MARITIME SOLUTIONS FOR A CHANGING WORLD

#178 - SPRING 2026

TERRA ET AQUA

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EXPERTISE ON THE STAND

THE CRUCIAL ROLE OF A DREDGING EXPERT WITNESS

EXPERT IMPACT

In arbitration or court proceedings, the role of an effective dredging expert witness can significantly influence the outcome of a case by providing clear, unbiased and well-supported testimony. Read about the lessons learned from two notable expert witness cases on page 6.

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CHARTING THE NEXT CHAPTER

In a world marked by rapid change, geopolitical uncertainty and intensifying climate pressures, the work of the dredging industry remains quietly foundational. Ports must expand to support global trade, waterways must adapt to shifting sediment dynamics and coastlines and reservoirs require careful management as climate pressures intensify. As infrastructure systems face new challenges, the role of dredging in enabling resilient water management and maritime access has rarely been clearer. Against this backdrop, this spring edition brings together perspectives that reflect both the technical depth and evolving responsibilities of our sector.

This issue also marks a moment of transition for the association itself. We are pleased to welcome Arnold de Bruijn as the new Secretary General of IADC. In the feature on page 16, Arnold reflects on the professional path that brought him to this role and the experiences that shaped his perspective on the dredging industry. With a career spanning operational and strategic aspects of the maritime industry, he shares his thoughts on strengthening collaboration within the sector and ensuring that the industry continues to play a constructive role in addressing global water and infrastructure challenges. Leadership transitions offer a chance to both recognise past achievements and look ahead, and this insight provides an engaging introduction to the priorities that will help guide IADC in the years to come.

> **The role of dredging in enabling resilient water management has rarely been clearer.**

Elsewhere in this issue, we explore several themes that demonstrate the increasingly multidisciplinary nature of dredging today.

Disputes in complex marine infrastructure projects are not uncommon, and when they arise, clarity and objectivity are essential. The article on the role of a dredging expert witness examines the responsibilities and challenges faced by specialists providing independent technical evidence in arbitration and litigation.

Climate adaptation and sustainability remain central to the industry's future. Winner of the IADC Young Author Pitch Talk Award 2024, Lara Gehrmann explores reservoir sedimentation and its impact on long-term water storage capacity. By examining continuous sediment transfer as a potential solution, the article highlights how effective sediment management can contribute to environmental sustainability and infrastructure resilience.

Environmental stewardship is also at the heart of our final feature, examining turbidity forecasting to support adaptive dredging operations at the Port of Sohar. The case study shows how predictive modelling enables proactive decision-making, allowing dredging to proceed efficiently while maintaining environmental compliance.

Together, the articles in this issue illustrate an industry that continues to evolve while adapting to ever-changing challenges, underscoring IADC's commitment to guiding its members and strengthening the resilience and global impact of the dredging sector.

Frank Verhoeven
President, IADC


BB/RS

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THE ROLE OF A DREDGING EXPERT WITNESS

In arbitration or court proceedings, the role of an expert witness is crucial, especially in a specialised field such as marine infrastructure and dredging. An effective dredging expert witness can significantly influence the outcome of a case by providing clear, unbiased and well-supported testimony. This article explores what makes an effective dredging expert witness, their duties to the tribunal, what to look for when selecting an expert, common mistakes made by experts and lessons from two notable expert witness cases.

Why use a dredging expert witness?

There is no specific definition of "expertise", but it is demonstrated to the court by virtue of an expert's knowledge, skill, experience, training and education. A dredging expert witness is a professional with specialised knowledge and experience in all facets of dredging operations who provides independent, unbiased testimony in arbitral or court proceedings. Their role is to assist the tribunal or court in understanding technical aspects related to dredging, such as methodologies, equipment, estimates, environmental impacts and regulatory compliance.

A dredging expert witness can be used in various situations where specialised knowledge of dredging operations is required to provide clarity on technical matters in a dispute that proceeds to arbitration or the courts.

Key characteristics of a dredging expert witness

Specialised knowledge: They possess in-depth expertise in dredging, including technical, operational, and environmental aspects.
Impartiality: They provide objective and unbiased opinions, regardless of which party engaged them.
Communication skills: They can explain complex technical information in a clear, concise and understandable manner.
Professionalism: They maintain a high level of professionalism and credibility throughout the proceedings.

In essence, a dredging expert witness plays a crucial role in ensuring that technical aspects of dredging disputes are accurately and clearly presented, aiding in the fair resolution of the case. Often there is a perception that the dredging expert appointed by each party is a "hired gun" and is answerable to the party that engaged them. As will be discussed later in the Lester case, the expert has a primary duty to the tribunal not to the party that engaged them.

Below are some scenarios when and why to consider using a dredging expert witness in a court or tribunal setting:

Contract disputes: In cases where there are disputes over the terms, performance, or completion of dredging contracts, an expert witness can provide insights into dredging process physics, industry standards, best practices and whether the work was performed according to the contract specifications.

Environmental Impact Assessments: When there are disputes about the environmental impact of dredging activities, an expert witness can assess and testify on the potential or actual environmental effects, regulatory compliance, practical feasibility of imposed restrictions and effectiveness of achievable mitigation measures.

Project delays and cost overruns: If a dredging project experiences delays or cost overruns, an expert witness can analyse the causes and effects, estimate efficiency, productivity and costs, evaluate the reasonableness of the delays or costs, and independently determine if they were avoidable or justified. Their independent evaluation provides clarity on whether inefficiencies, unforeseen conditions or contractual misalignments contributed to the overruns.

Duties of a dredging expert witness

Providing independent opinions: Offering unbiased analysis and opinions based on evidence.
Assisting the tribunal: Helping the tribunal understand technical issues related to the case.
Preparing reports: Creating comprehensive, concise and clear reports that outline their findings and opinions.
Testifying: Presenting their findings and answering questions during tribunal or court proceedings.

Technical disputes: In cases involving technical disputes, such as the physical feasibility of dredging operations, adequacy of dredging equipment, suitability of methodologies or the quality of the dredged material, an expert witness can provide impartial technical evaluations and well-supported opinions.

Regulatory compliance: When there are allegations of non-compliance with regulatory requirements, an expert witness can

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review the project's adherence to relevant laws and regulations. They provide an independent evaluation of compliance, identifying potential breaches, their implications and whether corrective actions were taken in accordance with regulatory requirements and industry best practices.

Specialised knowledge: Dredging is a highly specialised field that requires in-depth technical knowledge grounded in both scientific principles and field experience. An expert witness brings this combined knowledge to the tribunal, helping to clarify complex issues, assess technical feasibility and provide well-informed evidence-based opinions.

Objective analysis: An expert witness provides an independent and objective analysis of the issues at hand. Their impartiality ensures that their testimony is credible and reliable.

Clarification of technical issues: Expert witnesses can explain technical terms, methodologies and the implications of their findings in a way that is understandable to non-experts, including arbitrators and legal professionals.

Support for legal arguments: The testimony of an expert witness can support legal arguments by providing evidence-based, objective opinions that align with the technical facts of the case. Their expertise ensures that complex dredging-related matters are accurately interpreted.

Resolution of disputes: The insights and opinions of an expert witness can help disputes resolution by providing a clear and authoritative perspective on the issues. Their objective analysis can help parties reach early settlements or support informed decision-making by the tribunal.

Using a dredging expert witness in these scenarios ensures that the tribunal has access to the necessary expertise to make informed decisions, ultimately contributing to a fair and just resolution of disputes.

Characteristics of an effective dredging expert witness

Selecting the right dredging expert is crucial for ensuring credible and effective testimony in court or arbitral proceedings. Here are key criteria to consider:

Expertise and experience: An effective dredging expert witness must have extensive academic knowledge and experience in the field of dredging and their knowledge should be current. This includes understanding the technical aspects of dredging operations, environmental impacts and regulatory requirements. For example, an expert with years of hands-on experience in managing dredging projects and a solid academic background in marine engineering or a related field would be highly valuable.

Track record, professionalism and credibility: Review the expert's history of providing credible and reliable testimony in similar cases. Conduct thorough research into their professionalism, ability to remain impartial and preparedness for cross-examination. Not all experts are suited for a tribunal setting, so selecting one with proven experience, composure under scrutiny and a reputation for delivering well-substantiated opinions is essential.

Impartiality and independence: An expert witness must remain impartial and independent, providing unbiased opinions based on facts and evidence. Their primary duty is to the tribunal, not to the party that engaged them. This impartiality ensures that their testimony is credible and reliable.

Effective communication skills: The ability to communicate complex technical information in a clear, concise and understandable manner is essential. A good expert witness can explain their findings and opinions in a way that is accessible to non-experts, including arbitrators and legal professionals.

Thoroughness and attention to detail: A good expert witness applies methodical approach to analysing all relevant data and documents. They must be meticulous in their work, ensuring that their assessments are comprehensive, accurate and well-substantiated with evidence. Credibility and professionalism: An expert witness must maintain a high level of professionalism and credibility. This includes being well-prepared for cross-examination and presenting themselves confidently and respectfully in tribunal proceedings.

Duties to the tribunal

The primary duty of an expert witness is to provide independent and unbiased opinions to the tribunal. They must base their testimony on objective analysis and evidence, regardless of the interests of the party that engaged them.

Expert witnesses help the tribunal understand complex technical issues related to the case. This involves explaining technical terms, physics, methodologies and the implications of their findings. They must prepare detailed reports that outline their analysis, findings and all the reference sources for any opinions. These reports should be clear, concise, well-structured, methodical and supported by tangible evidence.

Expert witnesses may be required to testify in tribunal proceedings, presenting their findings and answering questions from the tribunal and opposing counsel. They must be prepared to verbally defend their opinions and withstand sometimes intense cross-examination by legal counsel.

Common mistakes made by expert witnesses

Not all experts make effective expert witnesses. The following is a listing of some of the most common mistakes made.

Lack of impartiality: One of the most common and fundamental mistakes made by experts is failing to maintain impartiality. An expert who appears biased or aligned with the interests of the party that engaged them can undermine their credibility and the weight of their testimony. This is a common, yet basic mistake made by expert witnesses. Experts are most often recruited by one side of the adversarial system and work within the team and objectives of that side. This places many experts in a non-neutral environment and posture and can subconsciously influence their perception and judgments.

Inadequate preparation: Failing to thoroughly prepare for the case, including reviewing all relevant documents and data, requesting for missing information can lead to inaccuracies and weaknesses in the expert's testimony. Ensure the expert has the availability to dedicate sufficient time to the case. They should be responsive and able to meet deadlines for report submissions and testimony.

Overconfidence: Overconfidence or arrogance can lead to an expert making unsupported assertions or failing to acknowledge the limitations of their analysis. This can be extremely detrimental during cross-examination. An expert should be prepared to admit when they have made a mistake and adjust their submissions accordingly.

Poor communication: An expert who cannot effectively communicate their findings and opinions may struggle to convey the significance of their testimony to the tribunal. This can result in misunderstandings and reduced impact.

Failure to address counterarguments: A good expert witness anticipates and addresses potential counterarguments. Failing to do so can leave their testimony vulnerable to challenges from opposing counsel.

The Lester and Sullivan expert witness cases

The Lester case is well known and reported on and serves as a cautionary tale for the conduct of expert witnesses. In the case of the English Technology and Construction Court issued a judgment that was highly critical of the claimant's quantum expert.

The case involved the laying of a gas export pipeline for the Shetland Gas Project. The project faced delays and the claimants sought compensation for disruption and prolongation costs. The quantum expert for the claimants valued the claims at GBP 10 million. However, the court found Mr Lester the expert's evidence to be entirely worthless for several reasons:

Lack of independent analysis: The expert took the claimants' pleadings at face value without independently verifying the underlying documents. This lack of independent analysis undermined the credibility of the expert's testimony.

Ignoring actual costs: The expert disregarded actual costs incurred by the claimants in favour of made-up or calculated rates. This approach was not supported by evidence and was heavily criticised by the court.

Fundamental errors and concessions: The expert made fundamental errors in their analysis and was forced to make multiple concessions under cross-examination. This significantly weakened the expert's testimony.

Unhappiness with reports: The expert admitted under cross-examination that they were unhappy with their own reports and found them confusing and, in one instance, misleading. This admission further damaged the expert's credibility.

Failure to critically analyse claims: The expert failed to critically analyse the claimants' claims and did not consider alternative assumptions or valuations. This lack of critical analysis was a major flaw in the expert's approach.

As a result of these issues, the court relied wholly on the defendant's expert, who was found to be independent and clear in their testimony.

In considering Lester's expert's evidence Mr Justice Coulson did not hold back in his criticism. Coulson J stated:

"[the expert's] abrupt departure from the witness box at a short break for the transcribers, never to return, was an indication of the stress he was under. But I regret to say that I came to the conclusion that his evidence was entirely worthless".

The Lester case is not alone. More recently in the UK's High Court of Justice between *Iya Patarkatsishvili/Yevhen Hunyak and William Woodward-Fisher*, the High Court Judge Mr Justice Fancourt, in his ruling, expressed concerns about the expert Mr Sullivan's approach. Sullivan is the CEO of Royal Institution of Chartered Surveyors (RICS). The judge noted that Sullivan appeared to have a limited grasp of case details and demonstrated "flawed" judgement. Furthermore, the judge observed that Sullivan seemed reluctant to make reasonable concessions or consider revising his opinions when challenged. Contrasting Sullivan's performance, the judge praised the other expert witness, Mr Daly, for his sensible and helpful testimony, particularly on costs matters.

The apparent attitude of Sullivan as commented on by the judge is all the more surprising given that the experts' own supervisory body, the RICS, provide practice notes and guidelines to ensure expert witnesses meet the standards and expectations required of them. With all this literature and guidelines in mind, it is surprising that cross-examination disasters such as these two highlighted cases continue to occur.

Both cases emphasise the importance of selecting, instructing and supervising expert witnesses carefully. It also underscores the need for experts to conduct thorough and independent analyses, maintain impartiality, be well-prepared for cross-examination and revise their evidence if the need arises.

Protocol for the use of party-appointed expert witnesses

The Chartered Institute of Arbitrators' protocol for the use of party-appointed expert witnesses in international arbitration (2015) provides a structured framework for the use of expert witnesses appointed by parties in arbitration proceedings. Below are the key points of the protocol:

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Purpose: The protocol aims to ensure the efficient and economical preparation and presentation of expert evidence in international arbitrations, especially those involving parties from different legal traditions.

Scope: It applies specifically to party-appointed experts, not tribunal-appointed or single-joint experts.

Flexibility: The protocol is designed to be adaptable. Parties and arbitral tribunals can adopt it in whole or in part or use it as a guideline to develop their own procedures.

Key provisions:

Independence: Experts must be independent and impartial.

Expert meetings: Experts may meet before producing their reports to identify and narrow down the issues.

Expert reports: Detailed guidance is provided on the content of expert reports, including what should and should not be included.

Testing opinions: Procedures for testing the experts' opinions through cross-examination or other means are outlined.

Alignment with IBA rules: The protocol is structured similarly to the International Bar Association (IBA) rules of evidence and expands on them by providing more detailed guidance on certain aspects.

The International Bar Association (IBA) publishes these rules. The IBA is a global organisation of legal practitioners, bar associations and law societies, which aims to influence the development of international law reform and shape the future of the legal profession worldwide.

