CANADA MEETS THE WORLD: HOW OILS SANDS TAILINGS MANAGEMENTK NOWLEDGE AND TECHNOLOGIES ARE APPLIED IN EUROPE AND BEYOND, AND VICE VERSA

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ABSTRACT

Oil sands fluid fine tailings, thickened tailings or sand–fines tailings mixtures have a lot of similarities with natural mud, sand–mud mixtures and soft soils commonly found in estuarine and coastal areas. While the specifics of oil sands operations are certainly different, the physics and physical processes at the basis of tailings treatment technologies (especially in the direction of tailings basins closure), and sediment management for land reclamation or coastal defense are very similar.

In various regions of the world sediment management is becoming a critical matter for sustainable development: coastal regions and river banks are eroding exposing towns to more recurrent flooding; coastal development activities demand for large quantities of sediment as building material, or development of harbors for access to remote coastal regions. Similarly to fluid fine tailings management and tailings basin closure, these challenges indicate that smart, integrated and technologically advanced sediment (and tailings) management is critically necessary.

With this in mind, EcoShape initiated the Living Lab for Mud (LLM) initiative. The LLM includes five pilots project in the Netherlands and Indonesia where innovative fine sediments knowledge and technologies are developed and tested in the field. These projects include utilizing dredge and natural sediments to: build islands for enhancing biodiversity; produce construction material for dykes reinforcement; and enhance the development of wetlands, salt marshes and mangroves. Similarly to oil sands tailings management, the underlying physic and processes at the basis of these pilots include: flocculation, dewatering and strength development (i.e. sedimentation, consolidation, drying and ripening); fines resuspension, fate and trapping; interaction of sediments with biota; and socio-economic aspects.

Not too dissimilar from the Canadian Oil sands Innovation Alliance (COSIA), EcoShape (www.ecoshape.org) is a Dutch consortium created to develop, collect and disseminate pre-competitive innovative knowledge and technologies based on the Building with Nature (BwN) approach. EcoShape unifies research institutes (Deltares and Wageningen University and Research), consultants (Witteveen en Bos, Arcadis, Royal Haskoning – DHV, HKV), contractors (Boskalis, Van Oord, IHC) and government agencies (Dutch Ministry and Municipalities).

This paper presents the LLM initiative and gives a general overview of these pilot projects, highlighting the similarities in knowledge, (numerical) tools and technologies with oil sands tailings management and tailings basins closure. This presentation has the ambition to continue inspiring international collaboration and knowledge exchange between Canada, Europe and beyond.

INTRODUCTION

Based on the assumption of general and fundamental similarities between Canadian Oil sands tailings and natural mud, this paper describes a selected numbers of international, Dutch-based experience and pilot projects, where knowledge partly developed in oil sands research is utilized for the beneficial nature-based use of natural mud. This paper intends to demonstrate that collaborative pre-competitive knowledge development and dissemination approaches are similarly developed in Canada and in the Netherlands. This paper therefore pledges for even closer international collaboration.

Canadian Oil Sands Tailings Challenges

One of the largest challenges of Canada's oil sands is the production of large volumes of slow dewatering oil sands tailings during bitumen extraction (Martin and Davids, 2000). Oil sands operators are required to comply with Alberta Energy Regulator (AER) requirement to manage fluid tailings (FT) volumes during and after mine operation in order to manage and decrease liability and environmental risk resulting from the accumulation of fluid tailings on the landscape. FT management should be achieved while balancing environmental, social, and economic needs (AER, Directive 85).

FT are a mixture of process water, sand, silt, clay and residual bitumen. During deposition or as part of tailings management processes sand is often separated from the rest of the tailings generating fluid fine tailings (FFT). FFT is at the core of the oil sands tailings management challenge. FFT has very poor dewatering (i.e. settling and consolidation) properties largely caused by the bitumen extraction process which disperses the clay fraction.

Independently or through COSIA, the industry is investing significant resources to develop effective technologies to minimize production and treat legacy of FFT[1]. The key objective is to reclaim FFT into boreal landscape soon after mine life. Example technologies include (a combination of):

- Flocculant treatment, generally synthetic anionic polymers;
- FFT centrifugation with large centrifuges;
- Atmospheric drying of FFT with subsequent deposition and drying of thin FFT layers;
- Non-segregating tailings, mixing sand and fines before deposition, and avoiding segregation of sand and FFT during deposition;
- Co-mixing, mixing coarse and fine tailings during deposition or within existing deposits;
- Capping, covering existing deposits with a layer of sand of other lighter material;
- Deposition of treated FFT in deep mine-pit deposits;
- Biological (nature-based) methods, such as enhancing dewatering through vegetation, worms, bacteria.

