award: “On the Sedimentation Process in a Trailing Suction Hopper Dredger”

The Trailing Suction Hopper Dredger (TSHD) is very often used for large-scale land reclamation works. During dredging the TSHD lowers one or two suction pipes to the seabed. From the bed a sand-water mixture is sucked up and discharged into a large cargo hold, the so-called hopper. In the hopper sand settles and the excess water flows overboard. A part of the inflowing sand may not settle during loading into the hopper, but flows back overboard with the excess water. Therefore, the VBKO (Vereniging van waterbouwers in Bagger-, Kust- en Oeverwerken) initiated a research programme to improve knowledge on the subject of hopper sedimentation.

Different models were developed in the past to estimate the amount of material lost overboard and the particle size distribution of the sediment in the hopper and in the overflow mixture. These models were based on relative simple models developed for the field of sewage water treatment (Camp, 1946) and were based on an idealised inflow and outflow configuration and a prescribed velocity distribution in the hopper. Because the velocity distribution is prescribed, its relation with the inflow and outflow structures is absent. The second effect is that the concentration distribution does not influence the velocity distribution in these simple models.
With the increase in scale of the TSHDs, the validity of these simple models became questionable.

The research programme started in 1997 with a literature survey from which it was concluded that knowledge about the physical process inside the hopper was lacking and the existing models were too simple. The second step was the execution of laboratory hopper sedimentation tests with the smallest length scale possible (hence geometry as large as possible to minimise scale effects) at WL|Delft Hydraulics. Based on the improved phenomenological description that resulted from the laboratory tests, a one-dimensional vertical (1DV) model was developed. The difference between the earlier models and this new model with its (mostly one-dimensional) predecessors is that the dimension is in vertical direction instead of horizontal. The 1DV model proved capable of simulating the model hopper sedimentation tests quite well. It was however unsure if the model could simulate the process on prototype scale equally well since the horizontal transport in the hopper was not included owing to the one-dimensional character.

It was therefore decided to extend the one-dimensional model to two dimensions (two-dimensional-vertical: 2DV). At the same time it was recognised that quantitative information on the influence of the bed shear stress on sedimentation was missing for the conditions present in a hopper (large concentration and velocities below the deposition limit).
Consequently special sedimentation tests were carried out in a closed flume. With these tests the sedimentation-erosion processes close to the bed could be examined. The developed two-dimensional model is compared with benchmark situations and with the model hopper sedimentation tests. To validate the models prototype measurements were executed onboard the *TSHD Cornelia*. These measurements were used to validate both the 1DV and the 2DV model. The agreement between the 2DV model, based on the Reynolds-Averaged Navier-Stokes equations and the measurements is good.

Cees van Rhee, during his promotion ceremony, flanked by his advisors, left, Professor Wim Vlasblom, and right, Professor Emeritus Kees D’Angremond.

Presented on December 3 2002 at Delft University of Technology

For almost twenty years, Cees van Rhee has been engaged in research for the dredging industry. From 1985 to 1990, he was at WL|Delft Hydraulics, and from 1990 to the present at Ballast HAM Dredging. At Ballast HAM he was employed in the Research Department, Estimating Department and worked for two years in Hong Kong where he was responsible for the Production and Planning of one of the large land reclamation projects that were executed at that time. From 1997–2001 he was posted for two days per week at Delft University of Technology in a PhD research programme, sponsored by major Dutch dredging contractors. In December 2002 Mr van Rhee received his degree and was awarded a special IADC Award for his research paper. A summary of this is published here.
A more extensive article based on his thesis can be found in *Terra et Aqua*, nr. 86, March 2002.

Charles W. Hummer, Jr.

The Panama Canal: A Look Back, A Look Forward

Charles W. Hummer, Jr.

Charles Hummer is a technical author, consultant on dredging and environment, and book reviewer for *Terra et Aqua*. Born in Panama, he worked there until 1979 when he left his position as Assistant Chief of the Panama Canal Dredging Division and went to the Headquarters of the U.S. Army Corps of Engineers Dredging Division in Washington, D.C. He is past president and chairman of WEDA and WODA. In 1989 he retired from the Corps and from 1989-94 he lived in The Netherlands and was active in the Environmental Committee of CEDA. He is the editor of the book *Dredging for Development*, published by the IADC. He is cofounder and presently president of the Panama Canal Museum in St. Petersburg, Florida, USA.

Abstract

This year 2003 marks the centennial celebration of the signing of the Treaty by U.S. Secretary of State John Hay and M. Bunau-Varilla, appointed minister to Washington DC, in which Panama, newly liberated from Colombia, gave the United States the rights to build a canal on the Isthmus. The canal officially opened in 1914 and the large labour force necessary to operate it was primarily American. Eventually this led to unrest in the Panamanian government, which in turn led to the signing of the Carter-Torrijos Treaties of 1977 that set in motion the complete transfer of the Panama Canal to the Republic of Panama by the end of the 20th century. Since this transfer the "new" Panamanian Panama Canal Authority has undertaken several extensive studies to improve the Canal and bring it up to the requirements of the present-day post-Panamax fleets.

This article was prepared drawing directly and indirectly from historical records of the Panama Canal Commission, the references listed, from the Panama Canal Authority Official Website and as a result of meetings with the Panama Canal Authority staff during July 2001 through March 2002. The Panama Canal Authority Office of International Communications kindly provided many of the graphics.

Introduction

The narrow 50-mile Isthmus of Panama was recognised as a key potential link between the Atlantic and Pacific oceans and the maritime trade flowing between those seas as early as 1524, when Spanish King Charles V commissioned the first study of a canal to connect the two oceans (Figure 1). On the way back to Spain, slaves and mules carried tonnes of gold from Peru across the narrow Panama isthmus.

The first mechanised trans-isthmian transportation bridge was the Panama Railroad constructed in 1855. The railroad met the pressing need for transport from the eastern coast of the United States following the California Gold Rush. The savings in time and distance from this shortcut were compelling. The Panama Railroad's success explicitly indicated the demand for use of the Isthmus as a travel shortcut. American interests soon focused on the proposed utility and economic return a canal would provide. Surveys during the 1870s to select the best route for a canal resulted in both Panama and Nicaragua being presented as the proper location. The United States did not act upon these recommendations.

The French then took the initiative by purchasing construction rights from Colombia in 1879. Construction of a sea-level canal across the narrowest part of the Isthmus began in 1881. Ferdinand de Lesseps, who played a major role in building the Suez Canal in 1869, directed the Compagnie Universelle Du Canal Interoceanique de Panama. Time and mileage would be dramatically reduced when travelling from places on the Atlantic Ocean to places on the Pacific Ocean and vice versa. For example, a total of 7873 miles would be saved on a trip from New York to San Francisco. Clearing the jungles, excavating, and dredging

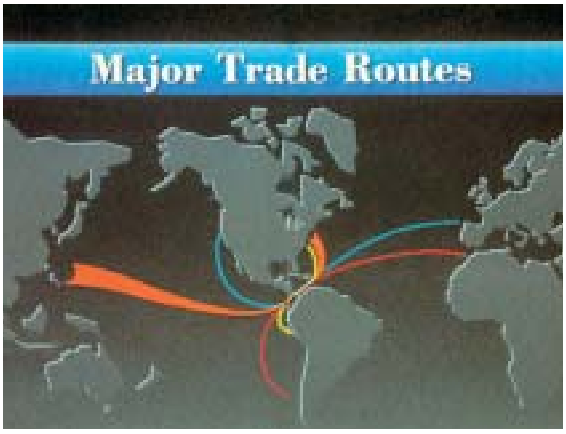


Figure 1. Since 1524 when Charles V of Spain commissioned a study for a canal to connect the two oceans, the canal has been a focal point of maritime trade.

– combined with poor sanitation and rampant disease – took a huge toll on the workforce. By the time the French canal effort ended in 1889, more than 20,000 lives had been lost, and no canal was in place.

With France out of the picture, Congress and President William McKinley continued investigating canal possibilities in Panama and Nicaragua. The only impediment to U.S. canal construction was Colombia, which refused to agree to the deal. This problem was resolved through the establishment of an independent Panama, separate from Colombia. Several times during the 19th century, Panama had briefly seceded from Colombia, only to rejoin it. The first years of the 20th century saw an independence movement again gathering steam.

U.S. President Theodore Roosevelt, who became president after McKinley was assassinated, fully supported a canal through Panama rather than the Nicaraguan route favoured by many in the United States and had successfully obtained congressional approval to construct a canal through Panama on June 19, 1902 for $40 million. With his encouragement, in the autumn of 1903 several prominent Panamanians, including Dr. Manuel Amador Guererro, were involved in plotting the course of a Panamanian revolution. The revolution succeeded and three days later the United States formally recognised the new republic.

On 18 November 1903, the Hay-Bunau-Varilla Treaty granted the United States "in perpetuity the use, occupation, and control" of a 10-mile wide area of land across the Isthmus to construct and defend a canal, with "all the rights, power and authority within the zone ... which the United States would possess and exercise as if it were the sovereign of the territory". The United States agreed to pay Panama $10 million in compensation and an annuity of $250,000 per year after canal completion. In addition, the United States also agreed to pay Colombia $25 million over disputes from the rather controversial "Panamanian Revolution", and allowed specified Colombian ships free transit. Initially, normal tolls for the Canal were $1.20 per cargo tonne.

Building the Canal

The French property on the Isthmus was officially turned over to the United States on May 19,1904. Colon and Panama City were outside the Canal Zone. The first task was cleaning up. Poor sanitation contributed largely to the number of malaria cases present in the work force, and a more deadly yellow-fever epidemic began in early 1905. Chief Sanitary Officer William C. Gorgas targeted mosquitoes carrying yellow fever for eradication through proper sanitation. Gorgas was given 4,000 workers and an unlimited budget for supplies. Panama City and Colon were fumigated house by house, provided with running water, and streets were cleaned and paved. Entire new communities were established. By the end of 1905 the yellow fever epidemic had stopped, and construction resumed.

From 1904 until its opening August 15, 1914, the Canal had cost $352 million and 5,609 workers died. Labourers did not come to the Canal Zone in sufficient numbers during the early years, necessitating recruiting offices in Europe, the West Indies, and the United States. A total of 43,000 men were imported under contract with the Commission, from 1904 to 1910, and it was thought that the labour problem had been solved. However in July, August, and September 1911, it became necessary to import 1,300 labourers to fill up the ranks depleted by the migration of employees to other Central and South American fields (Figure 2).

Figure 2. The spot where the U.S. Canal intersects the old French Canal on the Atlantic coast, June 1912.

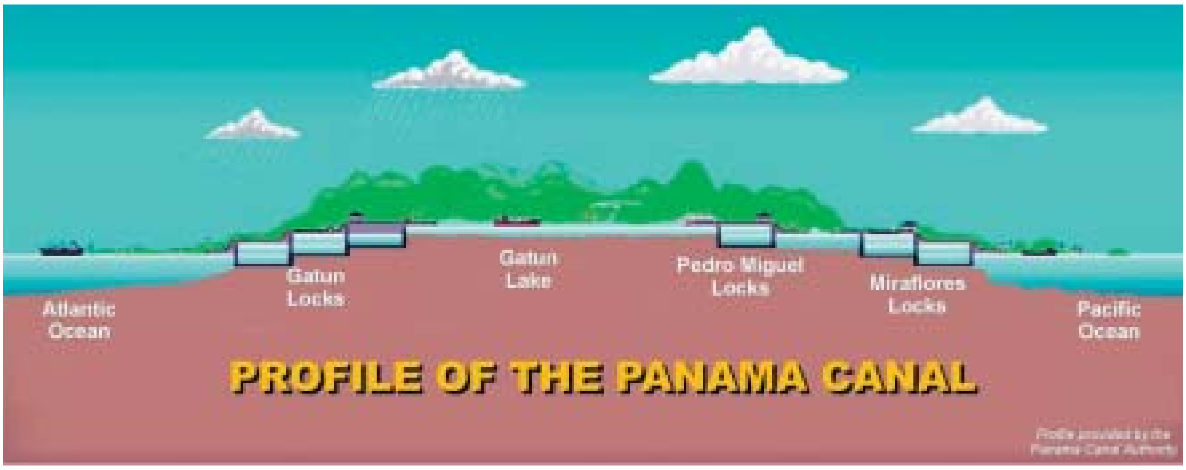


Figure 3. Profile of the Panama Canal, showing the locks and lakes that connect the two oceans.

