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Front cover:
Leaving the 20th century, the dredging industry is sailing into a golden future – a new millennium of larger dredging vessels, improved technology, and a concern for the environment. Responsible dredging changes the face of the world, improving the quality of life in developing countries and maintaining it in the industrialised nations.

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International Association of Dredging Companies
From Hand-drag to Jumbo: A Millennium of Dredging
If there is a single concept that underlines the development of dredging in this century it would have to be its continuous search for efficiency and innovation.

These words embody the focus of IADC members. They reflect their willingness to invest in the future, and they are responsible for the incredible leaps that the dredging industry has been able to achieve. They describe how the industry has worked together with government authorities in the struggle to find a balance between economy and ecology – an effort that has especially characterised the last thirty years.

Where have we leapt to? Through a process of continual renewal, technology has been developed that has led us beyond maintenance dredging and beach replenishment into new and exciting dredging markets. In addition to infrastructure projects, which have always occupied us – improving waterways, creating new land and building new harbours and ports – we now have an important presence in the energy sector as well.

Historically IADC companies have always been at the forefront of dredging knowledge. This expertise has now grown exponentially as huge areas of activity have forced companies to work in clusters where the sum of their knowledge is greater than its parts. Mammoth capital dredging projects have generated – and continue to generate – incredible innovations, be they in the development of environmentally sound technologies or the design of larger, and thus economically more viable, vessels. Through our advanced technologies we are able to build airports on artificial islands, thus protecting populations from air traffic disasters. We can regulate dikes and manage water resources so as to prevent floods as well as droughts. And all this is being done with strict attention to preserving underwater environments, protecting fish and coral and other sea life.

Through the years Terra et Aqua has sought to keep its readers well informed of such advances in the industry. However, in this, the last issue of the Millennium we would like to take a look back thousands of years to see where dredging began and to examine past achievements. And they are many. By looking at our “roots”, hopefully we can begin to appreciate how far we have come, how significant the technological developments have been. And we can perhaps better predict where we may be heading in the next Millennium.

How did dredging start? And how did it get to where it is today? Why has dredging become an intricate part of our daily lives, of our pursuit of economic and social well-being?
This last issue of *Terra et Aqua* in the “old” Millennium is a saga of how people progressed from shovelling a ditch to digging a canal with horse-drawn bucket dredgers. How these methods grew during the Roman and medieval periods developing into the major dredging accomplishments of the 19th century like the Suez and Panama canals. We want to recount the creation of the IJsselmee by the closure of the Zuiderzee with the Afsluitdijk in the 1930s, as well as of the construction of the Eastern Scheldt Barrier built over three decades from the late 1950s on. This innovative project, in which environmental considerations became important, signalled the beginning of a new era, an era in which transportation in Scandinavia – marked by the Storebaelt and Øresund bridges and tunnel systems – would also be transformed. Of course the laying of the NORFRA gas pipeline in the North Sea from Norway to France must be mentioned. And no overview is complete without mention of the Hong Kong Airport at Chek Lap Kok, a project that speaks for itself when it comes to magnitude and international cooperation, as well as environmental awareness.

At work on all five continents, there is nowhere that dredgers have not left their mark on the land, the beaches, the rivers and seas – at Rio de la Plata, Bahrain and the Jamuna, in Singapore, Hong Kong and Africa. The places are too numerous to name.

As this century draws to a close, the dredging industry can look back with honest pride at the significant contributions it has made to the world’s infrastructure, to the betterment of the quality of life of people the world over. And they can look forward to a New Millennium which will certainly be characterised by continuing international co-operation and increased environmental consciousness – by a continuation of innovation in all areas of dredging, especially in a concerted effort to dredge in populated areas in environmentally sound and responsible ways. No doubt about it, we are more than ready for the year 2000 and for a New Millennium filled with new challenges. In fact, plans are already on the table for huge infrastructure projects and bigger ships with ever improving technologies are already rolling off the wharf. As the world’s population increases dramatically and the demand for harbours, airports, housing and recreation areas continues to grow, IADC members are ready and able to create new infrastructure and space where the need arises.

At the turn of this Millennium we are taking a moment of reflection to review the past, knowing that a challenging and exciting future lies ahead of us. IADC members will take part in shaping that future.

Robert van Gelder
President, IADC Board of Directors
From Hand-drag to Jumbo: A Millennium of Dredging

Changes in marine engineering and water management have come in many ways throughout history. But at the turn of this millennium, it is not just change alone that is remarkable. It is the acceleration of the rate of change that is the determining factor. Hydraulic works have altered our world and our living conditions over the past centuries. Man has increased his control over nature, even in the most remote corners of the planet. Science, technology and organisation have turned the threat of water into a major challenge and a commercial opportunity.

More astonishing is the acceleration of the rate of change as seen in the last one hundred years of this millennium – a momentum which overshadows even some of the most radical advances of the past one thousand years. New developments in technology, breakthroughs in power supply, and fabulous increases in productivity are well documented. Other trends may be less visible, but are at least as important: the unprecedented improvement in labour conditions, the international scope of the business, the globalisation of the industry, the professionalisation and integration of dredging companies.

Harbour, river, reclamation and indeed offshore projects, on a scale of which former generations could only dream, have become common practice at the end of this millennium. In several countries, small family businesses grew into strong, privately capitalised groups of companies, which in turn became publicly held companies and still later ousted state-owned dredging. Innovative ways of collaboration and management have been established, such as public-private partnerships (PPP), concession-type contracts and build-operate-transfer (BOT) schemes.

Formal education of crew and skilled labour has replaced on-the-job training and inherited experience. Quality control and safety management have become inherent parts of any engineering project. Caring for the environment has added a completely new dimension – and even led to diversification of the core activity. Electronics, imaging and the combination of computers and communication have turned the dredging business into a high-tech industry.

On the eve of a new millennium, huge jumbo trailers and powerful cutter suction dredgers have come into service. Bold and daring mega projects are being executed, turning the sea into habitable land as well as extending navigable waters deep inland. The scope of the industry has broadened to offshore activities and environmental clean-up programmes.

Impressive as these changes have been over the last centuries, one characteristic stands out as a constant in the history of dredging: marine engineering continues to change the shape of our world. And members of the International Association of Dredging Companies, spanning the globe, have decisively contributed to this, for dredging is surely one of the most powerful instruments for economic growth, for development and for prosperity.

In The Beginning...

Civilisation was born on the banks of large rivers. As water is the prerequisite of life, mankind has settled along the Nile, the Euphrates, the Tigris, the Indus and the Yangtze-Kiang. Since ancient times and well before the past millennium, people have sought ways of dealing with water – their main commodity and primary source of drinking, sanitation, irrigation, cultivation, transportation and communication. In our days, where half of the six billion people on our planet live in cities, a full 80 percent of the world’s population live less than 50 kilometres from open water.

Ever since the early days of cultivated life, people have interfered with their environment to create a better world and a safer place to live and to work.

Facing page: From hand-drag to draghead: Once dredging meant a solitary person wielding a single instrument to clean a local river or canal. Today the enormous draghead of a jumbo trailing suction dredger, reaching many metres below sea level, moving millions of cubic metres of sand, all over the world is the industry standard.
From earliest times, heroic achievements are recorded in which brute manpower and huge numbers of labourers were the main instruments of technology. Early hydraulic projects were mainly carried out “in the dry” – but it was in the course of those undertakings that, very slowly, the technology was developed that ultimately would lead to the unprecedented productivity in present times.

Long before our present calendar, dikes, canals and embankments were built to protect the earliest settlements or to provide for irrigation. Terrace farming and plowed fields in Asia, Europe, Africa and the Andes area are ample proof. Phoenicians, Assyrians, Sumerians, Egyptians and Babylonians are known to have built quite impressive canal systems, traces of which can still be found.

In the 7th century BC, the Assyrian king Sennacherib constructed an 80-kilometre-long, 20-metre-wide stone-lined canal to bring fresh water to his capital Nineveh. Compared to 20th century standards, one is surprised to learn that the project, which included a 330-metre-long aqueduct, was completed in only one year and three months time.

According to the Greek historian Herodotus, an Egyptian pharaoh of the 26th dynasty, Necho II who reigned between 610 and 595 BC, began the construction of a canal between the Nile and the Red Sea, through which the goods of Arabia would flow into the delta. The works were discontinued on the authority of an oracle, but were later resumed by the Persian king Darius in the 5th century BC – as four stelae he erected at the time bear witness. When Ferdinand de Lesseps dug through the Suez Isthmus more than two millennia later, traces of the old Necho canal were still visible in the landscape.

Just as history is written by the victors and the winners, great public works are only recorded for their result – not for the laborious way they have been constructed. Very little is known about the workforce at that time, the number of labourers, the conditions of work, and the minimal technology they may have used. When we recall that the great pyramid at Giza consists of 2.3 million blocks with an average weight of 2.5 tonnes, one can only imagine that a powerful central authority, say an absolute and ruthless ruler, could organise and manage such projects, which required the mobilisation and control of forced labour on a massive scale and a continuing supply of slaves and prisoners.

A glimpse of what ancient water works may have looked like can be surmised from experiences or encounters in our own time: the legions of workers who are involved in some hydraulic works in modern Bangladesh; the yoke on the shoulders of women at a well in the Sahel belt of Africa; the “endless chain” which in some parts of India has hardly been modified in the last few thousand years; the primitive but still efficient small irrigation canals through melon fields and olive orchards in the Provence region of France.

For centuries, the lack of proper equipment and power was a serious obstacle for major public works to be executed “in the wet”. Yet, there is conclusive evidence that the Phoenicians built artificial harbours at Sidon and Tyre in the 13th century BC. Amongst the finest examples that have survived are the Phoenician cothon of Motya, off the western tip of Sicily – a harbour basin built in the 4th century BC, 50 metres long, 35 metres wide and 3 metres deep, with a paved access channel 7 metres wide – and the ancient port of Gadir built in the 9th century BC which is presently the city of Cádiz in Spain. Other famous harbours of the ancient world include Piraeus, Syracuse, Carthage and Alexandria, with the first man-made, 350-foot-high lighthouse of Pharos.

How these ancient artificial harbours were kept to depth for so many years is largely unknown. But it is a fact that the same siltation processes occurring today already did their destructive work at that time. Some historians claim, referring to ancient hieroglyphs, that the hand-drag was already known and used in Pharaonic Egypt.

All the same, the longer-term efficiency of primitive dredging techniques must have been rather poor. Littoral drift and currents, the advancing shoreline and the destructive activity of running river water, which is
Alcantara, Spain, in 110 AD. The equipment is also mentioned by Julius Caesar in his chronicle of the conquest of Gaul, when he elaborates on building a bridge across the Rhine. The Roman legions also canalised one of the mouths of the Rhône river. In the first century AD the Roman consul Marcus Livius Drusus dug a canal between the Rhine and Yssel to relieve the Rhine of surplus water, and the Roman general Corbulo is known for having linked the Rhine and the Meuse rivers with a 37-kilometre-long canal.

At the same time, the Chinese were building impressive canals, such as the 144-kilometre-long Ling Ch’ü in Kuangsi. As is clear from Chinese documents from 2000 years ago, the two great rivers of China, the Yellow River and the Yangtze, have always caused their share of flooding disasters. And the Chinese carefully recorded how to build and repair dikes as well as how to direct the river into retention basins and two large lakes, the Dongting and the Poyang. During rainy seasons the Dongting is quite deep but in the dry season it is impassable for ships. As far back as the 3rd century BC during the Qin dynasty, the Miracle Canal, as it is still called, was built to allow ships to sail through the Dongting into the Yangtze, all the way to Canton.

