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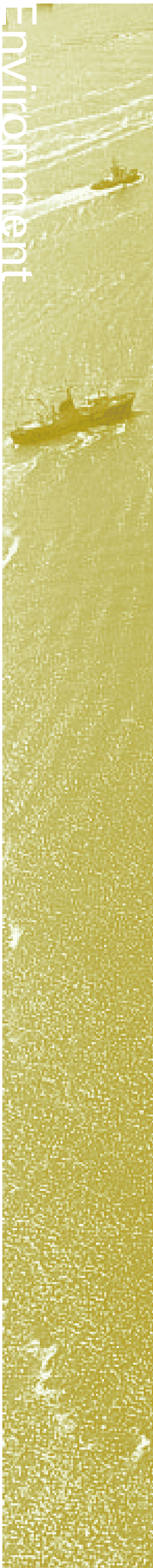


A Controlled Stable Tidal Inlet at Cartagena de Indias, Colombia

Abstract

Since the inception of Cartagena de Indias, Colombia as a Spanish colony, its sewerage was dumped into the nearby bodies of water. Not so surprisingly, the growth of population was marked by growth in sewerage and by 1980 60% of the city's sewerage was dumped on the Ciénaga de la Virgen, a shallow coastal lagoon of some 22 km^2, and 10 km canals surrounding and traversing the city. Whilst the bodies of water could absorb the sewerage dumped in the early days, by the 1980s the pollution level had become unbearable. Continuous strong odors attracting mosquitoes, eutrophication, and fish death became recurrent events.

In 1988 the Colombian Planning Department requested assistance from the Dutch Government to solve the pollution of the water bodies. In 1993 Royal Haskoning (RH) was commissioned by the Dutch Government to appraise and formulate recommendations.

The sewerage project was distributed between the World Bank and the Inter-American Development Bank whilst the Dutch Government continued its assistance for the Tidal Inlet project. On November 25, 2000 the sluices at the Tidal Inlet commenced operating, and within 3 weeks the lagoon had obtained the desired water quality.

The sewerage masterplan is presently being implemented. The estimate is that the submarine outfall which should discontinue the sewerage disposal into the lagoon, should start operating between 2005 and 2007, between 5 and 7 years after the Tidal Inlet commenced its operations.

Introduction

From the colonial fortress city of Cartagena de Indias the "silver fleets" departed regularly carrying silver from Mexico and Peru to Spain, where it contributed to fund the wars fought by the Spanish Crown.
The Spanish conquistador's selected Cartagena for its strategic geographic position and for the natural protection from raids by British, French and Dutch pirates offered by the surrounding bodies of water (see Figure 1).

Since the city's inception its sewerage was dumped into these bodies of water. As the volume of sewerage increased in tandem with the growth of the population, part of the city's sewerage was collected and dumped by marine outfall into the bay of Cartagena. This began about 1960. By 1980 however 60% of the city's sewerage was dumped on the Ciénaga de la Virgen, a shallow coastal lagoon of some 22 km^2, and 10 km canals surrounding and traversing the city.

Whilst the bodies of water could absorb the sewerage dumped in the early days, by the 1980s the pollution level had become unbearable. The city became exposed to continuous strong odors attracting hordes of mosquitoes thereby severely affecting the already precarious livelihood of some 400,000 poor people living along the southern lagoon border, many of them having been displaced by inland guerrilla actions. Localised eutrophication (decomposition of algae and other water plants distilling strong smell) was rampant and fish death was a recurrent event in those areas of the water bodies where there was still enough oxygen available for fish to survive during part of the year.
In addition, during the rainy season, the water level in the lagoon increased, inundating the surrounding borders and creating havoc amongst the population living in shacks on the border.

A Plan to Remedy the Pollution Problems

In 1988 the Colombian Planning Department requested assistance from the Dutch Government to solve the pollution of the water bodies. In 1993 Royal Haskoning

Ronald Moor

Ronald Moor received his BSc in civil engineering in Colombia and his master's degree in coastal engineering at the Delft Technological University in 1970. He worked with HBG in Colombia, with the FAO (United Nations) and with the Dutch Technical Cooperation in Peru, finally joining Haskoning, where he has spent the last 22 years. For almost a decade he managed Haskoning's International Projects Division, during which time he was a member of the Board of Haskoning, as well as holding membership in the Board of Directors Overseas of the ONRI (Dutch Consultants Branch Organization) and Nedeco, Chairman of Iran Nedeco Port Consultants, Managing Director of Nedeco-China, Director of Posford Duvivier (UK) and Director of Haskoning Nigeria. He has recently retired.

Marion van Maren

Dr Marion van Maren completed her undergraduate studies in biology at the University of Amsterdam. She then went to France where at the Université Claude Bernard in Lyon she did research on the Rhône River ecosystems. In 1980, she obtained her Doctorate from the University of Amsterdam. She then joined a research team at the University of Michigan, USA, carrying out an EIA study in the Gambia River basin, West Africa; thereafter at the University of Amsterdam, she was in charge of a water quality study of the Lake of Managua, Nicaragua, Central America . She then joined BKH Engineers. In 1990 she went to work for Royal Haskoning as a senior environmentalist where she continues to the present to be involved in environmental studies in countries all over the world.

Cees van Laarhoven

Cees van Laarhoven, Senior Project Manager, Boskalis International, has worked for Boskalis since 1969, specialising in coastal defence works, breakwater constructions, river closures and various ecology works worldwide. He was Project manager for the execution of the Cienaga Project. Since Cartagena he has been in charge of special tunnel protection works in Hamburg, and is presently working in Singapore, involved in mega- reclamation and protection works.