This collaborative research and technology development at pre-competitive stage is funneled via COSIA. COSIA was launched in 2012 with all largest oil sands companies contributing to fund and co-develop innovative technologies with focus on accelerating the pace of improvement the environmental performance of Canada's oil sands[2]. COSIA includes four Environmental Priority Areas (EPAs): greenhouse gases (GHG), land, water and tailings.

While the clay fraction of FFT has undergone dispersive treatment during the bitumen extraction process, FT presents many similarities with natural mud. Therefore the knowledge that is developed in Canadian oil sands is applicable to many other challenges in muddy areas world-wide. Vice versa solutions from international experience can be effectively imported in oil sands when appropriately adapted to the peculiarity of the oil sands tailings and the needs of the industry.

Worldwide Mud Challenges

Throughout the world, different coasts, shores, lakes, and rivers have to deal with excess sediment or sediment shortages. The natural balance between the erosion and deposition of sediment is disrupted by human interventions such as dams in a river, port developments in an estuary and dredging activities for the maintenance of existing ports and waterways. Disruption of the natural balance creates areas of sediment starvation (i.e., coastal erosion) and areas of sediment abundance (i.e., siltation in harbors), Winterwerp and Wang (2013), Winterwerp et al. (2013), Vörösmarty et al. (2003), and Brils et al. (2017). Human developments and natural ecosystems are directly affected by this sediment unbalance, with implication on industrial activities (e.g. navigation, logistic and tourism industry); space for living, flood safety and impact of climate change (e.g. loss of coastal areas and more frequent flooding) and food security (e.g. loss of productivity).

Optimizing sediment management by integrating human developments into the natural sediment cycle is one of present days' greatest challenges

[1] https://www.cosia.ca/initiatives/tailings#projects

[2] https://www.cosia.ca/about

as well as greatest opportunities. Sediment is therefore potentially a precious resource, not a waste.

Worldwide, various initiatives and programs exist that focus on the development and testing of sustainable and nature-based approaches for optimizing sediment management and reuse. The Central Dredging Association (CEDA) started a Working Group on Beneficial Use of Sediments in 2017[3], which collected the latest case studies and listed the most important worldwide initiatives regarding beneficial use of natural (and contaminated) sediments in an Information and a Position paper soon to be published.

THE LIVING LAB FOR MUD, ECOSHAPE AND BUILDING WITH NATURE

The Living Lab for Mud (LLM)[4] is managed by the consortium EcoShape – Building with Nature in The Netherlands[5]. EcoShape is a Dutch consortium that unifies many of the most important Dutch private (i.e. engineering and contractor), research institute and academic organizations, NGO and public entities of the Dutch water sector. The objective of EcoShape is to collaboratively develop, demonstrate through pilots, and publically share precompetitive BwN knowledge and solutions for water-(and dredging) related challenges. While different in the organizational details, EcoShape is not too dissimilar from COSIA.

BwN means proactively utilizing the ecological, physical and socio-economic system integral ingredient of an engineering solution (De Vriend et al. 2015 and De Vriend and Van Koningsveld, 2012). In coastal defense setting it may mean utilizing vegetation to trap sediments and decrease the impact of a storm on the dike, rather than increasing a concrete dike. It may also mean taking advantage of the too high turbidity of a river and harbor siltation to dredge and ripen these sediments to produce clay soil to strengthen and broaden dikes. BwN also means to incorporate local governance and stakeholder engagement and sustainable business models.

[3] https://www.dredging.org/ceda/working-groups
[4] https://www.ecoshape.org/en/projects/living-lab-mud/
[5] https://www.ecoshape.org

The main objective of the LLM is to develop, show and share innovative knowledge, technologies and techniques regarding the sustainable use and re-use of fine sediments (i.e. mud) based on the BwN approach (EcoShape 2017). The LLM is a real big living lab. It links five mud and BwN based concepts which are tested in five full-scale EcoShape managed specific pilot projects in The Netherlands and Indonesia (Figure 1). In these pilots we "learn-by-doing". Innovative mud based solutions are tested to: reduce flood risk and increase resilience to climate change; enhance ecosystem restoration and nature development; improve water quality; transform sediment into alternative building material and improve the navigability of waterways. The LLM extrapolates and exchange generically applicable concepts from existing specific pilots.