The IBA rules on the taking of evidence in international arbitration are a set of guidelines designed to provide an efficient, economical and fair process for the taking of evidence in international arbitration. These rules cover various aspects, including the presentation of documents, witness testimony, expert evidence and the conduct of evidentiary hearings.

The protocol and IBA rules of evidence help streamline the process of using expert witnesses in arbitration, promoting clarity and efficiency. An arbitral tribunal will likely adopt some guidelines such as the protocol or IBA rules of evidence to assist the parties experts in what is required of them.

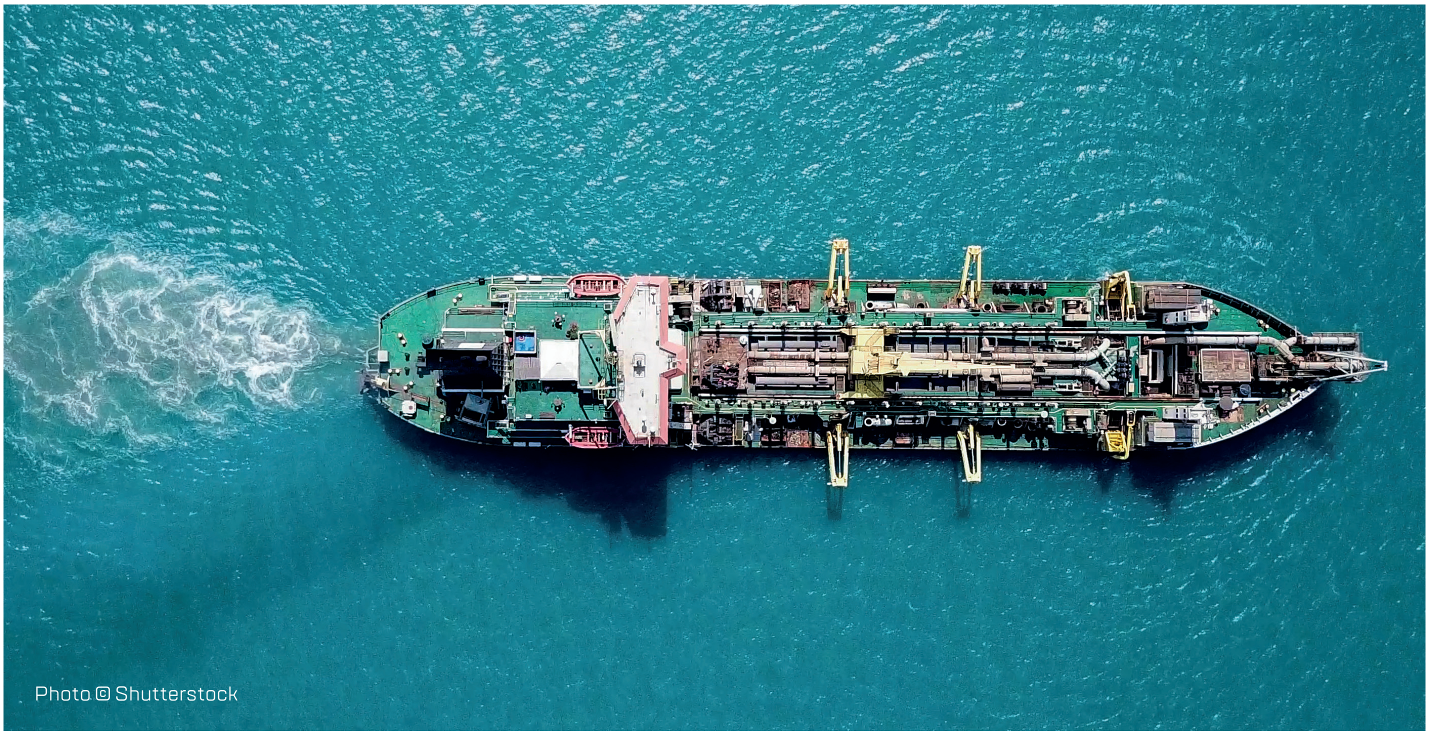
Hot-tubbing – what is it exactly?

Hot-tubbing, also known as concurrent evidence, is a practice in arbitration where expert witnesses provide their testimony simultaneously rather than sequentially, so that they might engage in discussion and address questions in parallel instead of being cross-examined individually by counsel. The practice, first introduced in Australia, has been used in Australian courts for over 20 years and has since gained popularity in other jurisdictions, including the United Kingdom, Singapore and Canada. The method was developed to address concerns about the efficiency and clarity of expert testimony in legal proceedings. The hot-tubbing method allows experts to discuss issues directly with each other and the tribunal, fostering a more interactive and efficient examination process.

Key advantages are:

Efficiency:

- Timesaving: By having experts present their evidence concurrently, the tribunal can address all relevant issues in one session, significantly reducing the overall time required for expert testimony.



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This avoids the repetitive questioning that can occur when experts testify sequentially.

- Focused discussions: Experts can directly respond to each other's points, which helps to quickly clarify and resolve technical issues, making the process more streamlined.
- Clarity: The tribunal can hear competing expert opinions on the same issue side-by-side, making differences and assumptions immediately apparent.
- Direct comparison: The tribunal can directly compare the opinions of different experts on the same issue, which helps in understanding the nuances and differences in their testimonies.
- Interactive dialogue: The interactive nature of hot-tubbing allows for a more dynamic exchange of ideas, which can lead to a clearer and more comprehensive understanding of complex technical matters.

Credibility:

- Real-time assessment: The tribunal can observe the demeanour and reactions of experts as they interact, which provides valuable insights into their credibility and the robustness of their opinions.
- Peer scrutiny: Experts are more likely to provide accurate and well-supported testimony when they know their peers will immediately scrutinise their statements.

Cost-effective:

- Reduced hearing duration: By shortening the time needed for expert testimony, hot-tubbing can lead to shorter hearings, which in turn reduces the costs associated with prolonged arbitration proceedings.
- Lower preparation costs: Since experts prepare for a single, consolidated session rather than multiple separate ones, the preparation costs can be lower.

Comfort:

- Collaborative environment: Experts may feel more comfortable and less adversarial in a setting where they can discuss issues collaboratively rather than being cross-examined in isolation.
- Enhanced testimony quality: This comfort can lead to more candid and precise testimony, as experts are able to explain their views in a more relaxed and supportive environment.

The hot-tubbing approach when used effectively streamlines the experts' submissions and evidence in the arbitration process and is proven as improving the quality of expert evidence.

Professional negligence of an expert witness

Since the case of Jones v Kaney (2011), expert witnesses can now face legal action for providing negligent expert evidence. In that case in what was seen as a landmark ruling, the Supreme Court – by a majority of five to two – decided that expert witnesses were not immune in the law of England and Wales from claims in tort or contract for matters connected with their participation in legal proceedings. This reversed a line of authority of immunity dating back 400 years.

It is widely recognised that a case often turns on expert opinion. Straying beyond the expert's field of expertise or offering an unsustainable opinion could result in the court or arbitral tribunal rejecting and dismissing the expert's evidence entirely or favouring the opposing party's expert opinion as happened in the Lester and Sullivan cases.

Consequently, this could scupper the prospects of a party successfully bringing or defending a claim that might otherwise have been won with competent expert evidence. In such circumstances, if the expert acts negligently it may deprive the party instructing the expert of a successful claim or defence, so the expert could find themselves facing a professional negligence claim and payment of damages.

Any expert acting in a case is well advised to obtain adequate professional indemnity (PI) insurance to avoid personal liability for any costs, damages or claims brought by an aggrieved instructing party. Where an expert witness already holds PI insurance, the policy wording should be checked carefully to ensure that expert witness work falls within the scope of the cover.

The most effective experts combine academic with hands-on field expertise, demonstrating impartiality, effective communication skills, thorough analysis and professionalism.

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Training for expert witnesses

Training is essential for expert witnesses to ensure they are well-prepared to provide effective and credible testimony in legal and arbitration proceedings. Listed below are key reasons why expert witnesses should undergo training:

Understanding legal processes: Training helps expert witnesses understand the legal framework and procedures of the judicial or arbitration system. Each jurisdiction is different in how expert witness evidence is handled. This understanding includes knowledge of courtroom etiquette, the roles of the expert and the stages of legal proceedings. Familiarity with these processes enables experts to navigate the system confidently and effectively.

Enhancing communication skills: Effective communication is crucial for expert witnesses and where having a knowledgeable expert may not be enough. Training programs often focus on improving the ability to convey complex technical information in a clear, concise and understandable manner. This ensures that the expert's testimony is accessible to non-experts, including judges, arbitrators and jurors.

Maintaining impartiality: Training emphasises the importance of impartiality and independence. Expert witnesses learn to provide unbiased opinions based on evidence, regardless of which party engaged them. This enhances their credibility and the reliability of their testimony.

Preparation for cross-examination: Cross-examination in a court setting is onerous and can be extremely challenging and unnerving. Training prepares expert witnesses to handle it effectively. They learn strategies to remain composed, answer questions accurately and defend their opinions under scrutiny.

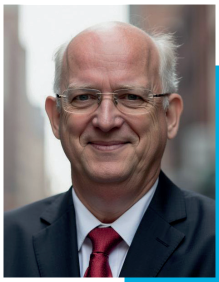
Report writing skills: Expert witnesses are often required to prepare detailed reports. Training helps them develop the skills to create comprehensive, well-organised and evidence-based reports that clearly outline their findings and opinions.

In summary, training equips expert witnesses with the necessary skills and knowledge to provide credible, clear and unbiased testimony, ultimately contributing to the fair resolution of disputes. Any person who intends to act as an expert is well advised to follow a structured training course, such as those run by Unisearch, the Academy of Experts or the Resolution Institute. Training is well worth the investment as the Lester case shows.

Conclusion

An effective dredging expert witness plays a vital role in arbitral or court proceedings by providing independent, unbiased and well-supported testimony. The most effective experts combine academic with hands-on field expertise, demonstrating impartiality, effective communication skills, thorough analysis and professionalism. Their duties to the tribunal include providing independent opinions, assisting in understanding technical issues, preparing clear, concise and readable reports, and clearly testifying in proceedings.

Common mistakes made by expert witnesses include insufficient analysis, lack of expertise, failure to maintain impartiality, inadequate preparation, overconfidence, poor communication and failure to address counterarguments. The Lester case serves as a stark reminder of the serious consequences of these mistakes and the importance of selecting and instructing expert witnesses with care. By adhering to these principles, a dredging expert witness can significantly contribute to the fair and just resolution of disputes in arbitral or court proceedings.



David Kinlan

David is a Contracts Manager with over 35 years of global experience in civil and marine infrastructure. He specialises in commercial management, contract risk, procurement, dispute avoidance and resolution. A practising adjudicator under the Queensland Adjudication Act, he has extensive experience in adjudication and arbitration. David has worked for major dredging contractors worldwide and is the author of a book on adverse physical conditions.

Simon Burgmans

Simon is the Director and Principal Dredging Consultant of in2Dredging, with more than 20 years of international experience across dredging and offshore infrastructure. He specialises in project execution, estimating, operational support and data-driven engineering. In addition, Simon provides independent expert witness and dispute resolution support, bringing an impartial, evidence-based approach grounded in academic physics and extensive field experience.

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MEET ARNOLD DE BRUIJN, IADC'S NEW SECRETARY GENERAL

On 1 November 2025, I stepped into the role of Secretary General of the International Association of Dredging Companies (IADC). In many ways, it felt like the natural continuation of a journey that started long before I ever imagined a career in dredging. My fascination with water, the maritime world, engineering and, above all, teamwork has shaped every decision I have made, from my earliest days in the Sea Scouts to becoming a naval architect and, later, an association professional. Looking back, each chapter prepared me for this new responsibility: helping guide an industry that shapes coastlines, protects communities and keeps global trade moving. This article reflects on that journey and shares my perspective on where our industry is headed. It is also the story of how I found myself "stuck in the mud," why I am grateful for it and why I believe dredging is more essential than ever.

Early currents: Discovering the maritime world

My maritime story began long before my professional life, during weekends spent with the Sea Scouts. I spent countless days on the water, learning to read wind and weather, navigating with a crew and developing not just the practical skills of sailing but also a deep connection with the sea. Oddly enough, I have never enjoyed swimming, but sailing a ship, adjusting the sails to squeeze out every bit of speed, or beating a course against the wind made me feel as if I could command the world.

Then winter came and the ships were hauled ashore. Maintenance was not optional; it was part of the culture. Working on ropes, wood, paint and hulls shaped an early and lasting interest in shipbuilding. When the time came to choose a field of study, naval architecture was the obvious direction. During my studies, I developed a strong foundation in ship design and construction, while gaining a growing appreciation for the practical realities of the maritime industry.

Into the mud: My introduction to dredging

My first job at Royal IHC opened the door to the dredging sector, though I had no idea that it would define my career. On my very first day, a colleague nearing retirement gave me a friendly warning: "Once you get stuck in the mud, you'll never get out." I laughed, thinking it was a joke. It turned out to be absolutely true.

Dredging captured me instantly. The complexity of the equipment, the scale of the projects, the fusion of engineering with geology, hydraulics and nature, it was unlike anything else. Compared to a dredger, a container vessel suddenly felt like a shoebox with an engine. A dredger is a world in itself: its design is driven by soil properties, hydraulic transport, excavation forces and constant interaction with the seabed.

During my years at Royal IHC, I learned about sediment behaviour, soil excavation, hydraulic transport, cutting forces and the challenge of translating all of that into reliable onboard systems. I worked with nearly every IADC member and experienced almost every phase of a vessel's lifecycle, from R&D and design to commissioning, sea trials and dredgers in operation.

Even in those early years, I gained a deep respect for the practicalities of production, the realities of operation and the need to design equipment that creates real value for the end user. Over the course of 12 years, I progressed from technical roles to leadership positions, ultimately managing an engineering department of 350 professionals.

Cutters, rock and real lessons

Some of the most influential experiences of my engineering career involved cutter suction dredgers (CSDs), by far my favourite type of dredger. CSDs concentrate technology, precision and raw force into a single vessel. Their seamless integration of mechanical cutting and hydraulic suction creates a continuous operation capable of handling everything from soft sediments to hard rock – capabilities unmatched by other dredger types.

> **What fascinated me most was the power of the collective voice.**

As a boy in the Sea Scouts, I was drawn to the sea without knowing that one day, like my grandfather, I'd be drawn into dredging. The Poseidon was part of his story – proof that some tides run in the blood.

Even as automation advances, people remain at the heart of every operation.

One of the highlights of my career was contributing to the development of simulation software that combined vessel motions in waves with the rock cutting process. This allowed us to better understand and predict forces on the hull and spud carriage, and provided crucial input for tuning the flexible spud carriage system during commissioning of a large self-propelled CSD.

Yet it was in the field, during a measurement campaign to validate these predicted forces, that I learned the most. I spent two and a half weeks on board that CSD working in rocky soil, expanding a harbour in the Middle East. There, theory met reality. The seabed pushed back. The vessel vibrated under full load. Hard spots sheared off cutter teeth or triggered a sudden roll that could throw you off balance. The calculations were correct, but the biggest lesson was human. We discovered that the crew needed more training and clearer instructions to harness the new system's full potential. Even as automation advances, people remain at the heart of every operation. Their expertise, intuition and adaptability are – and will remain – irreplaceable.

Standing on a cutter under load teaches you more than any simulation ever can. It teaches respect, for the forces of nature, for technological ingenuity and for the teamwork that makes dredging possible.