(RH) was commissioned by the Dutch Government to appraise and formulate recommendations. RH recommended the implementation of two complementary projects:

– To increase the lagoon's regenerating capacity connecting the Caribbean Sea with the Lagoon. This required the construction of a Stabilised Controlled Tidal Inlet, to allow the flushing of the lagoon by tidal currents;
– To reduce the dumped sewerage on the water bodies. This required the development of a sewerage masterplan including a reappraisal of final disposition of sewer water and/or a possible treatment plant.

The sewerage project was distributed between the World Bank and the Inter-American Development Bank whilst the Dutch Government continued its assistance for the Tidal Inlet project. In 1994 the Colombian Ministry of Transport commissioned RH to develop the Tidal Inlet concept including studies, modeling, structural design, preparation of tender documents, tender evaluation and supervision of construction. At the end of 1997 the construction was awarded to Boskalis International. On November 25, 2000 the sluices at the Tidal Inlet commenced operating, and within 3 weeks the lagoon had obtained the desired water quality.

On December 8, 2000 the president of Colombia Andres Pastrana and the Dutch Ambassador Teunis Kamper officially opened the project. On May 31, 2000 the project was handed over to the Colombian Government. By July 2000 the project was transferred to the Cartagena Municipality, which contracted an "Operator" to operate and maintain the facilities and monitor water quality. Financed by the Dutch Embassy, RH provided continuous onsite assistance to the Operator until March 2001. The total project cost was EUR 30 million, of which the Dutch Government donated about 45%.

The Tidal Inlet is nowadays managed and operated by DAMARENA, Cartagena's municipal body responsible for protection and conservation of renewable natural resources.

The sewerage masterplan is presently being implemented. The estimate is that the submarine outfall which should discontinue the sewerage disposal into the lagoon, should start operating between 2005 and 2007, between 5 and 7 years after the Tidal Inlet commenced its operations.

The Stable Controlled Tidal Inlet Concept

The design posed three interesting and important questions, which had to be addressed:

– How to ensure the Tidal Inlet's stability over time, considering coastal changes caused by sedimentation and erosion;
– How to optimise the self-regenerating capacity of the lagoon and canals, to maximise the effect of the Tidal Inlet;
– How to establish desired water quality criteria in the lagoon over time, before the implementation of a sewerage masterplan, and consequently determine the required capacity of the canal connecting the Caribbean Sea and the Lagoon.

In the following article the approach and conclusions on these questions will be summarised.

Inlet stability

At the north end of the lagoon a small, unstable Tidal Inlet (La Boquilla) existed (Figure 2). This generally opened yearly during the low-wave season (May to November) and closed during the high-wave season (December to April) in response to the existing longshore sand transport.

The rainy season, which extends from June to November, tends to overlap with the low-wave season creating a hydraulic gradient between the lagoon and the Caribbean Sea, aiding in maintaining the Tidal Inlet open for a number of months. Wave analysis and calculations with Delft Hydraulic's UNIBEST model showed that a net long-term average longshore sand transport exists from North to South, varying from some 30,000 m^3/yr at the Boquilla to 20,000 m^3/yr at the Cartagena airport. To ensure stability of the Tidal Inlet, therefore, two groynes or breakwaters are required, one at each side of the canal to avoid closure by longshore transported sand.

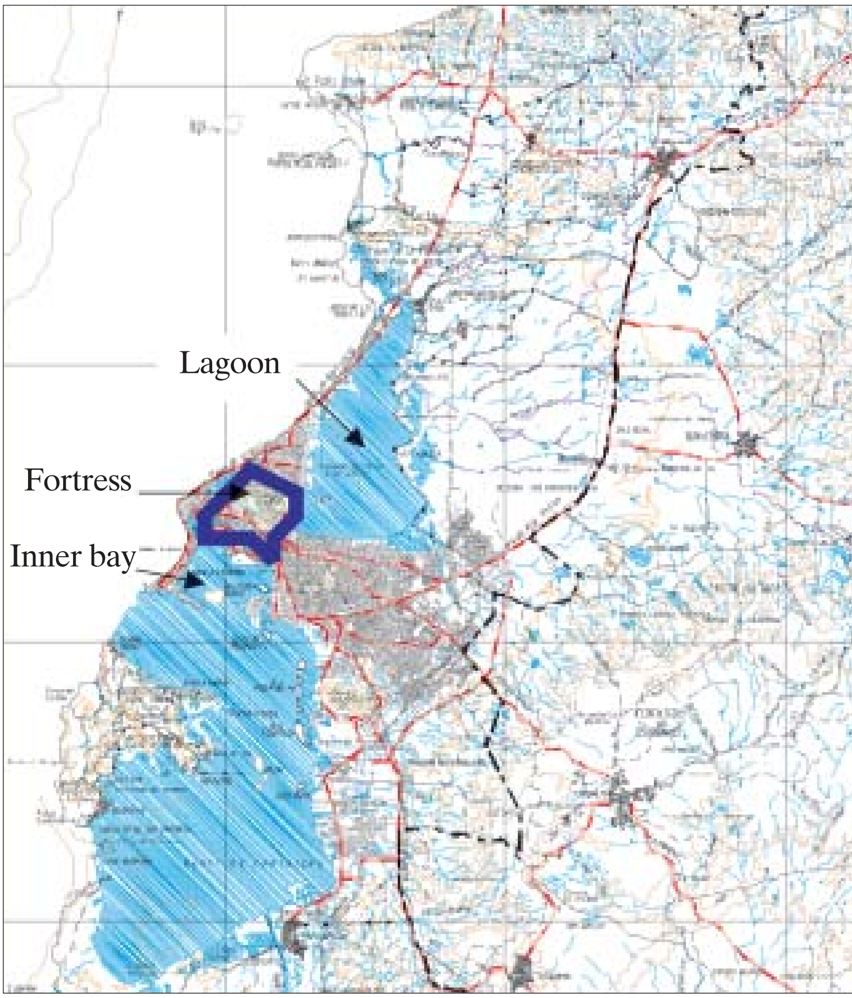


Figure 1. Map of Cartagena de Indias, Colombia showing the lagoon, fortress and inner bay.

