

Policy- and technical advice on the beneficial uses of marine dredged sediments in Colombia, including nature-based solutions

Assessment of the quality of dredged marine sediments in the port area of Barranquilla

January 30th, 2026

Contact

PARTNERS FOR WATER

info@partnersforwater.nl

www.partnersforwater.nl

Netherlands Enterprise
Agency (RVO).
PO Box 93144, 2509 AC
The Hague

The project "Policy and technical advice on beneficial uses of dredged marine sediments in Colombia, including nature-based solutions" is part of the collaboration between the Government of the Netherlands, through the Partners for Water program, and the Colombian Ministry of Environment, the National Planning Department (DNP) and the Ministry of Transport. The project was executed by a consortium formed by Arcadis, Fundación Herencia Ambiental Caribe, JESyCA and Netics, together with governmental entities from both Colombia and the Netherlands.

Content

1	Introduction	6
1.1	Background	6
1.2	Project objectives and results	6
1.3	Structure of this deliverable	7
2	General context on sediments and substances in the access channel to the Barranquilla port area.	8
2.1	Characteristics of the access channel	9
2.2	Entities involved and the governance framework for maintenance dredging activities.	10
2.3	Maintenance dredging depths and volumes of dredged material.	11
2.4	Substances in sediments	14
3	Physical and chemical quality of sediments in the access channel to the port area of Barranquilla.	17
3.1	Physical quality	20
3.1.1	Granulometry	20
3.1.2	Organic carbon content	21
3.2	Chemical quality in relation to the thresholds of Florida, Brazil and the Netherlands	22
3.2.1	Mineral substances	22
3.2.2	Organic substances	32
4	Chemical quality of sediments in the depositional zone near the access channel to the port area of Barranquilla.	38
5	Discussion of the substances of greatest concern	40
5.1	Mineral substances	41
5.1.1	Heavy metals and arsenic	41
5.1.2	Other mineral substances	41
5.2	Organic substances	41
5.2.1	Polycyclic aromatic hydrocarbons (PAHs)	41
5.2.2	Pesticides	42
5.3	Reliability of data	42

6	Information gaps to assess the chemical quality of sediments in the access channel to the port of Barranquilla.	43
6.1	Mineral substances	44
6.1.1	Heavy metals and metalloids	44
6.1.2	Other mineral substances	44
6.2	Organic substances	45
6.2.1	Polycyclic aromatic hydrocarbons (PAHs)	45
6.2.2	Pesticides	45
	Other Organics and Tributyltin	45
6.3	Additional information needed to assess sediment quality	45
6.3.1	Granulometry, organic matter content, pH and cation exchange capacity.	45
6.3.2	Mineralogy of clays	46
6.3.3	Other information to consider	46
7	Recommendations for evaluating the chemical quality of sediments in dredged areas of Colombian seaports and establishing sediment quality guidelines.	48
7.1	Comprehensive sediment chemical quality assessments to verify which substances are of concern in the sediments of maritime port areas.	49
7.1.1	Recommendations for sediment sampling	49
7.1.2	Recommendations on laboratory analytical techniques	50
7.2	Recommendations for establishing sediment quality guidelines for each maritime port zone in Colombia.	53
7.3	Recommendation for monitoring sediment chemical quality, aimed at determining what beneficial uses dredged materials are valid for .	53
8	References	55
	Appendices	58
	Appendix A – Contents of gravel, sand and silt + clay	58
	Appendix B – Thresholds for freshwater ecosystems from SQGs of Florida, Brazil and the Netherlands	60
	Appendix C – Substance contents by Cormagdalena	65
	Appendix D – Substance contents measured by INVEMAR	66
	Appendix E – Substance contents measured by UniCartagena	68
	Appendix F - Priority Substances for Sediment Quality Monitoring and for the Determination of Colombia's Own Thresholds	71
	Appendix G – Abbreviations and acronyms	74

1 Introduction

1.1 Background

Within the partnership between the Government of Colombia and the Government of the Netherlands in the field of water and climate change adaptation, the beneficial use of dredged (marine) materials is one of the priorities, at the specific request of the Colombian Ministries of Transport (MinTransport), Environment (MinEnvironment) and the National Planning Department (DNP). Beneficial uses of dredged marine sediments are not yet realized in Colombia, and dredged materials have been dumped in offshore deposition areas previously approved by the environmental authority. Taking advantage of the increased focus on beneficial uses and to further improve the regulatory guidelines on dredged materials in Colombia, this consultancy focuses on policy and technical advice for beneficial uses of dredged marine sediments, including nature-based solutions (SbN).

The policy partnership with the Government of Colombia on the issue of dredging and beneficial use of dredged materials has a long history, supported through several projects over the last decade:

- 1 The National Maritime Dredging Plan (PNDM, 2017) consisted of a conceptual analysis and main recommendations to achieve, in the short, medium and long term, improvements in: (i) institutional order, (ii) technical and environmental regulations, (iii) financing, (iv) dredging contracting methodologies in maritime access channels to ports and (v) maintenance dredging strategy by port area and capital dredging strategy for the two coasts, Atlantic and Pacific, including the beneficial use of dredged material. The PNDM also included an international comparison on the above aspects, in order to have a reference that would allow the Colombian Government entities to make qualified decisions, among which the use of dredged materials occupies a prominent place. Specifically mentioned were the lack of uniformity in the basic criteria for the formulation of designs and works, the lack of clarity on the final disposal or beneficial use of dredged material, the additional costs for unnecessary transportation to dispose offshore of materials that could be reused, and the imprecision on the final values of the projects.
- 2 A series of webinars on dredging and the use of dredged materials in Colombia to support stakeholders on dredging, including key principles such as Building with Nature and the use of dredged materials for other purposes (2020/2021).
- 3 In the project "Beneficial use of dredged materials in the Colombian context", opportunities to expand the range of beneficial uses of dredged materials were analyzed, including examples of legal frameworks and regulatory requirements in other countries. Additionally, a case study was included for opportunities for beneficial uses of dredged materials resulting from capital and maintenance dredging activities in the Buenaventura port area, as well as an analysis of barriers and facilitators for the use of dredged materials in Colombia (2022).

As a result of these projects, the National Development Plan 2022-26 indicated in Article 240 the need to use dredged material, complying with the environmental regulations issued for this purpose, prioritizing uses in the recovery of areas affected by coastal erosion, and in the recovery of mangrove areas or areas affected by flooding. In addition, in July 2023 the Colombian government issued CONPES 4118 (National Port Policy), which states that the disposal of dredged materials offshore or onshore may have a negative impact on marine and coastal ecosystems. Given these statements in these normative instruments, it is the responsibility of MinAmbiente to establish a regulatory framework of environmental and technical guidelines for the use of dredged marine sediments in Colombia.

Given this need, the governments of the Netherlands and Colombia agreed to launch the current project "Policy and technical advice on beneficial uses of dredged marine sediments in Colombia, including nature-based solutions".

1.2 Project objectives and results

The project focuses on further improving the regulatory guidelines for dredged marine materials in Colombia, providing advice for regulations to be established by MinAmbiente, and for updating the Guide to environmental management of infrastructure projects, maritime and fluvial modes (INVIAS, 2022). In addition, the project includes a case study for the port area of Barranquilla, showing what can be done with the dredged material.

The basis for improving the Colombian guidelines lies in providing technical advice in the form of standards and practical parameters for the beneficial use of dredged material, drawn from the experience of the Netherlands and

other countries. Accompanying this technical advice is capacity building of key stakeholders in Colombia in relation to the main technical components of the study.

The project consists of 5 main deliverables:

1. Standards and parameters applied in the Netherlands for dredging and use of dredged materials.
2. Standards and parameters applied in other countries: Australia/New Zealand, Japan, Brazil, Peru, Mexico, USA (Florida), Canada, Spain, Costa Rica and Panama.
3. Assessment of sediment chemical quality in the Barranquilla port area, and recommendations for establishing sediment quality guidelines for Colombia.
4. Additions to the INVIAS guidelines.
5. Case study of the Barranquilla port area.

1.3 Structure of this deliverable

This report presents an assessment of the chemical quality of sediments in the access channel to the port of Barranquilla, where dredging is necessary to ensure navigability. This evaluation is based on comparing the information reported at sites in the access channel to the Port of Barranquilla, with information from some Sediment Quality Guidelines (SCD) from other countries or regions, among those explained in deliverables 1 and 2. Based on this evaluation, this report also presents recommendations for the evaluation of the chemical quality of sediments in Colombian seaports, as well as recommendations for the establishment of the country's own SCD.