The LLM pilots apply the principle of BwN. It is the ambition of the authors, of EcoShape and its partners, to apply the knowledge developed with the LLM in practice and to extend the LLM experts network both nationally and internationally, since estuaries, coastal areas and inland waters, as well as various industry activities (e.g. oil sands) elsewhere in the world face similar sediment or tailings management challenges and opportunities.

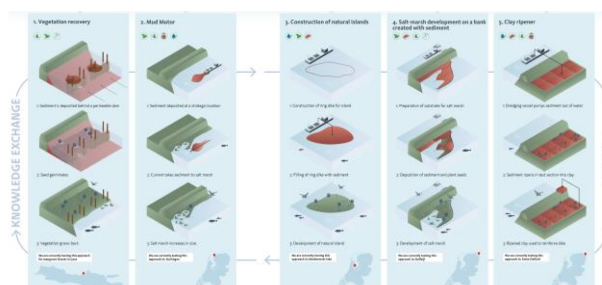

Figure 1. Representation of the 5 LLM concepts. The LLM concepts are tested in five pilot projects. From left to right: Vegetation recovery in eroding coastal areas, Pilot Building with Nature Indonesia; Strategic disposal of dredge sediment for salt marshes development, Pilot Mud Motor; Construction of natural islands from natural dredge sediments, Pilot KIMA Marker Wadden; Develop salt marshes from sand and mud, Pilot Marconi; Producing clay soil from dredge sediments, Pilot Kleirijperij. Generic knowledge regarding fine sediment physics, project implementation and governance is developed within each pilot. The knowledge and experts network are shared across the pilots. Image by EcoShape, 2017.

THE LIVING LAB FOR MUD PILOTS

The LLM includes five pilots as described in Figure 1. These pilots transition through:

- Trapping suspended fine sediments to enhance vegetation recovery (Pilot Building with Nature Indonesia in Demak, Indonesia)[6];
- Strategic disposal of dredged material to encourage salt marsh or wetland development (Pilot Mud Motor Koehoal salt march development in Harlingen, The Netherlands)[7];
- Construction of natural islands with fine dredge material within sand dikes (Pilot KIMA Marker Wadden, The Netherlands)[8];
- Develop salt marshes at different percentages of sand and mud content and through planting vegetation (Pilot Marconi, The Netherlands)[9];
- Producing clay soil through ripening fine dredge material (Pilot Kleirijperij, The Netherlands)[10].

These pilots cover the full range between: fines in suspension, fluid, consolidated and ripened mud; and between maximizing BwN with very limited human intervention and more involved human activities. These pilots integrate physical understanding of mud dynamics, ecology and vegetation science, innovative operational know-how on handling and constructing with very soft mud, and often complex innovative multi-party and multi-agency public-private-academic collaboration. When the world “tailings” is substituted to the world “mud” in the chapter above, the parallel with oil sands tailings management is apparent. Some of the EcoShape partners actively participate in oil sands research and development and engineering projects. Significant experience, knowledge and tools that are developed in oil sands projects are utilized in the LLM pilots, and vice versa.

In this paper we present in more details those pilots where the correlation between LLM knowledge development and application is mostly intertwined with oil sand applications. These are: 1. Kleirijperij; 2. Marker Wadden; and 3. Marconi. These pilots are all currently in execution with preliminary results fresh of the press. In this paper we present a general introduction to these pilots and the most important results to date. For additional information and background of all pilots, we refer to previous publications (van Eekelen et al., 2017) and to the EcoShape website referenced in the footnotes of each pilot. For a description of the full EcoShape Program and all EcoShape pilots we refer to van Eekelen et al. (2018).

Pilot Kleirijperij

The Pilot Kleirijperij is located at Delfzijl, on the west side of the Eems-Dollard estuary, which borders The Netherlands and Germany. Since a few decades, the turbidity in the Ems River has been increasing due to an increase in suspended sediments concentration (van Maren et al. 2015). This leads to an increase in required maintenance dredging for the harbors in the Ems Estuary, such as Delfzijl. At the same time, the clay that is needed to maintain or strengthen the dikes in the area is bought and brought in from distant locations.