The canal entrance and the sluices should be protected from wave action; hence an L-shaped North breakwater was selected to create wave protection. This North breakwater will stop longshore sand transport, creating a beach North and allowing erosion to the South. In time sand will bypass the breakwaters and enter into the basin created by the breakwaters, therefore a sand trap was dredged to allow recurrent dredging not more frequently than once every 8 years. To the South some 1200 m of unprotected coast existed, which was protected by three new groynes and the extension of a fourth groyne. Sand from dredging the sandtrap was supplied between the groynes and from a nearshore borrow area.

Optimisation of self-regeneration capacity of the water bodies

To increase the self-regenerating capacity of the shallow waters of Ciénaga de la Virgen coastal lagoon, it was decided early on that the Tidal Inlet should be located as close as physically feasible to the pollution sources, being a dozen outfalls located along the southern lagoon border, and a multitude of make-shift toilets of the 400,000 people draining either directly or through some 10 channels into the lagoon. This resulted in the choice of a site just North of the Cartagena airport landing strip (Figures 2 and 3).

In view of the very low tidal range present at Cartagena — 0.50 m is the highest difference, but on average it does not exceed 0.30 m — it was decided to include sluices to control the incoming and outgoing tidal currents in tandem with a 3400 km guiding sheet piled wall to direct the tidal currents towards the pollution sources and from there out into the ocean. This would maximise the flushing capacity of the system.

Furthermore, it was decided to reconnect the main channel between the lagoon and the internal bay of Cartagena by extending and deepening the Caño Juan Angola, allowing water circulation through this channel. To maximize the effect, a one-way sluice was planned at Chambacú, near the inner bay, to allow only tidal outflow and prevent inflow (Figure 4).

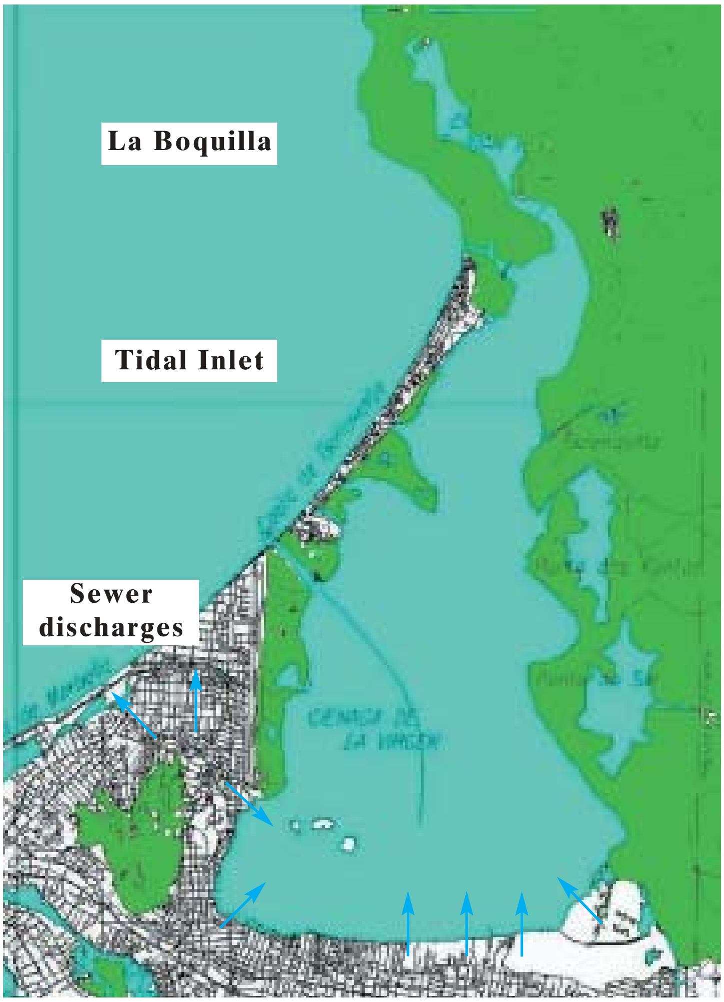


Figure 2. A map of the Tidal Inlet, La Boquilla, and sewer discharges.

Figure 3. Photograph of the Tidal Inlet which has been placed near the pollution sources.

Table I. Combined main design criteria for water quality and aquatic systems.

Parameter	Measuring unit	Project aim
BOD	G/m^3	<6
DO	G/m^3	>4
Ammonia	G/m^3	<2
Phosphates	mg/l	<0.3
Bacteria	MPN/100ml	<5000

Water quality criteria and connecting channel capacity
Water quality requirements were simplified into those applicable for recreational water bodies for which Colombian regulations could be applied and requirements for aquatic systems for which, in the absence of Colombian regulations, Dutch regulations were applied. The combined main design criteria were established as given in Table I.