From engineering to advocacy: A new chapter

Over the years, I found myself increasingly drawn to roles that connect people, ideas and disciplines. Whether through complex engineering projects or industry-wide collaborations, I discovered that I enjoy building bridges just as much as I do building systems.

In 2016, I joined the Dutch Association of Shipyards and Maritime Equipment Suppliers, now Maritime & Offshore NL. There, I helped shape the conditions enabling members to excel – advocating for a level international playing field, contributing to sound rules and regulations, supporting sector wide innovation projects, securing appropriate subsidy programmes and promoting the industry through guest lectures and conference presentations.

I eventually became responsible for organising the association's advocacy on national, European and international levels, covering a wide spectrum of topics. What fascinated me most was the power of the collective voice. As the saying goes, "If you want to go fast, go alone. If you want to go far, go together." In an association, competitors collaborate for the greater good because meaningful impact requires shared commitment.

Speaking at the 6th Hemispheric Conference on Sustainable Port Management in Lima, Peru (Sept 2025), on how dredging supports long-term port sustainability."

Life between flights

Travelling to share the work of IADC is a vital part of my role as Secretary General. Visiting members, attending conferences and meeting partners around the world helps ensure our industry's voice is heard and our knowledge is shared. Those conversations spark collaboration and support innovation across the dredging community. I find the constant exchange of ideas, cultures and perspectives both energising and inspiring. Outside work, I enjoy travelling just as much, taking time to explore new places at a slower pace, experience local cultures and connect with family and friends along the way.

Coming full circle: Joining IADC

In early 2025, the opportunity arose to apply for the role of Secretary General at IADC, a position that drew together my passion for dredging, my technical background and my experience in association leadership. When the Board offered me the position, I felt honoured and deeply motivated.

The dredging industry plays an essential, often invisible role in society: keeping ports open and global trade flowing; protecting coastlines from erosion and rising sea levels; creating new land for growing populations; restoring wetlands and natural environments; and enabling the infrastructure of energy and critical raw materials.

> **In an association, competitors collaborate for the greater good because meaningful impact requires shared commitment.**

These activities shape economies, protect communities and create opportunities for future generations. As an engineer, I was always driven by designing solutions. As Secretary General, I am driven by enabling the industry to tackle its greatest challenges and create impact on a large scale.

Key themes for the years ahead

As I take on this role, several priorities guide my focus. Above all, I aim to strengthen the dredging industry by working with and for our members, ensuring the sector thrives through collaboration and shared expertise.

1. Climate adaptation and resilience

The shift from climate mitigation to adaptation is accelerating. Rising sea levels demand more coastal protection. Geopolitical shifts make energy infrastructure and access to ports strategic priorities. Every country should have a National Adaptation Plan and dredging activities should be a central component. Cleaner, quieter and more responsible dredging technologies must continue to evolve, not only because regulations require it, but because our responsibility to future generations demands it.

2. Innovation and digital transformation

Digitalisation, monitoring, real time data and automation are transforming many industries. Artificial intelligence (AI) will accelerate this shift even further. Yet technology is only an enabler, potentially increasing efficiency and reducing costs, but people remain the heart of dredging operations.

3. Knowledge sharing and next generation engagement

Just as large maritime structures once inspired me, we must inspire future engineers, sailors and technicians. Their talent and creativity are essential for the industry's future.

4. Global collaboration

Climate challenges are international by nature. Our solutions must be too. With members across the globe, IADC is uniquely positioned to bring together stakeholders across borders, fostering shared insights and promoting best practices worldwide.

First steps in the role

During my first months, I focused on strengthening visibility, collaboration and knowledge sharing by:

- presenting the Dredging for Sustainable Infrastructure philosophy and the *Sand as a Resource* paper at the 24th World Dredging Congress & Exposition (WODCON XXIV) in San Diego;
- awarding the IADC Young Author Award to encourage fresh insights from the next generation;
- inviting external speakers to IADC Committees to stimulate discussion and support the formation of industry positions;
- increasing the association's visibility among stakeholders through targeted social media outreach; and
- adapting the Young Management Programme to include reflections on the opportunities and threats of digitalisation and AI.

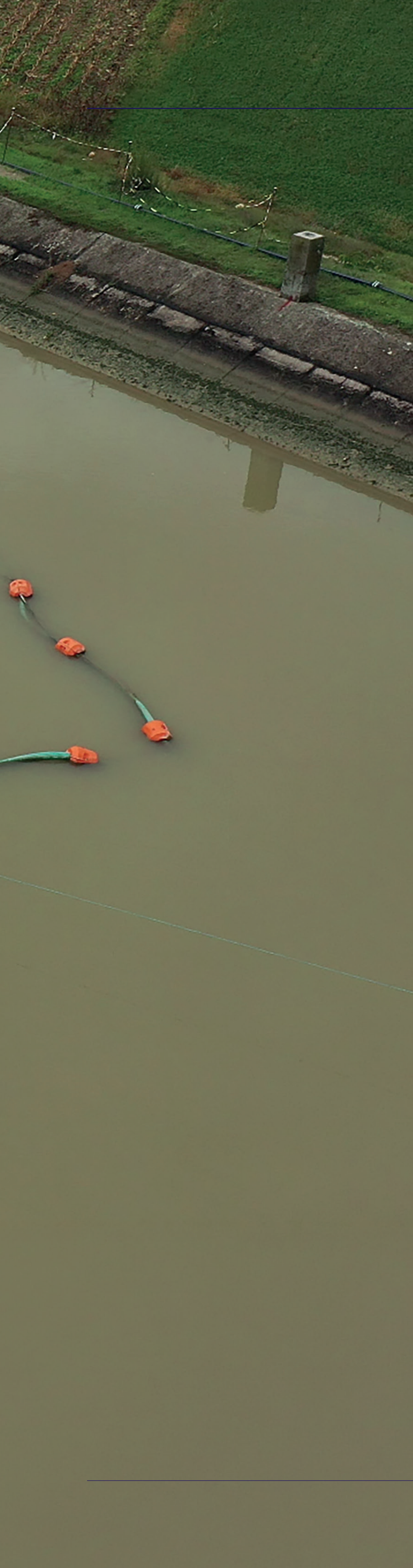
These actions are just the beginning, reflecting IADC's outward-looking, future-focused approach and its commitment to strengthening the global dredging community.

Grateful to be stuck in the mud

More than 20 years after hearing that memorable warning on my very first day, I can confidently say, "I did get stuck in the mud and I'm very grateful I did!" Those muddy boots are a reminder of the hands-on experience, challenges and lessons that shaped my understanding of dredging – an extraordinary industry that is driven by purpose, innovation and people.

I am honoured to serve as IADC's Secretary General and am committed to guiding the sector, strengthening the global community around it and helping shape the resilient coasts and waterways of tomorrow.


HÜLSKENS



SEDIMENT: THE SILENT THREAT TO RESERVOIR SUSTAINABILITY

Reservoirs are critical elements of global water infrastructure, supporting water supply, flood protection, hydropower generation and ecological functions. Their long-term performance, however, is increasingly undermined by sedimentation – a slow and often overlooked process that reduces storage capacity and disrupts natural sediment continuity along river systems. This article examines sedimentation as a key sustainability challenge for reservoirs and impounded waters. It outlines the causes and impacts of sediment trapping, from declining reservoir capacity to downstream river and delta erosion, and explains why proactive sediment management is essential. The article concludes by presenting continuous sediment transfer as a sustainable approach to maintaining reservoir functionality while restoring sediment continuity.

Sedimentation and the silent loss of water storage

While reservoirs are vital for water management, their greatest long-term challenge is sedimentation, which threatens both infrastructure and ecosystems.

Dams and reservoirs are crucial infrastructure. They secure drinking water supplies, provide retention volume for flood protection, enable hydropower generation and allow for the regulation of water levels. Beyond these primary functions, reservoirs often serve as habitats for fish, birds and other species, and are frequently used for recreation.

However, the impoundment of rivers fundamentally alters natural flow and sediment dynamics. When a river is dammed, flow velocities decrease significantly as the water body widens upon entering the reservoir. Sediment that was previously transported downstream begins to settle, with deposition typically starting at the head of the reservoir. As a result, reservoirs act as sediment traps, interrupting the natural sediment continuity of the river system.

Reservoirs are a cornerstone of global water infrastructure, providing reliable water supply, hydropower generation and flood mitigation.

The retention of sediment has far-reaching consequences downstream. A deficit of sediment in the tailwater can alter river morphology, degrade wetlands and delta regions, and compromise the stability of riverbanks, hydraulic structures and other infrastructure. At the same time, ongoing sedimentation within the reservoir progressively reduces its useful storage capacity. Over time, this loss of volume can severely limit the reservoir's ability to fulfil its core functions, including water supply, flood control and energy generation.

In the initial years following dam construction, sedimentation generally has little impact on operation. As deposition continues, however, the available storage volume decreases rapidly and operational constraints become increasingly severe. Once a critical threshold is reached, the reservoir's functionality can be fundamentally impaired.

Sedimentation is a global challenge that has largely been postponed rather than systematically addressed. It is estimated that, on average, 1-2% of global reservoir storage capacity is lost each year due to siltation. This loss exceeds the storage capacity added by newly constructed reservoirs, resulting in a net global decline. In Europe, projections suggest that up to 70% of existing reservoir capacity could be silted up by 2060, while in parts of Asia similar conditions are expected as early as 2025 (Perera et al., 2023).

According to the World Bank, the 20th century was the era of large dam construction, whereas the 21st century must focus on preserving the functionality of existing reservoirs. Preventing and managing sedimentation will therefore be one of the key challenges for the water and hydropower sector if reservoirs are to remain operational and economically viable in the long term (see Figure 1).

Why sediment management is key to reservoir longevity.

Reservoirs are a cornerstone of global water infrastructure, providing reliable water supply, hydropower generation and flood mitigation. Their importance is particularly pronounced in regions with high hydrological variability, where river flows fluctuate strongly on seasonal and interannual timescales. In such settings, large storage volumes are required to bridge dry periods and multi-year droughts, ensuring continuity of water and energy supply.

Sediment accumulation progressively reduces effective storage in reservoirs, directly impairing hydropower production, water supply reliability, irrigation capacity and flood control functions. In addition, altered flow and sediment regimes degrade aquatic habitats. In Run-of-River projects, sediment

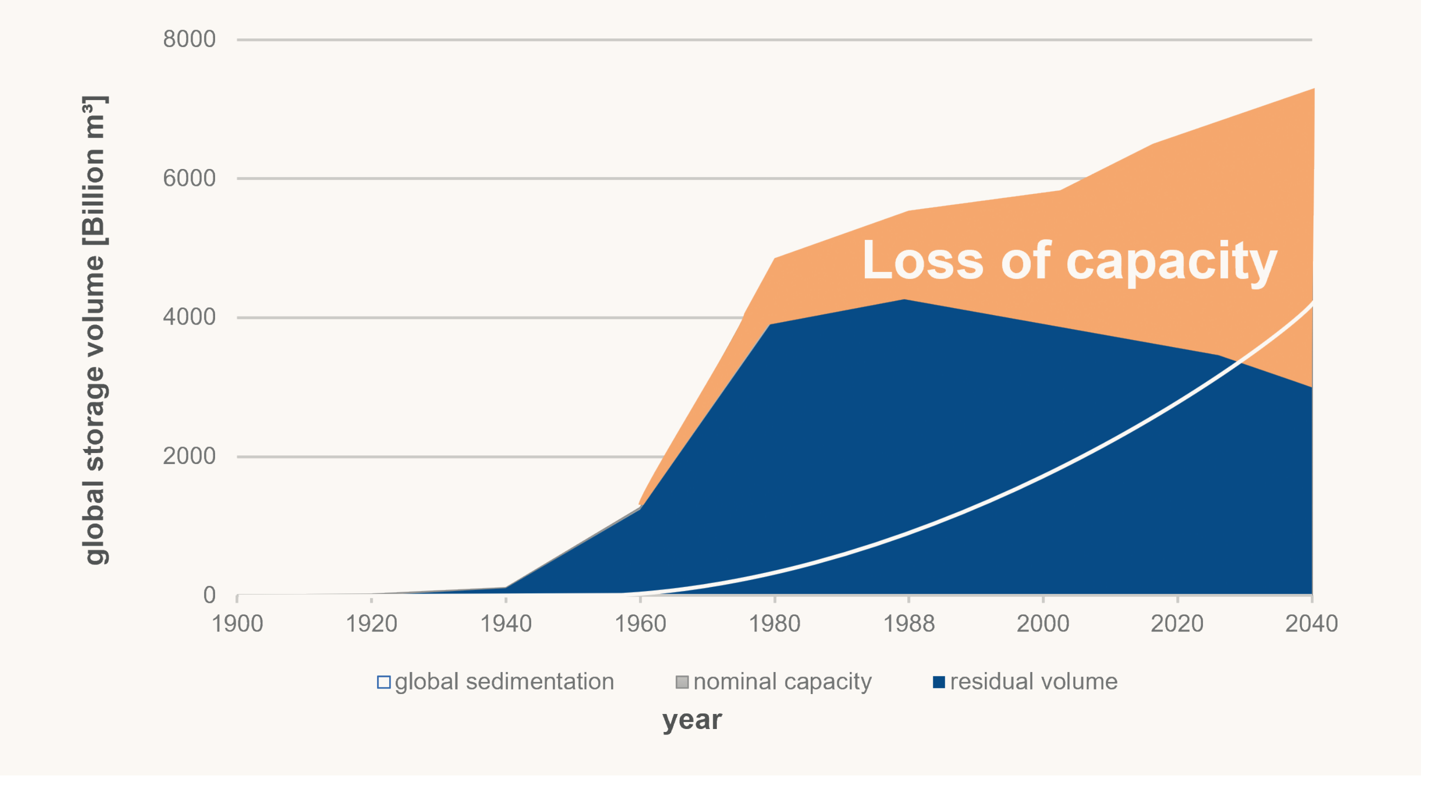


FIGURE 1

Global loss of capacity due to sedimentation (edited, Jenzer et al., 2006).

does not primarily reduce storage but causes abrasion and damage to turbines and hydraulic structures, leading to efficiency losses, increased maintenance and high repair costs. Across all impounded systems, sedimentation is therefore a key limiting factor for operational longevity.

Historically, dams have been designed according to a fixed "design life" concept. This approach estimates sediment inflow and trap efficiency and allocates a finite sediment storage volume, typically corresponding to 50 or 100 years of operation. Impacts beyond this horizon are often not considered, implicitly accepting reservoir capacity loss and eventual decommissioning. Today, this paradigm is increasingly inadequate. Suitable dam sites are scarce, construction costs are rising and social and environmental constraints strongly limit the feasibility of new reservoirs. At the same time, dam removal or decommissioning can be technically complex and economically prohibitive.

Beyond reservoir boundaries, sediment trapping has downstream consequences. Retention of sediment disrupts sediment continuity, often leading to riverbed erosion, bank instability and ecological degradation downstream. These effects further underline the need to rethink sediment management not only at the reservoir scale but across the entire river system.

As many reservoirs approach or exceed their original design life, operators and owners are increasingly focused on extending functionality rather than replacing infrastructure. This shift requires a transition from passive sediment storage toward active sediment management. The central objective is to manage reservoirs and their catchments in a way that balances sediment inflow and outflow as far as practicable, thereby stabilising storage capacity and enabling a greatly extended-potentially indefinite-operational life.