Between the Black Sea, the Mediterranean and the North Sea, the Romans built and operated an extensive network of harbours. It has been calculated that by 400 AD, they had constructed 30 lighthouses in their empire, including at Boulogne and Dover on both shores of the English Channel, and at Ostia, the busy trading port and naval station off Rome. All these harbours were threatened by siltation. In the second century Ostia had a record population of 50,000, but in the following centuries the booming port became obsolete and partly obstructed by a sandbar.

A modern hydraulic project in Bangladesh uses legions of labourers to carry and dump rock, not unlike our dredging ancestors must have done.
Several techniques were applied for turning the tide, including the use of the semi-circular arch when constructing moles and breakwaters. These allowed for a better inflow and outflow of the sea and a beneficial scouring action in the harbour. But in the longer term, all measures were inadequate. In recent years, new evidence of this was found during construction of a tunnel at Velsen in North Holland, once a Roman harbour which played a role in raiding barbaric tribes in Germania. Archaeologists found evidence of repeated dredging activity in the harbour basin between two solid moles. They concluded that an open jetty was added to the old harbour piers, after frequent dredging had failed to produce the desired result. By the year 30 AD, the harbour was abandoned – hardly fifteen years after being built.

The European Centuries

Dredging and marine engineering are part of the heritage of the Old World. From pre-Columbian empires to Chinese imperial dynasties, all civilisations have looked for methods, and some did find solutions, for dealing with water – always a threat for human life as well as an opportunity for commerce and communication. Yet, it is a fact of history that major technological breakthroughs of the past millennium have come from Europe, slow and painful as this process may have been.

This is not to minimise the input of important technological improvements from other parts of the world – especially in the last two hundred years. But it is true that the history of the Old Continent can be written by way of the highlights in the fight against water. For the better part of the past millennium nation-states did not exist, and no single country had a predominant role. Marine engineering is a truly European legacy, with contributions from Italy and England, the Netherlands and Belgium, France and Spain, Germany and Sweden.

The development of this technology has been a painful and laborious process, with much human suffering and an incredible loss of life. But in the final account, when all basic modern technology became available somewhere at the beginning of this century, the European dredging companies, which were rapidly evolving towards full-grown conglomerates, were set to assume a leading role in a global market.

In the last decades of this century, the foundation of European innovations in dredging has expanded to include Japan, Korea and other parts of the world. IADC is proud of the contribution all its members have had in the development of dredging technology, and, hence, in the improvement of worldwide economic and social progress.
For centuries after the Roman Empire collapsed, the Old Continent slid back into a heterogeneous world of local communities and families who were left on their own to fight the forces of nature. People worked the land for a less-than-decent living. Without a central authority, hydraulic engineering did not exist as such. Caring for protection against flooding was not a profession—it was a duty and part of daily life for all farmers and their families.

In the region which is currently named the Hamburg-Le Havre range, the coastline was not yet firmly established. Transgression and regression of the sea happened in continuous succession. Deep creeks of up to 20 kilometres behind the coastline, and tidal rivers penetrating the inland were a constant threat for permanent settlement.

On the fertile alluvial plains, people looked for a sanctuary on terps and refuge mounds, which were either natural features in the landscape or could be built by a single family. Close to their mud huts or on the high ground of some salty marshes and tide-land, they bred sheep whose wool would later be traded in the cloth commerce between England and Flanders. The Halligen Islands to the west of Schleswig-Holstein, Germany, still provide examples of these early terp settlements. In this largely autarkic society, navigation and indeed any form of communication was limited to Lombardian and Frisian trade.

Colonisation of uncultivated land, salty marshes, peaty soils and fens (after which the famous marshland of Cambridgeshire has been named) was the setting for the earliest reclamation projects in Northwest Europe. By the end of the first millennium, the unifying power of the Christian church, together with the Frankish landowners, was able to mobilise the illiterate population for engineering works that exceeded the possibilities of individual farmers. The revival of large estates, the landed nobility as the power base of the Carolingians, the educated Anglo-Saxon missionaries and the emergence of abbeys provided the organisational skills for major public works after the turn of the first millennium.

As the feudal overlord donated huge salty marshes to abbeys all over Europe, the old Benedictine rule of praying and working (ora et labora) was the ethic and the driving force behind cultivation and development of the time. In the Low Countries, the name given to the lands from northern Normandy to the large river mouths of Holland, huge and partly inundated waste lands were systematically diked in between 1075 and 1175. A second wave of diking was carried out at the end of the 13th century by Floris V, count of Holland and Zeeland and a son of the German king. Every inhabitant under the authority of church or count had to make his contribution as part of the feudal duties.

**Early Land Reclamation**

In the course of time, the reclaimed marshes would become extremely rich land for cultivation and breeding, in addition to their potential for peat digging. It is interesting to note how part of that reclaimed land, still visible on old maps, has completely disappeared from earth after calamitous floodings. The prosperity of the land, however, has been preserved in old legends. Only a generation ago, elderly dredging workers recalled the old stories of the Saeftinghe-polder, where carriage-horses of the rich landowners had silver and even golden horseshoes on their hoofs. One of the storytellers even claimed he once found such a golden horseshoe in his dredging bucket, which enabled him on the spot to buy a new vessel. The same story is told in several ways, in different areas of Belgium and the Netherlands—which may suggest it is part of a collective phantasm of hard-working but poor people. Formerly, Saeftinghe was a 3000-hectare salty marshland on the border between Belgium and the Netherlands. It drowned forever in a calamitous flooding in 1570. Although some of its salty marshes are actually rediscovered as a nature reserve, the village of Saeftinghe will never reappear as it is currently in the middle of the deepened Western Scheldt fairway.

Reclaiming polders and salty land behind the dikes is an integral part of European heritage and tradition. Major reclamation after donations of marshland were executed by the abbeys of Fulda in Germany, Saint Rémy from Reims in France, Saint Panthaleon in Cologne, Saint Amand in Tournai, Sint Baafs and Sint Pieter in Ghent, and the Flemish Cistercian monks

A dredging rake, operated by manpower, was an early means of draining and cultivating land along riverbanks and in marshy areas.
of Ter Doest and Ter Duinen who became famous for their hydraulic engineering projects in Zeeland. One of the earliest recorded reclamations was in 1103 when Frederick, Bishop of Bremen, had the Wilster Marsh, a huge area east of the River Elbe, drained and cultivated. Hand in hand with the authority of the count, monastic orders were the only organised power, able to recruit and to mobilise whole populations.

By the end of the 12th century, the defensive approach of erecting dikes as a protection against flooding had given way to offensive projects by purposefully reclaiming land. At about the same time, cutting and digging peat which was the main heating fuel in those days, began to be carried out “in the wet”. Owing to population growth and increasing needs, surface supply had been running low, making it inevitable to cut for peat under the water line. The subsequent lowering of the soil would have disastrous effects in the future causing flooding, especially in the Netherlands. Efficient draining only became feasible when windmills were more common after 1500.

Reclaiming land required providing and maintaining access to open water. In the same way, specialised equipment was required for winning peat in the wet. The hand-drag may have been known for a long time, but it was in the first half of this millennium and indeed only until a few centuries ago that it became the instrument of choice for what must still be considered a very primitive dredging and extracting activity.

At the end of a pole some three metres long, a net or a bucket was fastened around an iron ring. The ring would be scraped over the bottom and lifted, emptying the bucket in a flatboat or directly on shore. Although the hand-drag has been somewhat improved in later days, adding more flexibility to the iron ring and extending the length for reaching greater depths, there can be no doubt about the hard work that came with it.

As late as the 1950s, a variation of the medieval hand-drag was still being used to clean canals.
Flanders and England, its strategic location between the Rhineland and the North Sea, and between the Mediterranean and the Baltic played an important role in this development. Sailing under the red and white colours of the Hanseatic League, merchants from the cities of Lübeck, Riga and Oslo settled in 14th century Brugge. At the same time a flourishing financial activity developed with early banking institutions in Lombardia.

In addition, from the 8th century on, the Frisian trade had spun an extensive network of commercial relations with England, the Rhineland, Denmark, Sweden, and the Alsace and Jura regions of France. The old Roman fortress of Dorestad near Utrecht was a focal point in the Rhine river trade. Clearly the importance of free trade for improving the infrastructure and economic prosperity in general, which we see manifest today in the North American Free Trade Association (NAFTA), the South American Mercosur, and the European Union, was already recognised centuries ago.

The rise and decline of Brugge is noteworthy, however, because of the continuous but futile attempts to fight against the threat of silt. Originally, Brugge was connected to the Zwin estuary into which the Reie, a canal which was dug in the 11th century, debouched. Dredging works in this Reie canal are chronicled as early as 1292. At the very peak of its fame in the 14th century, the city attracted traders and goods from Scandinavia and the Baltic to southern Europe. Yet, even at that time the city could no longer be reached by sea-going

Nowadays to prevent siltation, maintenance dredging is done regularly in rivers and access channels.
vessels even though they generally measured less than 100 tonnes. European goods for the marketplace were offloaded and transshipped in outports, such as Damme, which was still connected to the sea and where reportedly the first lock in history was built.

Even then, the 14th century represented the first of three so-called Golden Ages in the Low Countries – the others being focused at Antwerp in the 16th and Amsterdam in the 17th centuries. In all three cases, access to the sea and the availability of open water acted as catalysts for increased economic growth. In all three cases as well, silting up, closing of access, or serious restrictions on depth in the fairways were permanent threats for a sustained expansion – whether they were caused by nature or by man.

This represented an immense problem which was faced by other ports as well all over Europe. Medieval societies simply did not have the technology and the power supply for keeping open access to the sea. The increased draught and size of vessels in later centuries only intensified the challenge. Cargo ships of 50 tonnes in the 12th century had evolved to the common size of 150 tonnes in the 16th century, with some of them having a record tonnage of up to 500 tonnes. This was clearly too much for overcoming sandbars in the old medieval harbours.

In the centuries that followed, many significant projects were executed throughout Europe. King James I called upon the Dutchman Cornelius Vermuyden to drain large expanses of marshland at Windsor, York and Lincoln. His successor, Charles I, employed these men to drain the Great Level in the Fenland districts of East Anglia. And Czar Peter the Great sought the dredging skills that he had seen in Holland to be used in the founding of St. Petersburg in 1703.

Yet hundreds of years after the useless attempts in Brugge, the famous fishing and trading ports on the Dutch Zuiderzee (later dammed up to become the inland IJsselmeer) were still as helpless and powerless to find lasting solutions. Silting up was a European problem. For the Old World, the sea was a window to the world but an eternal threat and frustration at the same time.

Manpower and Horsepower

From early medieval times to the spectacular days of the Industrial Revolution, people have been occupied with developing solutions for dredging and marine engineering. The old mechanisms of draining sluices or creating a counter current against siltation of the harbours, did not satisfy. The ancient hand-drag remained the same and was kept in use, but its capacity was limited in terms of depth, volume and time. The evolution of inland navigation and the increasing size of sea-going vessels required new dredging equipment to be developed.