With the aid of the Danish Hydraulics Mike 21 bi-dimensional model an average flow requirement of 30 m^3/sec was established, taking into account the increase in sewerage discharge on the lagoon as forecast by Aguas de Cartagena (the water and sewerage operating entity), to allow until about 2008 for the implementation of a sewerage masterplan and discharge of sewerage outside the lagoon or on the lagoon after passing through a treatment plant.

The design was modelled with an open and a closed Boquilla, resulting in an average flow of between 32 and 34 m^3/sec. The anomalous semi-diurnal tide in Cartagena, where the flood tends to last about 1.5 times longer than the ebb, translated into having 6 inflow and 4 outflow sluices.

Selected Comments on the Construction

The contract was based on a standard FIDIC contract blended with Colombian requirements as contained in Law 80, which governs tender procedures and contracts with the Colombian State. Whilst in essence the FIDIC approach was maintained, the Engineers' powers were restricted in those areas that could generate additional cost to the Colombian Government, i.e. approval of time extension, issuing variation orders involving more monies and the approval of new unit rates.

Law 80 normally limits the task of the supervising engineer to controlling technical specifications and quality of the work, whilst the Government body retains all decision power. It is therefore surprising how well the contractual setup worked, albeit that there were frequent explanations on the FIDIC contract where necessary. Still each party avoided getting involved in other parties' responsibilities. In addition to the Construction and Consultancy contracts of Boskalis International and Royal Haskoning with the Ministry of Transport, both companies had a contractual responsibility towards the Dutch Government.

The construction started with a one-year delay owing to procedural time required to formalise the construction and consultancy donation agreements between the two Governments, and cash flow rescheduling by the Colombian Government leading to a change in construction time from 13 to 18 months.

Boskalis decided early on to construct the whole connecting channel and the associated structures in a dry pit. This involved the installation of a well system along some 700 m long and 120 m wide channel, with 16 m deep wells at both ends. This system lowered the water level over some 3 m on a 24-hour basis for a period of 9 months.

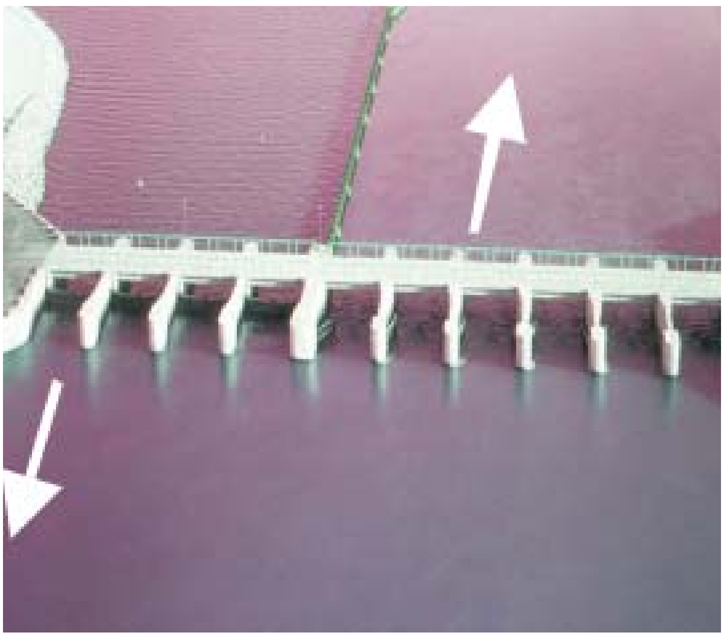
The connecting channel is lined with geotextile and a rock revetment on the slopes and small stones on the bottom. On the seaside a box-culvert was constructed

Figure 4. Map indicating the Caño Juan Angola and the one-way sluice at Chambacú which would allow only tidal outflow and prevent inflow.

Figure 5. The road connection between Cartagena and the port city of Barranquilla.

Figure 6. Aerial view of the channel, sluice complex and box-culvert.

Figure 7. The sluice complex on the lagoon side.



bridging the road connection between Cartagena and the port city of Barranquilla, whilst permitting the flow of tidal current underneath. A variety of connections cross the box-culvert, including water and sewerage pipes, electricity, several TV and telephone cables and a gaspipe, with each owner having its own specific requirements for the temporary and final solution.

On the lagoon side a sluice complex was built including 10 sluices (6 in, 4 out). The photographs in Figures 5, 6 and 7 show the main elements and the sluice complex.

Fishing boats
Unexpectedly, significant traffic of small fishing boats exists along the Caño Juan Angola. Therefore at the Chambacú sluice a derrick had to be installed to allow lifting of fishing boats when the sluice is closed (Figure 8).

Airport
The construction of the breakwaters and the dredging of the sandtrap as well as the dredging of the connection between the Caño Juan Angola with the lagoon were limited as regards the height of construction equipment, which had to remain outside the flight approach cone on both sides of the runway. This led to a protracted procedure where radio communication between the control tower and the construction site whilst constructing the breakwaters optimised the utilisation of construction equipment, lowering booms when airplanes landed or departed.

Originally the sandtrap was to be dredging with one cutter suction dredger (CSD) dredger working only night shifts when there is no air traffic, since spuds could not be lowered. But production proved insufficient and a second smaller CSD was deployed. The main CSD would dredge a large sandtrap outside the basin, whilst the smaller CSD would dredge and deposit sediment just south of the basin, where the larger CSD would then re-dredge some of the sand to nourish the 1200 m coast south of the Tidal Inlet. Figure 9 shows the breakwaters, the basin, the box-culvert and the smaller CSD in operation.