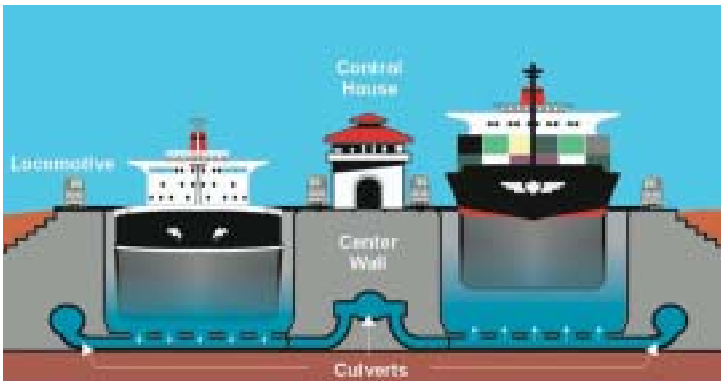


Figure 4. A cross-section of the Canal locks.

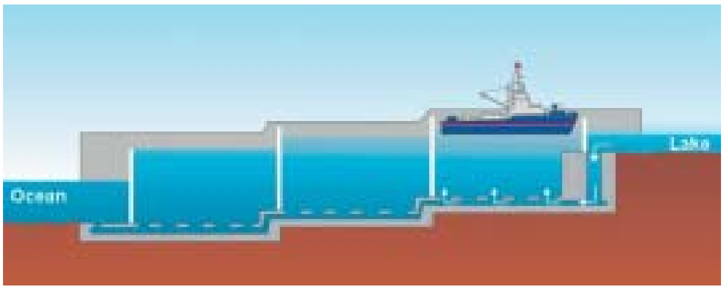


Figure 5. Elevation of the Canal locks chambers.

Spain furnished the largest number of European labourers to the canal until the government of that country, in 1908, forbad further emigration to Panama. The Spaniards also proved to be the most satisfactory common labour employed by the Commission.
Out of a total of 11,797 European workers imported in 1910, 8,222 were Spaniards, and the others came principally from Italy, France, and Armenia.

Black labour predominated in the Canal Zone and was obtained from the islands of the West Indies. Barbados furnished the largest number, 19,448; Martinique, 5,542; Guadeloupe, Jamaica, Trinidad, St. Kitts, Curacao, Fortune Islands, etc., 4,677 – a grand total of 29,667. Costa Rica, Colombia and Panama furnished 1,493; unclassified, 2,163. The largest immigration for one year was in 1907, when 14,942 laborers were imported, while in 1906, 12,609 arrived.

The American effort had excavated over 177 million cubic metres (232 million cubic yards) which when added to the 57 million cubic metres (75 million cubic yards) of the French effort came to 234 million cubic metres (307 million cubic yards). This is over three times the quantities that had been required for the building of the Suez Canal (Figure 3).

Operation and maintenance
Rather than the sea level canal attempted by the French, the American canal was a lock-type canal that involved an intermediate lake some 27 metres above sea level (Figures 4 and 5). Ships are raised in three lifts from sea level to the level of Gatun Lake, and then lowered in three steps on the opposite end of the canal. The locks are in pairs so that ships may transit in both directions at the same time, or two vessels may transit in the same direction at the same time in separate lanes. Initially the locks at Gatun had been designed as 28.5 metres wide. In 1908 the United States Navy requested that the locks should be increased to have a width of at least 36 metres. This would allow for the passage of U.S. naval ships. Eventually a compromise was reached and the locks were to be constructed to a width of 33.5 metres.

Each lock is 305 metres long with the walls ranging in thickness from 15 metres at the base to 3 metres at the top. The central wall between the parallel locks at Gatun has a thickness of 18 metres and stands in excess of 24 metres in height. The lock gates are made from steel and measure an average of 2 metres thick, 19.5 metres in length and stand 20 metres in height. The locks operations involve the gravity filling and draining of the lock’s chambers to raise and lower the vessels. Some 196,841 cubic metres (52 million gallons) of fresh water are used for each transit. The availability of a stable supply of fresh water was inherent to the successful operation of the canal.

After a slow start as a consequence of the aftermath of World War I, canal transits steadily grew both in numbers and size of vessels (Figures 6 and 7).

Constant maintenance and improvements marked the history of the canal. The entrance channels and the portion of the canal running through the continental divide, the 13.6 kilometre (8.5 mile) Gaillard Cut, required routine dredging to maintain navigation depths. Historically the canal, using its own dredgers, removed over 2.3 million cubic metres (3 million cubic yards) of material each year.

The widening of the narrow 76.3 metres (250 foot) wide Gaillard Cut commenced almost as soon as the canal was completed. Again in 1979 the Cut was widened to 164 metres (500 feet). This made the transit of the largest vessels safer. The number of so-called Panamax vessels grew rapidly in the 1990s and continues to grow at a steady rate (Figures 8 and 9).

The storage in Gatun Lake and the later-built Lake Alajuela (Madden Lake) proved satisfactory to meet the high demand for water to operate the canal. As transit levels and size of vessels continued to rise, the canal was faced with restricting the 13 metre (39.5 foot) operating draft during periods of dry weather as the lakes drew down. This proved particularly problematical in the late 1990s when the major impacts of El Niño were felt. Deepening of the Gaillard Cut began in the late 1970 as a measure to increase the usable volume of the lake for use by transiting vessels.

Labour force as the key

The smooth operation of the canal was dependent on a skilled work force and a commitment to constant maintenance and improvement of the equipment and the channels. The canal administration established a training programme to provide a constant supply of trained personnel to handle the large variety of jobs required for this labour-intensive type operation. As late as 1974, this work force was made up of 16,000 people (10,000 of them were American). As time and the availability of a trained Panamanian work force grew, the number of Panamanian employees continued to grow. But it was the tendency to reserve the best jobs for American employees that helped feed the long-simmering move by Panama to increase its participation in the canal and the benefits of its geographical position as a center for maritime trade.

Ultimately, this led to the signing of the Carter-Torrijos Treaties of 1977 that set in motion the complete transfer of the Panama Canal to the Republic of Panama by

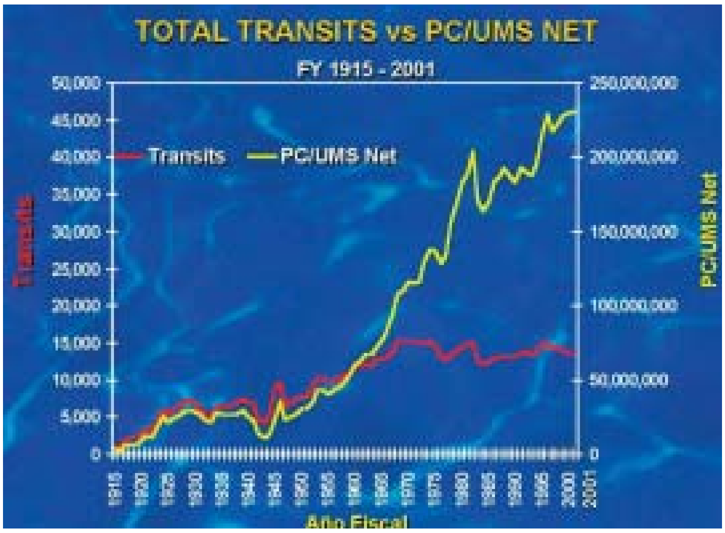
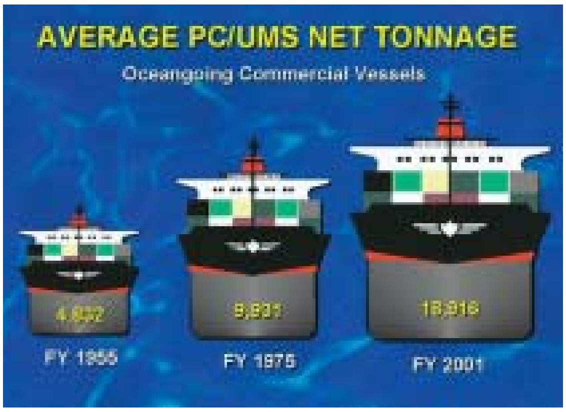


Figure 6. The number of transits from the Canal's opening (1915) to the present (2001).

Figure 7. The growth of vessel sizes from 1955 to 2001.



the end of the century. The history of the canal was punctuated with many attempts to negotiate treaties to increase Panamanian presence and participation. The 1977 treaties were the culmination of this long-standing objective by Panama. With the shedding of the civil government activities of the American operation, the Panamanian canal work force stabilised at 9,000.

The Transition Period

The treaties provided for a transition period of 20 years, during which portions of the American controlled lands and facilities were gradually moved to Panamanian control. At the same time, training of Panamanians to take over the skilled labour, technical and managerial positions necessary to run an efficient waterway would be accelerated. The programme to continue improvements to the canal continued through the transition period at a level of nearly $100 million annually. This meant continuing the widening and deepening of

Figure 8. A Panamax vessel going through a lock with very little room to spare.

Gaillard Cut, major channel improvements on the Pacific terminus of the canal, and the addition of new electric towing locomotives, towboats and structural improvements to the ageing locks.

This transition was felt at all levels. The board of directors of the canal operation first became bi-national, then with a majority of Panamanian members, and at last, with the final turnover, completely Panamanian. Likewise, the senior management was transformed into a completely Panamanian work force. By the time Panama assumed complete control over the Panama Canal on December 31, 1999, the American workers had been reduced to less than 300 from the earlier total of 10,000. During this transition period, canal operations and service were not only maintained, but improved transit times were experienced in the face of increasing numbers of larger vessels (Figure 10).

Figure 9. The number of Panamax vessels has grown in the last 35 years.

Figure 10. Canal Waters Times improved from 1999 to 2001, during the Canal's transition from U.S. to Panamanian control.

Table I. Panama Canal toll rates from 1914 to the present[1]. Charges by net tonne [2].

Laden		Ballast	Displacement	% Change
1914-1938	$1.20	$0.72	$0.50	0.0%
March 1, 1938-1974	$0.90	$0.72	$0.50	-25.0%
July 8, 1974-1976	$1.08	$0.86	$0.60	19.7%
November 18, 1976-1979	$1.29	$1.03	$0.72	19.5%
October 1, 1979-1983	$1.67	$1.33	$0.93	29.3%
March 12, 1983-1989	$1.83	$1.46	$1.02	9.8%
October 1, 1989-1992	$2.01	$1.60	$1.12	9.8%
October 1, 1992-1997	$2.21	$1.76	$1.23	9.9%
January 1, 1997-1998	$2.39	$1.90	$1.33	8.2%
January 1, 1998-present	$2.57	$2.04	$1.43	7.5%
Total increase since 1914	**$1.37**	**$1.32**	**$0.93**	**114.2%**

1 In general, vessel tolls are calculated based on their volumetric capacity, measured in net tonnes of 100 cubic feet; and other floating craft, including dredgers, floating dry docks and warships, are calculated based on their displacement. The only differentiation in the current tolls system is that vessels in ballast pay less than laden vessels.

2 The net tonne concept has changed throughout the history of the Panama Canal. The current measure in effect is the PC/UMS net tonne implemented in October 1994. Minimum tolls implemented in 1998 for small vessels are not shown.

The tolls for transiting vessels increased for the first time in 1974 and thence at regular intervals to reflect the increasing cost of operations and improvements. Table I shows the canal toll rates over the course of 85 years.

As of August 2002, the Panama Canal Authority (ACP) announced a change in the tolls structure for the Canal. The new structure includes factors for size of vessels, commodities and whether the vessel is laden or in ballast.

The New Era: Panama Takes Over

By the time the canal was placed under Panamanian control, the senior Panamanian managers had been successfully at the helm for a period necessary to allow the canal customers to face the future with confidence. Where the United States had George Goethals to bring its effort to a successful conclusion, Panama has Alfredo Aleman, the Canal Administrator to lead them into the future. Aleman has been at the helm since 1996 when he became the first Panamanian Administrator. He assembled a team of skilled technocrats and Panamanian managers to carry on the tradition of an efficient and innovative waterway operation. The Panamanian law that established the new Panama Canal Authority provided for an autonomy that maintains the political separation and integrity of the operation. Annex I is a description of the nature of the Panama Canal Authority.

Sensitive to the perception of Latin American governments being branded as corrupt, the senior canal officials have been rigourous in establishing and maintaining an image of transparency and honesty that marked the canal since its inception.
They have also stepped up the search for improvements to all aspects of the canal necessary to keep it competitive and in touch with maritime needs.
In short, the Panamanian Era has been brought in with determination, commitment and a move towards making the operation an example of a successful business model.