And a remarkable variety of early dredging machinery were designed. The overwhelming challenge of course was to find the required energy and power supply for handling the equipment. No satisfying solution would be found before the development of new materials and the coming of steam power.

For many centuries, manual labour and animals were the main energy supply for what was an extremely hard and laborious work. Spades, wheelbarrows and barges, pulleys and winches, cranes, tackles and hand pumps, even wind and current were helpful, but in the end it was the brute power of man and animal that had to provide the drive for even the most ingenious equip-
vessels, but some descriptions have them mounted on a pontoon, being pulled by winches from the banks. It is said the Turks forced sailing vessels to drag a kind of harrow behind them at the time they were in control of the mouth of the Danube River. When in the 1670s the Dutch engineer Cornelio Meyer Olandese was asked by the pope to carry out hydraulic works in Rome’s Tiber River, he used horse-pulled scratchers and harrows to deepen the river.

Dredging rakes and harrows were still being used in the early 19th century. In 1824 the Flemish miller David Van de Velde from Diksmuide invented a “marl plough” with iron rakes, mounted on a raft and pulled by horses from ashore. When building the port of Bremerhaven, Germany, in 1858, harbour authorities ordered the construction of an “eisernen Kratzschiff”, one of the latest variants of this relatively successful technology.

Removing the loosened material was something else altogether. From very ancient times, the “endless chain”, sometimes called a Jacobs ladder or paternoster, was known – a tool which would ultimately be applied in the bucket dredger. Combined with a treadmill, driven by two men or an ox, a 17th century Chinese author describes how this device had been used for centuries to irrigate paddies. The system is also mentioned in 1570 by the French engineer Jacques Besson.

When the late Middle Ages turned into modern times, machines were developed which may be considered as the precursors of modern day dipper and backhoe dredgers. After emigrating to the Protestant provinces of the Low Countries at the height of the wars of religion, the Flemish mathematician Simon Stevin published his theorem of the triangle of forces in 1586.
Applying this finding in the field of hydraulic engineering, he obtained a patent for hoisting and levering the hand-drag – a major improvement. After being promoted quartermaster general of the army under Prince Maurice of Nassau, Simon Stevin would be appointed to the post of first surveyor of national hydraulic works in the newly founded republic. His son Hendric by the way was the first person to devise a practical plan for damming up the Zuiderzee.

The Mud Mill

For more than three centuries, the mud mill became the machine of choice for maintenance dredging works in Europe. The new technology coincided with the Golden Age of Holland, marked by rapid economic growth, overseas expansion and prosperity. As Dutch engineers played an important role in the development of the new technology, the device became known as the Dutch or the Amsterdam mud mill – all the more understandable since Amsterdam had replaced Antwerp in the 17th century as the commercial centre of the Low Countries.

Basically, the mud mill was an “endless chain” being driven by a wheel in which men were walking. The soil was lifted on little planks and later on in buckets, and then dumped through a gutter in a scow or a barge alongside. The machine was efficient in soft mud, but less so in sand. It was extremely hard labour, for which prisoners were brought in. Being sentenced “to the wheel” was a severe punishment.

By the early 17th century, the system was improved by introducing “horse power”. This may not have been a first, as Chinese drawings refer to oxen as the driving power for dry earth works by means of an “endless chain”. Around 1550, an Antwerp-based merchant, Gilbert Van Schoonbeke, used a horse mill for pumping up clean water to a local brewery. In 13th century Brugge, a treadmill was used for primitive and inefficient dredging works.

The Amsterdam mud mill proved to be a success story, and variants of it are found in several European countries. In 1623, a man-powered dredging mill with copper buckets was used for deepening works on the Meuse river. In 1628 a Flemish engineer by the name of Adam Clippens obtained a patent for a mud mill, which he called “slyckmeule.” One year later, a Dutch mud mill was built in the Polish city of Gdansk. After horse power was introduced, the mud mills became even bigger and were able to dredge to greater depths. A stable was constructed on deck, and by 1670 a mud mill in Rotterdam was driven by no less than six horses. The drive mechanism was also significantly improved in the course of three centuries, a process that continued when further developing the bucket dredge in the steam period.

Seldom if ever is the development of technology a single person’s achievement. Different technologies often exist alongside each other. For instance, today African countries operate their own airlines at the same time that the yoke is still a major piece of equipment in the countryside. In China, the traditional abacus is used side by side with computers. In dredging works in Bangladesh, manpower and armies of local workers are involved together with powerful cutter suction dredgers. These parallel developments were no different in the past.
Horse-driven, the so-called “Amsterdam” mud mill (left) replaced the wheel dredger (see below). In the beginning, the mud mill was economically more viable than steam, but eventually, by the end of the 19th century, steam-powered dredgers became the industry standard.

Other Early Dredging Machines

Thus, alongside the mud mill, other machines coexisted – sometimes using the same treadmill or wheel technology. Around 1592, a grab dredger operated from ashore and driven by manpower and winches, became known as the “Venetian dredging machine” as it was invented by the Italian Pietro Venturino and improved by his fellow countryman Lorini. This device was known in several countries, traces of which can be found in Antwerp, Kampen, Hamburg and Bremen. A variant was pontoon based and did reportedly work successfully in the Venice lagoon.

In the 18th century, several French engineers such as Bélidor, Guyot and Macary developed spoon dredgers which found their way all over Europe. They were true precursors of modern day dipper and clamshell dredgers. Galley slaves in tread mills supplied the manpower for these engines in several French harbour projects. The French spoon dredger was quite famous in its time, as may be concluded from the fact that even 18th century Dutch navy preferred this machine to the classical mud mill. Spoon dredgers were still being used in France during the first half of last century.

In the mid-18th century, a Swede by the name of Knutberg invented a new way to drive the dredging wheel, using a four-armed swing lever and a catch system. Quite original was a wind-driven wheel dredger, designed by the Frenchman Martin Peltier de Bellfond. A windmill was constructed on a flat-bottomed vessel, driving a dredging wheel of about twelve metres in diameter. From a depth of 3.5 metres, sixteen blades on the wheel lifted the silt to the highest point. There it was dumped in the hollow shaft of the wheel, before running away through a gutter in a barge.

Peltier built this famous wind-driven wheel dredger in 1738, on behalf of the city of Bremen for deepening the Weser River. The client was clearly satisfied as he was asked, within four years after the first order, to build a second and even bigger one. However, the Peltier machines were scrapped in 1747, probably because they did not succeed in reversing the trend of siltation.

At the end of the 18th century, dredging technology and continuous improvements had clearly reached their limits. Compared to early medieval days, important technical breakthroughs had been achieved. Skilled workers had been trained through the bitter experience of their fight for survival. Capital became available, as small contractors made a practice of joint ventures. In short, a professional dredging industry was in the making.

Moving beyond the technical constraints of the time, however, still required one or two major breakthroughs, a true revolution in drive, energy and power. The original technologies were developed on the European continent, especially in the prosperous Low Countries. The new technology would come from the other shore of the North Sea, where the Industrial Revolution was under way.
The Age of Steam

Although the steam engine was invented in England in the late 18th century, it took almost a hundred years to perfect the steam dredger. Once accepted, however, the advent of steam marked a revolution in the capability of dredging vessels. All over the world steam-driven dredgers became the industry norm, increasing the capacity of dredgers and the kinds of projects they could do. Steam-powered dredgers were still being utilised well into the 20th century.

Counter-clockwise from top right: bucket ladder pumping ashore in Venice, Italy around 1915; steam mud dredger at work in the Harbour of Portsmouth, England – where the first really successful steam dredger was probably used; steam bucket dredger Walter Glynn built in 1895; steam dredger at work deepening the harbour of New York; and suction hopper steam dredger Dracpoli in 1944.
Several technologies, old and new, existed alongside each other and indeed overlapped each other in use.

The design and capacity of steam-powered bucket dredgers were still being improved when the completely new technology of hydraulic dredging emerged with the invention of the centrifugal pump. Forty years after the first steam dredger was built, the German city of Friedrichshafen still ordered the construction of a man-driven bucket dredger – the eighteen bucket chain being operated by six men and a supervisor. Even in 1873, a chief engineer of the Dutch hydraulic engineering ministry advised sending out 25 skilled workers with as many hand-drags to the colonies, instead of buying a steam-powered dredger.

Not only did major infrastructure works become feasible because of the innovations of the Industrial Revolution. These inventions also dramatically changed the customary way of life and social conditions. Dredging and marine engineering had always been an extremely hard and laborious work, born and sometimes executed on the verge of life and death. The days of the hand-drag or slaving away at a whim or a handle of a hand-bucket dredger were clearly over. Family and village life at the end of the 19th century could in no way be compared to what it had been in the rest of the millennium. Skilled dredging workers swarmed out all over the world for long-term assignments. For the first time in the millennium, people could make a decent living out of what for centuries had been a struggle for survival, a community service and a duty.

The impressive improvement of social conditions became possible after the innovative technology had increased productivity dramatically.

Steam Power/Diesel Engines

Although the 20th century has seen many improvements as well as an extraordinary increase in scale, all basic inventions in the dredging industry occurred between 1800 and 1900. By the year 1900, all the fundamental dredging technology that is being used today was already available. The 19th century was a hundred year period that changed the world more than all other centuries taken as a whole.

The Industrial Revolution was not a single event, nor did it happen at one moment or at one place. It was a process which started in the late 18th century in England, and soon would spread to the European continent and the United States – marking the passage from an agrarian and handicraft society to one dominated by machines. That process was driven by a cluster of innovations, such as the introduction of steam power, new ways of making iron and steel, and a completely different organisation of work and company structures.

In the field of dredging and marine engineering, the impact of the transition from manpower to steam power, and later from wood to steel cannot be exaggerated. Whilst former generations had only been able to draw plans, now dredging, deepening, reclamation and marine projects became feasible: building the Suez and Panama canals; the enclosure of the Zuiderzee in the late 1920s and the famous Delta plan shutting out the sea in the Netherlands; the extraordinary extension of ports and harbours along the Hamburg-Le Havre range; the Great Lakes and big rivers infrastructure projects in the Americas; the unprecedented reclamation and artificial islands in Southeast Asia. And, not to be forgotten, the completely new challenges in major offshore works all over the world.

The process of innovation was slow, spanning more than 120 years between the time James Watt patented his separate condenser in 1769 and Rudolf Diesel took out his first patent in 1892 for the high compression engine. At the beginning of the Industrial Revolution, innovations were just a matter of common experience and empiricism; later on they became science-based in the first place and were the result of systematic and patient research. It took many decades as well to improve and refine the new and innovative technology. Some of the early steam-powered dredgers were clearly technical failures, and were perceived as such as well. In the early days, not all new technology performed with the satisfaction and productivity as the proven traditional techniques.

The new technology encountered significant resistance, either because of conservative attitudes, private interest, local conditions, economic calculations, or simply because it was not yet well enough developed.
Using a hand-drag, one worker could dredge a maximum of 2 cubic metres per hour – depending on soil conditions and depth. Working for 165 consecutive days near Rotterdam in the 1870s, a Dutch contractor was proud to report one of his newest steam-powered suction dredgers had achieved a daily average of 580 cubic metres of sand, including sailing time.