Hurricanes
Whilst hurricanes are a normal phenomenon in the Caribbean, they usually move in a westerly direction and pass far enough away from Cartagena not to generate any inconvenience. Alas, in November 1999 hurricane Lenny moving in an easterly direction passed much closer than usual and had a devastating effect on various sites along the Caribbean coast of Colombia including Cartagena. The breakwaters were not fully finished at the time of the hurricane and suffered no damage. The dramatic effect on the coast, however, was not foreseen during the design.

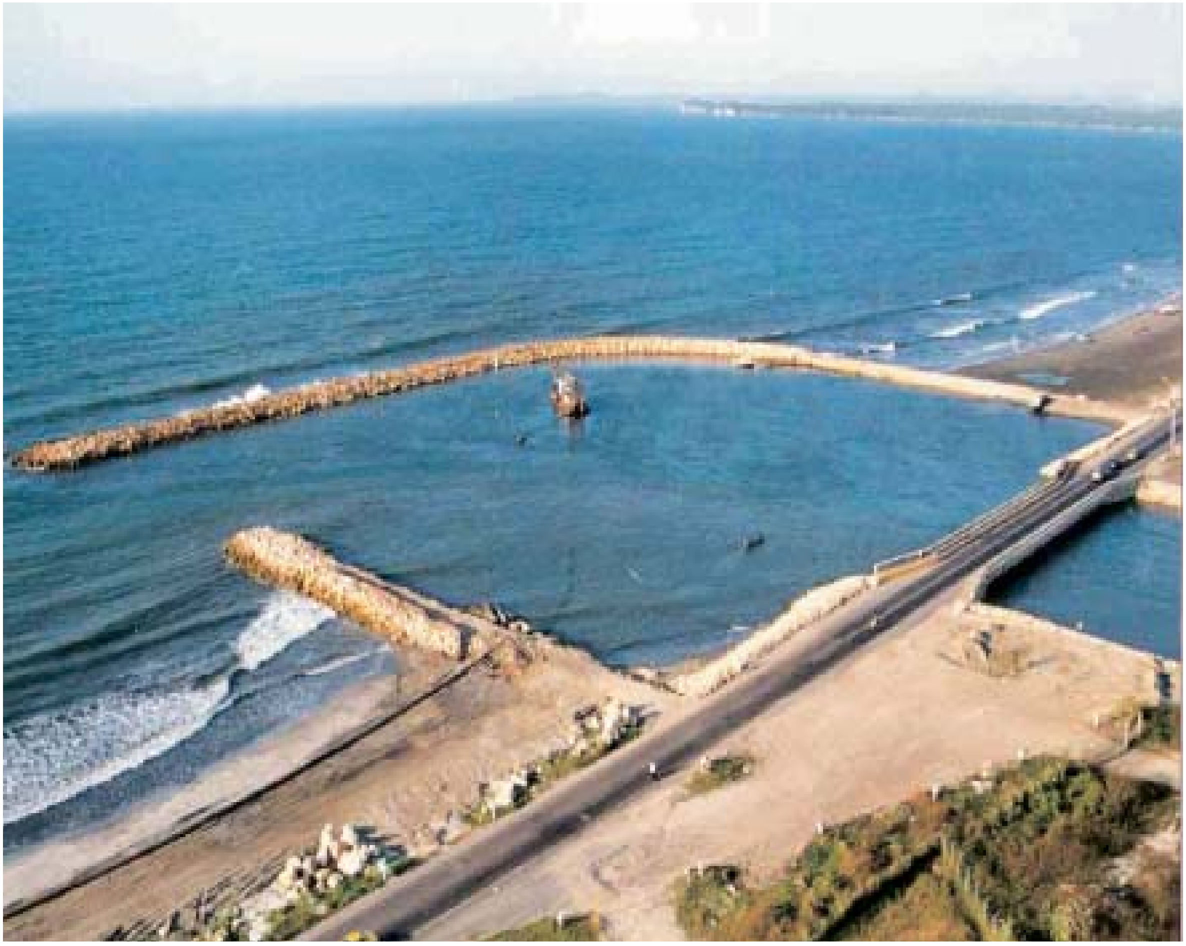
Environmental permit
Project approval included obtaining an environmental permit from the local environmental agency (Cardique). In addition, Dutch Government donation approval requires environmental project assessment by the Dutch MERCie (EIA Commission). Both agencies collaborated efficiently. As part of the permit a monitoring programme was developed involving the evaluation of coastal processes and water quality during construction and one year after operation of the sluices. The results of these monitoring programmes will be briefly discussed.

Figure 8. Small fishing boats are lifted by a derrick when the sluice is closed.

Environmental Monitoring of Coastal Processes

Figure 10 shows the measured advance of the MSL –1 m depth contour, considered reasonably representative of the coastal advance, at profile 7, located some 150 m north of the northern breakwater, as compared to the UNIBEST-model forecast. It can be observed that in March 2002 some 90% of the total sedimentation expected by 2011 had already taken place.

Figure 9. The breakwaters, the basin, the box-culvert and the smaller cutter suction dredger in operation.