The structure of this report is as follows:

- Chapter2 : Contextual information to improve the understanding of the following chapters.
- Chapter3 : The evaluation of the chemical quality of sediments in the access channel to the port of Barranquilla, based on the description of the substances reported by the Colombian entities, in comparison with the respective thresholds included in the SCD of Florida, Brazil and the Netherlands.
- Chapter4 : Information on the chemical quality of the sediments in the marine deposit zone, where the dredged materials are dumped in the access channel.
- Chapter5 : A discussion of which of the reported substances are of concern in the sediments of the access channel and the marine deposition zone.
- Chapter6 : An analysis of the information gaps for assessing the physical and chemical quality of sediments in the access channel to the port of Barranquilla.
- Chapter7 : Recommendations for future sediment chemical quality assessments.

Appendices:

- Appendix A - Gravel, sand and silt and clay contents (Granulometry).
- Appendix B - Thresholds for freshwater ecosystems of the Florida, Brazil and the Netherlands SCD.
- Appendix C - Concentrations of substances reported by Cormagdalena
- Appendix D - Substance concentrations reported by INVEMAR
- Appendix E - Concentrations of substances reported by UniCartagena
- Appendix F - Priority substances for sediment quality monitoring and for the determination of thresholds specific to Colombia.
- Appendix G - Abbreviations and Acronyms

2 General context on sediments and substances in the access channel to the Barranquilla port area.



Chapter 2 - Executive Summary

The key points of this chapter are:

- [D 1] Presents the importance of assessing the chemical quality of sediments in dredged areas and the relevance of sediment quality guidelines (SCD) for assessing risks from contamination in the port of Barranquilla, Colombia.
 - [D 1] The entities involved in the maintenance of the access channel are: Cormagdalena, control entities, contractor, Corporación Autónoma Regional del Atlántico (CRA), Dirección General Marítima (DIMAR), and Asociación de Sociedades Portuarias (Asoportuaria).
 - [R 1] The access channel of the port of Barranquilla is subdivided into 4 intervention sectors; the volume of material dredged per year varies by sector.
 - The Magdalena River has one of the highest sediment transport rates in the world. These sediments can transport substances of concern both to the access channel and to the sea, which are both organic and mineral.
-

2.1 Characteristics of the access channel

To access the Barranquilla port area, vessels must cross two sectors with different navigational characteristics. The first sector corresponds to a maritime channel (see green line in Figure -21), which is indicated by the existing maritime guides/ buoys starting from the northern end of the western Tamar of the Magdalena River. The second sector corresponds to a 22 km fluvial access channel, which starts to the north with the western Tamar, and connects directly to the port area. In addition, to the west of the maritime channel is located the deposit area authorized by the national maritime authority (DIMAR), for the dumping of dredged materials (Figure -21 and Figure -22).



Figure -21 : Location of the maritime channel and the fluvial channel of access to the port area of Barranquilla (Own elaboration).

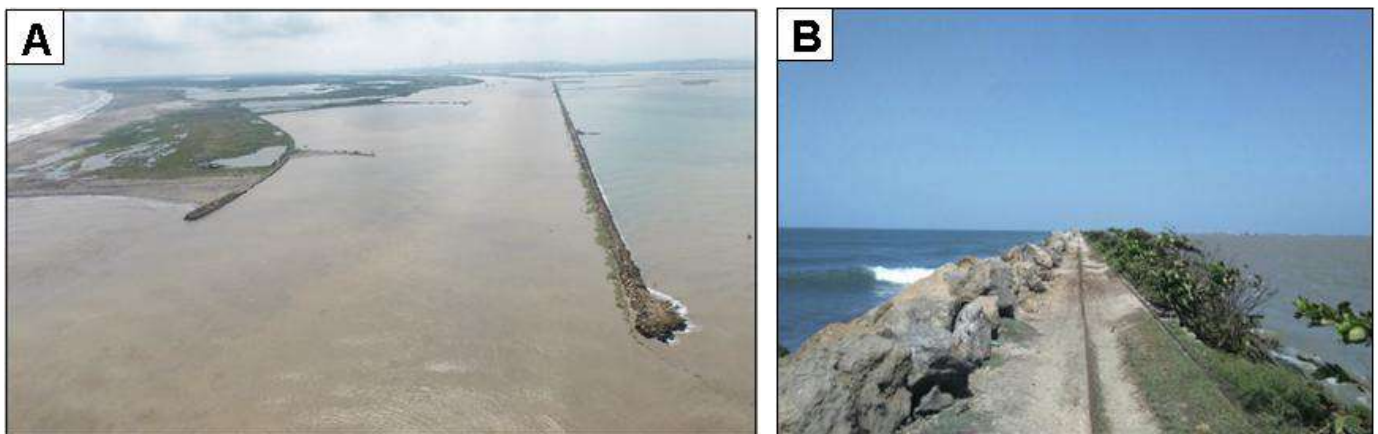


Figure -22 : A. Aerial view of the entrance to the fluvial access channel, delimited on the right of the image by the western cutwater where the access channel begins (Source: Consorcio Estudio Canal de Barranquilla, 2020). B. View to the north from the western cutwater (sea to the left and Magdalena River to the right (Source: Google Maps)).

The development of both access channels has been consolidated through 22 port concessions on the western bank of the Magdalena River, which offer various options for the mobilization of specialized and multimodal cargo. Additionally, the metropolitan area of the city of Barranquilla has a series of industrial sites and six (6) free trade zones that stimulate regional development.

The report on estimation of dredging volumes in the Magdalena River with quantity forecasts between 2024 and 2026, carried out by Cormagdalena's research and engineering center, analyzes the hydrological, geomorphological and sedimentological characteristics of the river, as well as climate variability and its impact on sediment accumulation. This document describes from a hydrosedimentological perspective, that the Magdalena River presents exceptional transport dynamics at a global level, with a specific sediment production of 661.5 Ton/year/km², a figure substantially higher than that of other major river systems such as the Yangtze (105.8), the Danube (82.7), the Mississippi (68.45) and the Rhine (27.0).¹ Entities involved and governance framework in the activities of maintenance dredging

2.2 Entities involved and the governance framework for maintenance dredging activities.

In accordance with Article 12 of Law 105 of 1993, the Port of Barranquilla is a transportation infrastructure, owned by the State and under the responsibility of the Ministry of Transportation, which in accordance with the rights granted by the paragraph of Article 34 of Law 1 of 1991, must be built, conserved and maintained with resources from the National Government. In view of the growing national interest in consolidating the Magdalena River Navigability Recovery Project, the National Government, through the Ministry of Transportation and Cormagdalena, has identified the need to carry out interventions on the Magdalena River and its navigable channel, in order to guarantee adequate and sustainable navigation conditions, and to optimize costs.

In order to guarantee the navigability of the access channel to the Port of Barranquilla, ensuring safe navigability and port operation conditions, it is necessary to implement maintenance dredging in this channel. These dredging operations have been carried out between kilometer K2-800 (hypothetical sea buoy) and K21+750 (Pumarejo Bridge), by means of hydraulic dredging with a suction hopper dredge in operation.

The following is a list of the entities involved in the maintenance dredging activities of the access channel:

- **Cormagdalena:** Institution in charge of public works bidding processes (including dredging), and of managing the maintenance project of the navigable section of the access channel.
- **Interventoría:** Responsible for the integral supervision of compliance with the dredging contract (technical, administrative, financial, and environmental aspects, among others).
- **Contractor:** Responsible for the execution of the maintenance dredging in the access channel, in accordance with the conditions and specifications established in the contract.
- **Corporación Autónoma Regional del Atlántico (CRA):** Regional institution in charge of deciding when the environmental management plan (PAGA)² is viable, as well as deciding when the environmental license is granted for the execution of public works, including dredging. Once the environmental license is approved by the CRA, it is communicated to the DIMAR.
- **Dirección General Marítima (DIMAR):** National maritime authority responsible for granting permits for the transit and stay of vessels and equipment for dredging and re-cleaning activities in the access channel.
- **Association of Port Companies (Asoportuaria):** Association of port companies and users of the navigable waterway, which represents their interests related to the transportation of cargo for exports and imports.

In accordance with the functions of each entity, Figure -23 represents the procedure required to authorize the initiation of a maintenance dredging contract in the access channel, by means of hydraulic dredging.

¹ Sources: The variability of large alluvial rivers (Schumm & Winkley, 1994); River Discharge to the Coastal Ocean (Milliman & Arnsworth, 2011).

² Environmental management plan for projects that do not require an environmental license, which applies to maintenance dredging contracts. This type of plan is known as Plan de Adecuación a la Guía Ambiental (PAGA), and its name comes from the fact that the plan is based on the Environmental Management Guide for infrastructure projects in maritime and fluvial areas (INVIAS, 2022).