Panama Canal Facts

- From the Atlantic Ocean the Panama Canal runs south for 16 km (10 miles) and then eastward 64 km (40 miles) to the Pacific Ocean.
- When the French abandoned the project they had spent over twenty years and $260 million.
- When the Panama Canal opened to traffic in 1914, the United States had spent $352 million on construction.
- A train of flat cars needed to carry all the excavated material from the canal would circle the earth four times at the equator.
- The total soil excavated from the canal would build a pyramid 4,200 feet (1,280 metres) high.
- The project consumed as much as twelve million pounds of dynamite per year.
- Gatun Lake, the highest part of the canal, is about 26 metres (85 feet) above sea level.
- At the height of construction 9,000 workers were busy excavating Culebra Cut.
- The Commissary Department provided food for the entire work force and baked as many as six million loaves of bread, 650,000 rolls, and 250,800 kilos (114,000 pounds) of cake per year.
- Passage of the first ship through the canal took 9 hours and 40 minutes.
- When the canal opened tolls were set at $1.20 per tonne for freight and $1.50 per tonne for passengers. A freighter carrying a cargo of 4,500 tons paid a toll of $5,400.
- More than 850,000 vessels have used the waterway.
- The fastest transit was made by the US Marine hydrofoil,Pegasus, which passed from Miraflores through Gatun Locks in two hours and 41 minutes in June 1979.
- Upon completion of its maiden voyage on December 3rd, 2001, Panama Canal authorities confirmed that the luxurious passenger ship *Norwegian Star* paid $208,653.16 in tolls, breaking the toll record set earlier this year by the *Radiance of the Seas* with $202,176.76.

Canal improvements

The Canal Improvements Programme has been elevated to the highest management levels within the Canal administration. Deputy Adminstrator Ricuarte Vasquez is now tasked with direct oversight of the improvements programme and the programme is headed by Augustin Arias, an engineer with over twenty years of canal experience. The Department of Engineering and Projects has been given the resources and management responsibilities to push the programme with deliberation and expertise. The Canal Improvements Programme covers such diverse projects as:

- Enhanced Vessel Traffic Management System
- The Channel Deepening Project,
- Tugboat Augmentation Programme,
- Locks Towing Locomotive replacement and modernisations,
- Long-Term Water Supply Requirements, and project options for meeting traffic demand increases.

These are truly major improvement projects that are in the same league as the building of the canal at the outset.

Figure 11. The Gatun Lock as it is today, January 2003.

Post-Panamax studies

Currently the canal has contracts in place to study the possible alignments of a new large set of locks on both ends of the canal (Figure 11). These projects can result in construction costs of $4-12 billion. The deepening of the terminals is now being studied and could result in projects with excavation quantities of 30.6-53.5 million cubic metres (40-70 million cubic yards) of dry excavation and 11.5 million cubic metres (15 million cubic yards) of underwater excavation on the Pacific terminus and 11.5 million cubic metres (15 million cubic yards) of dredging on the Atlantic terminus. In all cases, the disposal of the excavated material is a major hurdle to be addressed. The canal plans to investigate such innovative disposal alternatives as an offshore island with an aim to make this area a commercial venture in and of itself.

The Panama Canal Authority has been working on canal expansion studies for several years and came to a preliminary conclusion that new locks should be designed for large 12,500 TEU container vessels. Presently, only 4,500 TEU container ships can transit the waterway. Authority officials say that the dimensions of post-Panamax locks would be 61 metres wide by 427 metres long and by 18.3 metres of clearance (compared to the existing 33.5 m by 305 m by 12.5 m), but depending on the results of the marketing investigation, post-Panamax lock dimensions may be adjusted.

Figure 12. The watershed which presently serves the Canal.

As part of the studies to determine the viability of expanding the waterway, the Panama Canal Authority awarded a contract for the conceptual design of the post-Panamax locks to the Belgium-French consortium Tractebel Development Engineering, Coyne-et-Bellier, Technum N.V., and Compagnie Nationale du Rhone. The bidding was open to the international community, and eleven proposals were received.

The contract, for $1,597,000, was awarded after considering the financial and technical aspects of the proposals received from American, British, German, Belgium-French, Brazilian, and Russian companies.

The conceptual design of the post-Panamax locks is a key element of the study plan for the expansion of the Panama Canal. The Authority decided to proceed with the conceptual design by means of two independent contracts to develop four different locks configurations and to identify the best option for the transit of post-Panamax vessels through the Canal. The winning consortium will develop the conceptual design for one and three-level locks on the Pacific. The Authority is simultaneously negotiating a second contract with the U.S. Army Corps of Engineers to develop two and three-level locks on the Atlantic. Both conceptual design efforts will include the use of water conservation systems, and both are due to be submitted during the course of 2003.

Figure 13. Drillboat Thor working in the Gaillard Cut on the next phase of deepening the cut to increase water storage in Gatun Lake. Six-inch holes are drilled, filled with dynamite and blasted. The fractured rock is then removed by the dipper dredger Rialto M. Christensen.

Channel deepening/water storage increases
The goal of the Gaillard Cut Deepening project is to increase the water storage capacity of Gatun Lake by 45 percent and augment the Canal's watershed output by 113,550 cubic metres (300 million gallons) of water per day (Figure 12). Deepening will directly benefit Canal customers by providing more efficient draft administration and reducing the impact of water shortages requiring draft restrictions on shipping. Additional storage will also permit meeting long-term demand for potable water for the metropolitan area that depends entirely on sharing the two lakes used for canal operations.

Approximately 6.7 million cubic metres (8.7 million cubic yards) will be dredged. Although the deepening will only be done along the navigational channel, it will, in effect, increase the lake's entire surface storage area, which represents a much greater volume than what will be excavated. The deepening will augment the Canal's total water reservoir volume, which includes Gatun and Alhajuela (Madden) Lakes.

The Authority is implementing more rigorous water conservation and management measures given the increasing demands caused by growing populations adjacent to the Canal watershed and anticipated long-term traffic growth. Current water storage of Gatun Lake is 2 metres (6 feet), from its maximum 26.7 metres (87.5 feet) above sea level up to its minimum operating level of 24.8 metres (81.5 feet).

The Panama Canal navigational channel has a width between 192 and 305 metres. The bottom of the navigational channel is currently at elevation 11.3 metres (37 feet), but when the deepening work is completed, it will be at 10.4 metres (34 feet). To guarantee that the channel bottom elevation is above 10.4 metres, it will be dredged to an elevation of 9.8 metres (32 feet), known as *dredging tolerance*.

The deepening will be completed using available Authority resources. The project will require drilling and blasting for rock material. For this project, the Authority's drillboat *Thor*, hydraulic dredge *Mindi* and dipper dredge *Rialto M. Christensen* will be employed (Figures 13 and 14).

Figure 14. Dipper dredger Rialto M. Christensen working on the channel deepening project at the Gaillard Cut.

Improvement Spectrum
The Department of Engineering and Projects now has 125 separate projects underway. Many of them are under contract to consultancies and have the potential result of becoming new sets of locks which will accommodate the larger vessels commonly used in the worldwide fleet. There are studies underway to look at the construction of three new major dams to create the additional water storage required to meet the projection of 26,000 annual transits or double the current number within the next 50 years.

The first major part of tying these improvements together is the development of a long-term master plan that will address capacity limitations and identify viable options. The plan is intended to be a progressive time-phased programme of project implementation to parallel traffic (and revenue) growth. It will provide for continuous and expanded service to the canal customers and do so at competitive costs to the user fleets.

Conclusions

As the Panamanian Panama Canal looks to the future, its customers are being assured that their interests and satisfaction remains a paramount consideration. To do this, the canal will continue to rely on a widely diverse range of skills of consultancies and contractors with worldwide experience. Under the present Panamanian leadership, there is certainly optimism for the canal user and those that supply the canal with consultancy and construction contracting services. In an effort to

ANNEX I
The Panama Canal Authority (Autoridad del Canal de Panama)

The Republic of Panama assumed full responsibility for the administration, operation, and maintenance of the Panama Canal at noon, Eastern Time, December 31, 1999. Panama complies with its responsibilities through a governmental entity, designated as Panama Canal Authority, created by the Political Constitution of the Republic of Panama, and organized by Law 19 of June 11, 1997.

The Panama Canal Authority is the autonomous agency of the Government of Panama in charge of managing, operating, and maintaining the Panama Canal. The operation of the Panama Canal Authority is based on its organic law and the regulations approved by its Board of Directors.

Due to its nature and importance, the Panama Canal Authority enjoys financial autonomy, own patrimony, and the right to manage it. The Authority shall have the exclusive charge of operation, administration, management, preservation, maintenance, improvement, and modernization of the Canal, as well as its activities and related services, pursuant to legal and constitutional regulations in force, so that the Canal may operate in a safe, uninterrupted, efficient, and profitable manner.

The Panama Canal Authority is led by an Administrator and a Deputy Administrator, under the supervision of a Board of Directors integrated by 11 members. The Administrator is the Canal's chief executive officer, and legal representative of the Panama Canal Authority, and is responsible for its administration and the implementation of the policies and decisions of the Board of Directors. The appointment of the Administrator shall be for a seven-year term, after which the person may be reelected for an additional term.
In accordance with the Political Constitution of the country and the Panama Canal Authority Organic Law, the Panama Canal Authority Board of Directors has the primary responsibility of establishing policies for the operation, improvement, and modernization of the Canal, as well as supervising its management. The 11 members of the Panama Canal Authority Board of Directors are appointed as follows:

- Nine Directors are appointed by the President of the Republic with the consent of the Cabinet Council and ratification of the Legislative Assembly by absolute majority of its members.
- A Director is designated by the Legislative Branch, who may be freely appointed and removed.
- A Director, who shall chair the Board of Directors and shall have the rank of Minister of State for Canal Affairs, is designated by the President of the Republic. The Minister for Canal Affairs shall have say and voting rights in the Cabinet Councils.

The appointment of the first Panama Canal Authority Board of Directors was done for staggered periods to guarantee its independence from any given government administration.

The Panama Canal constitutes an inalienable patrimony of the Panamanian nation; therefore, it may not be sold, assigned, mortgaged, or otherwise encumbered or transferred. The judicial regime established for the Panama Canal Authority has the fundamental objective of preserving the minimum conditions that make the Canal an enterprise at the peaceful and uninterrupted service of the maritime community and international commerce.

solicit the best expertise worldwide, the Authority Internet website (www.pancanal.com) has a full listing of advertised solicitations for all procurement of goods and services. The website also maintains and explains the objectives of the canal and the status of the operations and plans for the future.

References

Abbot, Willis J. (1914).
Panama and The Panama Canal in Picture and Prose.
New York, Syndicate Publishing Company.

Commemorative Album: *The Panama Canal Eightieth Anniversary - Providing Passage into the Twenty-First Century.*
Balboa Heights, Canal Zone. (August 1994.)

Department of the Army, Treaty Implementation Plan Agency (Undated.)
Implementation of the 1977 Panama Canal Treaty – An Overview.

Enscore, Dr. Susan I.; Johnson, Suzanne P.; Pedrotty, Michael A.; and Webster, Julie L. RA. (September 1997).
Historical And Architectural Documentation Reports for Albrook Air Force Station and Howard Air Force Base, Former Panama Canal Zone, Republic of Panama.
Headquarters Air Combat Command.

Knapp, Herbert and Mary (1984.)
Red, White, and Blue Paradise: The American Canal Zone in Panama.
San Diego, CA: Harcourt Brace Jovanovich.

McCullough, David (1977.)
The Path Between the Seas: The Creation of the Panama Canal, 1870-1914.
New York, Simon and Schuster.

Shaw, James L. (1985.)
Ships of the Panama Canal.
Annapolis, MD, Naval Institute Press.