Less than thirty years later, the American engineer Lindon Bates was the winner of a US-government-sponsored competition to build a cutter suction dredger, with a capacity of 1600 cubic yards (1212 cubic metres) per hour. During 175 hours of official trials, this famous Lindon Bates Bêta dredger realised an average output of 5945 cubic yards with a record of up to 7789 cubic yards per hour. A Belgian government mission, sent out to study the dredging techniques used on the Mississippi river, concluded this dredger was “very superior” to everything known in the Old World. Bates himself claimed the Bêta productivity was ten times superior to any other dredger of his time.

The next year, Bates was invited to address the 7th International Congress of Navigation (PIANC) in Brussels, where he was welcomed amidst the most enthusiastic cheers of a specialist audience. It was 1898. The 20th century was yet to begin.

According to historical research by Skempton, the very first steam dredger was a spoon dredger, operating in the North English port of Sunderland by the year 1798. It was driven by a 4 HP steam engine from Boulton & Watt, installed on an existing vessel.

Very few details have been passed on, perhaps both because the device was rather unsuccessful and was already scrapped in 1804 and possibly because the hand-drag was still more efficient.

Other sources report that the Spanish engineer Agustín de Betancourt, founder of the first school of civil engineering in Spain, designed the first-ever steam bucket dredger in 1791. This dredger was built in Russia by Tsar Alexander I to dredge the port of Kronstadt. Betancourt served for 16 years in the court of the tsar, establishing there as well a school of civil engineering, the first in Russia.

Americans, however, referring to the strange “Orukter Amphibolos” machine, claim they were the first to build and operate a steam-powered dredger. The vessel is attributed to Oliver Evans, who used it in the port of Philadelphia in the year 1805. It was able to sail by way of a paddle wheel behind the afterdeck, and even had wheels to move on land. Driven by a small high-pressure steam engine, the bucket ladder seems not to have been a great success either. Traditional dredging machines had been known in America as early as 1774, when a whim-driven grab dredger built by Arthur Donaldson was used in the port of Baltimore. In the mid-19th century, very powerful dipper and clamshell dredgers in America won the admiration of many European visitors.

Probably the first really successful steam dredger was brought into operation in Portsmouth, England in 1802.
Innovative infrastructure:
In response to the disastrous floods of 1953 in the southern part of the Netherlands, the formidable Delta Works project were begun. The Eastern Scheldt Storm Surge Barrier laid the technological groundwork for some of the major dredging activities which followed in the next few decades.
It was a purpose-built 100-by-26-foot vessel, with a central bin 18 by 8 foot. A bucket ladder was powered by a 12 HP steam engine. It must have been successful, as the same designer was asked to build a similar dredger for the marine port at Deptford. This nr. 3 steam dredger on Skempton’s list, which began operations in 1806, is said to have realised a production of 90 tonnes of sand or 60 to 70 tonnes of gravel per hour. How long this production rate could be sustained is not recorded.

In the same year, the famous steam dredger Brunswick was built for deepening the Thames river at the notorious “Blackwall Rock” bar. Instead of the traditional rock removal by dynamite, the Brunswick could drop a heavy chisel and remove the pieces through a bucket chain. For the winning of softer material, the production of these early machines seem to have been clearly outweighed by the hand-drag of “ballast men”, as these workers were locally called.

In 1808, one of the main problems of the emerging steam dredging technology was solved when a friction clutch was developed for the Plymouth II – preventing the whole machine from breaking up when dredging harder material. The Plymouth II had a 16 HP engine and two bucket chains, one at each side of the vessel.

Several decades passed before the steam dredger was further developed and the engine and mechanics had been improved. In the first designs, the bucket ladder was still suspended alongside the hull. Later on, a vertical bucket ladder was installed amidships in a moonpool. All ships at that time were still made of wood, as was the ladder, although it sometimes was iron fitted. Some twenty years after the very first steam dredger, serial production became available.

In the New World where a complete range of dipper and clamshell dredgers was being developed, steam technology was rapidly spreading and accepted. On the Old Continent, the innovations found their way through Belgium – a frontrunner in other applications of the Industrial Revolution as well, such as railways.

Belgium’s receptiveness was a result of the presence of coal and other raw materials in the Walloon part of the country, a centuries-old tradition of iron forging, and the availability of a skilled although pre-industrial workforce. General political conditions played a role as well: France had isolated itself from developments on the other side of the English Channel and after 1815 became a defeated power. Germany was still divided and fragmented into an infinite number of toll-protected principalities. Not before 1841 would the Elbinger Kaufmannschaft (currently the Polish city of Elblag) order a steam-powered dredger to be built in a German yard. Russia was greatly dependent on West European capital and skills.
To a great extent, the northern part of the Low Countries remained an agrarian society, which clung to its traditional and much-proved dike building knowledge. The country did not possess raw materials and disposed of an abundant energy supply through its 25,000 windmills. Yet, in an indirect way, the Lowlands played an important role as it emerged as the political power in the Belgian provinces after the Battle of Waterloo.

In one famous quotation to the Liège entrepreneur John Cockerill in the 1820s, King Willem I, who was sometimes referred to as the king-merchant, said: “Remember, the king of the Netherlands will always have money at the disposal of the industry”. This was no empty promise, as Cockerill was granted more than 1.5 million guilders in state loans, besides personal advances by the king.

By the time the northern and southern parts of the kingdom would split during the Belgian revolution of 1830, public authorities had a 50 percent stake in the Cockerill empire and British steam power technology had arrived via Liège in a Rotterdam-based joint venture. It was not until the 1860s and ‘70s, however, that the new steam technology had generally ousted traditional equipment in the Netherlands.

The Cockerill Family

John Cockerill was a remarkable man, who, amongst others, would play a decisive role in the rapid spread and further development of steam-powered dredging vessels. In 1799 his father William, a mechanic, coming from England after an unsuccessful stay in Sweden, arrived in Belgium, eventually moving to the city of Liège, where he and his two sons started up mechanic engineering workshops. Besides many interests in other industrial activities all over Europe, Cockerill’s company owned or rented shipyards in Liège, in Antwerp and, from 1864 till 1869, at the Gontouriefsky island off St. Petersburg.

Steam power had been known in the Liège area of Belgium as early as 1790 and was mainly used in the coal mines. Cockerill applied the new power technology in a very broad range of mechanical equipment. Not only was he greatly favoured by his privileged relation to the king, but he also enjoyed a state-monopoly in the short-lived reunited Low Countries.

His company would later introduce the British Bessemer steel technology on the continent, another major breakthrough. For more than one hundred years, Cockerill-built dredgers were used in France, in Prussia, in the Netherlands, in Russia and elsewhere. Even after other Liège-based companies, such as Tilkin-Mention, Bonivert, Spiroux, Jacques Piedboeuf and Perin Dosogne began building steam-powered dredgers in the mid-19th century, the “Liégeois” dredging vessel still set the European standard and reference. The first privately owned steam dredger in the Netherlands, bought for 30,000 guilders by Adriaan Volker in 1864, was a Liégeois bucket dredger. As late as the time of the enclosure of the Zuiderzee between 1926 and 1932, several “Liégeois” were still being used – although its heyday certainly was over by then.

Several designs of the Liégeois dredger have been developed in the course of the 19th century. In 1863, Tilkin-Mention offered a towed and a sailing version (by way of a steam-powered paddle wheel) at the price of respectively 17,000 and 27,000 guilders. Both bucket dredgers were driven by a 25 HP engine. Its output was said to equal 33 dredging workers. In 1865, no less than 22 Tilkin-Mention dredgers were operating on Dutch and Belgian rivers alone.

The Cockerill company developed a long-term commercial relation with tsarist Russia, supplying, amongst other things, a complete dredging installation for the port of Loban. In the final years of the 19th century, the Cockerill yards were licensed by the US government to export the American Bates cutter dredger to the imperial court of Russia. It was an improved version of the iron-built Bêta dredger, with a total installed power of 5500 HP. Cockerill christened it Volga. Another one was named Nicholaev, after the reigning tsar.

The Hydraulic Dredger

Simultaneously as the mechanical bucket dredger was still being improved, the completely new hydraulic dredging technology was developing. It would ultimately evolve into plain suction dredgers and cutter suction dredgers, the workhorses of the marine engineering business at the end of the 20th century.

Whilst steam-powered, both mechanical and hydraulic dredging were practised and competition from traditional dredging techniques still continued – mainly on economic grounds and regarding matters of scale. It is interesting to note that competition between bucket dredgers and suction dredgers would persist even in this century, until the old bucket would virtually disappear by the last decade of the 20th century – having reached its maximum capacity. In the end, both hopper and cutter suction dredgers would endure and continue to grow in size finally reaching the magnitude of present-day jumbo dredgers.

Although the centrifugal pump had already been used in 1851, the early suction pumps were directly coupled onto the steam engine. This was the case on a famous French dredger at St. Nazaire in 1859, built by the French engineer Gâche Aîné, an iron vessel with a 240 cubic metre bin and a 20 HP steam engine. It was another French engineer, Bazin, who signed on for the...
real breakthrough in 1876 with a cheap and very efficient technique. At the time, sources claimed his suction dredger was eight to ten times as powerful as the existing bucket dredgers.

In a heroic crossing of the sand dunes at Hook of Holland between 1877 and February 1880, no less than 6 million cubic metres were removed – a record volume in those days. The owner of the Adam II was jubilant, not only at the extraordinary output rates, but also at the cheap operating cost of this suction dredger. He claimed the cost of dredging one cubic metre of sand had decreased from 60 Dutch cents to 25, thanks to the suction technology. Comparing volumes, time, sailing distance and cost with the Fives-Lille I, he concluded that the Dutch dredger was very superior to his French competitor. Two years later, he was indeed assigned important dredging works in the port of Dunkirk by the French administration of “Ponts et Chaussées”.

The aforementioned US-developed Bêta dredger of Lindon Bates marked a third important step in the development of suction technology, as we have seen. Other innovations followed, such as the patented floating pipeline in 1867, the hopper barges and the hopper dredger. In 1857, the first hopper dredger in the United States, the General Moultrie – using the Bazin centrifugal technology – became operational off Galveston, Texas.

By the end of the 19th century, all basic technology, short of automation, that is used in modern-day dredging, was already known. Out of individual and family businesses, new forms of companies would grow. In 1900, the framework of most of the dredging groups that exist now at the turn of the millennium became visible. Improvement and refinement of technology, increase of productivity and scale, the emergence of diesel engines and booster stations in the interbellum period, and finally the merging of companies would appear on the agenda of the 20th century.
Production Increases

All dredging equipment used nowadays derives from three inventions of the 19th century: the steam engine which replaced human-, horse- or wind-driven engines, the centrifugal pump, and the rotating cutterhead. These three developments resulted in a tremendous increase in the production rates of dredgers.

A period of consolidation of the “invented” dredging equipment followed in the early 20th century. The change-over to mechanically driven engines made scaling-up possible.

After the Second World War diesel engines became the prime movers and a further increase in production per unit became possible, especially for the hydraulic dredgers. Three types of dredger reached perfection: the plain suction dredgers, the cutters and the trailing suction hopper dredgers.

During the 1950s and 1960s the demand for sand for reclamation areas, roads, dikes and such grew enormously. With limited environmental restrictions, nearby, easy borrowing sand could be utilised and the plain suction dredger had its heyday. After this, however, the number of plain suction dredgers decreased drastically and is presently 50 percent of what it was then.

Secondly, the large extension of the harbours in the Middle East in the period 1975 to 1985, led to the development of the heavy rock cutter dredgers, which became known as the workhorses of the European dredging industry.