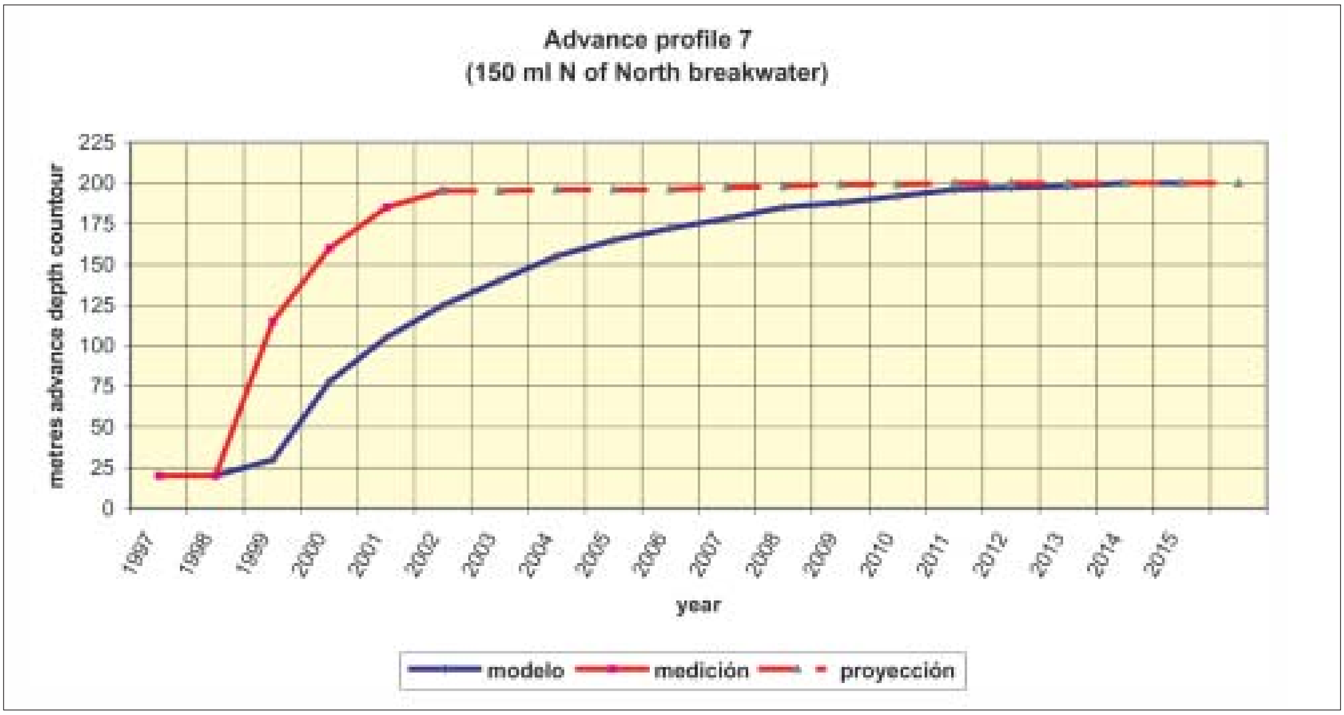


Figure 10. The measured advance of the MSL –1 depth contour considered reasonably representative of the coastal advance, at profile 7, located some 150 m north of the northern breakwater.

Figure 11. The advance of the MSL, MSL –1 and MSL –2 m depth contours are shown here. The effect of seasonal high and low waves can clearly be observed in the variation of the coastal slope, whilst the coast as a total is growing.