Errata

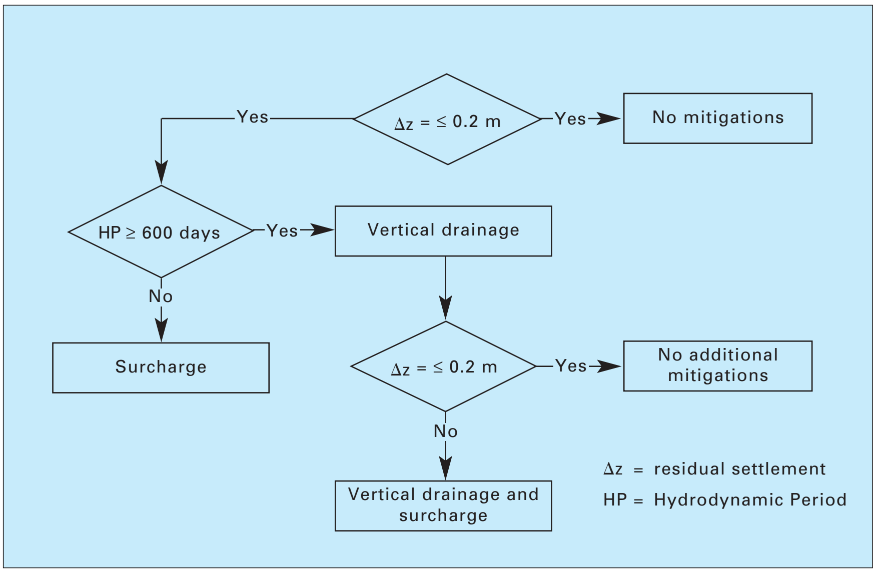
In *Terra et Aqua, Number 89, December 2002*, “Reclamation on Soft Suboil by Spraving Thin Layers of Sand: The IJburg Project near Amsterdam”, the followingcorrections should be noted:

Françios Mathijssen is presently a project engineer and geotechnical advisor at Hydronamic, the inhouse engineering department of Royal Boskalis Westminster nv. (page 10)

On page 18, first sentence, column 2 should read:
The representation of the Attenberg limits in the plasticy chart in Figure 14 indicates that the very soft Holocene clay layer is high plasticy clay.

Figure 19 on page 22 should be amended as shown below:

Figure 19. Decision-tree for improving engineering properties.



Chakib Biar

Geographic Information Systems for Modelling Sediment Transport and Deposition in Harbours

Abstract

The limit between the land and the sea is an unstable and vulnerable area. It is exposed to multiple aggressions and undergoes changes generated by hydrodynamic factors. Such factors cause erosion and depositions that may be harmful to the natural balance of any site or seaport. Therefore, constant tracking is necessary to determine and possibly control the evolution of the sea bed.

DRAPOR is a state-owned company in charge of navigation works maintenance in the seaports of the Kingdom of Morocco. It is seeking new possible ways to know in advance sea bottom levels in order to optimise dredging operations. Hence, the initiative to study the prospects of G.I.S. application in modelling sediment transport and erosion inside seaports. In various sections, this paper deals with sea phenomena that cause sediment transport. It also examines the mathematical models used for the purposes of sediment transport modelling, the general design of a prediction model for sand encroachments and erosions inside any seaport that is subjected to shoreline transit. Besides, in view of the necessity to give an example of integration of the various mathematical models in a Geographical Information System, an application has been developed with the Arcview G.I.S. 3.2 software using *AVENUE* language. Such application would make it possible to assess coastline evolution during the construction of a protection structure, namely a cross-shore jetty. The application hence made proved that the combination of mathematical models of sediment transport with a G.I.S. provides a tool that has management, analysis and processing capabilities and that is able to simulate coastline evolution after the construction of any coastal structure.

This article was first presented as a paper at the CEDA Dredging Days in Morocco, October 2002, and appears here in a slightly adapted version with permission.

Introduction

The sea coast is undoubtedly the area that has, at all times, stirred the interest of man if it were only for the fact that most countries were discovered, colonised and developed from the sea because navigation is the means of transport that man has mastered for a long time. No surprise then that the coastal areas have witnessed the erection of all kinds of structures first for economic and trade purposes, then, in more recent times, for tourist attraction purposes. Hence, man has come to know the techniques of maritime hydraulics when he learnt that the frontier between land and sea is most of the time particularly vulnerable and that it cannot be altered without special precautions being taken in advance.

Engineers found themselves quickly faced with some problems:

- sand encroachments which are very often a hindrance to the smooth operation of ports, and
- erosions with the conceivable consequences they can have on the various infrastructure built on the coast.

This paper lies within this perspective as it is aimed at assessing the potential uses of Geographical Information System (G.I.S.) applications in predicting the incidence of sand encroachments and erosions by means of mathematical models of sediment transport in harbour areas.

Erosion and Sediment Deposition in the Sea

Under the action of waves, currents or wind, solid particles that form sediments may be snatched from the bottom of the sea and carried in suspension or on the seabed over more or less long distances to be deposited in still areas.

Diversity of coastline factors

Diversity of coastline currents

As they approach the shore, the waves generate various kinds of currents: currents of oscillation on the seabed, currents of translation in the boundary layer, currents of compensation in the body of water, long-shore currents in parallel with the shore. Under tidal action, currents may begin along the coast then change direction according to the time of tide. The winds have considerable impact on the coast currents. The speeds and directions of such currents are, in general, closely linked to the wind climate but with some delay.

Morphological diversity of the seabed

The shape of seafloor profile is significant for the problems of sediment transport owing to hydrodynamic action and so are the nature and thickness of mobile sediments that cover the rocky substratum.

Sediment diversity

There are two configurations of sediments:

– cohesive sediments: the cohesion of sediments results in that particles tend to form rudite in which the particles stick to each other;
– non-cohesive sediments: Non-cohesive sediments contain coarser sediments which are not subjected to any interaction and which can, therefore, move independently from one another.

Behavior of sediments under the action of waves

Sediment transport perpendicular to the coastline

As they are suspended in the waves orbit movements, solid particles may be displaced inside the profile. They are carried towards the coast in the currents of translation or they are swept from the shore by the breaking waves. The coarsest sediments build up to form a swash near the breaking waves while the finer sediments can be scattered in the open sea by the currents of compensation. The movement inside the profile entails erosion of the coast as well as accretion of the small seabeds during storms and vice versa when the weather is fine.

Sediment transport in parallel with the shore

Under the action of oblique waves, a wave current originates and goes along the coastline forming a real "littoral river" comprised between the coast and the surf zone. The current is likely to carry considerable suspended loads or bed loads which were taken from the sea floor by the current of translation or from the coast by the wave.

J. Larras (1955) considers that an acceptable estimation of the speed of the wave current may be obtained by taking:

$$V = 2.6 \times \left[\frac{g H^2 i \sin(2\alpha)}{T} \right]^{1/3}$$

Chakib Biar (left) receiving the IADC Award from Mr Peter Hamburger; Secretary General of the IADC.

IADC Award 2002

Presented at the CEDA Dredging Days, Casablanca, Morocco October 22-24 2002

For the first time ever, the CEDA Dredging Days, were held outside of Europe in Casablanca, Morocco. As part of this conference, an award for young authors was presented by the International Association of Dredging Companies (IADC) to Mr Chakib Biar. Mr Biar received his degree with honours as a Surveyor Engineer from the Hassan II Agronomic and Veterinary Institute in Rabat, Morocco. He worked for a year with the dredging company Drapor developing under the ArcView GIS a module for the modelling of bottom changes in harbours and during dredging.

Each year, at selected conferences, the IADC grants awards for the best papers written by authors younger than 35 years of age. At each of these conferences, the Paper Committee is asked to recommend a prize-winner whose paper makes a significant contribution to the literature on dredging and related fields. The purpose of the IADC Award programme is "to stimulate the promotion of new ideas and encourage younger men and women in the dredging industry". The winner of an IADC Award receives US$1000 and a certificate of recognition, and the paper is then published in *Terra et Aqua*.

Where:

- H Amplitude of the breaking wave
- i Beach average slope (expressed in its tangent)
- α Obliqueness of the waves from the open sea to the shore
- T Wave period

Various studies have shown that shoreline transit of fine sand depends on the result of the wave transport and may be expressed as follows:

$$Q = \left[\ (Kg/c) \right] x\, H^2\, T \qquad f(\alpha)\ t$$

Where Q is the cubic-metre volume carried by the wave at an amplitude H (in metres) and over a period T (in seconds) showing in beds ranging between 15 and 20 m an obliqueness (α) to the coastline and over some time T (in seconds).

The various expressions used for the function f(α) are: Sin (7α /4), Sin (2 α), and so on, while the term (Kg/c) describes the coefficient of sand transport and remains approximate to $0.4{,}10^{-5}$ for the finest-grained sand of 250 microns, and to $0.2{,}10^{-5}$ for coarser sand of 1 mm.

Impact of maritime works on shoreline transit

The overall scheme of shoreline sand transit may show a significant transport activity in the surf zone which acts as a center of attraction of sediments where the largest quantity of material will be suspended and may later be carried in the general direction of the wave current.

Depending on the position of a maritime works in relation to the surf zone or, more accurately speaking, the swash, shoreline transit may be intercepted in whole, deviated along the works leading to a very confined concentration of sediment transport or will finally be very slightly disturbed by the works if it is located very near the coast.

Works erected at great depths

Such works are likely to hinder most of the transit activity and may be illustrated by three seaport types:

1. Seaport allowing shoreline transit (Figure 1).
   The accumulations along the secondary jetty depend on the configuration of the coastline and the general direction of the dominant waves. After secondary accumulation along the jetty is done, sediments may reach the entry passage and clog it during storms.

2. Seaport in the opposite direction to shoreline transit (Figure 2).
   Accumulations in the windward zone are relatively slight in view of the transit. A good part of the deposit is scattered in the open sea where they accumulate in small beds areas. Along the secondary jetty and the passage of entry to the port, sedimentation

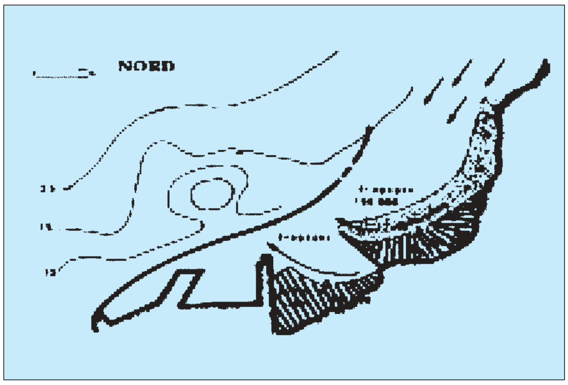
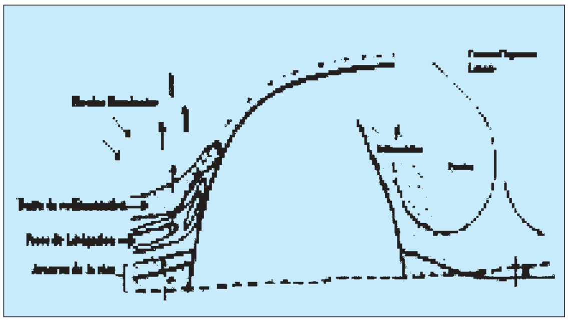


Figure 1. A seaport allowing shoreline transit (Migniot, 1977).

Figure 2. A seaport not allowing shoreline transit (Migniot, 1977).



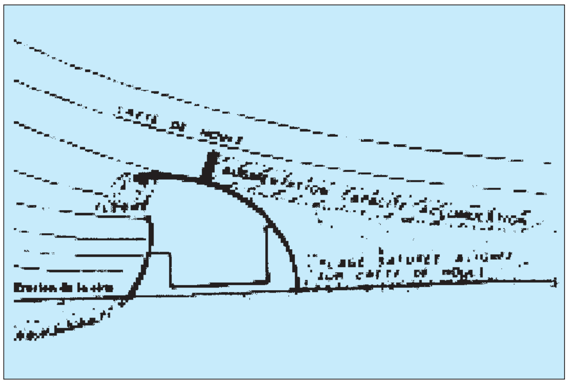
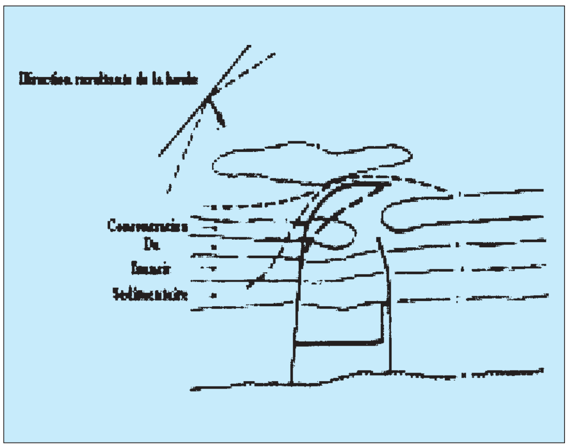


Figure 3. Seaport accumulating the shoreline transit (Migniot, 1977).

Figure 4. Seaport set-up at a medium depth (Migniot, 1977).



occurs due to the supply of the swell side-to-side expansion current which originates in the area protected by the seawall.