Finally, the trailing suction hopper dredgers enjoyed two periods of gargantuan growth – from the late 1960s to 1970s and from 1995 on. Both periods are characterised by a scaling-up of the existing dredgers with a factor 2 within less than five years. The advantage of mega trailers is mainly based on the higher weekly outputs, resulting in shorter execution times. Based on installed power of the TSHDs, the specific power consumption during dredging as well as the specific energy consumption during transport and construction cost are for well-designed trailers almost independent of the payload.

The scaling-up of the dredging equipment is one of the reasons for today’s high production rates. Other reasons are: a better understanding of the dredging processes, resulting in the use of underwater pumps, jetwater systems and better-designed cutter- and dragheads; the application of new developments from other disciplines, such as computers, positioning systems, hydrographic surveys and so on; the use of wear resistant materials; and better-educated personnel on board the dredgers.

Production rates of hydraulic dredgers will continue to increase until concentrations have reached values of 90 to 95 percent of situ densities. Automation and information technology will make the water clearer and the soil more transparent, so that dredge masters know exactly where and what they are dredging. The information technology should make it possible to assist the crew directly from head office, reducing urgent problems and increasing efficiency and safety.
The development of the rotating cutterhead facilitated dredging in areas where there is hard rock, such as the Middle East and Singapore. Shown here, one of the largest self-propelled cutter suction dredgers at work in Singapore. Opposite below, a cutterhead from the front and the back.
The Agenda of the 20th Century

Two separate events and developments would accelerate these processes of change: First, heavy loss of plant and equipment in two world wars and during the Bolshevik Revolution in Russia led to important renewal of capital goods. Second, the expansion of European dredging groups on foreign markets, after major public works on the Old Continent were completed in the 1870s, the 1930s and the 1970-80s, drove the dredging business into a higher gear.

In combination with the improved mechanical dredging technique and the invention of hydraulic dredging technology, steam power and diesel-electric engines offered unexpected opportunities for extraordinary marine engineering works. Centuries-old projects returned to the drawing boards of the engineers as the new technology enabled old dreams to become reality.

Overlooking a time span of one century and a half, from the 1820s till 1970, the phenomenal expansion of the European ports along the Hamburg-Le Havre range stands out as a lasting achievement of what marine engineering and dredging can realise. The size of seagoing vessels may have increased in the centuries before 1800, but in terms of infrastructure, access, precincts, yards or harbour territory, these ports had not significantly changed since the 16th and 17th centuries. People simply did not have the means for major hydraulic works.

That perspective changed dramatically in the 19th and 20th centuries. Dunkirk/Gravelines and Le Havre became major hubs along the English Channel, at the same time as Marseilles and Fos were deepened to become the French window on the Mediterranean and the Middle East. Zeebrugge was built behind impressive 4.4-kilometre breakwaters, with an outer harbour, an inner harbour and an inland port at Brugge. Antwerp bloomed into its second Golden Age after the reopening of the Scheldt river in 1795 and the redeeming of taxes on shipping traffic in 1863. Decades of intensive marine engineering works and reclamation expanded the port to its current 14,600 hectares, including a completely new 6,400-hectares of land on the left river bank.

Whereas even in the mid-19th century, Rotterdam only had but a regional importance, in the course of these last one hundred years it has developed into the number one port in the world – handling a record volume of 315 million tonnes at the turn of this millennium. Construction of the New Waterway connection to the open sea in 1865, requiring the removal of 6 million cubic metres, was a major achievement in its time. It meant the ultimate breakthrough of corporate dredging in the Netherlands and, at last, catching up with the achievements and opportunities of the Industrial Revolution in what had largely remained an agrarian society.

The port of Amsterdam, which had faded away between 1839 and 1859, found a renewed dynamism after obtaining a better link with open water through the North Sea Canal in 1867 – a huge undertaking as part of the very ambitious enclosure of the Zuiderzee, completed in 1932. The size of those works would only be overshadowed by the even more ambitious Delta plan executed from the 1960s through 1980s, which protected the main coastline whilst maintaining the tidal flow by a series of dams, locks and dikes.

The continuous deepening of navigation channels and an extraordinary expansion of harbour territory, turned the North German ports of Wilhemshaven, Bremen, Bremerhaven and Hamburg into central distribution points in one of the richest nations on earth. The Aussenjade fairway was deepened to minus 18.5 metres, turning Wilhelmshaven in the only deep-sea port of Germany.
A number of modern European ports from top to bottom: Hamburg, Germany; Zeebrugge, Belgium; and Rotterdam, the Netherlands.

Most recently maintenance dredging on the Latin American continent has increased remarkably. Supported by the Argentine government, the port of Buenos Aires and its main waterways the Rio de la Plata and the Parana River have all undergone major and vital dredging activities. Even the port of New York/New Jersey (USA), which because of a lack of maintenance dredging, slipped from being the number one port in the world in the post World War II era to a much lower ranking, has resumed dredging works in the last year of this millennium.

Maintenance dredging, obviously of the utmost economic importance, greatly improved in the 19th and 20th century – not only in terms of productivity but also with respect to efficiency and precision. In the 1970s, maintenance dredging in the Scheldt river and in the maritime access routes of Belgium amounted to 20 to 40 million cubic metres of spoil per year. In Rotterdam alone, 25 million cubic metres are dredged every year. In 1977, the navigation channel to Europoort was maintained at a depth between 21.5 and 23.5 metres below low-low-water-spring.

Replenishment of beaches and coastlines also gained in importance in the last 50 years, not only for coastal protection, but also for recreational uses. The beaches of Spain and Italy, the southern coast of England, the shoreline from Maine to Miami, Florida (USA) and the southern part of the so-called Gold Coast of Australia would have long since disappeared without the constant replacement of sand by dredging companies. These are achievements no engineer could even have imagined merely one century ago.
Dredging activities in South America are opening up: Left, maintenance dredging on the Rio de la Plata. Right, Capital dredging for the turning basin at Itajai, Brazil.

The Suez

In a historical perspective, the opening of the Suez canal on 17th November 1869 is even more representative for the phenomenal achievements marine engineering was able to realise in the 19th century. A maritime crossing of the 163-kilometre-long Isthmus of Suez had been a dream for millennia, and only but a dream. Nowadays, it is the busiest canal in the world, with a width between 305 and 365 metres and a minimal depth of 19.5 metres. It shortened the sea lanes between Europe and the Far East by 16,000 kilometres.

Despite a clear decline in the number of vessels using the canal since 1992, still some 15,000 ships per year pass through, including fully loaded oil tankers of 150,000 tonnes and ballast navigation of up to 370,000 tonnes. In the course of the century following its opening, the original canal has been significantly enlarged and deepened – an important achievement of marine engineering in itself. Only the digging of the Panama canal from 1904 can be compared to the challenges and the difficulties of building a waterway link between the Mediterranean and the Red Sea forty years earlier.

The Suez canal was dug in fifteen years time, following the 99 year concession act the French diplomat Ferdinand de Lesseps obtained from the viceroy of Egypt in November 1854. Preliminary reports calculated that no less than 100,000 people, 40,000 donkeys and 12,000 camels would be needed. In the final count it was a multiple of that figure. The history of the Suez canal is fascinating, built as it was on the cusp of a moment when the clock was turning, but not yet fully turned, when massive manpower was used alongside powerful dredging machines – a project designed and executed by engineers of the industrial West in a largely feudal society.

Works included construction of Port Said, requiring the building of two 1.6-kilometre-long breakwaters, capital dredging of 1.8 million cubic metres of sand, and the reclamation of 118,000 square metres. Before the digging of the canal proper could begin, a work that would last for ten years, a freshwater canal was dug.

In those days, Suez was but a small fishing village at the Red Sea shores where most of the people had never seen a tree or a flower in their life. There was no drinkable water, so water had to be brought in either from the so-called Wells of Moses at the gates of the then-Syrian desert or from Cairo where it was traded in goatskin sacks or purses. Even after a weekly “water train” arrived in Suez from Cairo, one bottle of Nile water was said to cost as much as ten bottles of wine.

As part of what would become the Suez canal, works started with the digging of a 6-metre-wide service canal.
Connecting the Atlantic and the Pacific: A 1913 map of the Panama canal.

through which people and equipment were brought in. During a full ten years till the end of 1864, five years before the ceremonial opening, most dredging works at the service canal and the canal proper were executed “in the dry”. In conditions which can hardly be imagined, 15 million cubic metres of sand were removed by an army of forced labour.

Travellers at the time who saw those people at work compared them with an anthill, working in shifts and getting whipped and lashed. Their main equipment was a shovel, a pickaxe, and a reed or wicker basket which the French called une couffe. The baskets were passed on from one to another. After political turmoil and criticism arose in Europe about the forced labour, the viceroy Mohammed-Saïd Pasha issued a decree on labour conditions: every worker would receive a daily salary of 2.5 to 3 piasters, besides food worth one piaster. Workers who were younger than 12 years old, received a daily salary of one piaster, and the full allowance of food.

How many people did not survive this slave work, will probably remain untold. In 1865 one traveller claimed there had been, over the last year, “only” twenty dead out of the 1250 Europeans and only 23 out of the 123,933 fellahs. That last figure at least must be considered a manifest understatement, probably to be explained against the background of mounting criticism in Europe.

In the last five years until the opening of the canal in 1869, digging was carried out in a more professional way. In five years time, steam-powered bucket dredgers would remove 60 million cubic metres.

Special plant was designed by the French main contractor Borel, Lavelley & Co. Besides operating bucket dredgers, removed material was also transported by barge to the open sea. In addition, the contractor used excavators which transported the material to the shore by means of a gutter. At its peak, the dredgers had a total installed power of 10,000 HP and could handle 180,000 cubic metres per month.

Built at a turning point in industrial history, the digging of the Suez canal was a strong symbol. People were still being used as slave labour as they had been in antiquity. Yet, the age of machines was emerging, and the power of new technology was inevitably surging forward. That paradox may be seen as a symbol for the revolutionary changes in the 19th and 20th centuries in other parts of the world.

Panama Canal

Buoyed by their success with the Suez canal, the French were ready to repeat their achievements by building a waterway across the Isthmus of Panama. Work was to start in 1883 and be completed within 12 years. But plagued by malaria and yellow fever, and other diseases and accidents, some 25,000 people died and the project was threatened.

After a revolution in 1903 in which the Republic of Panama was born, the United States was granted “the Canal Zone” in perpetuity and took over the task of completing the canal. It was a monumental task, with colossal locks, that was finally completed in 1914 and has been used ever since as commercial link between the Atlantic and Pacific Oceans.

As the millennium draws closer, the Panama canal is entering a new age. According to new treaties signed in 1977, the U.S. will turn the canal back to Panama at the end of this century. A billion-dollar-modernisation programme is already in place. This will increase the canal’s operating capacity by some 20 percent by enlarging the “Gaillard Cut” – one of the narrowest parts of the canal – to handle two-way Panamax shipping traffic. About a third of the material to be removed will be done by a hydraulic excavator, equipped for high-accuracy underwater dredging – a far cry from the early steam dredgers used when the canal was first excavated.
Acceleration of Change

In the course of one generation, the dredging industry changed more profoundly than ever before. In terms of plant, automation, projects and companies, almost nothing today can be compared to the environment of only 30 years ago. If the speed of change continues at the same pace, one can predict that even bigger dredging vessels with even more computerised equipment will carry out even larger projects of reclamation and marine engineering in the next millennium. The acceleration of change may be the overall characteristic in the marine engineering industry at this turn of the millennium, but qualitative changes will happen as well.