Climate change reinforces the urgency of this transition. Projections indicate increasing hydrological variability in many regions, with more intense floods and more frequent or prolonged droughts. These trends increase dependence on reservoir storage while simultaneously raising sediment yields due to enhanced erosion. Without effective sediment management, the reliability of reservoirs under future climate conditions will be fundamentally compromised. Ensuring the long-term sustainability of reservoirs and impounded waters therefore requires that sediment management be treated as a core design and operational criterion. New projects must explicitly incorporate long-term sediment strategies, and existing infrastructure should be adapted wherever feasible. This perspective aligns with international efforts such as those promoted by the World Bank to integrate climate resilience and long-term performance into water infrastructure planning and operation. (Annandale et al., 2016)

FIGURE 2

Erosion of the Ebro Delta (Spain) between 1985 and 2023.

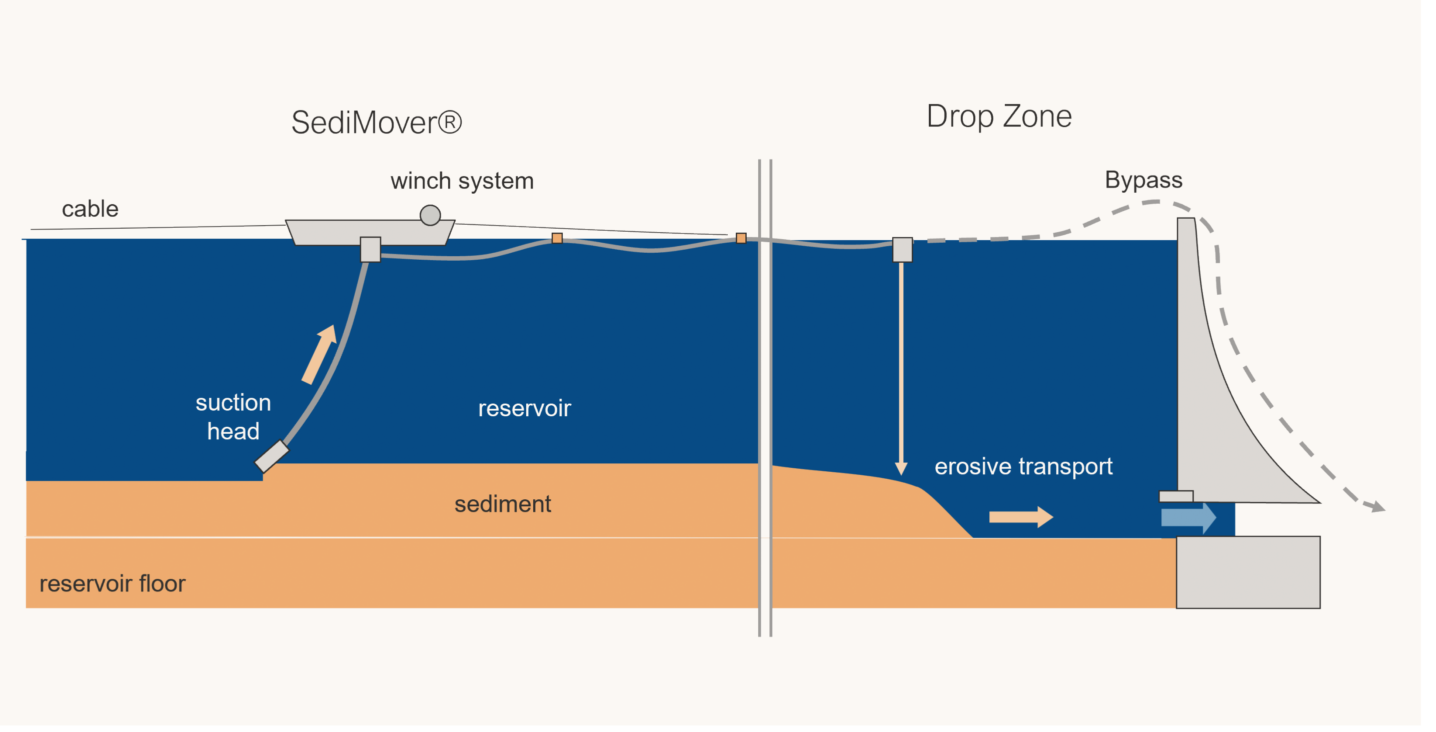


FIGURE 3
Working principle continuous sediment transfer.

Consequences of sediment trapping for downstream environments

Fine-grained sediments are a fundamental component of river systems and play a key role in maintaining ecological and hydraulic functions. Organic particles in suspension readily attach to fine sediment and are transported with the flow. In this way, fine sediments act as carriers of nutrients that support aquatic flora and fauna. During flood events, these sediments are deposited onto floodplains and riparian forests, supplying nutrients that sustain alluvial ecosystems and contribute significantly to biodiversity.

Fine sediment also has an important water-cleansing function. Suspended particles can bind pollutants and residual substances from wastewater treatment plant discharges, facilitating their transport and gradual removal from the water column. In natural rivers, a dynamic equilibrium exists between erosion and sedimentation, governed by channel morphology and the sediment transport capacity of the flow. When sediment availability is reduced, this balance is disrupted.

A sediment deficit in tailwater areas leads directly to increased erosion of the riverbed and banks. This poses a serious risk to hydraulic structures and infrastructure such as bridge foundations, bank protections and water level gauges. In the absence of sufficient sediment, flow velocities and erosive forces around these structures increase, often resulting in local scour. Over time, this can compromise structural stability and safety.

The effects of sediment deficit are already evident in many large European rivers, including the Elbe, Danube and Ebro (Figure 2), where progressive riverbed incision has been observed. Erosional processes propagate downstream, extending as far as river deltas. Under natural conditions, land subsidence and coastal erosion caused by waves and tides are counterbalanced by the continuous supply of fluvial sediment, particularly fine material. Where this sediment supply is interrupted, however, these compensating processes fail, leading to ongoing land loss and delta retreat.

Riverbed structure also strongly influences oxygen and nutrient exchange. A heterogeneous bed with interstitial voids promotes hyporheic exchange, supporting oxygenation and nutrient cycling. In contrast, an armoured riverbed limits this exchange, creating undersupply conditions that negatively affect benthic habitats and overall biodiversity. As such, sediment deficit in tailwater areas represents not only a geomorphological and structural challenge, but also a critical ecological issue that must be addressed in sustainable river and reservoir management strategies.

Erosion of river deltas – lessons from the Ebro and Mississippi

River deltas form where rivers discharge into standing bodies of water, such as seas, lakes or reservoirs. These transition zones are among the most productive and valuable landscapes worldwide, providing high

> The effects of sediment deficit are already evident in many large European rivers.

FIGURE 4

SediMover-130 at a project in Italy during continuous sediment transfer.

biodiversity, fertile soils for agriculture, carbon storage, natural coastal protection and space for settlement and recreation. The stability and evolution of river deltas are primarily governed by sediment dynamics.

Delta growth or retreat depends on the balance between fluvial sediment supply and sediment removal by waves, tides and marine currents. Where sediment input exceeds removal, deltas prograde. Where sediment supply is insufficient, deltas retreat. This balance has been increasingly disturbed by human activities, such as dam construction, river regulation, water abstraction, sediment mining, land-use change and climate-induced sea-level rise. These pressures reduce sediment delivery while simultaneously increasing erosive forces, resulting in widespread delta degradation (Perera et al., 2022; Edmonds et al., 2023; Speerli et al., 2020).

A prominent European example is the Ebro Delta in Spain. As the largest wetland in the western Mediterranean, it supports extensive rice cultivation, fisheries and diverse bird populations. However, more than 100 dams in the Ebro catchment have reduced fluvial sediment supply by approximately 99%, triggering severe coastal erosion and the loss of roughly 20% of the delta's original area. Without intervention, rising sea levels and continued sediment starvation are expected to accelerate land loss. Current research emphasises the urgent need for sediment reintroduction, hydrological restoration and adaptive land-use strategies to stabilise the delta (Speerli et al., 2020).

Similar processes can be observed at a much larger scale in the Mississippi Delta. Once one of the most dynamic and sediment-rich deltas globally, it now suffers from extensive land loss due to river regulation, levee construction and more than 6,000 dams in the basin. These interventions have reduced sediment delivery by approximately 80%, resulting in the loss of around 5,000 km² of land since the 1930s. Projections indicate that an additional 4,000 km² could be lost by the year 2100 if sediment supply is not restored. Large-scale sediment diversions, wetland restoration and controlled delta building are therefore considered essential countermeasures (Edmonds et al., 2023).

These examples illustrate that sediment deficits originating far upstream propagate through river systems, affecting tailwater reaches, coastal zones and deltas alike. Delta erosion is thus not an isolated coastal issue, but a downstream symptom of disrupted sediment continuity at the basin scale. Given these escalating risks, innovative sediment management is essential.

A new approach to address two challenges: continuous sediment transfer

Sustainable sediment management in reservoirs must go beyond the mere removal of deposited material. Its primary objective should be the restoration of sediment continuity within the river system. Sediment is a fundamental component of aquatic environments and their associated ecosystems. It must remain available to the natural system to sustain ecological processes. Re-establishing sediment

> **The key advantage of continuous sediment transfer lies in its adaptive control.**

continuity helps compensate for sediment deficits downstream and can significantly reduce or even prevent adverse impacts on river morphology and ecology.

A promising solution to this challenge is continuous sediment transfer. Hülskens Sediments has developed the ConSedTrans® (Continuous Sediment Transfer) system, operated in combination with the SediMover® floating dredging platform. Together, they form a fully monitored, controlled and largely autonomous process that relocates sediment from upstream reservoir areas to downstream reaches, keeping the sediment within the aquatic system rather than removing it entirely. Figure 3 shows the working principle of ConSedTrans. A fully automated small dredging system is installed in the reservoir, where dense sediments are loosened at the bed using mechanical or hydraulic tools, directly suctioned and conveyed downstream.

During operation, key transport parameters, such as sediment density, mass flow and volumetric discharge are continuously measured and evaluated in real time. These data are used to actively control the dredging and pumping process. This parameter-based control ensures that only as much sediment is released downstream as the river's current transport capacity allows. As a result, excessive colmation or siltation is avoided, while environmental thresholds and hydraulic constraints are respected.

Several transfer pathways are available. Sediment-laden water can be introduced upstream of the turbine intake or directly into the intake itself. In this configuration, the water used for sediment transport simultaneously contributes to power generation, ensuring that hydropower production is not reduced. Alternatively, sediment can be conveyed directly into the tailwater via a bypass system or, where site conditions allow, pumped over the dam crest. These options provide flexibility to adapt the system to site-specific hydraulic, operational and regulatory constraints.

The key advantage of continuous sediment transfer lies in its adaptive control. The process can be adjusted dynamically to changing hydrological conditions, allowing operators to intervene directly and regulate sediment release as needed. This ensures that sediment is transported downstream in a natural manner, remaining available for riverine processes such as bedload transport, channel self-cleansing and the mitigation of erosion.

Compared to conventional sediment management approaches, which often interrupt sediment continuity and exacerbate downstream deficits, continuous sediment transfer represents an active, sustainable and ecosystem-oriented solution. By restoring sediment connectivity, it supports the long-term ecological functionality of rivers while maintaining reservoir storage capacity and hydropower operations.

Lessons from the field: Real-world applications of sediment transfer

On a project in Italy 22,000 m³ in total of sediment (solids) could be transferred from an artificial upper basin through the turbine intake and into the downstream reaches. In this case, the SediMover (Figure 4) was operated around the clock at an average delivery rate of 130 m³/h of mixed sediment and water. This parameter-controlled operation continued around the clock and yielded very good results. Before and after the project we conducted a bathymetric survey. With the results of the mass differences, we could testify our monitored sediment transport rates. Using in-between bathymetric survey data, we can update the basin model to optimise the sediment transfer.

In a small pilot project at a pond in southern Germany, we tested the combination of a SediMover-130 to a dewatering system. The MUD unit from Amodes GmbH – a mobile belt filter system for dewatering fine sediments – was fed with material by the fully automated SediMover.

During the project, the SediMover was operated in a semi-manual mode and controlled according to the solids demand of the MUD dewatering unit. In the future, the interface between the dewatering technology and the SediMover will be further developed and increasingly automated, to enable operation with reduced personnel requirements.

Next steps: making sediment management a priority

Sediment management is one of the major challenges of the 21st century in dam and reservoir operation, as it is essential for prolonging the lifespan and functionality of these infrastructures. In contrast to conventional dredging methods, which remove sediment from the river ecosystem,

Lara Gehrmann receiving the IADC Young Author Pitch Talk Award from René Kolman (former IADC Secretary General), during the CEDA Dredging Days in Rotterdam, the Netherlands (May 2024).

continuous sediment transfer supports both the preservation of reservoir storage capacity and the ecological integrity of downstream rivers. This approach employs fully automated, small-scale dredging systems that loosen consolidated sediments from the reservoir bed and transport them downstream in a controlled and parameter-based manner.

To ensure the long-term sustainability of dam and reservoir infrastructure, sediment management must be made a strategic priority in design and operation of dams. Sediment management strategies that restore and maintain sediment continuity are a key enabling technology and must be integrated more widely.

Lara Gehrmann

Lara is a civil engineer and project manager at Hülskens Sediments GmbH, specialising in sedimentation management for impounded waters. She has worked in field of sustainable sediment management since 2021, covering consulting, planning and implementation of sediment-related projects. She is an active member of national and international technical committees on sediment management, including the DWA working group on reservoir desilting and the ICOLD Committee on Sedimentation of Reservoirs. In 2024, Lara was awarded the IADC Young Author Pitch Talk Award for her presentation on “Sustainable reservoir sediment management using fully automated dredges”.

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WILLEM VAN ORANJE
LIMASSOL

TURBIDITY FORECASTING TO SUPPORT ADAPTIVE DREDGING OPERATIONS

The Port of Sohar, located in the Gulf of Oman, is constructing a jetty close to a critical industrial seawater intake. The project includes capital dredging of a navigation channel, turning circle and berth pocket, where turbidity control is essential to protect water supply operations. A pre-tender assessment identified potential exceedance of turbidity limits under unfavourable conditions, leading to strict permit requirements. To address this, a turbidity forecasting model was developed to support daily operational decisions. Using wind, tides, dredging plans and soil properties, the model enabled proactive, adaptive dredging while maintaining compliance and optimising productivity.

The Port of Sohar is a deep-sea port at the coast of Oman, which is a joint venture between the Government of Oman and the Port of Rotterdam in the Netherlands. The port is currently expanding through the development of a new exposed jetty for LNG bunkering and export, serving an LNG facility being constructed on land reclaimed in 2018. This project includes capital dredging to create a navigation channel, turning circle and berth pocket, with a total dredging volume of nearly 4 million cubic meters. The dredged material will be transported to a designated offshore disposal site located 12 kilometres away, as instructed by the environmental authority. Bathymetry surveys were undertaken at the dredging and offshore disposal site before starting the dredging operation. An overview of the project location is given in Figure 1.

The dredging area is situated near the seawater intake of the port's industrial water service provider. This company supplies essential water services, such as cooling, potable and process water, to key operations within Sohar Port's various industries. These services ensure a steady and sustainable water supply for the port's tenants, bolstering their operational reliability. Increased suspended sediment concentrations at the seawater intake, particularly near the pumping station, pose a critical risk to the reliability of both industrial tenants and desalination facilities. Consequently, turbidity monitoring and control are crucial for the project. If turbidity levels exceed specified limits, the contractor must immediately halt dredging activities until the levels return to within acceptable limits.