3. Seaport accumulating shoreline transit.
   When the beach is saturated and becomes aligned with the crest of the wave (Figure 3), sands will pass over the works to form a rise in front of the pass unless shoreline transit is stopped with the works completed at 1.0 or 1.5 km from the port.

Works set up at medium depths from 5 to 7 m (Figure 4)
Such works would form a tight screen to shoreline transit in the whole small beds area. The sediments that move ordinarily in that area will hence be deviated seaward and increase the amount of solid flow into the swash. In order to take in the excess amount of solid flow, the depths in that part of the swash will decrease to create an equilibrium between the possibilities of tidal transport at that spot and the quantities of sediment supply.

Works set-up near the coast at low depths
Such works have only a very limited effect on shoreline transit inside the swash. The entry passage can be protected only from the material transported into the sea by the foreshore. Protection of the entry passage must not be too heavy as it is likely to create a zone of expansion of the wave that carries sediment supply.

Mathematical Models of Sediment Transport

From the point of view of physics, phenomena related to sediment transport in the areas near the coast and the morphological changes the coast goes through (erosion and sedimentation) are all subjected to hydraulic and hydrodynamic forces. Therefore, any design, construction or operation of a coastal structure must be based on a comprehensive study of such factors.

Depending on the degree of turbulence and on the power of the long-shore current, there are two kinds of sediment movement:
1. Bed Load Movement formed by the grains that roll on when they come into contact with the sea bottom or move in little successive hops and touch the bottom from time to time.
2. Suspended Load Movement when the carrying fluid, namely water, contains a high concentration of sediments as it nears the bottom which rapidly decreases towards the surface.

Formulating models of sediment transport
There are three models of sediment transport examined:
– the general equation of bed variation;
– mathematical bed load models; and
– mathematical suspended load models.

The General Equation of Bed Variation
The mathematical relation that predicts coastline or depth development in a coastal area subjected to considerable sediment movement is derived from the mass conservation principle of moving grains.

By defining the aggregate volume of the sediment load along the horizontal directions x and y by q_{sx}, q_{sy}, q_{bx}, q_{by}, where s = "suspended load" and b = "bed load" ([q]=m3/m/s) while, for a pseudo-horizontal bed, the bed variation dependent on time ∂_b is given by (Christopher, 1984):

$$\frac{\partial \delta b}{\partial t} + \frac{\partial}{\partial x}(q_{sx} + q_{bx}) + \frac{\partial}{\partial y}(q_{sy} + q_{by}) = 0$$

Mathematical Bed Load Models
This kind of transport concerns only a thin area beneath the bed. In case the bed is smooth, the thickness of this area approximates (2-3)D_{50} where D_{50} is the average diameter.

DUBOYS suggests a simple and practical relationship to quantify the bed load:

$$q_b = x \cdot \tau_b \cdot (\tau_b - \tau_{cw})$$

where x is a dimensional factor whose value depends on the size, geometry and specific weight of sediment grains.

$$\tau_{cw} = \tau_b \; 1 + \frac{1}{2}\left(\zeta \frac{\hat{u}b}{U}\right)^2$$

Where:
- τ_b *Bed shear stress exerted by the current only.*
- ûb *Speed of the wave current near the bed.*
- ζ *Dimensionless factor depending on the coarseness of the bed.*

Mathematical Suspended Load Models
Depending on the shape and dimension of sediments as well as the turbulence of flow, sediment transport may occur without sediments touching the bed.
This requires that the speed w_f at which grains fall be lower than the turbulence vertical component.
The dimensionless factor that defines such requirement is the factor z* (Christopher, 1984):

$$z^* = w_f \,/\, (\beta \cdot K \cdot U \cdot u^*)$$

Where:
- β *Ration (current scattering/viscosity)*
- K *Von Karman constant (≈ 0.4)*
- U *Average flow speed*
- u* *Speed of abrasion depending on the current (waves + currents)*

$$u^* = \sqrt{(\tau_{cw} / \rho)}$$

The equation that defines suspended sediment transport in a quasi-horizontal flow is expressed as follows:

$$\frac{\partial c}{\partial t}+\frac{\partial(cu)}{\partial x}+\frac{\partial(cv)}{\partial y}-w_f\frac{\partial c}{\partial z}=\frac{\partial}{\partial x}\left(\epsilon_h\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(\epsilon_h\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial z}\left(\epsilon_v\frac{\partial c}{\partial z}\right)$$

In accordance with the definition of concentration, *c* defines the volume of sediments in mixture volume unit (grains + water). The suspended load is given by the integral depending on the degree of depth:

$$Q_{SX} = \int_{-h+a}^{0} UC.DZ, \quad Q_{SY} = \int_{-h+a}^{0} VC.DZ$$

The integration is restricted to a distance *a* above the bed that is equal to the thickness of the area where transport is carried out on the seabed.

The average concentration of sediments in such area is:

$$c_a = q_b / (a.u_a)$$

where u_a represents the average velocity of the bed load.

At a distance *a* from the bed, the rate of sediment deposition is given by the product $w_f.c$. The erosion rate is given by the product $\epsilon_V.dc/dz$

$$D = W_F\, C/_{Z=-H+A}\ , \ E = -\epsilon_V.DC/DZ\ /_{Z=-H+A}$$

The distribution of the coefficient of vertical scattering is given depending on the vertical distribution of viscosity v_v:

$$\epsilon_v = \varphi\ .\ \beta.\ v_v$$

Where:

- β *Dimensionless factor (2> β >1) that describes the variance in behavior between fluid and particles in a stirred environment.*
- φ *Dimensionless factor that describes the impact of a significant concentration of sediments on the hydrodynamic forces.*

Recent research suggest that a ϵ_v value can be assigned to the upper half of the depth, a constant that is equal to $\epsilon = \epsilon_{max}$

For a given distribution of $\epsilon(z)$, the concentration *c(x, y, z, t)* over an *h* depth is given by:

$$c\,(z) = c_a \left(\frac{h-z}{z}\ \frac{a}{h-z}\right)^{z^*}$$

The *c(z)* function is defined in the range *z = 0 to z < h–a.*

To calculate the z* factor, the formula of logarithmic series distribution of u(z) speed is given by:

$$u\,(z) = \frac{u^*}{k}\ ln\left(\frac{h+z}{z_o}\right)$$

k coefficient depending on the environment

with $z_0 = k_s/33$ and z is measured from the surface down to the bed (k_s = absolute bed roughness equal to half the height of the bosses).

The aggregate load is hence defined by the sum $q_t = q_s + q_b$.

Shifting the coastline

Any obstruction (groins, seawalls, and so on) that lies in the way of solid sediment transport driven by the dominant wave results in an accumulation on the « windward » side of the groins and in an erosion of the "lee" side (Figure 5).

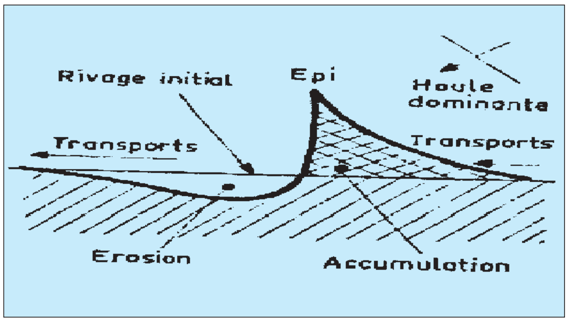


Figure 5. The impact of an obstruction on the coastline (Bonnefille, 1982)..

Penlard-Considère's theory allows the computation of the coastline development in the area of accumulation on the basis of some hypotheses which have proved to be true in the case of pebble beaches.Those basic hypotheses are as follows:

– The characteristics of the wave are constant over time.
– The flow of solid sediments in an abscissa section *x* depends only on the amplitude H_{br} and on the angle φ_{br} between the breaking wave and the local coastline: $Q = f\,(H_{br}\,\varphi_{br})$
  $Qbr = -\varphi'_{br} + \tan^{-1}(dy/dx)$; $H_{br} = H/k$

- *k* *Wave breaking coefficient*
- *H* *Amplitude of the incident wave*
- φ'_{br} *Angle between the breaking wave and the x axis*

If *y(x,t)* is the coastline ordinate depending on *x* and on time *t*, the evolution of *y* in relation to time is:

$$dy/dt = (1/h).(dQ/dx)$$

The result of the computation of the values of $y(x_v,t_n)$ and $Q(x_v,t_n)$ in typical areas defined by indices *i*, in horizontal space *x* and in temporal space *t*.

The equations that have to be resolved successively and repeatedly are:

$$\varphi'_{bri} = -\varphi'_{bri} + TAN^{-1}\left(\frac{Y_i^n - Y_{i-1}^n}{\Delta x}\right),$$

$$Q_i^{n+1} = f(H_{br\,i}, \varphi_{br\,i}),$$

$$Y_i^{n+1} = Y_i^n + \frac{(Q_{i+1}^n - Q_i^n)\,\Delta t}{\Delta x.h}$$

Geographic Information Systems

According to the definitions given in *Le Petit Larousse*:

- A *System* is "a combination of components brought together to form a whole".
- An *Information* is "an element of knowledge that can be encoded to be kept, processed or communicated".
- *Geographic* means "that is relevant to geography and aiming at describing the surface of the earth".

In this instance, the term "system" means in general an *information system* with information science being "the science of automatic and relational processing of information as a vehicle of knowledge and communication using hardware and software".

However, such a purely structural description does not clearly define the idea of G.I.S. especially as compared to automatic mapping systems as, in fact, *"a Geographic Information System is a group of numeric data which are geographically located and structured inside an information processing system equipped with functional applications that allow the building, modification, questioning and map representation of the data base in accordance with semantic and spatial criteria"*.

Use of G.I.S. in the Management of Coastal Areas

As a response to the value that the coast has taken on and to the propagation of protection works, new coast management techniques have emerged based on the discipline called Integrated Coastal Zone Management (ICZM). That subject brings together a number of specialised disciplines with the participation of coastal zone specialists, biologists, social scientists, and so on.

Basic concepts of Integrated Coastal Zone Management

This discipline is based on the structuring and coordination of the various activities and resources available in the coastal zones with the purpose of ensuring its development on the economic, environmental and social planes.

An ICZM plan puts forward an all-inclusive solution that guarantees a balanced development in various fields such as:

- protection of the coast and the shoreline;
- agriculture and fishing;
- housing developments, infrastructures, industries, navigation and public utilities;
- conservation of the natural heritage, and so on.

Advantages of Geographic Information Systems (G.I.S.)

The main hurdle in any coastal zone management plan is the huge quantity of data that have to be processed in order to help the specialists find the most adequate political and social solution to achieve development.
It is within such context that Geographic Information Systems are called on to draw benefit from their capabilities of collection, analysis and processing of loads of data.

Here are some examples of the kinds of data that may be integrated in a G.I.S. within the framework of an ICZM plan: charts, aerial photographs, satellite pictures, river lines, vegetation species, sediment types, population density, climate, pollution sources, development areas such as seaports, cities, and such. Now, it is clear that G.I.S. are a powerful tool whereby various types of data can be collected, structured, organised, and processed before being finally handed down to various experts who can use them easily.

The use of Geographic Information Systems to manage and analyse the various data from various disciplines gives experts a tool with which they can:

- edit charts;
- lay down basic conditions;
- manage data;
- identify problems and their causes;
- generate prediction models;
- simulate data for the calibration of digital models;
- assess the impact of any management plan;
- generate management scenarios; and
- report results.

Model for the Prediction of Sand Encroachments and Erosions in Seaports

This model is intended to optimise the dredging operations by improving the predictions concerning the volumes that have to be extracted as well as the areas of action (Figure 6).

Data analyses

Port-relevant data

(a) Bathymetric Mapping: A bathymetric mapping is the basis of simulation of the action of hydraulic and hydrodynamic factors.