The increase of scale is overwhelming at the end of the 20th century. In 1870, a modern steam-powered suction dredger in Europe had a bin content of 139 cubic metres. In 1993, the largest trailing suction hopper dredger had a capacity of 11,000 cubic metres. Only one year later, the record was set at an additional 55 percent with the commissioning of a 17,000 cubic metre dredger. By the year 2000, a 33,000-cubic-metre dredger will become operational offering a hopper volume some 40 percent greater and carrying capacity more than 70 percent in excess of the largest jumbo dredgers available to date. The most powerful cutter suction dredger nowadays has an installed power of more than 27,000 HP.

The depth at which dredging is executed has increased as well and may now reach more than 100 metres, as has recently been demonstrated on offshore projects in Taiwan and off the coast of Newfoundland, Canada.

Although investment costs have raced upwards, productivity has followed. Larger economies of scale, especially when long sailing distances are involved, justify the huge investment costs of these large trailers. After all, when deployed correctly their overall operating costs are lower, a savings which can be passed on to benefit the client. During the 1950s, production of the larger dredgers varied between 25,000 and 50,000 cubic metres in a work week of about 125 hours service – depending on the nature of the soil and the transport distance. In 1993, the largest hydraulic dredgers were able to produce 800,000 cubic metres per week in good running sand, at a transport distance of 5 kilometres. On the same job, the double would be accomplished by a 33,000-cubic-metre mega dredger. At long sailing distances, e.g. 100 kilometres, economies of scale have a beneficial effect, and would boost productivity of the mega dredger with factor 3 compared with the productivity rate of the largest dredgers in 1993.

On the biggest reclamation projects being executed at the end of this century, for instance in Hong Kong and Singapore, where sailing distances currently could vary between 50 and 100 kilometres and multiple dredgers are involved at one time, production rates are feasible of up to 1.2 million cubic metres per week. Some 130 years before, the combined dredging capacity when digging the Suez canal had been, at best, 42,000 cubic metres per week.

Yet, the 25,000 to 50,000 cubic metres output in the 1950s, was a phenomenal rate at the time – compared to the previous one hundred years. In 1838, the newly built hand bucket dredger of Schwahn required seven men to operate handles and winches, moving the eighteen buckets. They reached a production rate of 4.6 cubic metres per hour and per man, or 2709 cubic metres in a seven days week of twelve-hour working days. Working in open water off Rotterdam around 1880, a modern suction dredger realised a weekly production of 4060 cubic metres of sand including sailing time, which was considered an extraordinary volume. The most powerful cutter suction dredger in the United States at the end of the 19th century showed an average production of 4545 cubic metres per hour – albeit over a rather short period of time.

Small equipment also has a role to play:
A swamp buggy in operation in a development project in Lomé, Nigeria in the 1970s.
Hong Kong:

Dredging Project of the Last Decade

In the 1990s Hong Kong witnessed a dramatic land reclamation programme. This included: the construction of the new Chek Lap Kok airport in the sea on a platform artificially created by joining two separate islands; extensive port development with the addition of numerous container terminals; and programmes for the development of New Towns and renovation of existing urban areas.

The Airport Core Programme, as it is known, in itself required some 167 million cubic metres of fill. The port development works which will extend well into the next millennium – around 2015 – will require an additional 300 million cubic metres of fill. In total an estimate of fill needed will reach close to one billion cubic metres.

The technology involved and developed for these projects was unique and only possible because of the extensive sharing of professional knowledge by numerous, primarily IADC, companies. The plant necessary to meet these tasks was as well remarkable. At the peak of dredging in 1993, sixteen of the world’s eighteen largest trailing suction hopper dredgers were operating in the waters of Hong Kong.

The environmental impacts of such vast undertakings were – and are – of major concern. Careful monitoring of impacts by the Hong Kong Government Environmental Protection Department was an essential part of the dredging operations. Remote sensing for turbidity by SPOT satellites, the Acoustic Doppler Current Profiler, Sidescan Sonar, Chirp Profiling and Profiling Siltmeter are some of the methods used for the measurement of suspended solids. Underwater ecological surveys by marine biologists who are qualified scuba divers was an additional expression of the will to protect valuable coral reefs.

Hong Kong continues to be an outstanding example of how dredging at the end of this millennium set the tone for dredging in the 21st century – the realisation of major infrastructure projects executed with environmentally conscientious techniques.
Projects of Unimagined Scale

The improved power technology and the increased size of the dredgers made it possible to realise marine engineering projects on an unimagined scale. In the mid-1970s, the economic outlook of the Middle East completely changed after very important infrastructure works were carried out. Building the ports of Dammam, Jeddah, Jubail, Yanbu, Dubai or Abu Dhabi profoundly modified the economic potential of the Arabian peninsula. The scale of these undertakings may be guessed, recalling the adventurous transports of supplies by truck from Europe to the Arabian desert before the new ports were constructed, the hundreds of ships that were waiting in line before being unloaded at the single quay wall in Jeddah, or the congestion supplements of 35 and 70 percent shipping agents were charging for destinations such as Dammam or Jeddah.

Another boom period followed less than twenty years later, this time in Asia – yielding the same beneficial effect for the regional economy. In Japan the new Kansai International Airport was built on an artificial

In the 1990s, major dredging projects have taken place in Hong Kong – including new container terminals and its new airport (opposite) – and in Singapore (below). New reclamation plans in Singapore (right) have recently started which will last well into the 21st century.
Built on an artificial island two miles off the coast of Japan, Kansai International Airport is connected by a bridge for trains and vehicles to the mainland.

Kingsford Smith Airport in Sydney, Australia was originally built in the 1970s and then expanded with a new parallel runway in the 1990s.

Below, sand replenishment in Qatif, Saudi Arabia.

island two miles off the coast of Osaka. The Kingsford Smith Airport, in Sydney, Australia, already developed on a peninsula in the 1960s, was once again given a new runway on the water in the 1990s. During the years preceding the hand-over of power in Hong Kong on 1st July 1997, all major dredging companies of the world took part in reshaping the former Crown colony. Several container terminals were built; major reclamation was carried out at Yau Ma Tei near Kowloon; express roads were constructed along the northern shore of Lantau island; a suspension bridge was built between Lantau and Ma Wan. And finally, like the cherry on a cake, the new airport of Chek Lap Kok replaced the overcrowded Kai-Tak. In the meantime, dredging contractors built yet another new airport in nearby Macau.

All these projects were carried out at the same time, and all major IADC members were involved. Besides some of the most powerful cutter suction dredgers in the world, up to twenty trailing suction hopper dredgers were assigned at one time – including nine out of the ten biggest in the world. Not without reason, the fairway at the foot of Victoria Hill was nicknamed –“hopper lane” – for the busy and seemingly never-ending comings and goings of huge dredging vessels.

As the Hong Kong marine infrastructure works drew close to completion, new requests for tenders for projects were arriving from Singapore and Malaysia, where already for decades important dredging assignments had been taking place on the peninsula. In the course of recent years, IADC member companies very significantly extended the territory of Singapore.
Guayaquil, Ecuador

Most of the time, marine engineering works are carried out under the water line and the result remains invisible but for the increased traffic or the booming port activity that follows. Uncommon evidence of the contrary could be seen in the Ecuadorean harbour of Guayaquil in the early 1990s. A complete suburb for more than 100,000 Indians was cleaned up after huge volumes of sand were blown under thousands of dwellings on stilts. People who until then had always lived in extremely unhygienic conditions, were given solid ground under their feet for the first time in their lives. The winning of sand in the Rio Guayas may have been a routine job. But blowing the sand under the swamp dwellings of Guayaquil, in an area which was subject to tidal movements, proved to be quite risky, with a permanent danger of dikes and dwellings sinking in the mire.

The Scandinavian Connections

The creation of a trans-European rail and road network is one of the goals of the European Union. In the 1990s two significant infrastructure projects to achieve this goal have been the construction of the Storebaelt (Great Belt) East Bridge in Denmark and the Øresund Fixed Link connecting Denmark with Sweden.

Both projects are monumental. The Storebaelt consists of a combined traffic and railway bridge extending on the western side from Funen to the island Sprogø and a railway tunnel and a traffic bridge on the eastern side from Sprogø to the mainland (Zealand). The East Bridge is 6.8 km long, the longest suspension bridge ever built. Dredging, cleaning and the stones placement for the substructure of the bridge pylons was excruciatingly precise work. The Øresund Fixed Link, totalling 16 km, consists of a dual track railway and a four-lane motorway connecting Copenhagen, Denmark with Malmö, Sweden. Millions of cubic metres of materials were dredged and millions of tonnes of stones were handled whilst digging the tunnel trench and building the artificial islands and peninsula for the highway to tunnel to bridge to highway connections. Finally hydraulic compensation areas were deepened to ensure the stability of the marine environment. Totalling all aspects of the works, some 7,000,000 cubic metres of material has been dredged. The bridge was opened in the summer of 1999. This is the fulfilment of a century-old dream of a transportation link for Scandinavia.

Both projects have adhered to the strictest environmental restrictions, design tolerances and have withstood many risks including difficult weather conditions.
The single largest reclamation yet in the city-state is the linking together of seven islets off the western tip of Singapore, to become the integrated chemical and petro-chemical hub of Jurong Island. In Malaysia, dredging contractors carried out major reclamation projects at Port Klang, the seaport off Kuala Lumpur. Near the border with Singapore and in fact close to the Jurong & Tuas extension, several dredging contractors built the new Johor West Port of Tanjung Pelepas.

In Latin America – Argentina, Mexico and other countries – where they were recovering from the recession of the 1980s, economic reform programmes have been implemented. Anxious to really take part in the global world economy, these South American nations determined that a key element in this process would be privatisation of ports and harbours. Dredging contractors are playing a major role there in effectuating this change as can be witnessed by the concession contract along the Parana River in Argentina. The care and maintenance of this 790-kilometre-long river has been privatised based on a revolutionary concept of toll collection. This system has proven to be a showcase for the capabilities of the entire dredging industry, and for the virtues of privatisation.

Privatisation: Case Studies

As long ago as the mid-1970s a multimillion-dollar-dredger investment plan in the Federal Republic of Germany was abandoned in the wake of an official investigation which concluded that it would be less expensive to delegate part of the annual dredging activities to the private sector. Not only was the state relieved of the initial investment burden of building new dredging vessels, but they were able to realise an operational savings amounting to ten percent.

In the late 1980s three ports – Tauranga, Taranaki and Timaru in New Zealand – in need of maintenance dredging and new dredging ships investigated their alternatives, collectively and individually. After thorough evaluation, the Government of New Zealand joined its harbours into a single agent, the Port Companies. As a group they settled on contract dredging as the most cost-effective solution. A private dredging company was made responsible for executing the dredging work in all three major harbours, thus making optimal use of its plant and staff. In addition, the investment costs in vessels as well as their efficient and cost-effective use became the responsibility of the private contractor.
The Jamuna

Creating infrastructure in developing countries means operating in unique circumstances where high technology has to cope with the lack of modern conveniences. The River Training Works for the Jamuna Bridge in Bangladesh was one such project. The project was funded by the International Development Association, the Overseas Economic Cooperation Fund, the Asian Development Bank and the Government of Bangladesh, and was executed by IADC members.