In the pilot Kleirijperij sediment is dredged from the harbor channel of Delfzijl and the nature area Breebaart. It is directly transported on land across the dike and deposited into 24 departments in two locations, covering about 22 ha. The size of the departments varies but is in the order of 100 m x 100 m. The mud is deposited in one or two cycles with a total initial thickens in the order of 1.5 m. There it is allowed to ripen for three years into clay soil. The objective of this pilot is to test different ripening strategies to determine efficient and cost-effective delivering of dike quality clay. Ripening strategies include different thickness, mixing with fresh water, overturning and mixing, and vegetation planting. At its termination in 2021, the pilot will have to deliver 70,000 m^3 of clay for use in a demonstration project of the green dike concept ‘Brede Groene Dijk’ (Van Loon et al., 2015). This dike has a grass-covered embankment with a slope that is less steep than in regular embankments in the Netherlands. If successful, the pilot will be scaled up in the future to extract up to 1 million cubic meter of dredge material form the Eems-Dollard.

While ripening dredged material or fine tailings is not new, for the first time this pilot aims to produce clay from dredge sediments that meets the requirements for application in Dutch dikes.

[6] https://www.ecoshape.org/en/projects/building-with-nature-indonesia/

[7] https://www.ecoshape.org/en/projects/mud-motor/

[8] https://www.ecoshape.org/en/projects/marker-wadden/

[9] https://www.ecoshape.org/en/projects/saltmarsh-development-marconi-delfzijl/

[10] https://www.ecoshape.org/en/projects/clay-ripening-pilot-project/

Simultaneously, this pilot contributes to decreasing the turbidity of the Ems River and improving its water quality. The Kleirijperij pilot represents therefore an attractive win-win opportunity which harnesses BwN processes such as evaporation and consolidation and ripening, to turn excess dredged sediment into a resource, by creating clay soil for dikes.

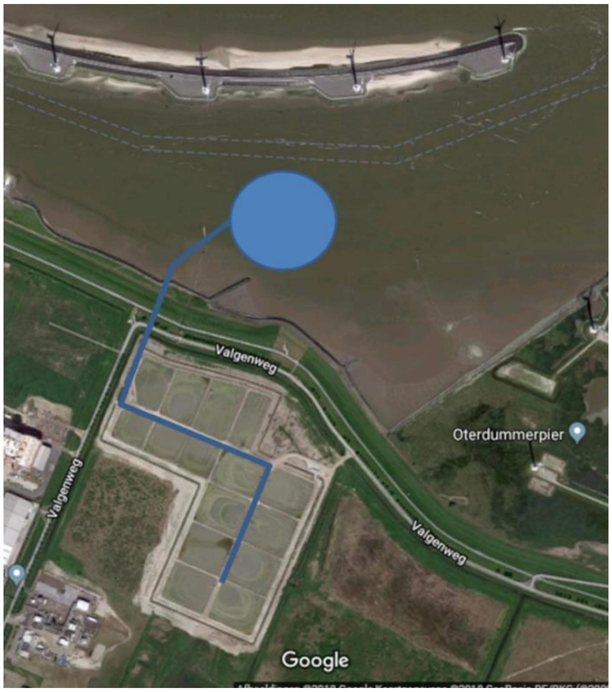

Figure 2. The Kleirijperij site of Delfzijl seen from Google maps about two months after deposition of the first layer. 15 cells are filled with dredged sediment coming from the entrance channel of the Delfzijl harbor (blue circle, approximate location) and transported directly to the cells with a pipeline (blue line).

Dutch legislation requires clay for dikes of a specific class (determined mainly by the Atterberg Limits and water content), a maximum salt and organic content. During ripening, the dredged mud needs to lose water and decrease its salt and organic content. A monitoring program, laboratory test and numerical modeling are associated to this pilot, to predict and continuously verify its performance. In the field, measurements are taken: during deposition; regularly throughout the year; and in detail one per year. During deposition, online measurements were taken for density and general dredge material characterization. During ripening, mud level is regularly measured with settling plates and fiber optic measurements. The latter is an innovative method to monitor mudline and mud density being tested in parallel in the pilot and in the lab. Drainage water is also measured from the sand drains. Each year in September, an extensive field monitoring investigation is carried out, through analysis of in-situ sediment samples. In parallel to the field pilot, settling columns, Seepage Induced Consolidation and permeability tests are carried out in the lab to assess and predict dewatering performance. An extensive literature study to collect pre-existing knowledge was performed before the pilot. Numerical modeling development and specific lab testing are foreseen dedicate to understanding and predicting ripening.