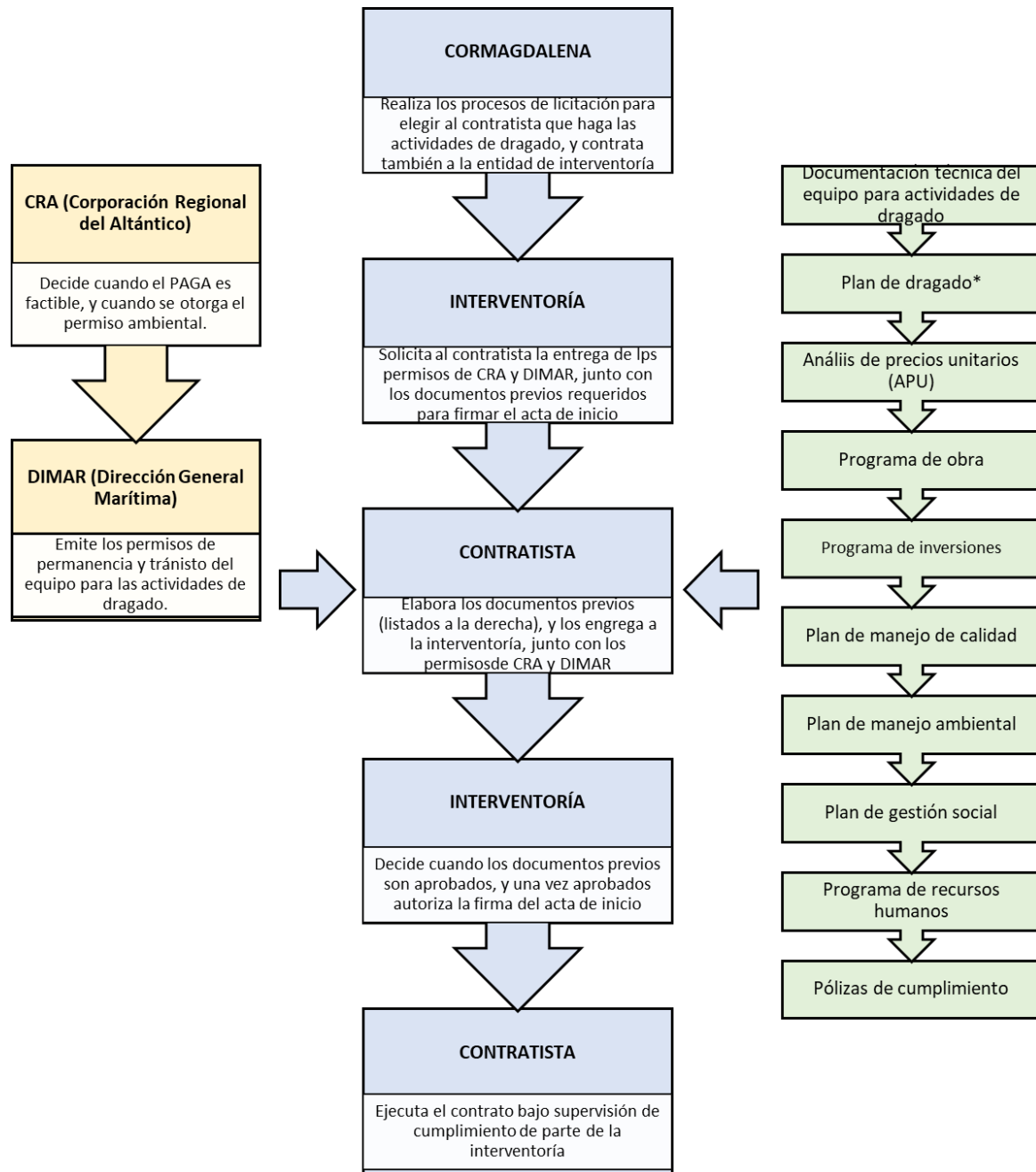


Figure -23 : Procedure to authorize the initiation of a maintenance dredging contract in the fluvial access channel (Own elaboration).

* The dredging plan is a technical document that presents a summary of the contract and explains the methodological and operational aspects. It includes a description of the bathymetric survey methodology, the dredging methodology and execution processes, the characteristics of the type of dredge to be used, the communications plan, the traffic plan, the signaling plan and the dredging schedule. The latter is subject to frequent changes depending on hydraulic and hydrological conditions and the results of monitoring/control bathymetries.

2.3 Maintenance dredging depths and volumes of dredged material.

Cormagdalena considers a subdivision of the access channel into four intervention sectors. Each sector has particular navigability conditions, including a maximum depth of the channel that can be reached in dredging activities, from the

water surface to the bed. According to the 2025 maintenance dredging contract, the navigability characteristics of each sector are as mentioned in the Table -21 (see also Figure -24

Table -21 : Navigability conditions by sector (Source: Cormagdalena).

Sector	Km Interval	Maximum channel depth (m)	Channel width (m)	Description
I	-K2-800 to K02+000	13.7	Begins with 315 m at -K2-800 and ends with 200 m at K0+000.	Sector with strong winds and waves that influence hydrodynamics. Some bars are located as a result of subtidal low growth in the east.
II	K02+000 to K8+000		200	Sector with hydrodynamics determined by the interaction between the Caribbean Sea and the Magdalena River. Normally in the area there are some bars that reduce the depth of the access channel. These bars are recurrent and require immediate intervention as soon as they occur.
III	K08+000 to K16+000		150	Imminently fluvial zone with incidence of some affections generated by waves. Due to the salt wedge that enters during low flows and other special conditions, there is a dynamic that requires dredging.
IV	K16+000 to K21+750	12.0		Fluvial zone requiring constant surveillance.

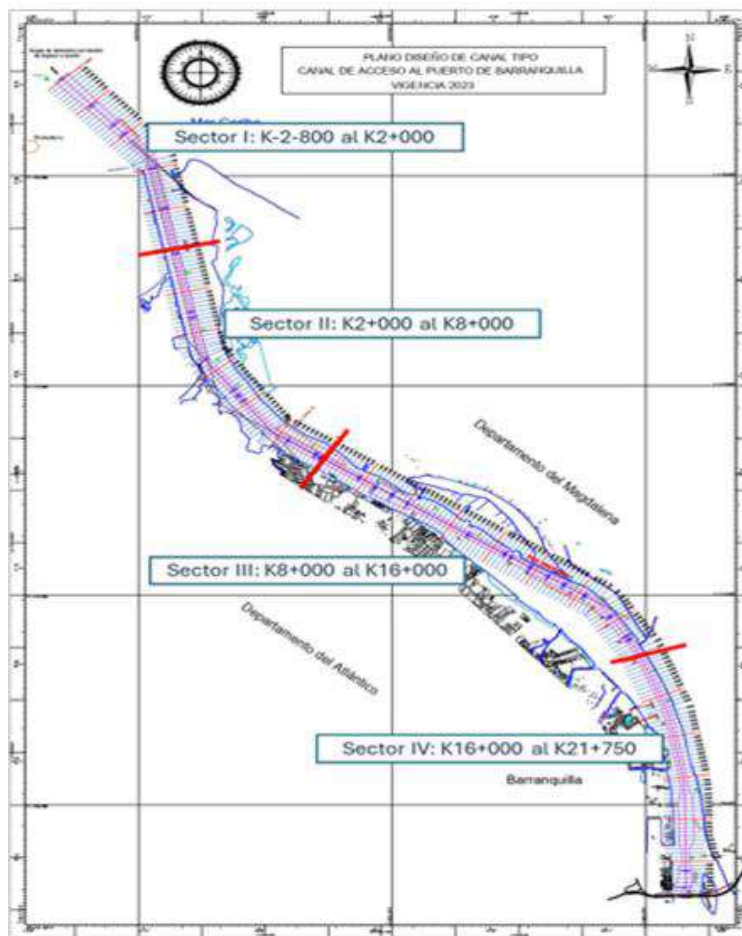


Figure -24 : Access channel intervention sectors (Source: Cormagdalena).

Volume information has been reported by Cormagdalena contractors in charge of maintenance dredging. Between 2022-24, the information reported by year shows that the total dredged volumes decreased from one year to another, and as for the distribution by sectors, more dredging has been done in sector I (66.8% in 2022, 45.8% in 2023 and 61.6% in 2024) (Figure -25). The differences in total dredged volumes and distribution by sector depend on operational decisions and changes in sediment dynamics; more dredging has been required in sector I due to the influence of coastal drift and the salt wedge at the mouth.