(b) Material Characteristics: Knowing the physical and

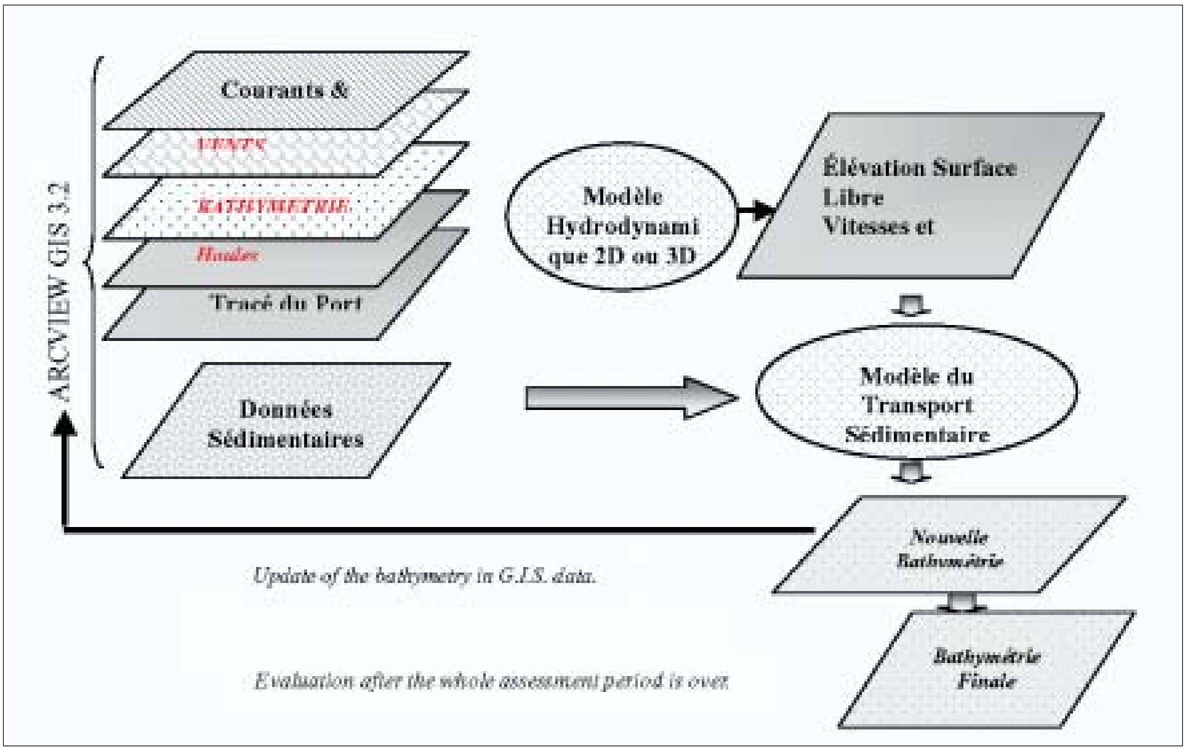


Figure 6. Design scheme of the prediction model of sand encroachments and erosions.

chemical characteristics of the materials that form the seabed allows the sampling of unstable and high-turbulence zones.

(c) The Site Lay-Out Plan: The site lay-out plan represents the general infrastructure of the site (quays, jetties, coast, and so on). It serves as a basis for integrating the phenomena of refraction, diffraction, and currents reverberation on obstacles.

Oceanographic and meteorological data

(a) Data Relevant to the Waves:
This is a comprehensive description of the three parameters relevant to the waves during the whole assessment period: significant amplitude, incidence angle and wave period.

(b) Data Relevant to the Studies of Currents:
In order to assess the action of both the wave and the currents, it is necessary to have a detailed description of the direction together with the speed of propagation of all the currents on site.

Analyses and processing

Computation of the agitation of the free surface

It is a matter of resolving the hydrodynamics equations model that results in a regular grid where each point is marked with the elevation of the free surface, flow density, flow direction and propagation speed of water particles.

Simulation of sediment transport

Once wave agitation is defined on site, the directions and speeds of sediment flows can be made out.
The loads of solids transported, whether seabed or suspended loads, have then to be calculated using the DUBOYS equations. After that, sediment concentrations in movement are deduced at every site point.
Eventually, the deposit rate D and erosion rate E are calculated in relation to the speeds and concentrations arrived at. The bathymetry hence reached replaces the original bathymetry and computations are resumed all over again.

It must be noted, though, that the G.I.S. is used all along this process. It takes care of:
– organising input data layers;
– managing the intermediate data in the data base;
– implementing the application if the G.I.S. software has a programming code, and
– laying out the results arrived at under separate themes which attributes show all information on the site development.

Bathymetry is reached all over the site and may be used:
– to sample the bathymetry relevant to the seaport zone;
– to define the areas where sand encroachments or erosion have occurred by comparing the original bathymetry and the bathymetry arrived at in the end;
– to sample the areas where the seabed exceeds the limits that ensure vessel access.

Model for the Prediction of Coastline Evolution

Within a practical approach, an example of integration

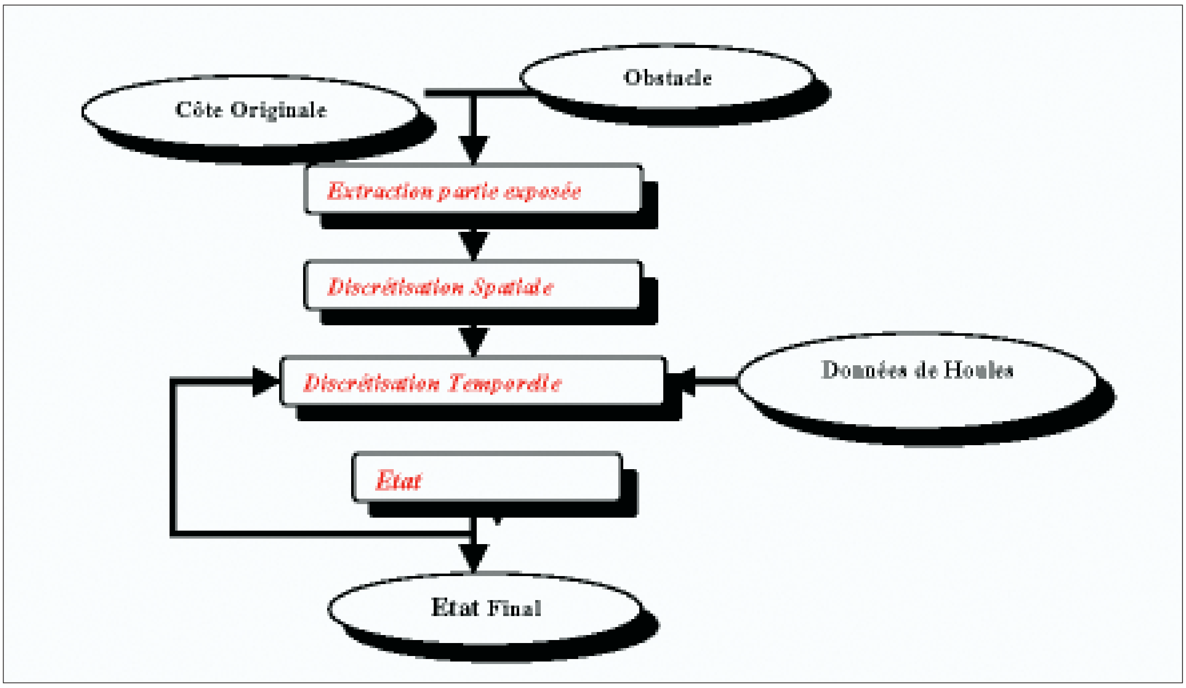


Figure 7. Design Scheme of the Prediction Model of Coastline Evolution.

of the various mathematical models and notions of marine hydrodynamics is introduced in a G.I.S. destined for the management of coastal areas (Figure 7).
It concerns predicting the behaviour of the coastline under the impact of the construction of protection works (seawalls, groins, jetty).

About the area under study
Lying on the Atlantic coast, at 9°15' longitude west and 32°18' latitude north, the port of Safi is set up inside a large bay that shelters it from the south-west storms.

Results of the model of coastline evolution
The data used firstly in the model are shown in Table I below.

The results yielded by the model using those data are as in Figures 8 and 9.

The results given by the model are acceptable in consideration of the input data. It must be noted, however, that such evolution is computed bearing in mind that no dredging was carried out during the test period.

In order to have better results:
- data accuracy can be improved by dividing the assessment period in homogeneous data periods based on studies and statistics provided by the seaport operation and management authorities; and
- a comprehensive study of sediment dynamics in situ can be carried out in priority and a shoreline transport formula can be adapted.

Impact of temporal discretisation
Temporal discretisation (TD) requires dividing the total duration of assessment into a series of equal intervals whose length is defined by the user. The smaller the discretisation is, the more logical the outcome of the assessment will be.

In Figure 10 are some examples of assessment using different parameters.

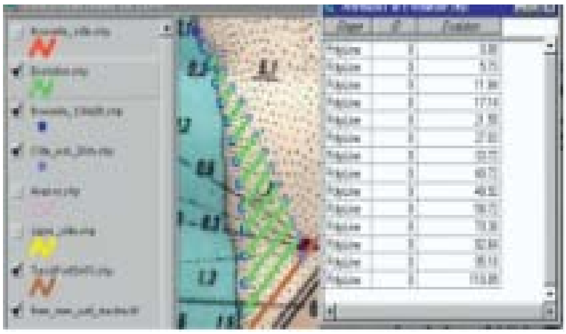


Figure 8. Evolution of shore points.

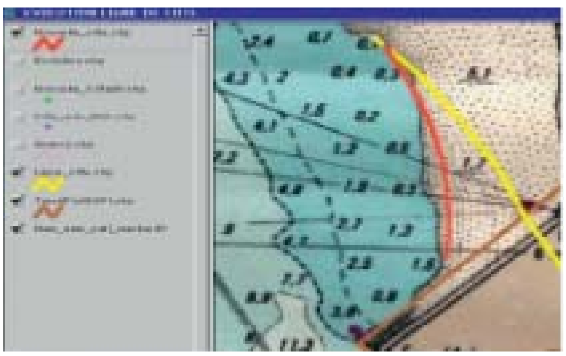
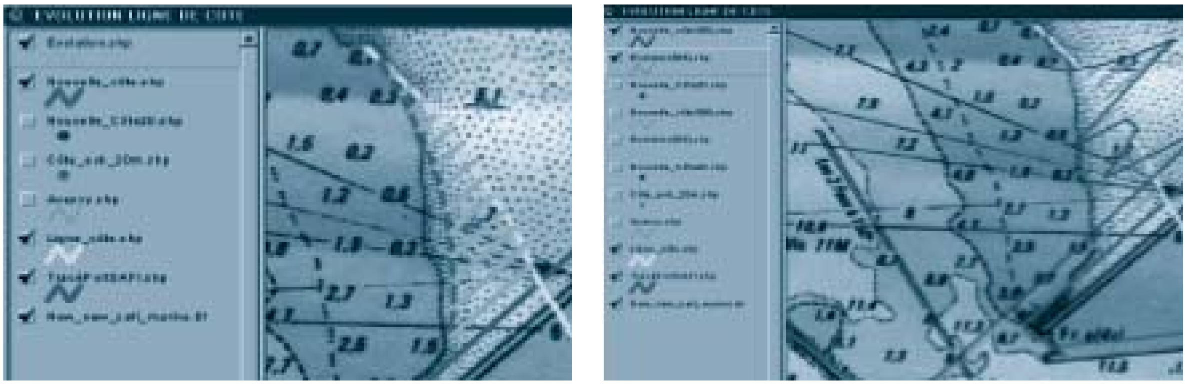


Figure 9. State of the coast after one year.

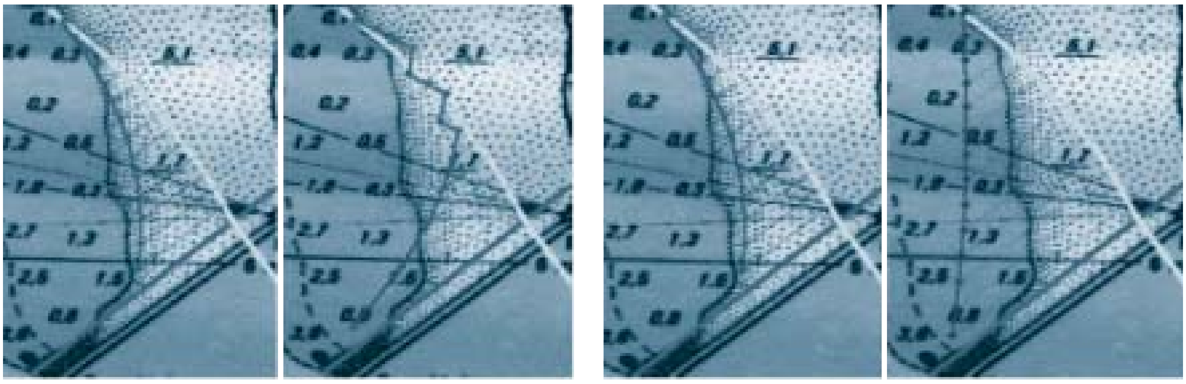
Table I. Data of the Coastline Evolution Model.