Pre-tender turbidity assessment

To evaluate the potential impact of dredging near the seawater intake facility, Sohar Port, in collaboration with a specialised consultant, conducted an early pre-tender turbidity assessment. The aim was to determine the sensitivity of the intake to the turbidity generated by on-site dredging operations. This step was critical to demonstrate the feasibility of dredging near the seawater intake. It also provided a foundation for open discussions with relevant stakeholders regarding realistic turbidity limits to be included in the required permits and No Objection Certificates (NOCs).

The objectives of the turbidity modeling study were as follows:

- To determine the extent of fine sediment plumes resulting from dredging activities;
- To assess the increase in suspended sediment concentrations above ambient levels caused by dredging operations; and
- To propose mitigation measures to minimise the impact of fine sediment plumes generated during the works.

At the time of the study, the exact details of how the dredging operations would be carried out were not yet determined. A conservative but realistic approach was taken, as described in the following section.

Model approach and input parameters

A detailed Delft3D-FLOW (http://oss.deltares.nl/web/delft3d/home) model was used to simulate the far-field dispersion of sediment spills resulting from dredging operations. The main location of interest for the computed suspended sediment concentration is directly in front of the pumping station, which is a sheltered area within the breakwaters of the seawater intake. This was considered the critical point, as from here the water flows into the pipeline system and is distributed to industrial users. Various exploratory dredging scenarios were developed and assessed, starting with conservative assumptions of high spill rates and continuous discharges. Based on the outcomes of these initial scenarios, more realistic scenarios were defined, incorporating a typical dredging cycle of a trailing suction hopper dredger (TSHD) and its accompanying overflow spills. Additionally, a scenario without overflow was considered, representing an adaptive dredging method that the dredging contractor could implement if necessary.

The simulations were run over a one-month period, factoring in 16 different relevant ambient wind conditions. The model also incorporated the operation of the seawater intake and outfall to ensure an accurate representation of the ambient flow conditions, including thermal effluent dispersion. All model scenarios included a weekly-averaged intake and outfall discharge of 540,000 cubic metres per hour (m^3/h).

The pre-tender turbidity model only calculates the excess turbidity caused by sediment spills from the dredging operation, excluding background turbidity. For each scenario, the sediment concentrations at the intake location were converted to turbidity, measured in nephelometric turbidity units (NTU). There is no generic relationship between in-situ turbidity (NTU) and suspended sediment

FIGURE 1

Location of Sohar Port, Oman and the location for dredging and the seawater intake.

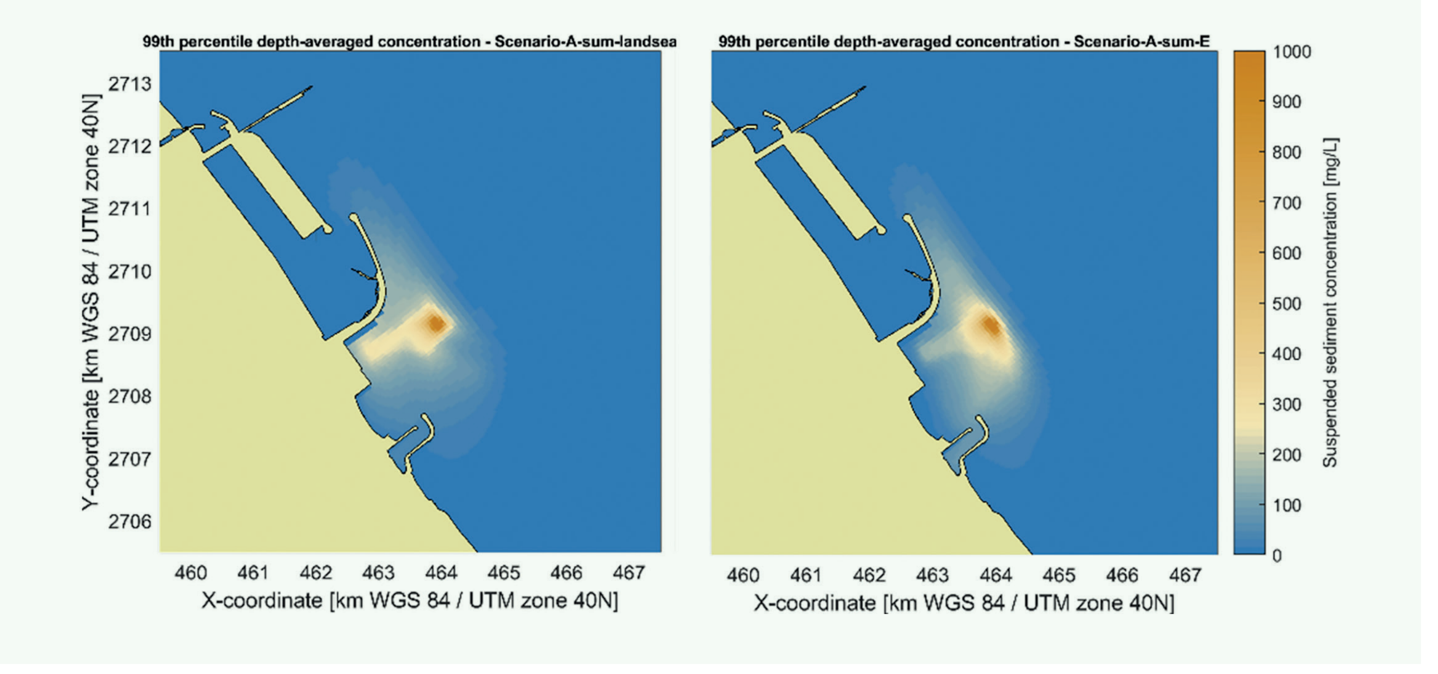

FIGURE 2

Left: Summer land-sea breeze conditions maximum – 99th percentile. Right: Summer Eastern wind conditions maximum – 99th percentile for the dredging Scenario A with a TSHD with typical dredging cycle and overflow conditions.

concentration (SSC), as computed by the model. This conversion depends on the type and size of sediment particles and is site-specific. The conversion factor was derived from a site-specific laboratory experiment that established the relationship between suspended sediment concentrations (milligrams per litre (mg/l)) and NTU turbidity levels by analysing soil bottom samples collected in the dredging footprint in combination with samples of seawater.

Fine sediment composition

The spills as fine sediment (4 micrometre (μm) to 63μm) are represented by three characteristic fine sediment fractions: 10μm, 20μm and 50μm, each with its associated fall velocities. These fractions illustrate an average distribution of 45%, 20% and 35% of the spill composition, based on data from geotechnical factual investigations conducted by a specialised geotechnical investigation company. The schematisation with three fractions is based on optimising computational efficiency while maintaining a sufficiently accurate representation of sediment dynamics, thereby avoiding the complexities that can arise from overly detailed modelling.

Modelled ambient wind conditions

Wind is a key factor in the coastal areas of Oman and plays a crucial role in the turbidity model. The region's wind climate is characterised by a combination of land-sea breezes (LSB), low wind speeds, storms/cyclones and more persistent wind events that can last for extended periods. Wind was analysed based on long-term Climate Forecast System Reanalysis wind data. The typical ambient wind conditions throughout the year were modelled in 16 one-month scenarios (eight for summer and eight for winter), accounting for the frequency of different wind conditions in each season to ensure the scenarios collectively represent the annual wind pattern. In each modelling simulation, the wind condition remained constant throughout the computation.

Dredging scenarios considered

To assess the sensitivity of the seawater intake to the turbidity generated by the dredging activities on site above the natural background levels the following dredging scenarios were considered:

- **Scenario A** – typical TSHD operation with overflow, considering a dredging cycle of 2 hours and 45 minutes (min), including 90 min loading with 60 min overflow. Conservative values were applied for the drag head and overflow spill rate, respectively 10 kilograms per second (kg/sec) and 300 kg/sec.
- **Scenario B** – typical TSHD operation with overflow equal to Scenario A, but additionally, a standing silt screen was considered in the model.
- **Scenario C** – continuous operation (no dredging cycle implemented) of TSHD without overflow and cutter suction dredger (CSD). This dredging scenario represents an alternative temporary dredging method that could be applied as part of an adaptive dredging approach when required.

Results: turbidity assessment and permit acquisition

The pre-tender modelling was conducted as a feasibility assessment. Based on this initial modelling, it was concluded that dredging near the seawater intake would be feasible for all considered wind and tide conditions, provided that only the excess sediment concentrations from the dredging operations are considered.

However, distinct effects of different ambient wind conditions were observed, resulting in varying plume dispersion patterns. Winds such as the more frequent land-sea breeze and westerly winds are generally favorable for the plume dispersion, while winds blowing from the East lead to higher turbidity levels at the intake. In addition to the computed excess turbidity because of the dredging activity, the natural background turbidity must also be considered at the seawater intake. In scenarios with unfavorable combinations of

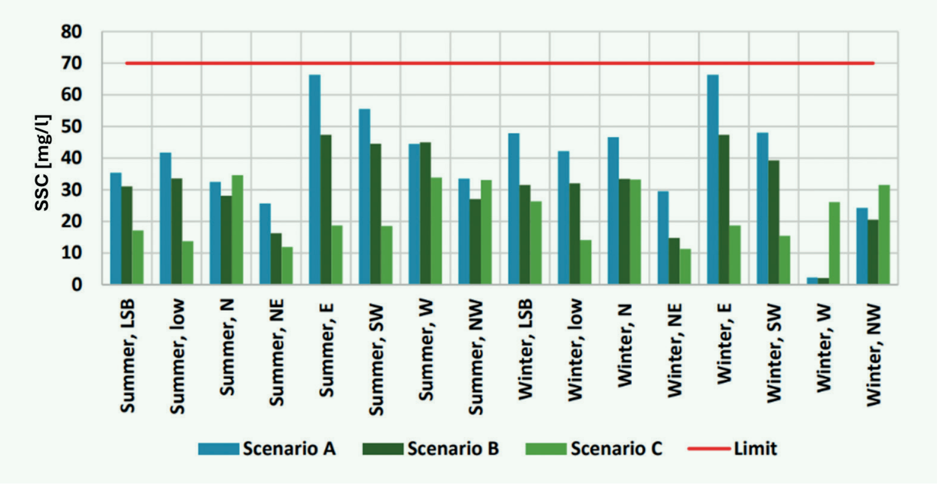

FIGURE 3

Summary of the maximum excess suspended sediment concentration (SSC) at the seawater intake during the different dredging scenarios.

dredging activities, wind conditions and elevated background turbidity, the resulting turbidity levels could exceed acceptable limits. In Figure 2, the model outcome is presented for maximum (99th percentile) depth-averaged suspended sediment concentration (SSC) for the typical land-sea breeze and the more severe Eastern wind during the summer.

Each scenario is modeled independently, but in reality combinations of operations with different equipment and methods may occur, particularly in projects with ambitious timelines. These factors highlight the importance of adopting an adaptive dredging method, one that is based on real-time monitoring and forecasting. This approach allows for the optimisation of dredging operations while minimising environmental impact.

The outcome of the modelling exercise is presented in Figure 3. It shows the maximum computed excess suspended sediment concentration over the simulation period at the intake location for the different scenarios considered. The highest values experienced do not exceed 70 mg/l (equal to approx. 20 NTU) and are related to dredging scenario under Eastern wind conditions. Further, the dredging operations as modelled in Scenario C (no overflow) clearly show lower values across most of the different wind conditions, which can be helpful as a turbidity control mitigation measure.

The modelling assessment also highlighted that, under certain unfavorable ambient conditions the turbidity value of 20 NTU for the seawater intake could be exceeded because the background turbidity is not included in the model. The same was discussed with stakeholders in order to obtain the relevant permits and NOC's and to set turbidity limits for the project. Turbidity limits must both prevent disturbance of the seawater intake and enable an economically feasible dredging project. The outcome of the pre-tender modelling (as presented in Figure 3) was helpful for the authorities to define the allowable turbidity limits for the project in the permits.

Following the turbidity assessment and Environmental Impact Assessment, a permit was granted by the seawater intake operator for the dredging activities incorporating strict turbidity limits. The not-to-exceed turbidity limits (including background value), as defined, are:

- Maximum allowed weekly average of 15 NTU; and
- Maximum allowed peak turbidity of 20 NTU for no more than a period of 15 minutes in one hour.

Tender and execution turbidity plume modelling

After the tender process, the project was awarded to Boskalis. The turbidity challenge transferred from the tender stage through to the successful completion of the project. Pre-tender turbidity studies rely on general information on dredging vessels and their source terms, which are crucial for a project to progress to execution. For dredging contractors, these studies provide a foundation to work from, but the assumptions need calibration and modification to develop project-specific work methods. Sharing information from the models developed during the pre-tender stage significantly enhances the contractor's ability to implement tailored work methods that benefit the project.

Turbidity model application during tender stage

For the project, Boskalis recreated a Delft3D Flexible Mesh (Delft3D-FM) model. Model assumptions from the pre-tender modelling assessment by Deltares were adopted, such as:

- Fall velocity of fine soil fractions.
- Model extents.
- Tidal boundary conditions.
- Wind scenarios.
- NTU to mg/l relationship.
- Average weather conditions.

Assumptions on the source terms were re-evaluated based on the source term assumptions of (Becker, 2015) and IADC (Laboyrie, 2018). Using the work methods and production estimates from the tender stage, the recreated model was utilised to estimate the impact of turbidity during operations. Average weather statistics estimated during the pre-tender phase were employed to identify the most stringent scenarios that required adaptation to prevent exceeding the intake NTU limits.

Operations causing turbidity

The work method planned during the tender stage involved dredging the majority of the material with a trailing suction hopper dredger (TSHD). An existing hard layer required the use of a backhoe dredger (BHD) to remove the material. The primary causes of turbidity include both the drag head and overflow of the TSHD.

Dredging with the BHD, filling barges, and ploughing activities were expected to have a much smaller impact compared to the TSHD and were therefore not considered to be governing. Depending on the soil conditions, the source terms were calculated using Becker's methodology (Becker, 2015), resulting in the source terms provided in Table 1. These source terms are significantly lower compared to the pre-tender estimated source terms, which were too conservative. The numbers indicate the effect of a shorter overflow time when dredging in sand. Dredging silt was assumed to be carried out without overflow, as overflow losses were expected to be large; however, due to the abundance of fines, the source term was expected to remain high. The source term for dredging rock was expected to be limited due to lower production rates and the trapped fines within the rock.

Operational measures for turbidity control

The highest contributor to the source term is the overflow from the TSHDs. This factor can be easily adjusted to mitigate turbidity in adverse weather conditions. Consequently, the decision was made to allow for lower production by limiting the overflow time in situations where the weather necessitates it. Table 2 shows the turbidity plume modelling conducted for various weather scenarios. By combining the percentage of occurrence for each weather scenario, a total overflow reduction has been determined for the project.

Pre-defined dredging scenarios listed in Table 3 have been modelled with wind scenarios. This results in an expected reduction in the source term. If a reduction of the source terms is required, adaptive management must be applied by reducing the overflow time of the TSHDs.

In total, it is expected that the NTU limits will be exceeded during 15% of the project duration if no adaptive management is applied, assuming a 3 NTU background turbidity and based on unrestricted overflow times. The goal of proactive adaptive management during project execution is to mitigate these exceedances and remain within the NTU limits.