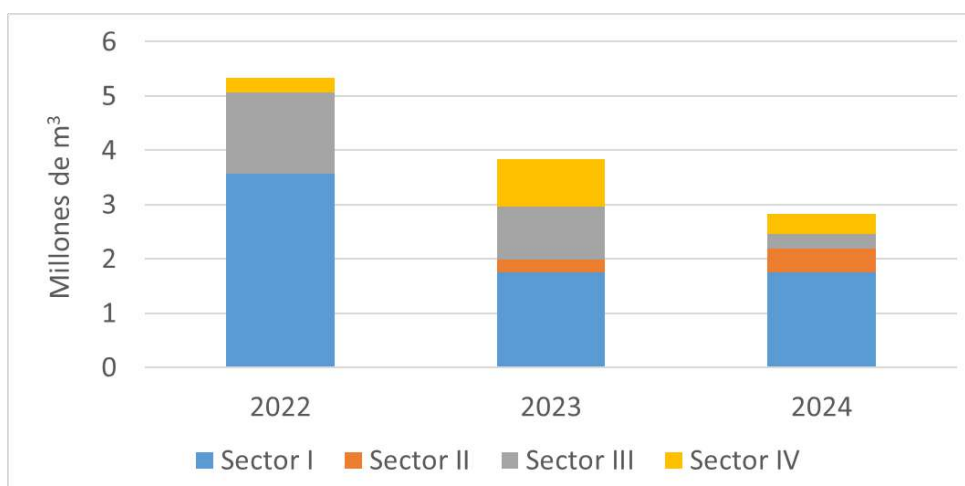


Figure -25 : Volume of material dredged in each sector of the access channel, between 2022-24 (Based on Cormagdalena data).

The most recent contract, between November/2024 and March/2025 showed that most of the dredging was done in sector I, and the volume of dredged material pending dredging corresponds to 64.3% of the total volume agreed in the contract (Table -22 and Figure -25)

Table -22 : Total volume of material dredged in each sector of the access channel, between Nov/2024-Mar/2025, and volume pending dredging during the remainder of the 2024-25 contract (Source: Based on Cormagdalena data).

Sector	Km interval	Volume (m ³)	Fraction of total
I	K-2-800 to K2+000	914.337,97	19.4%
II	K2+000 to K8+000	323.494,00	6.9%
III	K8+000 to K16+000	150.377,00	3.2%
IV	K16+000 to K21+750	294.566,00	6.2%
Total dredging between Nov/2024 and Mar/2025		1'682.774,97	35.7%
Volume to be dredged during the remainder of the contract		3'031.176,00	64.3%

Cost information for volumes dredged in the contracts that have been performed between 2022-25, will be analyzed in the report of element 5 of this consulting contract.

2.4 Substances in sediments

To understand the origin of the substances in the sediments of the access channel to the port of Barranquilla, it is necessary to consider not only the nearby sources, but also the substances transported through the upstream hydrographic network. This network corresponds to the Magdalena river basin, which has an area of 271054 km²(24% of Colombia's land area)³. This basin includes the basins of the San Jorge, Cauca and Cesar rivers, which flow into the Magdalena River in the internal delta of the Momposina Depression (swamp complex). Downstream of this depression, part of the water flows into the Dique channel that flows near of the city of Cartagena de Indias, while most of the water continues as the Magdalena River until it flows into "Bocas de Ceniza", near the city of Barranquilla (Figure -26).

³ [Hydrographic Zones of Colombia - Overview](#)

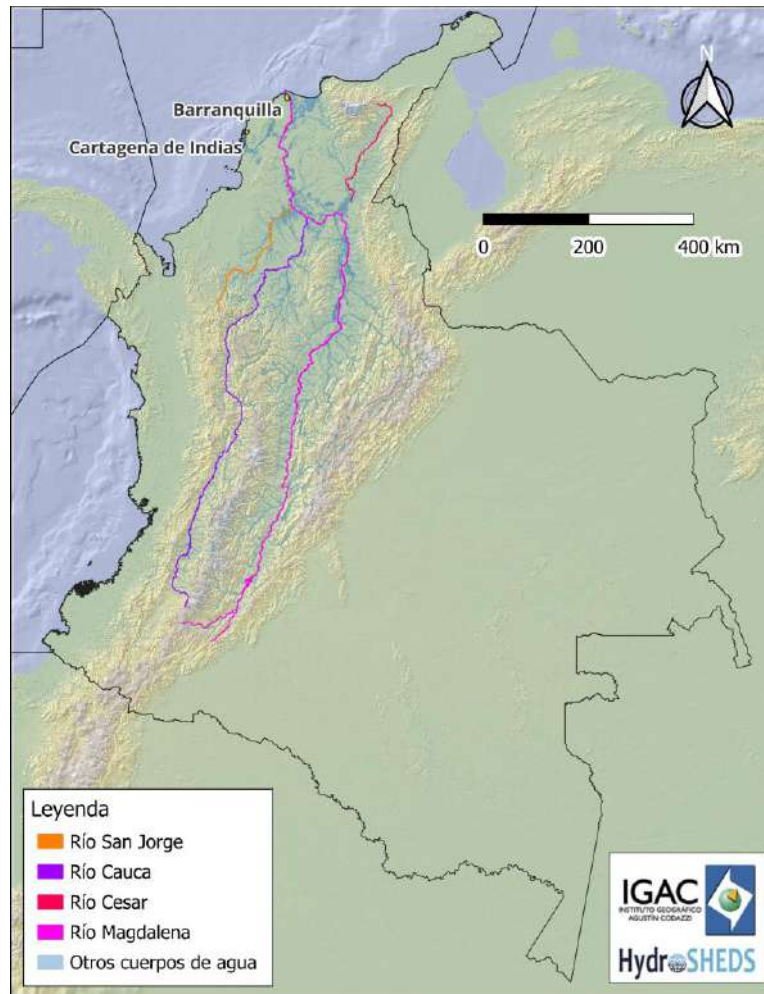


Figure -26 : Hydrographic network in the watersheds of the San Jorge, Cauca, Cesar and Magdalena rivers (Map prepared with QGIS, using IGAC cartography of main rivers and HydroSHEDS cartography of other flows).

About 80% of the settled population in Colombia is located in the area formed by the watersheds of the San Jorge, Cauca, Cesar and Magdalena rivers, where different human activities are developed (domestic water use, agriculture, mining, oil refining, industry and construction) (Cormagdalena, 2007; IDEAM, 2023). Due to the levels of water erosion in these watersheds, soil particles are transported through water flows and subsequently deposited as sediment at the bottom of downstream water bodies (IDEAM, 2023). The Magdalena River represents the largest source of sediment input to the Caribbean Sea; it discharges 560 t/km² of sediment each year, one of the highest sediment transport rates in the world, and the highest in South America (Restrepo et al., 2006).

Substances derived from inputs used in human activities reach aquatic ecosystems downstream, due to runoff from agricultural fields, waste flows from mining and hydrocarbon extraction activities, and direct discharge of municipal and industrial wastewater (some regions lack wastewater treatment) (Tejeda-Benitez et al., 2018; IDEAM, 2023). Considering that the aforementioned substances in aquatic ecosystems are retained by suspended particulate matter, which is then deposited as sediment, the impact of these substances transported through the Magdalena River is of concern. On the one hand, the substances enter the trophic chain through the feeding of benthic and benthopelagic fauna, or by absorption from pore water or sediment, and subsequently these residues are accumulated in fish and other organisms (Tejeda-Benitez et al., 2016; 2018); on the other hand, the disappearance of coral reefs in the Caribbean Sea has been attributed to sediment input from the Magdalena River (Restrepo and Syvitski, 2006; Moreno-Madriñán et al., 2015).

Substances of concern are some organic compounds and minerals. In Colombia, minerals of concern include some heavy metals and metalloids, while organic compounds of concern include petroleum hydrocarbons, pesticides,

polychlorinated biphenyls (PCBs) and asbestos⁴. Some sites contaminated in Colombia with these substances have been identified by the Toxic Sites Identification Program (TSIP), among others (IDEAM, 2023). Additionally, microplastics and fecal microorganisms have also been of concern in Colombian coastal ecosystems (INVEMAR, 2024), however the abundance of these components has not been reported in the sediments of the access channel to the port of Barranquilla.

Minerals that have been reported in sediments of the access channel include the heavy metals zinc (Zn), copper (Cu), chromium (Cr), lead (Pb), cadmium (Cd), nickel (Ni) and mercury (Hg), as well as arsenic (metalloid) (Tejeda-Benítez et al., 2016 and 2018; INVEMAR and CRA, 2024; Cormagdalena); toxicity risks from these minerals are described in Section 4.3 of Report 2 of this consultancy. Although these metals usually occur in very low amounts in natural environments, there have been reports of worrisome concentrations of these elements in sediments from regions within the Cauca and Magdalena river basins (Servicio Geológico Colombiano, 2020). There has been particular concern for Cd in a region located to the west of the eastern mountain range, in the jurisdiction of the departments of Cundinamarca, Boyacá and Santander, where high concentrations of this metal were reported in cocoa crop soils (Bravo et al., 2021).

In addition to the natural sources of the above-mentioned metals, their presence in sediments has also been attributed to residues derived from anthropogenic activities. Globally, gold mining and coal combustion are the main anthropogenic sources of Hg reaching aquatic ecosystems, and Cr is used in metallurgical and leather tanning industries (Rahman & Singh, 2019). Additionally, in general, heavy metals are part of the composition of paints, solder, light bulbs, batteries, and electronic devices⁵. In Colombia, some paint wastes end up in wastewater, and some of the other products end up degraded in landfills, from where the wastes are transported through water flows to rivers.