Wave	Breaking Amplitude Period Incidence Angle to Breaking Coefficient Depth of Influence	1.5 m 9 seconds 50° 1.25 5 m
Spatial Discretisation	PAS	20 m
Temporal Discretisation	Interval for Discretisation Total Test Duration	1 day 365 days
Transport Formula	$Q\ (m^3) = (1/10000) * H_{br}^2 * T * Sin\ (7*\varphi_{br}/4)$	



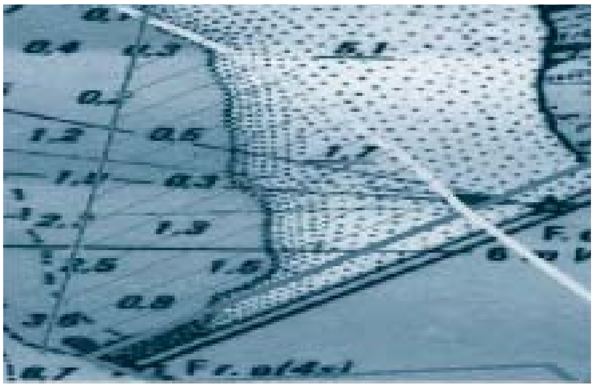
TD = 1 day and Total Duration = 365 days.   TD = 10 days and Total Duration = 1 year.

Figure 10. Evolution of the coastline with various temporal discretisation instances:



H_{br} = 1.5 m and φ_{br} = 45° (⟵) then φ_{br} = 35° (⟶) H_{br} = 1.5 m and H_{br} = 3 m (⟵) then φ_{br} = 50° (⟶)

Figure 11. Evolution of the coastline with various wave data.



$Q_1(m^3) = (10^{-3}) * H_{br}^2 * T * Sin(7*\varphi_{br}/4)$

$Q_2(m^3) = (10^{-4}) * H_{br}^2 * T * Sin(2*\varphi_{br})$

Figure 12. Evolution of the coastline with various transport formulae.

Impact of the wave data

Various results are presented in Figure 11 with various data to show the significant impact of the incidence angle and the amplitude.

Impact of the transport formula

The results reached using various formulations are shown in Figure 12.

It is observed that the solid transport formula is important and, therefore, it is necessary that it should be carefully worked out on the basis of statistical and dynamic study in the long run.

Conclusion

Sea phenomena, and more specifically sea coast phenomena, are too complex to be represented in a dependable manner using mathematical and empirical models. These models are the outcome of many a hypothesis and omissions of natural factors such as salinity and temperature. Progress in this field is still in process. However, unless the calibration of such models is based on long-term studies that are continuously updated, sound management of coastline zones development will remain doubtful.

Owing to their capability to manage and organise loads of data, which is their main asset, Geographic Information Systems (G.I.S.), are capable of modeling reality. By combining G.I.S. with the previous mathematical models, a powerful tool is created that is fully equipped to ensure sound management of coastal territory.

References

BonneFille, R. (1989).
Séminaire sur la protection du littoral contre l'érosion et des ports maritimes contre l'ensablement: Quelques aspects de l'ensablement des ouvrages maritimes.

Charrouf, L. (1992).
Littoral Nord du Maroc, Données Sédimentologiques, Direction des Ports.

Christopher, A. (1984).
Mathematical Models of Coastal Enginnering, Edition MASSON.

Migniot, C. (1977).
Action des courants, de la houle et du vent sur les sédiments, Extrait de LA HOUILLE BLANCHE, N° 1.

Nielson, P. (1988).
Three Simple Models of Wave Sediment Transport, Coastal Engineering, pp. 12, 43-62.

Savioli, BeenFeldt et Appendini (2000).
GIS-Based Tools and Numerical Models : a Powerful Combination for Shoreline Management, Danish Hydraulic Institute, Le Danmark.

WU.F.H.Y (2001).
Hydrodynamic Models and Their Applications, E-O.Tech. Inc., USA.
www.WorldNet.att.net/eot.cp.

Websites:
www.dhi.dk
www.appliedcoastal.com/service4.htm
www.einseeiht.fr/hfm/travaux/CD0001/travaux/optsee/hym/17

Charles W. Hummer, Jr.

Books/ Periodicals Reviewed

Fine Sediments Dynamics in the Marine Environment; Proceedings in Marine Science
Elsevier Science B. V., Amsterdam,
The Netherlands, 2002. Hardcover, 713 pp, illustrated.
Edited by Johan C. Winterwerp and Cees Kranenburg

This book represents the proceedings of the INTERCOH–2000 conference on recent progress in cohesive sediment research. INTERCOH–2000 was the sixth in a series of conferences that began in 1984 and was integrated with the final workshop of the COSINUS project. Almost all European cohesive sediment workers were involved.

The conference focussed on the behaviour and modelling of concentrated benthic suspensions (CBS), i. e. high-concentrated near-bed suspensions of cohesive sediments. Special emphasis was given to the following subjects and the papers of the proceedings are organised in chapters accordingly:
– Sediment – turbulence interaction,
– Flocculation and settling velocity,
– High-concentrated mud suspensions,
– Processes in the bed – consolidation,
– Processes on the bed – erosion,
– Field observations on mud dynamics
– Instrumentation, and
– Numerical modelling.

The proceedings begin with a paper by Prof. Jean E. Berlamont that aptly states the general relevance of the subject of fine sediments to the port and waterways industries:
"The managing authorities of coastal waters and estuaries face a large number of problems related to cohesive sediment transport, sedimentation and erosions, such as:
– How to maintain safe navigable depths (at minimum cost)?
– Where and how to dump dredged material?
— How can the volume of wetlands be maintained or increased?
— What will happen to the location of the turbidity maximum after constructing new harbour basins or deepening the navigation channels?"

This series of questions posed at the outset of the proceedings reveals the wider interest the conference should have to those not as intimately involved with the otherwise muddy subject of cohesive sediments. Prof. Berlamont postulates that the answers to the questions posed lies in a model capable of simulating the many different and interrelated sediment processes occurring in coastal and estuarine waters.

The goal of the COSINUS project was to contribute to the development of such an integrated sediment transport management model. The project was structured into six sub-tasks:
— Task A – turbulence modelling of sediment-laden flow: turbulence damping and turbulence production (internal waves) in concentrated suspensions.
— Task B – flocculation: floc model development.
— Task C – CBS dynamics: generalised entrainment model and generation and properties of CBS. (CBS is concentrated benthic suspensions or "fluid mud").
— Task D – bed dynamics: bed strength model and erosion/entrainment model.
— Task E – parameterisation, the implementation of the process models in the schematic estuary and the two test cases.
— Task F – Set-up and management of the database.

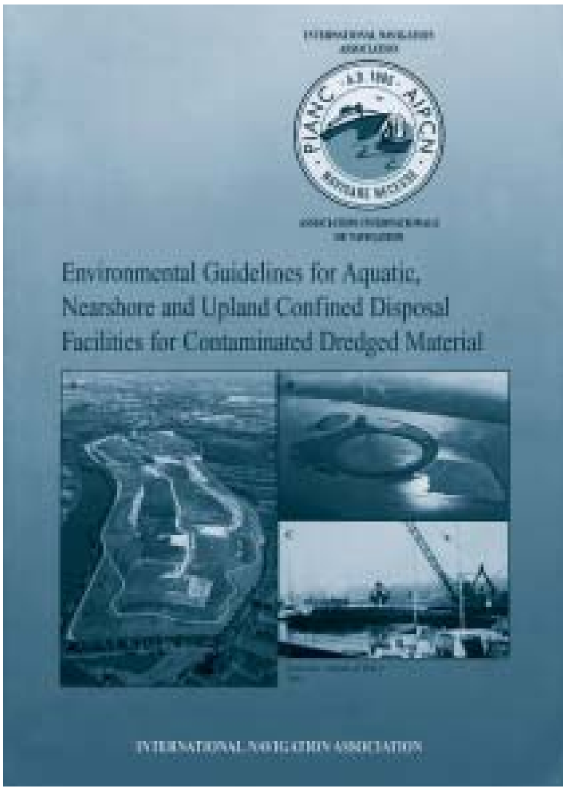
The papers in the proceedings fall within the goals of the COSINUS project and, as stated above, are organised into chapters as described in the initial paragraph.

The first chapter offers summaries of the five tasks around which the project was organised. In addition to the five summaries, there are 39 technical papers specific to each of the subject areas. The papers range from research results to case studies or examples of the various concepts and processes as experienced in specific locales.

There is no question that the goals of COSINUS and the results of the papers contained in the proceedings have a significant relationship to the practical aspects of port and waterways issues. The papers are of more interest to other scientist-technical experts in the field of cohesive sediments, but certainly, there are a number of the papers that have direct application to the more practical and mundane issues of interest to the engineer, port manager, educators and regulators.

The book may be obtained from:
Elsevier Science B. V.
Sara Burgerhartstraat 25
P.O. Box 211
1000 AE Amsterdam, The Netherlands

Environmental Guidelines for Aquatic Nearshore and Upland Confined Disposal Facilities for Contaminated Sediments
Report of Working Group 5 of the Environmental Commission, 2002. International Navigation Association, Brussels, Belgium. Soft cover, A4, 47 pages with Appendices 1, 2, and 3 on CD-ROM.
PIANC ENVICOM Working Group 5



This report by the Environmental Committee of the International Navigation Association (PIANC) is another in its ongoing series of reports that demonstrates PIANC's leadership role in providing technical guidelines on pivotal issues. Precursor to this report was "The Handling and Treatment of Contaminated Dredged Material from Ports and Inland Waterways" (PIANC 1996). Other companion reports from Working Groups 1 and 17 produced "PIANC Guidelines on Beneficial Uses of Dredging Material (PIANC 1992) and "Handling and Treatment of Contaminated Dredged Material (PIANC 1996) both of which served as a basis for the current report.

In the intervening period it has become clear that Confined Disposal Facilities (CDFs) are an effective way of dealing with contaminated sediments if their use involves the integration of engineering, environmental, regulatory, social and economic effects. In this perspective, the Environmental Committee (EnviCom) charged Working Group 5 with the development of a contemporary report that captures the technological advances which have occurred since the 1996 report.

PIANC working groups are composed of experts in a variety of fields relevant to the subject at hand, and this working group (WG5) represents a well-diversified international level of expertise. Chaired by Hypolite Laboyrie (Netherlands), with co-secretaries Neville Burt and Lena Papai (both UK), WG5 also includes members from Spain, the UK, Sweden, Denmark, Germany, Japan, Canada, the USA, France, Portugal, and Belgium.

The reader should view this and other PIANC reports with the qualification stated by the publisher: "The objective of this report is to provide information and recommendations on good practice. Conformity is not obligatory and engineering judgment 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".

That said, the report represents a major addition to the ports and waterways operators, managers and builders of techniques and recommendations borne out of carefully considered experience. The new guidelines cover the environmental aspects of design, operation and management of Confined Disposal Facilities (CDFs). The report is presented in the following manner:
- Description of a CDF and Definition of Terms
- Site Investigation and Site Selection Regarding Environmental Consideration
- Sediment Investigation and Characterisation of Contaminant Pathways
- Design of a Facility for Contaminant Control
- Operation/Management for Long Term Contaminant Retention

The introduction makes clear at the outset that this report is based on the assumption that a CDF has already been selected as the likely management option. Therefore, the starting point begins with where and how to design and construct the facility and what steps are to be taken to achieve it. The report uses a series of tables to describe the various types of CDFs and the advantages and disadvantages associated with each. It then follows with a particularly effective tool, a framework for planning, design, and implementation of a CDF. This framework approach gives the user a road map with many options and paths defined for the decision and design process. Because of the nature of differing national regulations and objectives, the report presents a generic approach to consideration of these factors.

The data requirements and properties of the material are discussed, as well as the factors to be considered in site selection and design. Some generic description of factors related to land use and the environmental setting follows. A section on the potential environmental impacts of the CDF is included and is both concise and sufficiently descriptive to be of true value to the reader.

Design and construction considerations are presented, which include such aspects as volume requirements, geometry and dimensions, dike design for upland and open water sites, outlet structures, and the essential elements related to isolating and controlling contaminant pathways. Management and operational aspects of CDFs are discussed for the various types of CDFs, the means by which material is introduced into the CDFs and the safety and health issues surrounding the effective use of CDFs including compliance with local regulations, protection of workers and protection of the public.