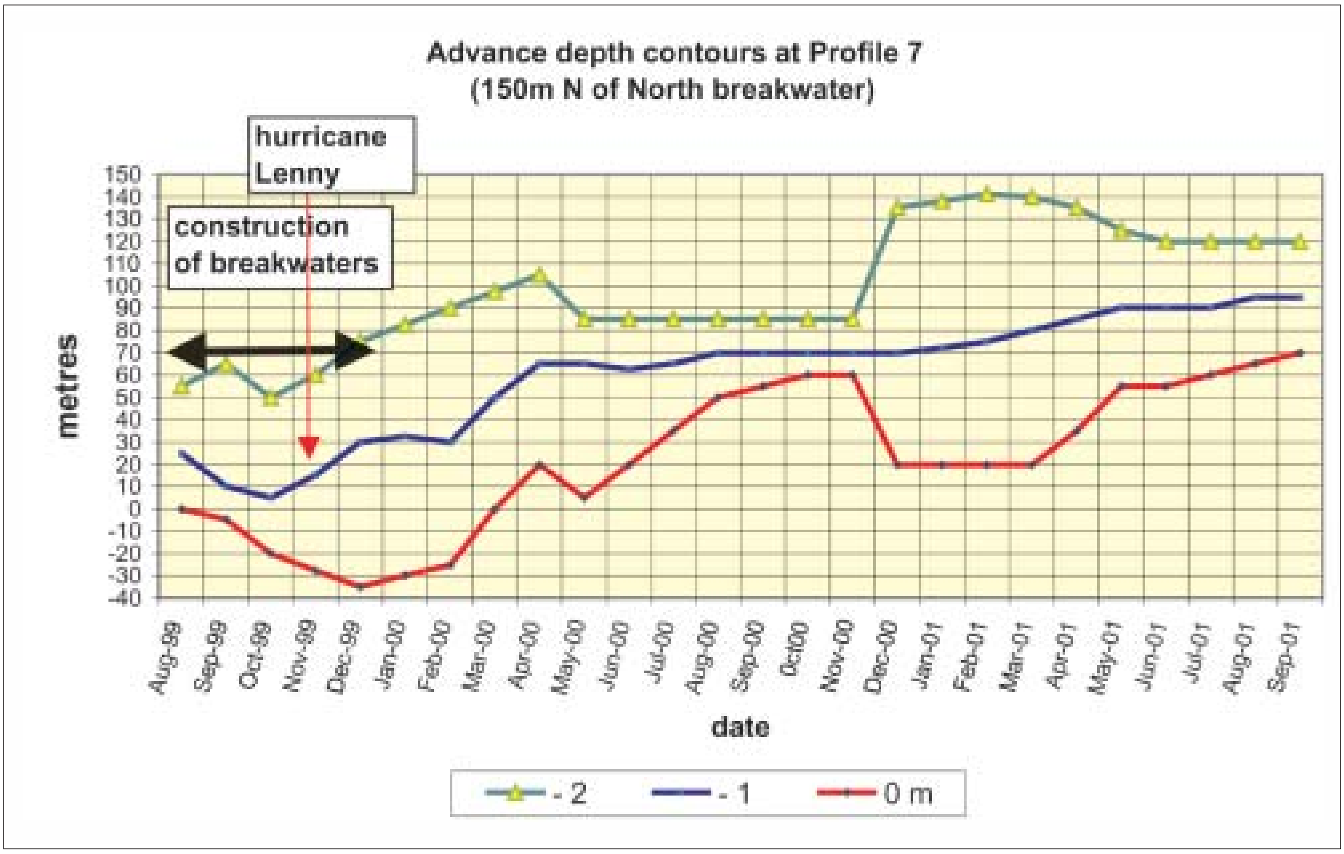


Figure 12. Under construction: Three new groynes were constructed and an existing one was extended.

The effect of hurricane Lenny on the coast, besides damaging coastal structures, caused the transfer of sand from MSL+1 to –1 m to MSL –3 to –4 m. This accelerated the sedimentation process north of the Tidal Inlet as waves broke over a far greater width than before. The effect and the restoration of the affected coast are shown in the Figure 11 where the advance of the MSL, MSL –1 and MSL –2 m depth contours are shown. The effect of seasonal high and low waves can clearly be observed in the variation of the coastal slope, whilst the coast as a total is growing.

The acceleration of the sedimentation process north of the Tidal Inlet could accelerate the sedimentation of the sandtrap and this in turn might require the advance of the next dredging operation by many years.

The identified risk of increased sandtrap siltation was evaluated. The sandtrap has a nominal capacity of some 85,000 m^3 while it was estimated that once some 50,000 m^3 sand has been trapped, the sandtrap should be dredged. From January 2001 to January 2002 the basin as a whole showed varying sedimentation and erosion in different sections of the basin as indicated in Table II.

Table II. Varying sedimentation and erosion in different sections of the basin.

Jan 2001 to May 2001:	+2,700 m^3	(+5,400/–2.700)
May 2001 to Sept 2001:	+ 900 m^3	(+4,000/–3,600)
Sept 2001 to Jan 2002:	– 100 m^3	(+5,300/–5,400)
Total sedimentation between Jan 2001 and Jan 2002:	some 3,500 m^3	

Sedimentation takes place mainly during the high-wave season. In addition it was observed that the access channel to the basin has deepened (erosion) whilst the two inside corners of the basin have silted. Whilst the total sedimentation in one year amounted to some 8,000 m^3 the erosion was some 4,500 m^3. Sand is a valuable resource in Cartagena and contractors are eager to remove it for free. Therefore, a selected contractor was allowed to excavate some 1,200 m^3 of sand from the two inside corners by back-hoe, thereby extending the life of the sandtrap. It was concluded that this could be repeated as many times as possible.

Figure 13. Water samples being taken. They were taken monthly at some 30 locations.

Figure 14. Bacteriological analysis was performed at the laboratory of the Cartagena University.

Probably the sandtrap would not have to be dredged for the next 10 years or more.

As an environmental mitigating measure, three new groynes were constructed and an existing groyne was extended to protect some 1200 m of coast south of the Tidal Inlet, whilst some 200,000 m^3 of sand was supplied to nourish the coast. Figure 12 shows the construction under way.

Environmental Monitoring: Water Quality and Ecology

Water samples were taken monthly at some 30 locations (Figure 13); physical parameters were established on site by a local laboratory setup by Boskalis and subsequently donated to the Cartagena municipality under a Dutch Embassy financed post-construction programme. Bacteriological analysis was performed at the laboratory of the Cartagena University (Figure 14).

Boskalis performed the monitoring 24 months before operation and 14 months after operation, under supervision of Haskoning and the environmental agency (Cardique). Haskoning evaluated the results and modified the programme according to the findings.

Commencement of sluice operation
Results of daily monitoring of bacteriological parameters during 3 weeks after the opening of the sluices concluded that there had been no danger to polluting neighbouring coastal areas.

Salinity
Once the Tidal Inlet became operational, salinity in the lagoon increased rapidly reaching levels of about 35 ‰ already in December, whereas in the past salinities corresponding with those of seawater were attained not earlier than in the month of April. In the tidal creek system, salinity levels also increased significantly.

Pollution as a result of sewage discharge
The overall improvement of bacteriological quality in the lagoon is striking. Before the project was operational, quality standards for recreational waters of secondary contact were exceeded in all sectors of the lagoon during the rainy season. Nowadays, in the wet season, only in the southern region of the lagoon, close to discharging points, bacterial counts do still not comply with these standards.