The organic compounds that have been recorded in the sediments of the access channel are polycyclic aromatic hydrocarbons (PAHs) and pesticides. According to Tejeda-Benítez et al. (2018), the main anthropogenic sources of PAHs are crude and refined petroleum, and incomplete combustion of fossil fuels and biomass; some PAHs discharged in untreated wastewater are adsorbed by suspended particles and deposited in downstream sediments. PAHs are considered carcinogens, mutagens and endocrine disruptors, and have been of concern in the Magdalena River following oil spills from some oil extraction activities, and other spills following pipeline ruptures by illegal traders and criminal gangs.

Regarding pesticides, globally Colombia was in 2022 the 9th country with the highest use of pesticides, and the largest user by crop area (FAO, 2024). Between 2017-21, the most used pesticides in the country were organophosphates (30.8%), phosphonic acid (18.2%), chlorinated compounds (13.1%) and pyrethroids (10.7%), among others, including organochlorines (after their national ban in 2001, between 2013-16 their use decreased from 3.8% to 1.6%). According to the classification of pesticides by hazard, made by the World Health Organization (WHO), in 2020 most of the pesticides used (57.1%) were moderately hazardous, and 5.9% were high to extremely hazardous. The most commonly used active ingredients in Colombia are mancozeb, 2,4-D, glyphosate, paraquat, imidacloprid and chlorpyrifos; the first three are considered to be probably carcinogenic to humans, paraquat is associated with Parkinson's disease, imidacloprid and glyphosate affect bees, and chlorpyrifos induces neurological damage (IDEAM, 2023).

To evaluate the level of contamination of each substance in sediments in coastal areas of Colombia, entities such as INVEMAR and Cormagdalena have taken reference from the sediment quality thresholds indicated in Buchmann (2008), which are thresholds from the USA, Canada and the Netherlands. Additionally, researchers from Colombia and South Korea compared thresholds from South Korea, Hong Kong, Belgium, United Kingdom and Florida (USA), with concentrations of heavy metals, PAHs and PCBs, reported in coastal sites in the Caribbean region of Colombia (González-Cano & Kyoungrean, 2022). The authors did this work with the objective of evaluating the possibility of making use of marine sediments, which is similar to the objective of this deliverable, which is more specific since it consists of making the same type of evaluation, but for the sediments of the access channel to the Port of Barranquilla. This evaluation is based on comparisons with thresholds in Brazil and Florida (USA), as they are regions with environmental conditions similar to those of Colombia, for which sediment quality thresholds have been determined.

⁴ [Chemical Substances Management - Ministry of Environment and Sustainable Development](#)

⁵ [Chemical Substances Management - Ministry of Environment and Sustainable Development](#)

3 Physical and chemical quality of sediments in the access channel to the port area of Barranquilla.



Chapter 3 - Executive Summary

This chapter describes physical sediment quality characteristics, and in terms of chemical quality, the concentrations of substances reported by Colombian entities are compared with the respective thresholds included in the Sediment Quality Guidelines (SCD) of Florida, Brazil, and the Netherlands.

The key points are:

- Different entities (INVEMAR, Cormagdalena and Cartagena University) have reported sediment physical and chemical quality information.
 - Mineral substances (heavy metals and arsenic): the reported concentrations were below the respective Dutch threshold levels 1, both for freshwater and coastal ecosystems. In relation to thresholds in Florida and Brazil, for some substances it is not yet possible to determine whether their concentrations are above or below these thresholds, since these concentrations are below the quantification levels of the laboratory equipment, and the thresholds for these substances are below these thresholds.
 - Organic substances: Of this type of substances, only the concentrations of some pesticides and some polycyclic aromatic hydrocarbons (PAHs) have been determined.
-

This section is based on physical and chemical sediment quality information generated by contractors of Cormagdalena, INVEMAR, and UniCartagena. While INVEMAR's objective is to support the CRA in monitoring the state of health of coastal ecosystems, Cormagdalena's contractors have generated two types of information: 1) Sediment granulometry reports, prior to maintenance dredging activities; 2) Environmental quality monitoring, required as part of the environmental management plan of each maintenance dredging activity contract⁶. The type of information reported by the above mentioned entities is shown in the Table -31

Table -31 : Type of information on physical and chemical quality of sediments in access channel sites, from monitoring activities of Cormagdalena and INVEMAR, and research by UniCartagena.

				Cormagdalena	INVEMAR	UniCartagena	
CALIDAD FÍSICA				Granulometría	●	●	
				Contenido de materia orgánica (%)	●	●	
CALIDAD QUÍMICA	Concentraciones de sustancias	Minerales	Metales traza	●	●	●	
			Arsénico			●	
			Otras sustancias minerales	●			
		Orgánicas	Tributilestaño (como estaño)				
			Hidrocarburos aromáticos policíclicos (PAHs)		●	●	
			Plaguicidas			●	
Otras características químicas			pH	●		●	

INVEMAR's monitoring has been carried out at the "Aguas Abajo Base Naval (CRA - 17)" site, where the last sampling was done after 13 months without dredging. For its part, Cormagdalena's environmental quality monitoring has been done at four sites, where dredging has been performed Table -31 at 3.1.1 [66] and UniCartagena's information was obtained from sampling at a location close to the port area. Since the UniCartagena information corresponds to surveys of the Magdalena River, the reported location is not seen with sufficient precision at the map scale in Figure - 31, so it was discarded to show such location in this figure.

Regarding sampling methods, while INVEMAR (2024) mentions that INVEMAR (2003) guidelines have been followed, Cormagdalena contractors have followed IDEAM & INVEMAR (2021) guidelines. However, both guideline documents describe various sampling tools, so it is unknown which tools have been used for sampling. In addition, the sampling depth interval and the number of subsamples in the sampling of both institutions is unknown. For its part, UniCartagena has sampled by collecting four (4) subsamples at each sampling site, with a Van Veen grab, and then the subsamples are mixed to obtain approximately 1 kg of composite sample (the depth interval of a sample collected with the Van Veen grab used by UniCartagena is also unknown).

⁶ Plan required for projects that do not require an environmental license. This plan is also known as Plan de Adecuación a la Guía Ambiental (PAGA), which is based on the Guía de manejo ambiental para proyectos de infraestructura en áreas marítimas y fluviales (Environmental Management Guide for Infrastructure Projects in Maritime and Fluvial Areas), prepared by INVIAS (2022).