The river, running north to south dividing the country, was to be spanned by a 5-kilometre-long bridge. This would provide an important economic and social link between two sides of the country. The real challenge was controlling the flooding of the river so that the bridge could be built and utilised.

Characteristically the Jamuna overflows its banks when the snows in the Himalayas melt and when the monsoon rainfalls begin. The difference in water level between the lowest levels in February and highest in August can reach 6.5 metres and the river can overflow its banks as much as 15 kilometres. Severe erosion can take place in only a few weeks time. The object of the activities was to "train" the river by means of guide bunds to remain within its banks and thus stream under the 5-kilometre-width of the bridge.

The logistics of such a project are a massive undertaking in themselves. Accommodations, medical and food facilities, and an extensive self-supporting technical facility including asphalt plant, docks and a fuel treatment plant had to be built. Communications were originally by HF radio until telecommunications equipment could be brought in by the contractor. Supplying and transporting rock, spare parts, fuel and people was a daily concern. The power of some 2200 local people was an important resource where other mechanical means were lacking. "People power" was used for preparing the fascine mattresses and for transporting rock. Since there is no blasted rock available in Bangladesh, 1.6 million tonnes of rock had to be transported over 1200 kilometres from southern India and 3000 kilometres from Malaysia. It was then transferred to barges and another 200 kilometres had to be sailed to the site and then dumped by people rather than machine.

Since the river training works could only take place during low water season, three working seasons, i.e. spread over three years, were necessary to complete the guide bunds and flood embankments.

In 1994 Mexico witnessed the sale of the bulk of its state-owned fleet and the transfer of maintenance dredging to the private sector. This process is being repeated in Argentina and Brazil as well. In Argentina the first step toward privatisation was taken when in 1993 the Puerto Nuevo of Buenos Aires was transferred into private hands. This led to the need for comprehensive dredging of the River Plate and Paraña River. A unique concept was conceived: a vital waterway would be constructed and maintained by a private dredging company which would be compensated in the form of a concession for a period of ten years – ships sailing along the waterway would pay a toll to the concession company. After an initial reluctance from the side of the shipping industry, the system is in place and now realising benefits. Transport prices of goods have been lowered considerably, and the port authority is guaranteed the expertise to maintain the depths and safe navigation of a vital waterway.

Public-Private Partnerships

Given the enormous sums of money needed to finance infrastructure projects, innovative financing methods are necessary. New harbours, airports, residential and recreational facilities require public support, both moral and monetary. The World Bank, European Union and IMF are unlikely to offer funds for development unless they are assured of society's need for the project and the financial feasibility. In other words, the project must be socially desirable and financially viable.

A public authority will seek to reduce economic risks, whilst achieving the maximum benefit. The private lending company on the other hand is commercially driven and, although they too wish to minimise risks, they are required to produce a reasonable return on investment.

Essential to a public-private partnership (PPP) is that each partner take responsibility for the success of the project, simultaneously helping to reduce the risk element. Therefore, a true public-private partnership is not based on what each partner contributes in terms of money, skill and so on, but based rather on a reasonable division of risks and responsibilities.

In a PPP, the contract should reflect not only the responsibilities of each partner but also the penalties for non-compliance. This must be reasonably distributed according to each partner's risk-bearing capabilities. And the public as well as the private partner must be held accountable.
Risk elements primarily borne by the private partner include technical, scheduling and economic (i.e. budgetary) risks. Risks borne by the public sector are structural, such as planning and permits (i.e. construction, environmental), political (elections), and regulations (changes in legislation).

PPPs can take several forms including: Build & Transfer; Build, Lease & Transfer; Build Operate Transfer; Build, Own & Operate; Design, Build, Finance & Operate, and so on. Whichever form is utilised, PPPs can prove a most successful form of collaboration when each partner is subject to the least degree of risk and the greatest chance of attaining their goals.

Offshore

New offshore activities are developing to the benefit of the oil and gas industry. Offshore exploration and exploitation require high-tech skills, and high standards of quality and safety in the field of dredging, marine engineering, landfalls and pipeline protection. Bold offshore projects are becoming feasible and a reality as well. Already in the 1970s when drilling for oil in the Beaufort Sea (Canada), an artificial island was constructed using specially designed hopper trailers, reinforced to withstand the ice conditions and equipped with helicopter landing pads. Offshore wind farms will be constructed and connected to the grid by way of directional drilling techniques. Airports are being built in the sea, avoiding noise nuisance, pollution and trafficking in densely populated areas. Artificial islands are being utilised for the disposal of heavily polluted soil or dangerous industrial refuse.

Norfra Pipeline

Dredging works related to laying pipeline for offshore projects is an increasingly significant activity for the dredging industry. Take the NORFRA gas pipeline stretching through the North Sea from Norway to Denmark, Germany, the Netherlands, Belgium and arriving in France. Of 835 kilometres of pipeline, 575 kilometres had to be buried in the sea bed in order to prevent damage from shipping traffic, anchors and fishing nets. Fighting against time, since bad weather in the North Sea is a given, the work encompassed presweeping of sand dunes on the sea bed, pretrenching, dredging, backfilling and civil works on shore.

Presweeping involved the dredging of 1.2 million cubic metres to provide a minimum 10-metre-wide pipelay corridor. After the pipeline was installed, post-trenching lowered the pipeline from its laid level of .70 to 2.00 metres below the sea bed. Some 20,000 cubic metres of water per hour were injected into the sea bottom under the pipeline, and by its own weight the gas pipeline settled into the resulting deeper trench. Sea-dredged gravel was then placed with a minimum of one metre above the pipeline. On land at Dunkirk, the pipeline crosses the Canal des Dunes through a tunnel and has been further installed up to the terminal building.

Owing to new technologies, extensive safety measures and keeping to a tight time schedule, the project was completed with a considerable underrun – 20 percent below the targeted budget.
Environmental Dredging

No overview of the last 30 years is complete without mention of the overwhelming advances in environmentally sound dredging. The value of clean water and protection of marine life has become one of the driving forces in almost any modern dredging project, be it in Hong Kong, New York or Hamburg. Without a doubt international treaties, such as the London Convention 1972 and the OSPARCON, have set new standards for the maintenance of oceans, rivers and seas.

And the dredging industry has risen to the challenge. Dealing with water nowadays requires a caring industry and people. IADC companies are in the forefront of developing new environmental dredgers to meet this challenge. Most recently, experiments on the highly polluted Ketelmeer in the north of the Netherlands as well as the Slufter depot in the port of Rotterdam have provided excellent data for dealing with contaminated materials. In Canada as well, remediation technologies for the removal of contaminated materials are being tested in the Great Lakes. Such massive clean-up projects as the restoration of Lake Tunis, Tunisia and development of its embankments are typical of dredging projects at the end of this century.

Restricting and monitoring turbidity when dredging and restoring natural habitats such as wetlands are part of...
Specially developed environmental dredgers, such as the auger dredger (below) and the disc cutterhead (opposite page), will continue to improve the high quality of dredging activities in the coming century.

In the 1980s, the Cosmos, with her sweeping arms afloat, was utilised in a clean-up campaign for skimming oil off the ocean’s surface.

the diverse environmental dredging techniques being implemented. Preventing the spread of contaminated materials, containment and cleaning-up are only a few of the challenges. Finding solutions for the disposal of polluted silts is an ongoing concern. Sediment sanitation and sealing or capping may help to solve environmental problems on land. Using marine engineering techniques, contaminated sites and landfills will be rehabilitated. Construction of environment friendly river banks will reconcile erosion protection and habitat restoration.

Dredgers have also proven to be effective means of cleaning up environmental disasters at sea such as oils spills. Both in the Prince William Sound, Alaska as well as in the Arabian Gulf off the shores of Saudi Arabia, dredging vessels were called in to assist. Even more recently, dredgers have been used to sweep the sea bottom to collect debris after airplane accidents.

International Conventions

The regulation of the disposal of dredged materials has become a worldwide concern. National interests have been superceded by international interests – waters obviously know no boundaries and they flow from one river into another, into the sea and into the ocean.

Some thirty years ago two basic treaties were constructed to govern international waters:
– The London (Dumping) Convention, created under the auspices of the International Marine Organisation in 1993, renamed the London Convention 1972;
– and the Oslo and Paris Conventions, which in 1992 were combined to become the OSPAR Convention.

Both were established to control the disposal of noxious substances at sea, but the regulations apply to dredged materials as well. Both Conventions embody two main principles:
Dredgers to the Rescue

In September 1998 a Swissair passenger plane went down off the coast of Nova Scotia, Canada. To expedite the inquiry as to what went wrong, a jumbo trailing suction hopper dredger was commissioned to vacuum the floor of the ocean, 8 kilometres out to sea. For 10 days the dredger, outfitted with gigantic suction arms, systematically searched the sea bottom, sucking up mud and sand mixed with important evidence of the airplane. The suction mouth is 1.2 metres wide and can reach down to 120 metres below sea level.

This is not the first time that a dredging vessel has come to the rescue at an accident site. Though the disaster was different in nature, in March 1989 dredgers were called into service to combat an enormous oil spill in Prince William Sound off the coast of Alaska.

Environmental disc cutterhead.

The high-tech sand-spreading "Marine Snow" method is being used in Japan to refresh the bottom of lakes and inner bays.

- a precautionary principle whereby preventative measures are taken if a hazardous situation is suspected even if there is no conclusive evidence of potential damage; and
- the principle that the polluter pays for the clean-up.

The OSPARCON covers countries which either border on the northeast Atlantic Ocean and the North Sea or which have rivers passing through that discharge into these waters (e.g. Switzerland and Luxembourg).

The London Convention (LC72) is open to all nations and some 75 countries are presently participants. Each country is obliged to create national legislation which complies with the LC72. The original dredged material guidelines in LC72 are in the process of transition into a Dredged Material Assessment Framework as part of the so-called “1996 Protocol”. This is in the process of being adopted. The Framework requires consideration of possible beneficial uses and assessment of the disposal site impacts before a disposal licence can be granted.

An important development has been the adoption of the “reverse list” whereby only substances which have been proved not to cause harm are permitted to be disposed at sea. However, the disposal of these materials (for which contamination is not a concern) will still be subject to an audit.

Other international agreements exist covering specific regional waters (South Pacific, South America, and so on) and these follow similar guidelines. The real challenge is now to encourage contracting nations to regulate their dredging accordingly and to issue regular reports to the appropriate secretariats.
Restoring Wetlands

The beneficial use of dredged materials has become one of the prevailing issues in the last quarter century. One solution to the disposal of dredged materials, primarily utilised in North America, is the creation or restoration of wetlands. Wetlands may vary greatly and therefore support different ecosystems. Consequently, constructing wetlands has developed into a scientific process where a habitat can be designed for specific plants and animals, including critical habitats for endangered species.

Two essential factors in wetland environments are the hydric (anaerobic) soil conditions and the hydrologic (water) conditions. Many wetlands are degraded or impacted or have been destroyed. Most, however, still have hydric soils even though they have been altered. For this reason, wetland restoration or rehabilitation is often a more feasible alternative than creation of new ones, because creating new wetlands may mean replacing one habitat with another and having to introduce appropriate hydrologic conditions. Dredged material can more easily be used to stabilise eroded natural wetland shorelines or to nourish subsiding wetlands, and dewatered dredged material can be used to construct erosion barriers and other structures that aid in restoring affected wetlands.