Bacterial counts registered in samples from the coastal waters near the outlet of the Tidal Inlet always complied with quality standards for recreational waters for secondary contact and primary contact.
Water quality in the creek system of Juan Angola improved greatly as a result of restoring the connection

between the lagoon and the Juan Angola creek and of the operation of the Tidal Inlet and the Chambacú sluice. Pollution of the creek system by discharge of sewage continues, but coliform counts are much lower than before operation of the project. Dissolved oxygen (DO) values are now met in a normal range and Biochemical Oxygen Demand (BOD) and concentrations of ammonia decreased significantly.

Trophic state of the lagoon

Prior to operation of the Bocana, dissolved oxygen values of the lagoon often reflected conditions of supersaturation and, sometimes, in the southern sector, of anoxic conditions. Nowadays, dissolved oxygen values are mostly in agreement with the objective of the project (> 4 mg O_2/l) regarding the trophic state to be attained. Moreover, supersaturation conditions became rare.

Until the start of the project, BOD values most of the time exceeded the project limit of 6 mgO_2/l, throughout the lagoon. As result of project operation, BOD was significantly reduced.

During operation of the project and also prior to the project, ammonia values rarely exceeded the norm of 2 mg/l. From these results it may be concluded that oxygen levels in the lagoon were and are not restrictive for completion of the nitrification process. Phosphates concentrations are significantly lower than in the past and generally do not exceed the value of 0.3 mg P/l, being the objective of the project. Also the rate of primary productivity has been strongly reduced. Figure 15 shows the bacteriological situation before and after operation.

Before the Tidal Inlet

With the Tidal Inlet in operation

NMP< 5.000/100ml. Good. Allows fishing and aquatic sports.

NMP >5.000 <30.000. Regular. Incidentally localised bad smells occur.

NMP>30.000 <100.000. Bad. Frequent bad smell and occasional fish death.

NMP>100.000. Very bad. Hideous smell, fish death and epidemic sickness.

Figure 15. The bacteriological situation before and after the operation.

Natural Values of the Lagoon

The lagoon ecosystem prior to operation of the project

Originally, the Ciénaga de la Virgen communicated with the sea near la Boquilla. At the onset of the rainy season, the connection with the sea was established, but disappeared progressively during the dry season. During maximum rainfall, salinities ranged from 3.6 to 5.6 $^0/_{00}$, whereas during the dry season salinities were in a range of 27.8 – 37.2 $^0/_{00}$.

The lagoon presented an annual cycle with the following characteristics:

- Onset of the dry season: lagoon still connected with the sea, allowing a biological and physicochemical exchange; increasing salinities; period of maximum biodiversity as a result of invasion of the lagoon by marine species.
- Dry season: connection with the sea closed by a sand bar; evaporation in the lagoon exceeded freshwater input; hypersaline conditions developed in the northern sector.

- Rainy season: connection with the sea re-established; freshwater input exceeded evaporation rate; salinities less than $5^0/_{00}$ in the southern part of the lagoon.

The high degree of pollution by wastewater was prohibitive for the number of species able to colonise the lagoon, especially in the southern sector.

The lagoon ecosystem during operation of the project
Since the opening of the Tidal Inlet, the north-south salinity gradients, which occurred seasonally, are no longer met. Moreover, salinities now are high during all seasons, throughout the lagoon. At the end of the rainy season, salinities registered in the lagoon were around 30 $^0/_{00}$, except for the monitoring stations in the south, where salinities were in the range of 18 - 20 $^0/_{00}$. Minimum salinities are met in places, where the discharge of domestic wastewater is high. Since the operation of the project, salinity in the Ciénaga de la Virgen seems to depend on salinity of the coastal waters and on wastewater inflow rather than on seasonal changes in rainfall.

During July and August 2001, hypersaline conditions were met in the extreme north of the lagoon. It is likely that, if the opening near la Boquilla remains closed in the future, hypersaline conditions will return during each dry season. In the lagoon sector, located beyond the influence of the Tidal Inlet, the lack of exchange with coastal waters will result in salinities higher than those of seawater, when evaporation rate is high and rainfall is absent.

Since the project became operational, seasonal peaks in primary production and phosphates no longer occur. This confirms the statement that nowadays the lagoon ecosystem is governed by the influence of the coastal waters rather than by seasonal changes is rainfall.

The general improvement in water quality resulting from project operation consists of a reduction in BOD, of changes in dissolved oxygen concentrations, presently met in a normal range, of a reduction in nutrient concentrations and of a significant reduction in bacteriological contamination.

Conclusion

With respect to the ecology of the Ciénaga de la Virgen, operation of the project generated the following positive impacts:
- The permanent connection with the sea allows marine species, including commercially important species such as penaeid shrimp, to enter the lagoon area throughout the year;
- The permanently higher salinities allow those marine species, which do not tolerate a major reduction in salinity (“stenohaline species”), to penetrate further into the lagoon area and to stay for a longer period than in the past;
- As a result of the reduction in nutrient concentrations, the degree of eutrophication has been reduced significantly;
- The improvement in water quality has a positive impact on the development of organisms, which colonise the lagoon.

The strong reduction in bacteriological contamination not only diminishes the health hazard for the fishermen, who are in direct contact with the lagoon waters, but also the health hazard brought about by eating bacteriologically contaminated fish and other organisms captured in the lagoon.

As soon as the Bocana had become operational, near the inlet and in the lagoon itself, large numbers of marine fish (red snapper for example), penaeid shrimp and blue crab have been observed. Moreover the different structures of the works (sluice gates, screen and so on) have been colonised by oysters, which presently offer an important source of income for the local fishermen.