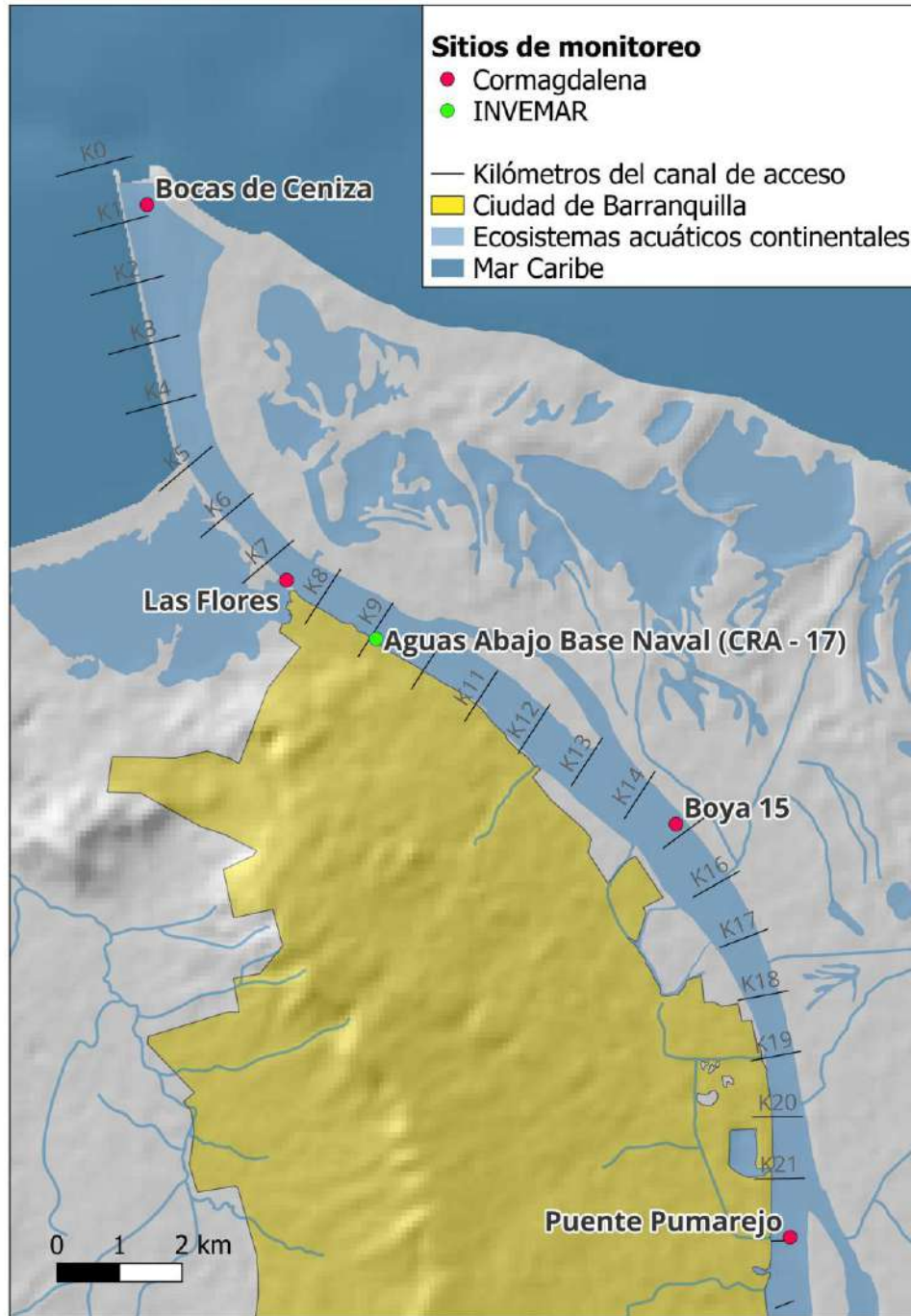


Figure -31 : Sites where INVEMAR and Cormagdalena contractors have done physical and chemical sediment quality monitoring (Map prepared with QGIS, using IGAC cartography and INVEMAR and Cormagdalena geographic coordinate information).

3.1 Physical quality

3.1.1 Granulometry

The granulometry information⁷ described in this section corresponds to reports made by INVEMAR and Comagdalen contractors, between March/2023 and September/2024. While the INVEMAR data was obtained from sampling done at the location of the Figure -31, the locations of the sampling done by Cormagdalen contractors are indicated in Appendix A.

Additionally, the methodology used by each entity to determine sediment granulometry is mentioned below:

- INVEMAR: Applied the gravimetric method with dispersion using sodium hexametaphosphate and sieving in sieves, according to the technical reference Dewis and Freitas (1984).
- Cormagdalen's contractor: Used the sieving technique, following the Colombian Technical Standard NTC 1522 (1979). This procedure was carried out by the subcontractor in coastal areas.

Information from Cormagdalen contractors was reported as the percentages of materials that passed through various sieves of different mesh sizes. From this information, materials below 75- μm , between 75 and 2000 μm , and above 2000 μm were calculated to describe the approximate concentration of "silt and clay", sand and gravel, respectively. INVEMAR reported the percentages of silt ("silt and clay" / <63 μm), and sand, in samples of their monitoring done every September at the site known as "Base Naval Aguas Abajo (CRA - 17)", located in sector III of the access channel.

- Of this information reported by Cormagdalen and INVEMAR between March/2023 and September/2024, most corresponds to sector I of the access channel (15 granulometry reports, out of 26). Of these 15 in sector I, 9 reported concentrations of "silt and clay" higher than 75%, from which it can be assumed that silt or finer materials are more common in this sector.
- Sector II was represented by three reports of sediments with a silt and clay concentration higher than 70%.
- Sector III was represented by five reports. In three of them, the concentration of silt and clay was higher than 74%, and in the other two the concentration was 54.1% and 6.0%.
- Sector IV was represented by three reports with "silt and clay" concentrations of 89.2%, 23.6% and 10.8%.

Given the few reports in sectors II, III and IV, this information does not allow us to identify which granulometry is dominant in each sector; however, it can be assumed that in sector II silt or finer material (<63 μm) could be dominant, as is the condition in sector I. As for gravel contents, these were less than 0.5% in all 26 reports (Figure -32 and Appendix A).

⁷ Distribution of soil and sediment mineral particles, according to their size classification (clay, silt, sand, gravel, and coarser particles).

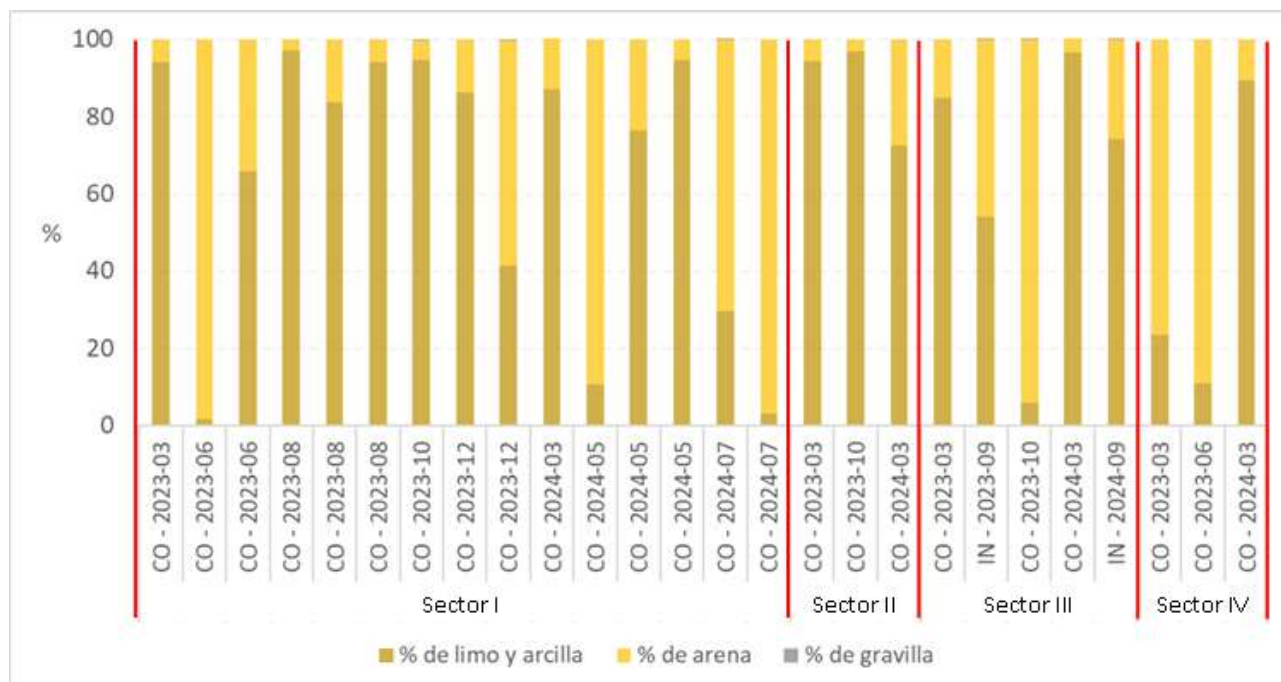


Figure -32 : Sediment granulometry in each sector of the access channel intervention, between Mar/2023-Sep/2024 (Elaborated from INVEMAR (IN) and Cormagdalena (CO) data).

It was expected that the sediments in sector I would be dominated by silts of finer material, taking into account the influence of coastal drift in the reduction of fluvial flow at the mouth of the Magdalena River, therefore allowing finer material to be deposited. On the other hand, compared to the methods applied by Cormagdalena and INVEMAR to determine granulometry, for the analysis of the chemical quality of sediments it is required to distinguish the contents of clay (<2 μm) and silt (2-63 μm), since the clay fraction is related to the bioavailability of substances. Recommendations on how to determine silt and clay contents are presented in section .6.3.1




3.1.2 Organic carbon content

The organic carbon content information (%) corresponds to reports made by INVEMAR in September 2024 and 2023, and to the environmental quality monitoring report made by Comagdalena's contractor in March 2024 (in March 2023 the contractor did not include in this monitoring activity the determination of organic carbon content).

While the Cormagdalena data show an irregular variation of organic carbon content along the channel, the information from the INVEMAR monitoring site shows that from 2023 to 2024 the content had a slight decrease (Table -32). Since organic carbon content is not a variable taken into account in the SCD of other countries, this section evaluates the organic carbon content in terms of the potential use of dredged sediment as a soil amendment in agriculture. According to the general considerations for interpreting chemical analysis of soils in warm climates, from the Agrology subdirectorate of the Agustin Codazzi Geographic Institute - IGAC (Colombia), these contents are considered low (Table -32

Table -32 : Organic carbon content (%) at Cormagdalena's environmental quality monitoring sites and at INVEMAR's monitoring site.