At the time of this paper (summer 2018), deposition is completed in Delfzijl while construction has begun in Breebaart. Deposition in Delfzijl took place in two subsequent events. A first event started on April 5th, 2018 (official opening of the pilot), and a second event in July. The cells were filled with a height of 0.4-1.6 m. The initial density of the dredged material was slightly below 1,200 kg/m^3. The overlying water was drained from the cells about two weeks after deposition. Soon after drainage, a crust formed on top of the deposited mud (Figure 3).

Figure 3. Image of one cell of the Kleirijperij taken on 16th of August (day 135), therefore about one month after the second layer was deposited. Photo EcoShape.

Preliminary measurements indicated dewatering rates in line with theoretical expectations, with faster dewatering rates in thinner deposits and with underlying drain. To facilitate dewatering, the crust was broken mechanically. Under the crust, the mud was still rather fluid, except in the cell with a thickness of deposited mud of 0.4 m, that showed very rapid dewatering. In June 2018 a second layer was deposited.

The Kleirijperij project is a collaboration between EcoShape, the Province of Groningen, the water authority 'Hunze en Aa's', the Delfzijl port authority Groningen Seaports, nature organization Groninger Landschap and the Dutch Ministry of Infrastructure and Water Management. The project partially financed by the Waddenfonds and the Dutch National Flood Protection Program HWBP. This pilot is part of the larger ED2050 program[11], which includes various pilots in the Eems-Dollard region with the same objective of improving the natural and economical value of the Region.

Oil sands experience with atmospheric fines drying was used to develop the filling and monitoring strategy of the pilot. Biological treatment methods will include vegetation and possible worms, techniques that are currently investigated in oil sands research by EcoShape partners Deltares together with Canadian partners (e.g. NAIT). The fiber optic tool is being developed and tested in this pilot to monitor mud – water – air interface and density profile development. This same tools is being considered for installation in oil sands tailings ponds.

Pilot Marker Wadden (KIMA)

Lake Marken in the center of the Netherlands is one of the largest freshwater lakes in Western Europe. Since the lake was artificially closed off from Lake IJssel, its ecological status has deteriorated severely due to a significant increase of the turbidity caused by re-suspension of fines. The nature conservation organization Natuurmonumenten and the Dutch government have joined forces with the ambition of improving the natural habitat in Lake Marken by decreasing suspended fines concentration. A potential strategy includes the excavation of deeper sediment traps that favor natural settling and sedimentation of fine particles and inflow of possible fluid mud. The trapped sediment can be utilized as part of the building material to create an archipelago of marsh islands: the so called Marker Wadden, which is intended to become a "bird paradise". The Marker Wadden intends to demonstrate that fine sediments can be used as a construction material for land reclamation, dike reinforcement and soil improvement. This ambition is in line with the Kleirijperij project described above, and therefore similar to turning FFT deposits into reclaimable landscape.

Figure 4: Aerial view of Marker Wadden under construction, April 2018. To the left of the the island, three smaller cells, where part of the KIMA research program will be executed. Photo by Natuurmonumenten.

After the construction of a ten-hectare trial island in 2014, the construction of a 600-hectare island began in 2016. Part of the island is opened for the public in 2018. The development of the Marker Wadden is monitored closely to improve understanding of how to build with mud (in oil sands terms, how to dewater and achieve strength and bearing capacity in fine deposits) as a form of BwN. Enclosed by sandy ridges, fines (clay and silt) sediments are deposited in the Marker Wadden to establish a productive marsh landscape.

The Marker Wadden project includes a construction project and a pilot knowledge development project associated to it. The knowledge development project (Kennis Innovatie programma Marker Wadden, KIMA) is designed to deliver generic as well as directly applicable knowledge to the construction project present and future phases, but without interfering directly with it. Questions are brought from the operational project to the research program and vice-versa knowledge and innovative products are delivered to the project (and to the community), without having the research program to interfere with operational logistics and schedule of construction. KIMA is carried out in collaboration between the operational department of Dutch Ministry for Infrustructure and Water (Rijkswaterstaat), Natuurmonumenten, Deltares and EcoShape, therefore in collaboration between Government, NGO, academia and research, and private partners.