The importance of monitoring during and after completion of the construction of the CDF is emphasised, as well as management actions inferred from the results of the monitoring. Disaster management and subsequent site use are also discussed. Finally, the report presents conclusions and recommendations as bullets that are intended to capture the essential points.

A CD-ROM with Appendices 1,2 and 3 is provided as part of the publication. The CD-ROM contains case studies on selected existing CDFs, an overview on conventions and regulations, and a list of modelling tools.

The report continues the quality and substance that has characterised previous PIANC publications and it makes a significant contribution to those who have an interest in managing contaminated sediments and doing so with the support of the combined wisdom of a group of international experts.

The report may be obtained from:
PIANC General Secretariat
Graaf de Ferraris-gebouw – 11th Floor
Boulevard du Roi Albert II 20, B.3
B-1000 Brussels, Belgium
www.pianc-aipcn.org

International Seminar on Dredging and Reclamation

October 11-15 2003
Dubai, UAE

This year the IADC is pleased to announce that its well-known seminar will be presented in for the first time in Dubai, UAE from October 11-15. The course has been held for a several years in Singapore, Delft and Buenos Aires with great succes. Recent enquires from the area about dredging have led the IADC to select Dubai as this year's renue.

The seminar includes workshops and a site visit to a dredging project. Highlights of the programme are:

Day 1: Why Dredging?
The Need for Dredging/Project Phasing

Day 2: What is Dredging?
Dredging Equipment/Survey Systems
(includes a Site Visit)

Day 3: Cost/Pricing and Contracts

Day 4: Preparation of Dredging Contract

Day 5: How Dredging?
Dredging Projects

Representatives of port authorities, companies, and individuals interested in attending are requested to complete the preliminary registration form below as soon as possible and return to:

IADC Secretariat, Duinweg 21,
2585 JV The Hague, The Netherlands
tel. +31 70 352 3334, fax +31 70 351 2654
e-mail: info@iadc-dredging.com

(please print)

Name ....
Title ....
Company ....
Address ....
....
Tel. ....
Fax ....
E-mail ....

For further updated information please visit our website www.iadc-dredging.com or contact the IADC Secretariat.

Seminars/ Conferences/ Events

Oceans III Millennium

Universidad de Alicante, Spain
April 22-26 2003

The first "Oceans III Millennium", an international congress on marine science and technology, was held in Pontevedra, Spain in April 2001. Some 350 scientists participated, 140 oral presentations were made, and 47 posters were displayed. As a result of the success of the first conference, in April 2003 a second Oceans III Millennium will be held on the campus of the University of Alicante, Spain.

For further information please contact:
Viajes Hispania, S.A.
Departamento de Congresos
Srta. Ma. Carmen Fernancez
Avda. Maisonnave no .11-piso
7o 03003 – Alicante, Spain
tel. +34 96 5228 393, fax +34 96 5229 888

The Organising Committee
Monserrat, 13 B, 28015 Madrid Spain
tel. +34 91 541 6743, fax +34 91 559 1295
email: fomar@fomar.org
www.fomar.org

First Chinese International Dredging Congress and Exhibition

Shanghai International
Convention Center, China.
May 20-23 2003

This dredging conference, being held for the first time, is sponsored by the Chinese Dredging Association (CHIDA), the Eastern Dredging Association (EADA) and the Shanghai Waterway Bureau.

For further information contact:
Capt. David Padman, Secretary General,
Eastern Dredging Association, c/o Port Klang Authority,
Mail Bag Service 202, 42005 Port Klang, Malaysia
fax +60 3 31670211
email: david@pka.gov.my

23rd IAPH World Ports Conference

Durban, South Africa
May 24-30 2003

The 23rd World Ports Conference will present varied subjects that reflect the primary concerns of the Maritime industry in general and Port Authorities around the world. The theme for the 23rd IAPH World Ports Conference will be: "Ports - The Catalytic Impact", with the sub-theme "Uniting World Economies through Ports and Harbours".

For further information contact:
Global Conferences
PO Box 44503, Claremont,
7735 Cape Town, South Africa
E-mail anneliese@globalconf.co.za
http://www.iaph2003.co.za

OI Americas 2003

Morial Convention Centre
New Orleans, Louisiana, USA
June 4-6 2003

After the success of Oceanology International in London in March of 2002, the marine science and ocean technology industries are now turning their attention to the Americas in the form of OI Americas, the Second Joint Ocean Forum. This follows the promising debut of Oceanology International Americas in Miami, Florida in 2001.
Moving the exhibition to New Orleans takes exhibitors straight to the heart of the US offshore oil industry, close to survey, charting and mapping companies.
It also opens the convention to emerging South American shipping and port development sectors.

In addition, a full programme of technical and scientific conferences and workshops will run alongside the OI, coordinated by The Oceanography Society.

For further information contact:
Craig Moyes
tel. +44 20 8949 9879
craig.moyes@spearhead.co.uk

WEDA XXIII & TAMU 35 Dredging Seminar

Hilton Suites Hotel &
Drury Lane Convention Centre,
Oakbrook, Illinois, USA
June 10-13 2003

The twenty-third Western Dredging Association Annual Meeting and Conference and the thirty-fifth Texas A&M Dredging Seminar will be held in June 2003 at the Hilton Suites Oakbrook, 18 miles west of Chicago. The conference will provide an in-depth technical programme based on the theme, "The Dredging Contractor" and will provide a unique forum for discussions between dredging contractors, port authorities, government agencies, environmentalists, consultants, academicians, and civil and marine engineers.

For further information contact:
Dr. Ram K. Mohan
Blasland, Bouck & Lee, Inc., Annapolis, MD
tel. +1 410 295 1205, fax +1 410 295 1209
email: rkm@bbl-inc.com

Dr. Robert E. Randall
Dept. of Civil Engineering, Texas A&M University
tel. +1 979 862 4568, fax +1 979 862 8162
email: r-randall@tamu.edu

Mr. Stephen Garbaciak, Jr.
Blasland, Bouck & Lee, Inc.
tel. +1 312 674 4937, fax +1 312 674 4938
email: sdg@bbl-inc.com

Dredging Today

Puerto de Avilès, Spain
June 19-20 2003

An international seminar on dredging "Dredging Today"is being organised by the Port Authority of Avilès and the Ports and Coasts Technical Association of the PIANC Spanish Section. Subjects will include: Public awareness on dredging; emergency dredging; recent dredging works in the world; presence of dredging in daily life; obtaining sand from the sea bottom for coastal environmental purposes; current dredging equipment and future trends; special equipment; dredging work costs structure; hydrography navigable draughts; up-to-date environmental recommendations.

For further information contact:
PIANC General Secretariat
Graaf de Ferraris Bldg., 11th Floor
Boulevard du Roi Albert II 20, POB 3
B-1000 Brussels, Belgium
tel. + 32 2 553 71 60, fax +32 2 553 71 55
email: info@pianc-aipcn.org
www.pianc-aipcn.org

Coasts and Ports Australasian Conference

The Hyatt Hotel,
Auckland, New Zealand
September 9-12 2003

This is the 16th Australasian Coastal & Ocean Engineering Conference and 9th Australasian Port & Harbour Conference. The theme of the conference is "Coastal Development – A Quest for Excellence" and the issues it covers include: models for "good" coastal development; change in port infrastructure and efficiency; costs of regulation and compliance; managing conservation and development; assessing impacts of coastal structures on the natural system; and changes in science and technology in modelling and monitoring coastal change.

For further information contact:
The Conference Managers
The Conference Company
PO Box 90040
Auckland, New Zealand
tel. +64 9 360 1240, fax +64 9 360 1242
email: coasts and ports@tcc.co.nz

COPEDEC VI

Bandaranaike Memorial
International Conference Hall
Colombo, Sri Lanka
September 15-19 2003

The theme of the sixth International Conference on Coastal and Port Engineering in Developing Countries (COPEDEC) will be "Engineering the Coastal Environment". Subjects include: Port and harbour infrastructure engineering in developing countries; port and infrastructure planning and management in developing countries; coastal sediments, hydrodynamics and control; coastal zone management in developing countries; and coatal and port environmental aspects.

At this conference an IADC Young Authors Award will be presented to the best paper by an author younger than 35 years of age recommended by the Paper Committee.

For further information contact:
The Local Organising Secretariat
COPEDEC VI- COLOMBO 2003
c/o Ace Travels & Conventions (Pvt) Ltd.
315, Vauxhall Street, Colombo 02, Sri Lanka
tel. +94 1 300589 / 300590, fax +94 1 331 816
email: acetravels@aitkenspence.lk
www.copedec.lk

Membership List IADC 2003

Through their regional branches or through representatives, members of IADC operate directly at all locations worldwide.

Africa
Ballast Ham Dredging (Nigeria) Ltd., Ikeja-Lagos, Nigeria
Dredging International Services Nigeria Ltd., Lagos, Nigeria
Nigerian Westminster Dredging and Marine Ltd., Lagos, Nigeria

The Americas
ACZ Marine Contractors Ltd., Brampton, Ont., Canada
Ballast Ham Sucursal Argentinia, Capital Federal, Argentina
Ballast Ham Dredging do Brazil Ltda, Rio de Janeiro, Brazil
Dragamex SA de CV, Coatzacoalcos, Mexico
Gulf Coast Trailing Company, New Orleans, LA, USA
Uscodi, Wilmington, DE, USA

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Dredging International N.V., Singapore
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Hyundai Engineering & Construction Co. Ltd., Seoul, Korea
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Van Oord ACZ B.V., Singapore
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Dredging International N.V., Tehran Branch, Tehran, Iran
Gulf Cobla (Limited Liability Company), Dubai, UAE
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Van Oord ACZ Overseas BV., Abu Dhabi, UAE

Australia
Ballast Ham Dredging Pty. Ltd., Brisbane, QLD, Australia
Dredeco Pty. Ltd., Brisbane, QLD., Australia
Van Oord ACZ B.V., Victoria, NSW, Australia

Europe
ACZ Ingeniører & Entreprenører A/S, Copenhagen, Denmark
A/S Jebsens ACZ, Bergen, Norway
Atlantique Dragage S.A., Nanterre, France
B.V. Bedrijfsholding L. Paans en Zonen, Gorinchem, Netherlands
Baggermaatschappij Boskalis B.V., Papendrecht, Netherlands
Ballast Ham Dredging b.v., Rotterdam, Netherlands
Ballast Ham Dredging Ltd., Camberley, United Kingdom
Ballast Ham Nederland b.v., Gorinchem, Netherlands
Boskalis B.V., Rotterdam, Netherlands
Boskalis International B.V., Papendrecht, Netherlands
Boskalis Westminster Aannemers N.V., Antwerp, Belgium
Boskalis Westminster Dredging B.V., Papendrecht, Netherlands
Boskalis Westminster Dredging & Contracting Ltd., Cyprus
Draflumar SA., Neuville Les Dieppe, France
DRACE (Grupo Dragados S.A.), Madrid, Spain
Dravo S.A., Madrid, Spain
Dredging International N.V., Madrid, Spain
Dredging International N.V., Zwijndrecht, Belgium
Dredging International Scandinavia NS, Copenhagen, Denmark
Dredging International (UK), Ltd., Weybridge, United Kingdom
Espadraga, Los Alcázares (Murcia), Spain
Heinrich Hirdes G.m.b.H., Hamburg, Germany
Jan De Nul N.V., Aalst, Belgium
Jan De Nul Dredging N.V., Aalst, Belgium
Jan De Nul (U.K.) Ltd., Ascot, United Kingdom
Mijnster Beheer B.V., Gorinchem, Netherlands
Nordsee Nassbagger- und Tiefbau GmbH, Wilhelmshaven,Germany
N.V. Baggerwerken Decloedt & Zoon, Oostende, Belgium
S.A. Overseas Decloedt & Fils, Brussels, Belgium
Sider-Almagià S.p.A., Rome, Italy
Sociedad Española de Dragados SA., Madrid, Spain
Società Italiana Dragaggi SpA. "SIDRA", Rome, Italy
Société de Dragage International "S.D.I." S.A., Marly le Roi, France
Sodranord SARL, Le Blanc-Mesril Cédex, France
Terramare Oy, Helsinki, Finland
Tideway B.V., Breda, Netherlands
TOA (LUX) S.A., Luxembourg
Van Oord ACZ B.V., Gorinchem, Netherlands
Van Oord ACZ Ltd., Newbury, United Kingdom
Wasserbau ACZ GmbH, Bremen, Germany
Westminster Dredging Co. Ltd., Fareham, United Kingdom

International Association
of Dredging Companies