Contratistas de Cormagdalena encargados de los dragados de mantenimiento					INVEMAR (REDCAM)
	Puente Pumarejo	Boya 15	Las Flores	Bocas de Ceniza	A. Abajo Base N.
Mar/2024	0.91	1.12	0.56	0.83	0.87
Mar/2023	-	-	-	-	0.95

	Bajo (<1.2)		Medio (1.2-2.3)		Alto (>2.3)
--	-------------	---	-----------------	---	-------------

3.2 Chemical quality in relation to the thresholds of Florida, Brazil and the Netherlands

This section is based on monitoring reports from Cormagdalena's contractors, from samples collected in March 2020, 2023 and 2024, and INVEMAR's monitoring reports from samples collected in September 2023 and 2024⁸. As for the UniCartagena data, as they correspond to samples collected between the years 2013-14, these served to complement the data from Cormagdalena and INVEMAR, or to describe information that has not been determined by these institutions.

The information on sediment chemical quality reported by these Colombian entities was compared with sediment quality guidelines (SCD) from Florida, Brazil and the Netherlands, both for freshwater and coastal ecosystems, and in this way it was possible to discuss in the chapter 4 which substances are of concern. Considering the emerging interest in knowing whether dredged materials in the access channel can be used as inputs to implement Nature-Based Solutions (NBS), it is necessary to identify the risks of contamination when spreading dredged materials in freshwater and coastal ecosystems. In addition, as the dredged materials in the access channel have been dumped in a marine deposit area, it is also necessary to assess the risk of contamination in this area (see discussion in chapter).4

The CSD thresholds for the coastal ecosystems of Florida, Brazil and the Netherlands are mentioned in the Table -41 of the Element 2 report of this consultancy. In this report, the DCS of Florida and Brazil were chosen because they are robust and correspond to regions with environmental conditions similar to those of Colombia, and the DCS of the Netherlands are of interest for comparison, taking into account the Equilibrium Partitioning approach that this country implemented in its Weight of Evidence framework to establish its DCS. Similar to the SCD for coastal ecosystems in these regions/countries, Florida's SCD for freshwater ecosystems were also made based on analytical frameworks oriented to assess bioavailability and toxicity risks to organisms, while Brazil's thresholds for these types of ecosystems are adopted from SCDs from the USA and Canada.

Element 2 of this consultancy mentions that the SCD is based on two concentration levels for each substance. Level 1 indicates a concentration below which negative effects on sediment-dwelling organisms are expected to be negligible or infrequent, while level 2 means a concentration above which negative biological effects are likely to occur or where there is a high probability of occurrence. The range between these levels is uncertain as to the likelihood of harmful effects occurring, and for cases falling within this range more research is needed.

3.2.1 Mineral substances

In the following, mineral substances are classified into the categories of "Heavy metals and arsenic" and "Other mineral substances".

⁸ In 2020 INVEMAR did not generate information, perhaps due to limitations due to the critical stage of the Covid-19 pandemic.

Heavy metals and arsenic

The heavy metals for which Colombian entities have determined their concentrations in sediments of the access channel are zinc (Zn), copper (Cu), chromium (Cr), mercury (Hg), lead (Pb), cadmium (Cd), nickel (Ni), and silver (Ag), and arsenic (As) is the only metalloid for which concentrations have also been determined. This set of substances corresponds to 75% of the "Heavy metals and metalloids" included in the Table -41 of report 2 of this consultancy. The concentrations of these substances have been determined by contractors of Cormagdalena, INVEMAR and UniCartagena, using similar methods. These methods involve a laboratory chemical digestion with an acid solution, in order to extract the potentially bioavailable concentration of the substance⁹, and this digestion is followed by quantification of the concentration through a spectrometry device.

From the Cormagdalena data it can be generalized that between March/2020 and March/2024 there was an increasing trend in the potentially bioavailable concentration of Zn, Cu and Cr, from "Puente Pumarejo" to "Bocas de Ceniza" (Figure -33 Table -35 and Figure -37). However, in March/2024 the concentrations were much lower in "Las Flores", which seems strange compared to the concentrations in the neighboring sites; from this it can be assumed that in "Las Flores" the Cormagdalena contractor in March/2024 may have had an error in the sampling procedure (e.g., part of the sample possibly diluted in the river water). In addition, in March/2024 Zn and Cu concentrations in "Bocas de Ceniza" were lower than in "Boya 15"; for this it is necessary to take into account that the sediments in "Bocas de Ceniza" were dredged 3.25 months before sampling, while in "Boya 15" the last dredging was done 5.25 months before sampling. However, it is possible that an inflow of wastewater near "Buoy 15" also influenced the higher concentrations of these metals at this site (Figure -33 and Figure -35). On the other hand, at the INVEMAR monitoring site, the concentrations of Zn, Cu, Cr and Mercury (Hg) increased from September/2023 to September/2024 (Figure -34 Figure -36 Figure -38 and Figure -310).

Descriptions of where the most recently reported concentrations for each heavy metal and arsenic were above the Florida and Brazil Tier 1 thresholds for freshwater and coastal ecosystems can be found below (Appendix B of this report, and Table 4-1 of Report 2 of this consultancy). The Florida and Brazil DCSs for freshwater ecosystems are respectively those of MacDonald et al. (2003) and CONAMA Resolution 454/2012. Regarding the SCDs for Brazil, while the SCDs for coastal ecosystems are those determined for the regions of Ceará and Sao Paulo, the SCDs for freshwater ecosystems apply to the entire country. As for the Netherlands thresholds, the reported concentrations of the heavy metals and arsenic were below the respective level 1 for both freshwater and coastal ecosystems (Appendix E of Report 1 of this consultancy).

Zinc (Zn)

The most recent Zn concentrations were reported by Cormagdalena and INVEMAR in 2024. Concentrations at the monitoring sites of these institutions were below the Florida and Brazil Tier 2 thresholds for freshwater and coastal ecosystems. The concentrations at "Buoy 15" and at the INVEMAR monitoring site were between Florida and Brazil levels 1 and 2 (closer to level 1), therefore the materials dredged at these sites could generate adverse conditions if discharged into freshwater ecosystems, but these conditions are not significantly toxic (Figure -33 a and Figure -34 a).

On the other hand, concentrations at all monitoring sites were above the Sao Paulo (Brazil) level 1 threshold for coastal ecosystems. Concentrations at "Buoy 15" and the INVEMAR monitoring site were between levels 1 and 2 in Sao Paulo (closer to level 2), and between levels 1 and 2 in Florida (closer to level 1) (Figure -33 b and Figure -34 b). Therefore, if all dredged materials had the concentrations reported by Cormagdalena and INVEMAR, it is uncertain how dredged materials at these monitoring sites would affect organisms after dumping dredged material into coastal ecosystems. While the Sao Paulo (Brazil) thresholds are the most stringent, followed by Florida, the Ceará (Brazil) thresholds are much more flexible (See Table -41 in report 2 of this consultancy).

⁹ Chemical digestion in analytical chemistry consists of adding a determined volume of an acid solution to a sample in order to extract the concentration of the substance. For a thorough contamination risk assessment, and to determine sediment quality guidelines, the acid solutions to apply are those that extract the "potentially bioavailable concentration" of the substance (also called "reactive concentration"). Some laboratory method references mention that these acid solutions extract the "total concentration" or the "total reactive concentration", and to avoid confusion it is suggested that the extracted concentration be referred to as the "potentially bioavailable concentration". Mentioning "total concentration" may confuse the reader with the "total composition of a sample", which is determined by destroying the sample with hydrofluoric acid (HF), or without destroying the sample by X-ray fluorescence (XRF). This total composition includes the concentration of a substance within the sand grains, gravel and mineral particles (concentration that is not potentially bioavailable).

Copper (Cu)

The most recent Cu concentrations were reported by Cormagdalena and INVEMAR in 2024. In relation to the thresholds for freshwater ecosystems, the concentrations at "Boya 15" and "Bocas de Ceniza", as well as at the INVEMAR monitoring site, were between Florida levels 1 and 2 (closer to level 1), and lower or almost equal to the Brazil threshold (Figure -35 a and Figure -36 a). Therefore, Cu in the dredged materials from these sites is less likely to generate adverse conditions if discharged into freshwater ecosystems.

In terms of the quality of these sediments for dumping into coastal ecosystems after dredging, the SCD is much more stringent. The concentrations in "Puente Pumarejo", "Buoy 15" and "Bocas de Ceniza", as well as in the INVEMAR monitoring site, were higher than the level 2 thresholds of Ceará and Sao Paulo (Brazil) (Figure -35 b and Figure -36 b). To this, it can be assumed that there is a considerable probability of toxic conditions in coastal ecosystems, but it is to be considered that the concentrations were between levels 1 and 2 in Florida and Brazil (closer to level 1).

Chromium (Cr)

The most recent Cr concentrations were reported by Cormagdalena and INVEMAR in 2024. Regarding sediment quality thresholds for freshwater ecosystems, concentrations in "Buoy 15" and "Bocas de Ceniza" were slightly higher than level 1 in Brazil, and almost equal to level 1 in Florida (Figure -37 a). In contrast, the concentration at the INVEMAR monitoring site was considerably higher, being also between levels 1 and 2 for both Florida and Brazil, but closer to level 2 (110 mg/kg for Florida, and 90 for Brazil) (Figure -38 a).