DESCRIPTION OF ACTIVITY	SOURCE TERM (KG/S)
TSHD dredging sand with overflow	122.5
TSHD dredging sand without overflow	14.5
TSHD dredging silt without overflow	62.2
TSHD dredging rock with overflow	25.8

TABLE 1

Source terms of the most critical activities.

WIND DIRECTION	WIND SPEED (M/S)	AVERAGED YEAR-ROUND OCCURRENCE (%)
Land-sea breeze	4.5	44.5
North	5	4.5
Northwest	6	7.5
West	10	10.5
East	5	8.5

TABLE 2

Modelled wind scenarios in tender phase.

DESCRIPTION	WIND CONDITION				
Wind direction and percentage of occurrence	LSB 44%	N 4.5%	NW 7.5%	W 10.5%	E 8.5%
TSHD in berth pocket, no overflow, dredging sand	green	green	green	green	green
TSHD in berth pocket with unrestricted overflow, dredging sand	green	red	red	red	green
TSHD in turning basin with unrestricted overflow, dredging sand	green	red	red	orange	green
TSHD in access channel with unrestricted overflow, dredging sand	green	green	green	green	green
TSHD in berth pocket with unrestricted overflow, dredging rock	green	green	green	green	green
TSHD 1 dredging rock in berth pocket, unrestricted overflow TSHD 2 dredging silt in turning basin, unrestricted overflow	green	red	red	red	green
TSHD 1 dredging silt in berth pocket, unrestricted overflow TSHD 2 dredging silt in turning basin, unrestricted overflow	orange	red	red	red	green
TSHD 1 dredging silt in berth pocket, unrestricted overflow TSHD 2 dredging silt in berth pocket, unrestricted overflow	red	red	red	red	green

TABLE 3

Compliance of turbidity at the intake. A green cell indicates turbidity at the intake is below the limit. For orange cells, a reduction of up to 20% is sufficient to comply. For red cells, a reduction of more than 20% is needed to comply with the limits.

Due to the critical turbidity levels significantly affecting the production rates of the vessels, a proactive adaptive management dredging approach, as proposed by CEDA (CEDA, 2024), has been developed for implementation during the execution phase.

Automated turbidity model development and use during execution

During the execution of the project, average occurrences of weather events are no longer valuable because they do not provide the necessary details for immediate decision-making and risk management. Instead, accurate weather predictions and associated mitigation measures are required for the foreseeable future. This requires additional sources of information, including:

- Water level forecasts;
- Wind forecasts;
- Production forecasts; and
- Intake volume forecasts for the seawater intake.

Of this list, the water level forecast is relatively straightforward, as the water levels are primarily caused by the tide, which can be predicted for any moment in time using tidal constituents. The wind forecast, being the main driver of the currents, is procured from expert weather forecasters. The production forecast is made internally based on optimal desired overflow times to achieve maximum production in a dredging cycle. Fluctuations in intake volumes and potential forecasts have been investigated; however, due to a lack of information and seemingly stable intake volumes, this factor was kept constant throughout the project.

To automatically run the Delft3D FM+WAQ model on a daily basis, the Microsoft Azure platform (Microsoft, n.d.) was utilised. Containerised processes and an in-house developed orchestrator perform multiple tasks either in sequence or simultaneously, in a so-called model train. This model train, in simplified form, can be schematised as shown in Figure 4. The input data is automatically downloaded via API calls or from internal network locations. Following this, the data is processed into suitable Delft3D input files for the hydrodynamic model. The production forecast is then used to calculate source terms for the Delft3D WAQ model. The outcomes of this run are automatically analysed against the NTU limits specified by the project. If the unmitigated results indicate an exceedance of the limits, the source terms are adjusted accordingly and the WAQ model is restarted. Model results are post-processed; hourly spatial plots are generated, and data is exported into graphs for use in a forecast dashboard. The output from the mitigated WAQ model run after one day is used as the input for the model run on the following day. As the plume remains suspended for 1 to 3 days, cumulative errors are short-lived and can be addressed by calibrating the model.

This final step of reusing model output for the next day's model run is crucial because the history of the plume is a significant factor in estimating the impact of turbidity. Depending on the settling velocity of the fine material, sediment plumes can remain in suspension for hours or even days. Therefore, the turbidity plume from the previous day can greatly influence the following day's concentration results; hence, the model should start with an existing plume each day.

Automated daily forecasting based on dredging and weather forecast

Since wind prediction is the main uncertainty among the environmental drivers of the model and the prediction becomes less reliable further into the future, it is important to limit the amount of time the model forecasts. However, because the impact of dredging on measured turbidity has a time lag of hours to days, it is essential to model at least the lifespan of the plume. In other words, the source term at moment A will influence the measurement at moment B. To mitigate a potential exceedance at moment B, the source term at moment A must be lowered. To provide flexibility in how far the model needs to forecast, three days are modelled. This means that, in total, the model will look 4 to 5 days into the future, depending on when the model is initiated.

Since the weather forecast can become less reliable over such time frames, the interval between starting a model and implementing its results must be as short as possible. If a model were 100% reliable, this period could be

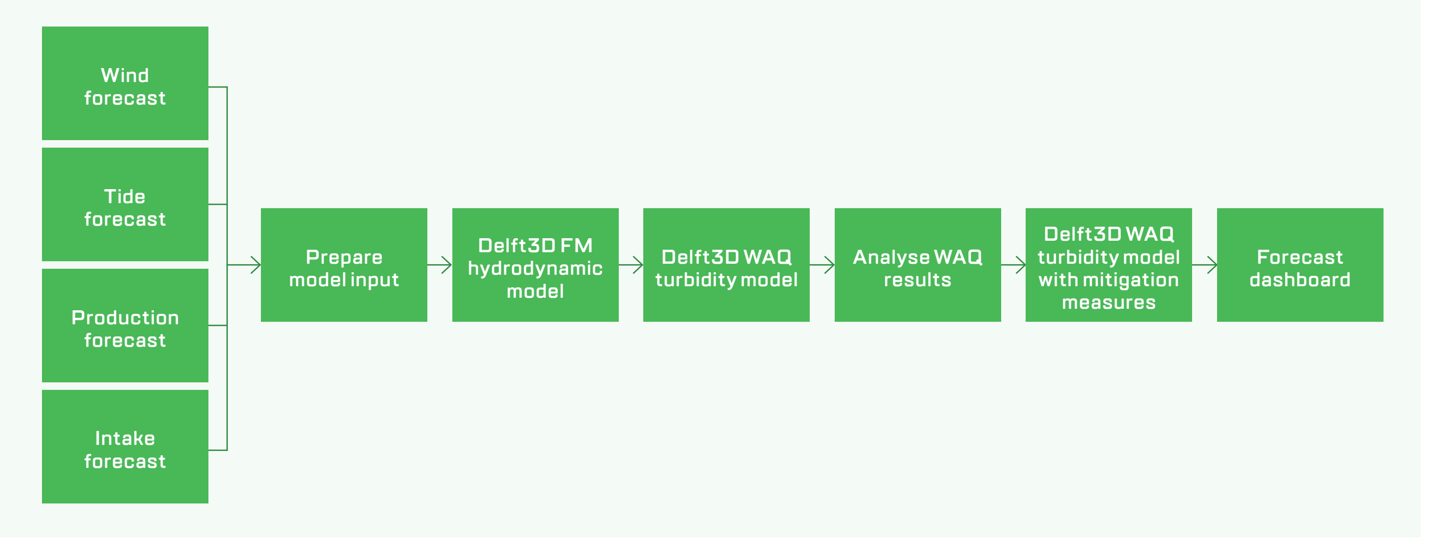

FIGURE 4

Simplified workflow of the automated daily model train.

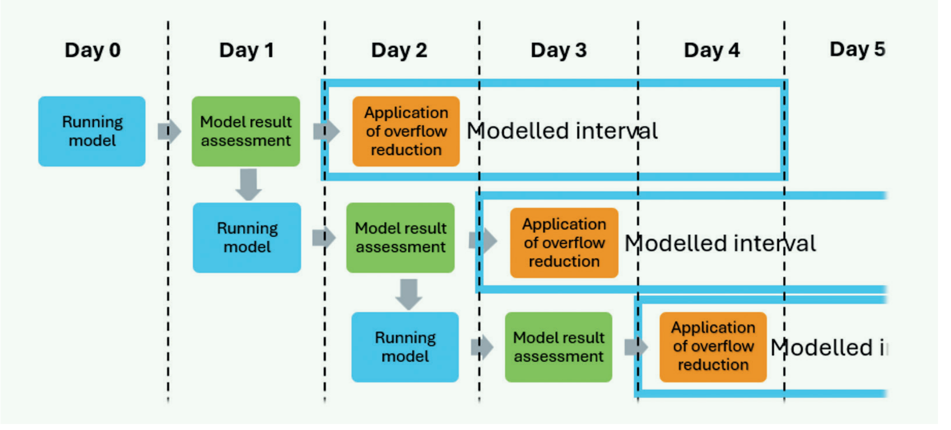

FIGURE 5

Overview of model timing and implementation of results as the project progresses. The model uses the restart file from the previous run to account for the historical plume.

FIGURE 6

Real-time measurement buoy locations.

Depending on the settling velocity of the fine material, sediment plumes can remain in suspension for hours or even days.

limited to the model runtime. However, because model results can be uncertain, additional time is reserved for interpretation and rerunning if necessary. Daily reanalysis of the forward-looking window is performed to minimize wind forecast uncertainty. The model timings are schematized in Figure 5.

Pro-active adaptive dredging approach

When the model results become available, they will be interpreted. This interpretation is crucial because the model is an approximation of reality. Therefore, the interpretation must consider the differences and their potential implications. Examples of differences between the model and reality include:

- Variability in weather predictions or deviations in measured conditions;
- Re-suspension or reduced settling velocities due to wave action not accounted for in the model;
- Variations in dredging productions;
- Equipment breakdowns;
- Changes in soil conditions;
- Alterations in dredging locations; and
- Updates to bathymetry.

Once the interpretation has been completed, mitigation measures can be determined. The primary mitigation measure is adjusting the overflow time, but the dredging location is often also considered when critical situations arise. Mitigation measures can be implemented on a day-to-day basis or immediately in response to rapid changes in weather conditions.

Continuous turbidity monitoring

Continuous live turbidity monitoring with buoys has been implemented for multiple reasons:

- To show contractual compliance to the NTU limitations;
- To check model results versus reality;
- To act as an early warning system in case the model results are deemed unreliable;
- To measure background turbidity in the

event of natural high turbidity events; and
- To measure other important parameters, such as chlorophyll, dissolved oxygen and current speeds.

The measurement buoys' locations are shown in Figure 6.

Buoy 1 and buoy 4 are designated as background buoys, buoy 2 serves as the early warning buoy and buoy 3 along with the quay wall station are buoys used to demonstrate compliance with contractual limits. Buoy measurements started prior to project execution for a baseline study on the background turbidity values. During project execution additionally spatial handheld NTU profiles over depth are measured multiple times per week at fixed locations within the dredging area for model calibration and validation. Figure 7 shows an example of handheld turbidity readings on the measurement grid. These handheld measurements provide valuable information to verify the concentrations in the forecasted plume and indicate the level of conservatism. If modelled levels are deemed too conservative, a manual calibration of forecasted NTU levels is performed. Handheld readings generally show lower values within 500 metres of the dredging area, which can be explained by the conservative settling velocity used in the model, accounting for the reduced settling caused by propeller wash.

Stakeholder involvement

The live buoy measurements are shared with relevant stakeholders through an online dashboard. Additionally, stakeholders are informed about the daily turbidity model and its interpretation. A daily turbidity forecast report is distributed, which includes the general outcomes of the model runs, the interpretation and its consequences on the mitigation measures.

Implementation and validation

During the initial stages of the project, a soft start to the dredging activities was implemented to account for assumptions in the model and to build confidence in the model results. During this ramp-up period, the model was calibrated by taking soil samples, analysing satellite imagery and conducting NTU measurements. After the ramp-up period, the conservativeness of the initial model was reduced by lowering the overflow source term fraction with a factor 2, linearly impacting the SSC in the plume. The forecasted production rates and dredging cycle times are adjusted to better reflect actual conditions.

Periodic validation and model update with on-site measured data

As the project progressed, both the soil and bathymetry changed. When it was determined that these changes significantly altered

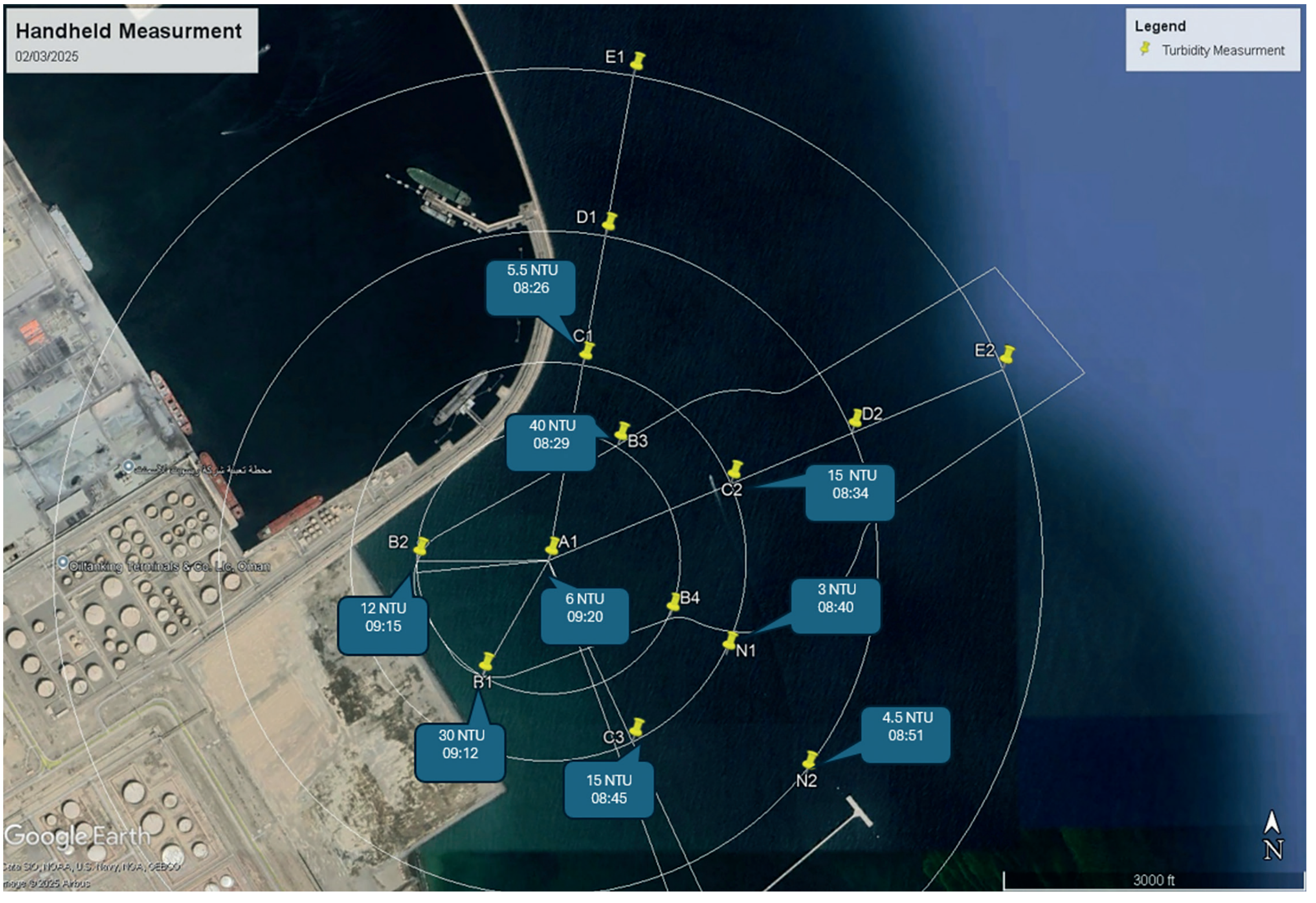

FIGURE 7

Example of handheld measurements during project execution.

model outcomes, a model update was implemented. This was deemed necessary after approximately 50% of the project was completed and harder soil had been dredged. The harder soil required longer overflow times due to less efficient dredging. However, this did not necessarily lead to a higher average source term since the percentage of fines was lower and the fines were trapped in lumps of material.