KIMA specifically focus on:

[11] https://www.eemsdollard2050.nl/

1. Fundamental and applied research, and scaling-up to engineering solutions regarding:

- Building with mud and sand (physics)
- Development of ecological systems (ecology)
- Adaptive Governance (socio-economics)

2. Field monitoring of the Marker Wadden;
3. Knowledge and data management, and dissemination.

Challenges, knowledge and tools developed in the Marker Wadden are potentially similar to those developed in various oil sands applications, especially related to tailings basin closure and reclamation, or in-pit lake management. The same numerical consolidation tool developed and utilized in oil sands tailings consolidation estimates is utilize to predict final topography of the Marker Wadden islands. Similar concepts of dewatering through vegetation studies in the oil sands are also implemented in the Marker Wadden. The KIMA program will offer the opportunity to study the continuous process of (hindered) settling or sedimentation, consolidation and ripening, and to develop and tests numerical tool and monitoring methods to quantify it. This same tool will allow improvement of performance of oil sands consolidation estimates to closure landscape.

Pilot Marconi

The Marconi pilot is located near the Kleirijperij Pilot, therefore along the Eems-Dollard. The Marconi Pilot is also part of the Eems-Dollard 2050 Program. The larger objective of this pilot is to improve the natural and economical value of the water front of the town of Delfzijl. This pilot includes the modification of the waterfront with improving its safety against climate change and sea level rise and at the same time providing areas for recreation and nature development.

EcoShape is responsible for a smaller portion of this project, which focuses on understanding and monitoring optimal conditions for salt marsh development. Different percentage of fine sediment is mixed with sand to provide the substrate for vegetation development. The initially sandy substrate is subdivided in ten different sections (Figure 5). In each section different percentage of fines and sand are mixed (5% - 20% and 50%). In some sections vegetation is planted. For about three years these sections will be monitored to track vegetation development as well as morphological changes. The overall idea of this pilot is to learn how to effectively establish a salt marsh, how vegetation develops in time and the effectiveness of the vegetation to trap sediment and self-sustain itself. The EcoShape part of the project will begin on November 1st, 2018. Therefore there are no data currently available.

This project may connect with oil sands application as far as opportunity for vegetation establishment in sand / fines substrates, which are typical of sand beaches or sand rich deposits. Vegetation may potentially be implemented also in combination with thin lift, so enhance fines capture and speed up dewatering. Similar concepts are currently under development in The Netherlands to utilize thin lifts to slowly raise dikes, or in USA by the Corps of Engineers to restore wetlands.

Figure 5: Infographic representing the development of salt marshes in front of the Delzijl harbor entrance channel (top), and the design of the Marconi salt marsh with the specific subdivision in different compartments with different fines content to be mixed in sand (5 – 20 – 50%), green represents sections where vegetation will be planted (bottom).

CONCLUSIONS

This paper shows that the fundamental underlying physical processes, predicting and monitoring methods behind atmospheric fines drying and making clay soil for dikes from dredge material, predicting and monitoring consolidation in of FT in deep deposits and final settlement of natural sediments in natural islands, or understanding the optimal condition for vegetation growth in tailings and in sand-mud soil are generally similar.

It is unneglectable that oil sand tailings present specific peculiarities especially related to the very poor dewatering likely caused by the clay treated with dispersant additives to facilitate the bitumen extraction process, and to the presence of residual bitumen in the tailings. These are important peculiarities that need to be considered when working in the oil sands and applying methods imported from different regions and environments.

When these peculiarities are considered, the world outside the oil sands offers a vast experience of knowledge and engineering solutions, and opportunities to co-development and co-funding that should be exploited for continuing improving the sustainable management of oil sands tailings and the mining industry in general.

The international experience in dealing with sediment (read also tailings) management is directing further and further toward a nature-based (e.g. BwN), beneficial reuse and circular economy approaches, centered on sustainable development. International collaboration and exchange of knowledge is central to these developments.

The LLM we presented in this paper is developed in this direction. The LLM currently includes five pilots, located in the Netherlands and Indonesia, and it is connected to the most important international programs and initiatives related to sustainable and beneficial sediment management.
Some of the experience, tools and monitoring methods acquired in oil sands research and engineering projects was instrumental in the design and success of these pilots. Therefore numerous pilots carried out by the oil sands industry, mostly under the COSIA umbrella, that connect the four COSIA EPAs (tailings, land, GHG and water), and that are directed in improving the sustainable development of the industry, offer a great opportunity for international collaboration.

Thus, we must close this paper with the ambition and the invitation to add at least a Canadian (oil sands) pilot to our LLM.

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