In the United States more than 16,000 hectares of wetlands have been restored or constructed. For instance, in southern Louisiana, thin layers of dredged material have been used to bring degraded wetlands up to an intertidal elevation. Wind and wave barriers have been built to allow the regrowth of vegetation at the wetlands of Weaver Bottoms in the upper Mississippi River. And wetlands and seabird habitats have been established at Gaillard Island, Mobile Bay, Alabama.

Although 95 percent of dredged material is not contaminated, experiments with wetland restoration also involve contaminated materials. In an experiment, at Black Rock Harbour, Connecticut, USA two decades of marsh development studies have successfully used contaminated dredged sediments to create vegetation in a wetland environment.

How long a soil takes to assume hydric characteristics is not entirely clear but current data indicate somewhere in the range of 15 years at a minimum. In any case, management control, adequate water supplies, long-term planning, design and maintenance are necessary to ensure the endurance of a created wetland.

Wetland environments in the United States include prairies, lakes and a forested wetlands. Pictured here in Black Swamp, Arkansas, forested wetlands being monitored.
A view from the bridge: the dredgemaster on today's largest jumbo trailers runs the dredging operations assisted by computer and other high-tech instruments.

**Dredging: Art vs. Science**

The acceleration of change in the dredging business at the end of the second millennium goes beyond the increase of scale of projects or the increase in size of the plant. Important qualitative changes are happening concurrently.

Not only are the design and the layout of the bridge no longer comparable to what they used to be, but automation and electronics have completely modified the dredging work itself. The bucket dredger, having reached its physical limits, did not change any more after 1960. For generations dredging had been a kind of an art, requiring a special touch and an almost intuitive feeling for whatever invisibly happened, out of sight, deep in the dark water. People knew but did not understand why the production rate changed that much from one spot to another. The art consisted of "feeling" the dredging vessel and "knowing" the characteristics of the different bars in a waterway.

With computers controlling the steering and measuring the flow rate, the concentration and the degree of loading, automation and instrumentation on the bridge and in the engine room have turned this traditional art in a high-tech industry. At the same time, electronic positioning systems have added a measure of precision that was never previously approached. Precision dredging at the feet of huge pylons sustaining the fixed link across the Storebaelt in Denmark, or precision stone dumping close to an oil platform in the high waves of the North Sea, would never be possible without global positioning equipment. Precision devices also increased the efficiency of maintenance dredging in tidal rivers.

**Precision Dredging**

The accuracy of dredging has increased tremendously in the last 40 years. As a result there is less overdredging and, for particular equipment, tolerances of centimetres are now possible.

The modern hydrographic survey is a good example. For instance, during the pipeline laying for Zeepipe in the North Sea, extensive pre-survey data were transmitted to the trailing suction hoppers via telemetry links. These were plotted and fed into computers which created an actual picture of the seabed. This information was then transferred by modem to the main contractors in the U.K. for further analysis.

Likewise, in Bahia Blanca, Argentina, remote-sensing techniques increased dredging accuracy. In the last 25 years satellites launched to observe earth provide valuable data by recording the electro-magnetic radiation reflected by the planet. Both Landsat TM and
SPOT XS images were examined and compared with other data. At the Øresund link project, Digital Global Positioning System (DGPS) was used to place stones precisely and also to monitor navigation and construction channels.

Multibeam echosounders can be built in the bow or the base of trailer dredgers and together with sophisticated software can make the seabed visible in a three-dimensional view during trailing or dumping operations. This enables the crew to anticipate directly during the operations and they are thus less dependent on survey data. In addition, using satellite imaging in support of dredging operations adds significant data to the soundings usually made with a computerised system of echosounder and track positioning, and is less expensive than aerial photos.
Education and Training

Instead of inherited, intuitive experience – the son following in his father’s footsteps – formal training has become the norm. A world travelling expert-technician, sent out on-call for urgent repairs to the four corners of the world, replaced the traditional blacksmith. In the old days, dredging workers got a starting job as a cook. They would become a deckhand or a “backman”, and eventually they could be promoted to become a bucket boss. Some of them could end their career as a captain. The complexity of modern-day dredging and the state of the technology have made it impossible to learn just by looking. Quality-assurance schemes and elaborated ISO procedures have set formal standards that would be perceived as a horror by former generations.

As the scientific and technological aspects of dredging continue to grow, the expertise and professionalism of dredging personnel urgently need to keep pace with the jumbo trailers they operate and the mega projects they are executing. “On the job” training is not sufficient.

A few universities worldwide offer degrees and courses in civil engineering, emphasising the “wet” aspects. Delft Technical University, The Netherlands, University of Ghent in Belgium, and Texas A&M University in the USA are outstanding institutions. Other related maritime organisations are also working to improve educational opportunities. The Maritime Institute “Willem Barentsz” at Terschelling (Netherlands) has started a course called Hopper Technology. The objective is to provide a full range of training for sailing a hopper dredger and the institute also works with a full-mission simulator of a hopper.

Various short courses also exist, such as the IADC International Seminar on Dredging and Reclamation which has been presented for many years in Delft at the IHE, in Singapore and in Buenos Aires, with the cooperation of their respective national universities. IADC also supports other organisations in the presentations of short courses, most recently in Ismailia, Egypt.

Despite the fact that working for such a high-tech industry is exciting and challenging, there remains a continual shortage of trained and educated personnel. As a result a great deal of in-company training and education is being undertaken by the dredging companies themselves. Sophisticated simulators have been developed for use in the training of operators of modern dredging equipment. One such simulator reproduces all aspects of the behaviour of a cutter suction dredger. It is used to train new operators and to improve efficiency of more experienced crew members.

But the shortage is still there, and the rapid changes in dredging technology occurring at the end of this millennium continue to demand an appropriate response from purveyors of education on all levels.
Today’s dredging industry requires a wide variety of well-trained and highly skilled technicians and professionals, who are ready to travel to the four corners of the world.
Minimising the potential for human errors which contribute directly or indirectly to casualties or pollution incidents is a task facing all shipping companies today. To meet this demand, companies should be able to ensure that personnel are properly informed and equipped to fulfil their operations safely.

Decisions taken onshore or at sea are equally as important. There is a need to ensure that every action affecting safety or prevention of pollution, taken at any level within the company, is based on sound organisational practices.

The International Code for the Safe Operations of Ships and for Pollution Prevention (ISM Code) has been developed to fulfil this objective. The ISM Code establishes an international standard for the safe management and operation of ships and pollution prevention.

In 1993 the International Maritime Organisation (IMO) adopted the ISM Code. In addition, the SOLAS Conference decided in 1994 to make the ISM Code mandatory for all shipping companies and for all ships, regardless of their date of construction. For "other" cargo ships, including dredging vessels, the code will be applicable no later than 1 July 2002. For this purpose, all shipping companies, including dredging companies operating sea-going vessels, must develop and maintain a Safety Management System. This system must ensure compliance with rules and regulations – and that non-mandatory recommended codes, guides and standards are taken into account.

Safeguarding against mishaps has always been a priority of IADC member companies, so it comes as no surprise that they have already taken the necessary measures to fulfil the mandatory regulations well in advance of the due date.
Dredging into the 21st Century

The technology of dredging as such has changed and fundamental research is carried out at universities and technical institutes. Deep dredging has become feasible, despite evident restrictions of working in high waves. Software packages have been developed, the technique of power transfer has been refined, and the draghead design has been improved. Yet, a swell-compensated cutter suction dredger has yet to be built.

Business environment and social conditions have changed beyond imagination. As the world economy turned global, dredging contractors have merged into mighty groups – sometimes as part of diversified conglomerates – and those have become global players who are active competitors for major tendering. Market shares have structurally shifted.

New players have entered the international market, such as companies from Japan, Korea and China. Engineers have surprised the dredging world with new designs. State companies have been privatised. New schemes of public-private partnership are being tried out. Law firms and standard contracts, such as the standards set by FIDIC, have replaced the tradition of the given word, a handshake and the unwritten deal. Major contracts are carried out in joint ventures – or in partnership or as an alliance of contractors – since the investments, risks and execution of today’s mega projects are beyond levels which can be borne by a single company.

As for social conditions, the better part of the heavy labour and often slavery of the past has disappeared. As can be expected in a high-tech profession, salaries and remuneration have much been improved. In the medieval days, marine works were simply a community duty and a compulsory necessity for individual survival. Even in the beginning of the professional era, dredging was largely a seasonal activity and in the early 20th century, dredging workers could at best earn a mediocre living.

Working abroad has become an even more inherent part of the job. Here as well, conditions of living and family life can no longer be compared to the past. Decent housing has become a rule, and at remote times established. Instead of a three- to four-year absence from the family, frequent holidays and relief are part of every work organisation – which was also made possible by the shortened time of execution of a project, a consequence of improved technology.

Old dredging workers still recall how their fathers had worked abroad for 25 of their 35 years of marriage. Children were sometimes remembered by the name of a particular dredger or the year of execution of a project – or so it is said. Sometimes when a dredging man returned home, it happened that his son had already
Modern dredging activities are often mega projects that demand both mega dredging vessels as well as cooperation and coordination amongst many companies, and a total commitment to working 24 hours a day, 7 days a week, by day and by night.

Left on another dredging assignment abroad. In those days, intercontinental transport was extremely demanding and telephone communication did not exist. Letters were written to the family, but they were under way for a long time – and on his relief vacation a dredging man would act as the postman.

The speed of transportation and communication today is beyond comparison. As fax communication is widely available and the Internet provides instant and cheap contact, news from remote locations is nowadays faster spread in some local dredging communities than at corporate headquarters. Not only information but staff members as well as spare parts for repairs can be on the spot within 24 hours, flown in from homebase to the four corners of the world, wherever the dredging vessel may be located.

At the turn of the millennium, the future becomes visible in the present day. Science-based technology improvement will go further. Dreams of the past will become reality by tomorrow or the day after. New activities will broaden the scope of marine engineering and dredging, in addition to ever more daring reclamation, port development and river management projects.

As long as people have lived on this planet, water has been a prerequisite of life. Since the early times of civilisation, clever people and far-sighted governments have looked for ways to manage water. Water has always been a potential threat to human life, and at the same time a major opportunity for communication, transportation and commerce.

At the beginning of a new millennium, the pressures of overpopulation, the growth of industry, and the need for protection of the environment are pushing people once again towards appreciating the sea. Preserving the prosperity of the industrialised nations requires a high standard of sustained hydraulic engineering and protection of the environment. Encouraging the emerging economies of the less developed nations requires the creation of a good marine infrastructure and access. The IADC, working together with other organisations like the World Dredging Association, the International Association of Ports and Harbors, the US Army Corps of Engineers and the International Maritime Organization, to name a few, is striving to meet these goals – economic success combined with ecological responsibility.

As a high-tech industry for the future of mankind, dredging and marine engineering have become and will continue to act as an essential tool for creating sound economic growth and prosperity all over the world in the next thousand years.
Acknowledgements

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We realise that our brief history is far from complete, and that there are many more anecdotes of dredging history from other parts of the world to be recounted. Therefore if any of our readers have untold stories to add to this short overview, we would be most pleased to learn of them, and we encourage you to send them to us.
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