As the project progresses and parameters change, deciding whether to update the interpretation or the model can be challenging. Updating the interpretation works well in the short term, but postponing a model update can result in the model becoming increasingly divergent from reality. However, updating the model comes with the downside that the interpretation of the model may change again. To address this, a test and a production model train are run separately. Model updates are first implemented in the test environment. When the test results are deemed reliable and the differences with the main production model train are understood, the model train is updated. This approach helps avoid errors in running the model train or in the interpretation.

Results and discussion

Accuracy of turbidity forecasting model

An example of model output from 25 February to 3 March is shown in Figure 8. This event is used to illustrate how the model functions and why the interpretation phase is important. Trends in the plume are predicted relatively well. The graphs show examples of events where the model predicted high turbidity and the measurements also showed spikes. The timing and level of turbidity events occasionally is inaccurate, which can be explained by differences in:

- The actual vs. modelled dredging cycle: A theoretical dredging cycle is implemented in the forecast model, which is unlikely to align exactly with the real dredging cycle. It is challenging to predict the exact timings when a vessel is dredging.
- The actual vs. modelled overflow times: Predicted overflow times are implemented in the model; however, real overflow times may differ due to varying soil types.
- The actual vs. modelled wind conditions: Predicted wind conditions often show differences from measured wind conditions. Variations in directions and peak velocities influence the currents in the model.
- Wave conditions, which are not included in the model.

The predicted turbidity levels during the peaks are overestimated by the model. This is due to a conservative settling velocity chosen to account for the increased turbulence caused by propeller wash. The low ambient velocities are significantly influenced by propeller wash eddies over larger

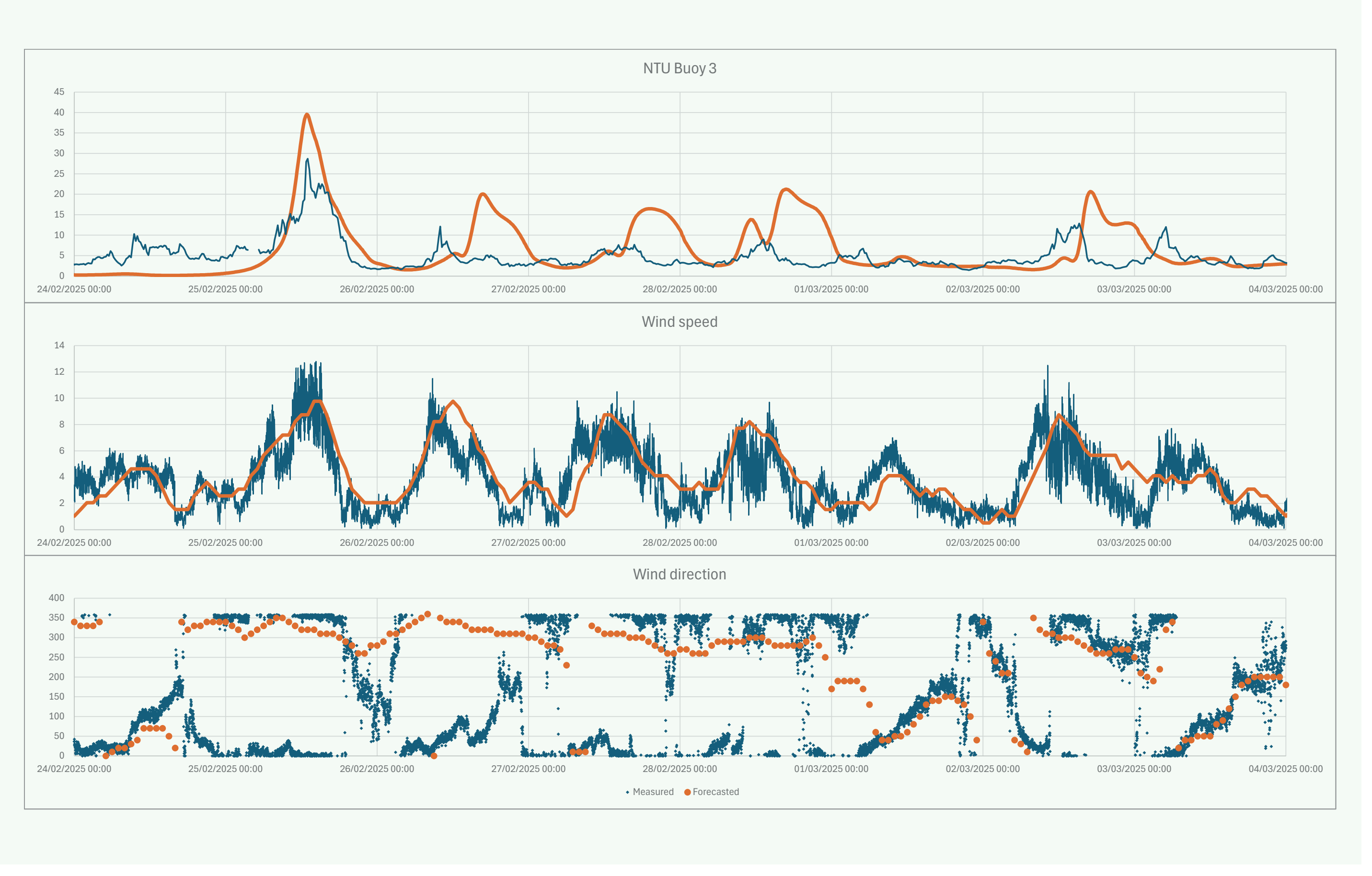

FIGURE 8

Example of model output versus measurements between 25 February and 3 March. The top graph shows the predicted (orange) versus the measured (blue) NTU in buoy 3, the middle graph shows the forecasted (orange) vs measured (blue) wind speed and the bottom graph shows the forecasted (orange) vs measured (blue) wind direction.

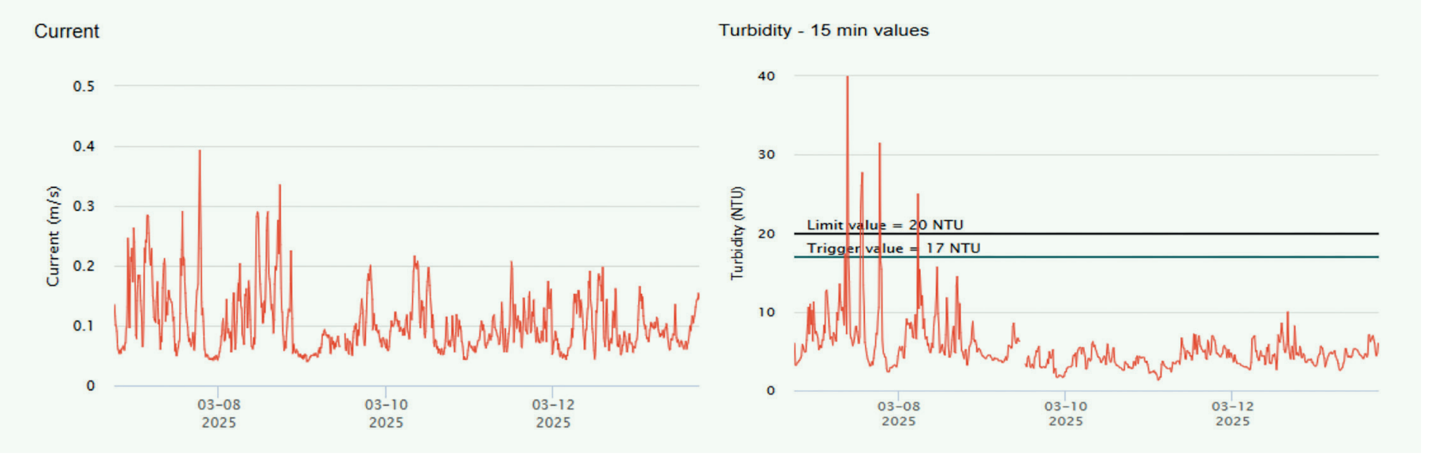

FIGURE 9

Measured current velocity vs measured NTU in buoy 2. The spikes around 8 March align with the turbidity spikes.

distances, which cannot be captured in the Delft3D model. The effect of this can be clearly seen in current velocity peaks in buoy 2, which coincide with turbidity peaks, as shown in Figure 9. The spikes around 8 March align with the turbidity spikes. The effect of vessel movement can also be observed when comparing satellite imagery with model output in Figure 10. Local eddies with high concentrations can be seen, whereas the model predicts a much more gradual plume. The plume location aligns well, although local differences due to vessel movements are visible.

Satellite or drone imagery proved to be a valuable tool to verify model results during the interpretation phase.

Impact on project execution

Taking the interpretation after the model results into account, advice is provided on which mitigation measures can be applied to remain within the limits. These measures may include options beyond overflow reduction, such as:

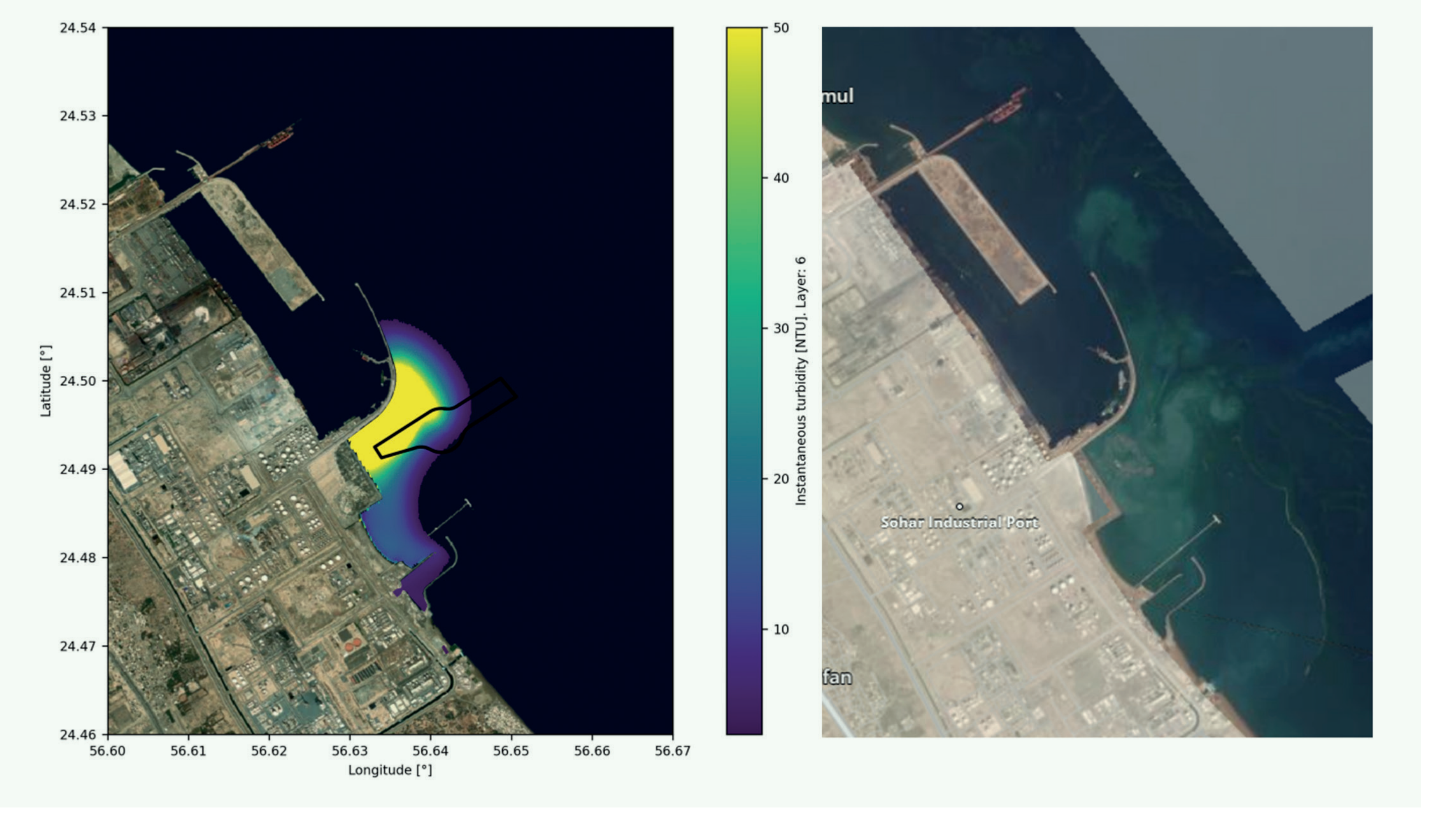

FIGURE 10

Plume model prediction vs satellite imagery. The plume location aligns well, local differences due to vessel movements are visible.

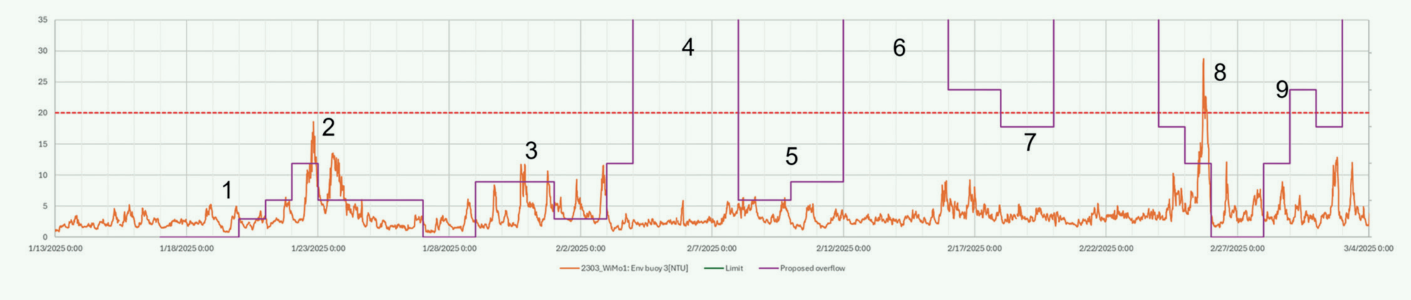

FIGURE 11

Proposed indicative overflow time (not related to the tick labels) based on turbidity forecast modelling (purple) versus measurements of buoy 3 (orange) compared to the limit of 20 NTU (green).

- Dredging in deeper water to prevent propeller wash;
- Avoiding dredging high up on the slopes of the design to prevent propeller wash;
- Choosing to dredge in a different material with lower fines content with overflow;
- Opting to dredge in a location with many fines without overflow; and
- Scheduling repairs or bunkering of one of the vessels to lower the total source term of the project.

Figure 11 shows the indicative proposed overflow duration against the buoy 3 turbidity readings and the turbidity limit of 20 NTU. This figure demonstrates how effective the overall approach of the model train with an interpretation phase has been for the project. Events where overflow time was restricted could have resulted in exceedances of the limit if no mitigating measures had been implemented. Conversely, during periods with low turbidity risks and thus no restrictions, the measurements show low turbidity values and optimal overflow times for maximum production were implemented. Several noteworthy events are listed in Figure 11.

From the above, it is concluded that although the predictive modelling shows some uncertainty, it provides significant confidence as a method for making decisions during project execution. Changes in weather systems are generally well captured and the general idea of the turbidity risk is known a few days in advance. The uncertainty of the model predictions will decrease over time as measured data provides information to update the model or the interpretation of the model results. The exact turbidity level will remain difficult to model precisely since local disturbances, such as eddies from vessel

NR.	EVENT	DESCRIPTION
1	Ramp-up phase	During this phase of the project, limited knowledge was available regarding how critical the turbidity would be; therefore, overflow times were limited.
2	Wave event 1	This was the first high wave event during the project and demonstrated the impact of waves on turbidity.
3	Overflow restricted, exceedance mitigated	Overflow was restricted due to model results. Some conservatism was applied, also because some waves were present during these days.
4	Unrestricted overflow	For the first time, the forecasted weather conditions allowed for no restrictions on overflow time. Readings showed low NTU values in accordance with model results.
5	Mitigated exceedance	Mitigation measures for the peaks during these days appeared conservative, providing valuable information for the interpretation phase for future modeling results.
6	Unrestricted overflow	No restrictions were applied. Readings showed low NTU values in accordance with model results.
7	Mitigated exceedance	This peak was lower than expected because a predicted wind peak did not occur in reality.
8	Wave event 2	This wave event caused a brief exceedance of the limits, resulting in the project being halted until readings returned to acceptable levels. The reason for the exceedance was a severe wave event causing high background turbidity. Because of several days of predicted waves, no overflow was implemented, although the model (excluding waves) did allow for some overflow.
9	Applying multiple mitigation measures	The dredging location was changed to coarser material, which allowed for longer overflow times due to lower source terms.

TABLE 4

Description of events during project execution.

propellers, cannot be captured in a predictive model. This uncertainty will persist throughout the project and therefore must be considered when advising on mitigation measures.

Challenges and lessons learned

Model validation before project execution

When the project started, the model was not calibrated and validated due to the absence of measured data during dredging activities. A comparison was made with the pre-tender turbidity assessment, which showed similar results. Validation and calibration of the model was required at the beginning of the project. During this phase, communication with stakeholders regarding the model's performance was essential to maintain trust in the model train.

Field data of soil is lagging behind on model forecasts

Soil samples from the hopper are taken and analysed continuously. The process time between taking a sample and receiving its results should be as short as possible, as dredging is ongoing and soil can change. For smaller projects, the soil data may not be fully representative for updating model settings if soil conditions change quickly with dredging depth. Sampling must be done carefully to ensure it provides a comprehensive picture of the dredged material.

Propeller wash turbidity

Separating turbidity caused by propeller wash from that generated by the drag head and overflow is challenging. In shallow areas, propeller wash is likely to be a significant source term. This is assumed to be accounted for by additional conservatism in the dredging source term.

Vessel movement

Effects from the vessel propellers appear to influence the current patterns in and near the dredging area. Buoy 2 indicated that spikes in current velocity significantly reduced during bunkering or repairs. Additionally, satellite imagery consistently showed a pattern in the plume, with an inflow of clear water into the dredging area from where the vessels started sailing towards the disposal area and old eddy-shaped plumes towards the south and north. With the current models, it is not feasible to include a moving propeller wash forcing, which means this factor must be considered during the interpretation phase after the model run.

> **Applying a pro-active adaptive dredging strategy based on forecasted predictions led to reduced environmental impact.**

Wave impact

Waves appeared to have a significant impact on (background) turbidity during periods of increased wave height. This was observed once during the baseline measurements and twice during dredging when no exceedance was predicted by the model. Waves were not included in the model as they were expected to be of low importance. Despite this, the majority of the time, waves did not have a substantial impact. Unforeseen effects during periods of increased wave height were considered during the interpretation phase of the model results.

CONCLUSION

Summary of findings

- A turbidity forecast model is an effective tool for determining short-term dredging strategies, considering the impact of predicted weather on sensitive receivers such as a seawater intake.
- Uncertainties in the turbidity forecast can be managed by the contractor. There are various mitigation measures beyond adjusting overflow duration, such as dredging in different locations, deeper water, different materials and planning repairs.
- Adaptation of the model compared to reality always lags behind real-time data. When soil conditions change, this leads to additional uncertainty. The source term is highly dependent on soil type and overflow duration alone as a mitigation measure can be a poor indicator when transitioning to a different material type. System knowledge is critical and the contractor can assess experience from the project and measurements to estimate the risk.
- As the project progresses and parameters change, deciding whether to update the interpretation or the model can be challenging. Updating the interpretation is easier in the short term, but postponing the model update for too long can cause the model to deviate significantly from reality.
- Satellite or drone imagery can greatly assist in calibrating and validating the model. The shape and intensity of the historical plume generated by previous dredging are crucial for accurate model results but are very difficult to verify with local measurements only.
- Investing in proper communication with stakeholders builds mutual trust. Online dashboards and visualisations are highly valuable tools for this purpose.
- The execution phase validated many pre-tender conclusions but also highlighted the need for ongoing adjustments based on real-time data. Continuous monitoring and adaptive management proved essential for maintaining environmental compliance and optimising productivity.

Significance of the forecasting model and adaptive approach

For the Sohar Port development project, the forecast model proved to be a valuable tool for making operational decisions. Applying a pro-active adaptive dredging strategy based on forecasted predictions led to reduced environmental impact and improved dredging and overall project performance, meeting the requirements set by stakeholders.

Recommendations for future projects

- A thorough system understanding backed by measurements during the pre-tender phase greatly increases the possibility of reliable and valuable forecast modeling for the project.
- Due to intrinsic uncertainty in turbidity forecasting, implementing realistic limits that can be exceeded for an acceptable duration helps to reduce an overly conservative approach. This includes allowances for spikes in turbidity readings that cannot be captured by a forecast model.
- Turbidity management is most beneficial if implemented by the contractor. This provides flexibility in the mitigation measures and benefits the project by allowing the trade-off between risk and production, considering all nuances known by the contractor. Providing reliable and sufficient site data by the client during the tender phase is crucial for an accurate risk assessment.
- Making the turbidity models used during the pre-tender stage available during the tender stage greatly enhances the contractor's flexibility to implement specific work methods, benefiting the project overall.
- Engage stakeholders regularly for open communication and share insights from models and forecasts.

Antoon Hendriks

Antoon is a civil engineer specialising in coastal, dredging and hydraulic engineering. Educated at Delft University of Technology in the Netherlands, he joined Boskalis in 2012, where he delivers detailed engineering assessments for international projects using advanced modelling tools. He furthermore managed commercial tenders across Europe coordinating technical input, commercial conditions and project planning. Antoon is driven by a commitment to solving complex environmental and engineering challenges, with the goal of contributing to a more sustainable and resilient future.

Tim Schmidt

Tim has over 18 years experience in large scale port and maritime projects in the Port of Rotterdam (the Netherlands) and Port of Sohar (Oman). As a project manager, his experience covers the entire project lifecycle, from feasibility and planning up to commercial aspects, design, tendering, construction and port operations. Since 2016, Tim has been working for Sohar Port and Freezone on a number of challenging port expansions, including port master planning, coastal protection, port structures, dredging, metocean studies, navigation and mooring studies, etc. Tim is currently responsible for the delivery of all maritime and coastal infrastructure required for a new LNG facility in SOHAR.

Tariq Al Kiyumi

Tariq is a senior assets development manager with 18 years' experience, specialised in strategic expansion projects of high-value marine and land assets. His expertise lies in spearheading complex maritime infrastructure projects and driving organisational growth through technical excellence and robust project delivery. Throughout Tariq's career he has consistently delivered large-scale terminal expansions, ensuring operational efficiency and long-term asset value in demanding global maritime environments.

Jeroen de Reus

Having specialised in Coastal Engineering at Delft University of Technology in the Netherlands, Jeroen joined Boskalis in 2005 and has since gained extensive international experience across a wide range of coastal and marine construction, as well as dredging and land reclamation projects. In 2011, he advanced to the position of project manager, overseeing complex marine works in diverse environments. Since 2019, Jeroen has served as tender manager at Boskalis' head office in Papendrecht, where he is responsible for leading multidisciplinary tender processes for large-scale marine infrastructure projects.

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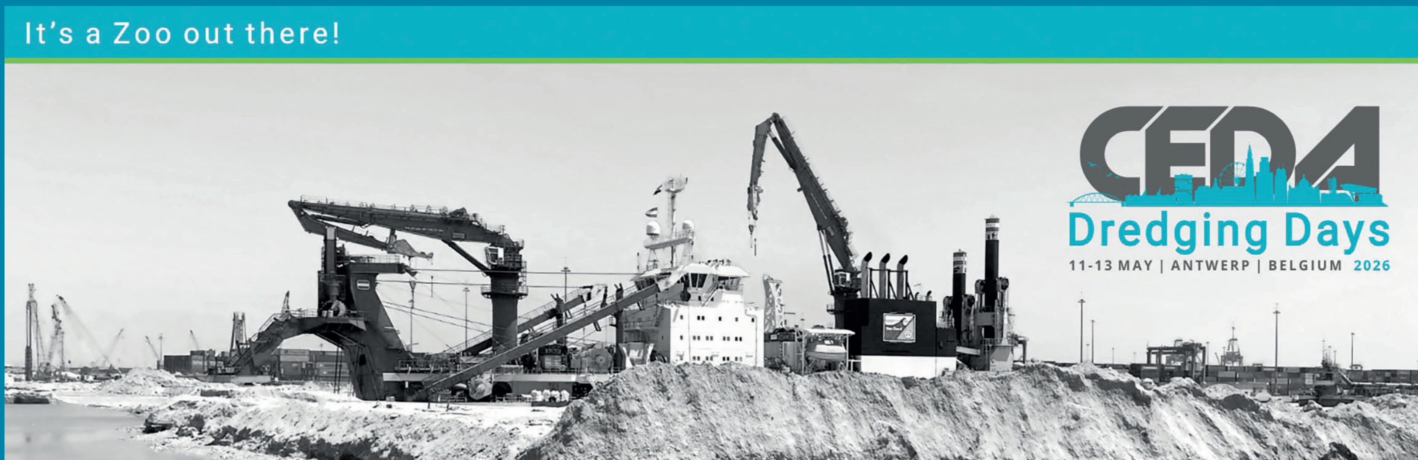

REGISTER NOW

IADC is delighted to announce its role as a media partner of the upcoming CEDA Dredging Days, taking place from 11-13 May 2026 in Antwerp, Belgium. The event will gather leading experts and stakeholders from across the dredging industry for three days of insight, innovation and networking. For more information and to view the full programme, visit https://ceda.eventsair.com/dd26.

Conference theme

It's a Zoo out there! Possibly an apt expression of the feeling many people and organisations have, given the current global developments. The international dredging industry is affected and pressed to adapt continuously.

The CEDA Dredging Days 2026 conference, taking place at A Room with a ZOO, in the splendidly charming Antwerp ZOO, founded in 1844, clearly offers opportunities to explore and discuss "the zoo out there" in many ways. Literally, by going out into the zoo and taking flora and fauna as the backdrop for interactive sessions, and metaphorically, by exploring and discussing what challenges and uncertainties the dredging industry is facing, as a result of the renewed raw geopolitical reality. Combine this with fun elements like impersonating characteristic animals in a role play, and we're set for an inspiring and dynamic event.

Paper sessions and interactive sessions will alternate, with classic and new topics. To name a few: Building with Nature, decarbonisation, dredging technology, environmental effects. The Organising Committee is designing the Dredging Days 2026 programme to be attractive for everyone across the dredging community: both technical and commercial oriented individuals, young professionals and seniors alike. Whether your goal is to gain knowledge, widen your network or to deepen your existing relationships, we look forward to seeing you in "the ZOO"!

CEDA Dredging Days in keywords

- A 3-day event dedicated to the dredging industry.
- The main event on the dredging industry calendar in the CEDA (EMEA) region.
- A bi-annual event.
- The platform to exchange and increase industrial knowledge.
- The place to develop and strengthen relationships within the dredging community.
- A central Clubhouse; the meeting place for social events, informal networking and some non-paper sessions.
- A widely varied programme, interesting for a broad audience and promoting attendee interaction.
- Parallel sessions featuring the latest technical developments, learning from other industries, innovation pitches, panel discussions and much more.

Main members

DEME Group
Head office Belgium
+32 3 250 5211
info@deme-group.com
www.deme-group.com

Dutch Dredging
Head office The Netherlands
+31 184 411 999
info@dutchdredging.nl
www.dutchdredging.nl/en

Group De Cloedt – DC Industrial N.V.
Head office Belgium
+32 2 647 12 34
office@groupdecloedt.be
www.groupdecloedt.be

Gulf Cobla (L.L.C.)
Head office United Arab Emirates
+971 4 803 7777
gc-info@gulfcobla.com
www.gulfcobla.com

Hyundai Engineering & Construction Co., Ltd.
Head office South Korea
+82 2 746 1114
webmaster@hdec.co.kr
www.hdec.co.kr

Jan De Nul Group
Head office Luxembourg
+352 39 89 11
info@jandenulgroup.com
www.jandenul.com

National Marine Dredging Company
Head office United Arab Emirates
+971 2 5130000
nmdc@nmdc.ae
www.nmdc.com

Penta-Ocean
Head office Japan
+81 3 3817 7181
poc_international_web@mail.penta-ocean.co.jp
www.penta-ocean.co.jp

Rohde Nielsen A/S
Head office Denmark
+45 33 91 25 07
mail@rohde-nielsen.dk
www.rohde-nielsen.dk

Royal Boskalis
Head office The Netherlands
+31 78 6969 000
royal@boskalis.com
www.boskalis.com

TOA Corporation
Head office Japan
+81 3 6757 3800
webmaster@toa-const.co.jp
www.toa-const.co.jp

Van Oord
Head office The Netherlands
+31 88 8260 000
info@vanoord.com
www.vanoord.com

Colophon

Editorial
For editorial enquiries, please email editor@iadc-dredging.com or call +31 (0)70 352 3334. Articles featured in *Terra et Aqua* do not necessarily reflect the opinion of the IADC Board of Directors or of individual members.

Editor
Ms Sarah Nunn

Front cover
Photo © Shutterstock

Back cover
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Design
Smidswater, The Hague, The Netherlands

Layout
Robert Dumay Graphic Design, Serooskerke, The Netherlands

Printing
Damen Drukkers
Werkendam, The Netherlands

ISSN 0376-6411

How to subscribe?
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Terra et Aqua is published four times a year by
International Association of Dredging Companies
Stationsplein 4
2275 AZ Voorburg
The Netherlands
www.iadc-dredging.com

FSC MIX Paper from responsible sources FSC® C114590 www.fsc.org
carbon neutral natureOffice.com | NL-077-843295 print production


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