Regarding the quality of these sediments for discharge into coastal ecosystems after dredging, some Cr thresholds are more stringent. The concentrations at "Puente Pumarejo", "Buoy 15" and "Bocas de Ceniza", as well as at the INVEMAR monitoring site were above the level 2 threshold of Sao Paulo (Brazil), and only the concentration at the INVEMAR site was above the level 2 threshold of Ceará (Brazil). Compared to the Florida thresholds, which are less stringent, only the concentration at the INVEMAR site was between levels 1 and 2 (closer to level 1) (Figure -37 b and Figure -38 b). Therefore, it could be assumed that dredged materials at this INVEMAR site could lead to toxic conditions when dumped in the marine deposition zone, while dredged materials at the Cormagdalena monitoring sites are less likely to generate these conditions. However, concentration differences between the INVEMAR site and the Cormagdalena monitoring sites may be due to differences in sampling or laboratory procedures.

Mercury (Hg)

The most recent Hg concentrations were reported by Cormagdalena and INVEMAR in 2024. While the concentrations at the Cormagdalena monitoring sites were reported as values below the limit of quantification of the spectrometry device (0.10 mg/kg), the concentration at the INVEMAR monitoring site was reported with the same value but not as the limit of quantification. As these concentrations did not exceed any threshold for freshwater ecosystems, it could be assumed that there is no adverse effect caused by Hg if dredged materials are discharged into freshwater ecosystems; but from the contrast with an almost six times higher concentration at "Bocas de Ceniza" in 2023, there is uncertainty as to why the sediments at this monitoring site increased dramatically from March/2020 to March/2023, and decreased dramatically from March/2023 to March 2024 (Figure -39 a and Figure -310 a).

Concentrations in 2024, indicated as limit of quantification, only exceeded the Ceará (Brazil) level 2 threshold for coastal ecosystems (Figure -39 b and Figure -310 b). To verify how concentrations at Cormagdalena monitoring sites differ from the Ceará thresholds, it is suggested that Cormagdalena request its contractors to contract a laboratory service capable of quantifying concentrations at least equal to 0.04 mg/kg (Ceará level 1 threshold).

Cadmium (Cd)

The most recent Cd concentrations were reported by Cormagdalena and INVEMAR in 2024 and 2023 respectively. The concentrations at the four Cormagdalena monitoring sites were reported as values below the limit of quantification of the spectrometry device (2.50 mg/kg), and the concentration at the INVEMAR monitoring site was also reported as a value below a limit of quantification of 12.50 mg/kg.

The Florida and Brazil Tier 1 thresholds for freshwater ecosystems are lower than the limit of quantification reported by Cormagdalena, as are the Ceará and Sao Paulo (Brazil) Tier 2 thresholds and the Florida Tier 1 threshold for coastal ecosystems. Considering that in 2020 Cormagdalena contractors reported concentrations above and below a

quantification limit of 0.1 mg/kg, it is suggested that Cormagdalena request its future contractors to contract a laboratory service with this quantification scope (Figure -311

Lead (Pb)

The most recent Pb concentrations were reported by Cormagdalena and INVEMAR in 2024. At all four Cormagdalena monitoring sites concentrations were below the limit of quantification of the spectrometry device (reported as 10 mg/kg); of the Brazilian and Florida thresholds for freshwater and coastal ecosystems, this limit of quantification is only higher than the Sao Paulo Tier 1 threshold for coastal ecosystems (6.70 mg/kg). Therefore, for the quantification of Pb concentration, it is suggested that Cormagdalena request its future contractors to hire a laboratory service capable of quantifying at least 5 mg/kg.

The concentration at the INVEMAR monitoring site was 16.50 mg/kg, lower than the level 1 thresholds for freshwater ecosystems (36.00 mg/kg in Florida, 35.60 in Brazil). Compared to the thresholds for coastal ecosystems, the concentration was only higher than level 1 in Sao Paulo (6.70 mg/kg) and almost equal to level 2 in the same regions (16.60 mg/kg).

Nickel (Ni), silver (Ag) and arsenic (As)

Ni concentrations have been reported only at the INVEMAR monitoring site, where the most recent concentration was reported in 2024. This concentration was 16.50 mg/kg, lower than the Florida and Brazil level 1 thresholds for freshwater ecosystems (23.00 and 18.00 mg/kg respectively). In terms of comparison with thresholds for coastal ecosystems, this Ni concentration is higher than the Sao Paulo level 2 threshold (14.60 mg/kg), but lower than the Ceará level 1 threshold (20.20 mg/kg), and slightly higher than the Florida level 1 (15.90 mg/kg). As to which of these thresholds should be taken into account, a discussion is described later in the section 5.1.1 .

On the other hand, the information found on Ag and As concentrations is only that reported by UniCartagena, from a sampling conducted in 2013 at a site near the industrial port of Barranquilla (Tejeda-Benítez et al., 2018). At that time, the Ag concentration was 0.40 mg/kg, lower than the level 1 threshold determined so far for freshwater and coastal ecosystems (Florida SCD, where level 1 is 1.00 mg/kg). Meanwhile, the As concentration was 8.54 mg/kg, which for freshwater ecosystems is between levels 1 and 2 for Brazil (5.90 and 17.00 mg/kg) and lower than level 1 for Florida, while for coastal ecosystems the concentration is above levels 1 for Florida and Sao Paulo (7.24 and 8.10 mg/kg respectively). Therefore, it can be assumed that in 2013 the concentration of As at the access channel sampling site was less likely to be harmful, and could be slightly harmful to organisms in the deposition area where dredged materials are dumped.

Zinc (Zn)

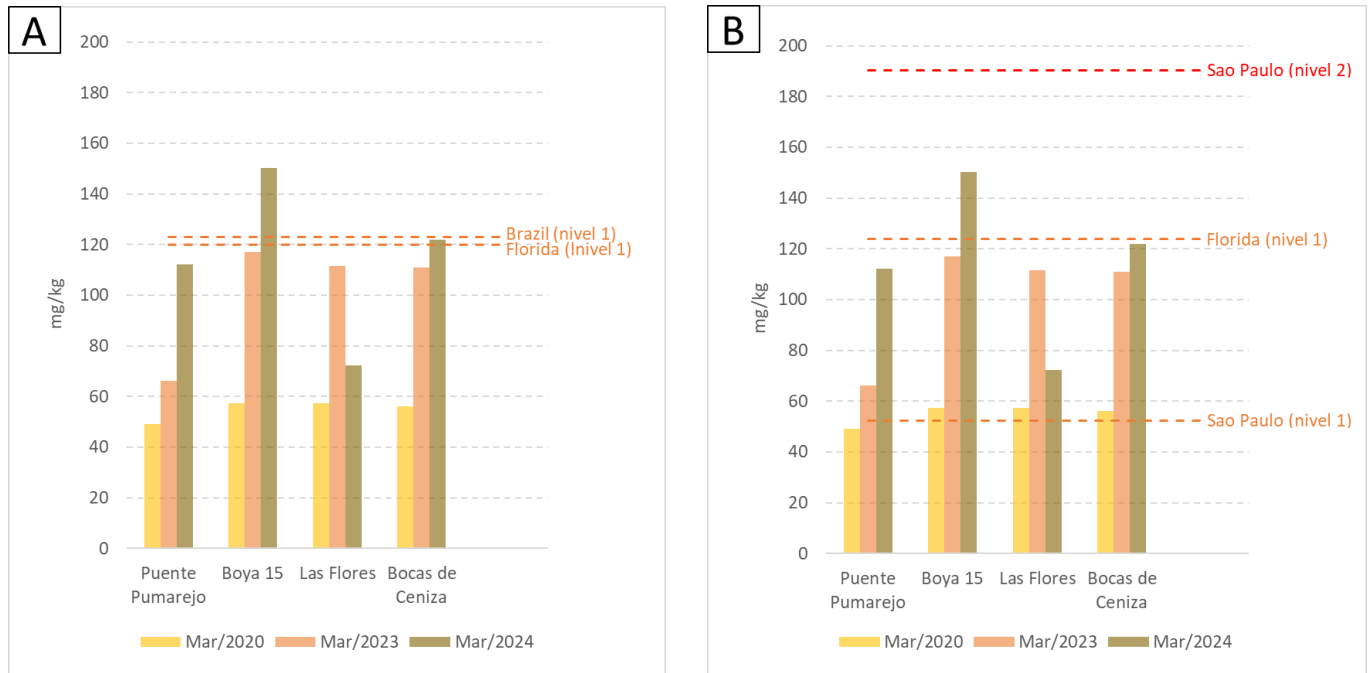


Figure -33 : Zinc concentration at Cormagdalena monitoring sites, compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B).

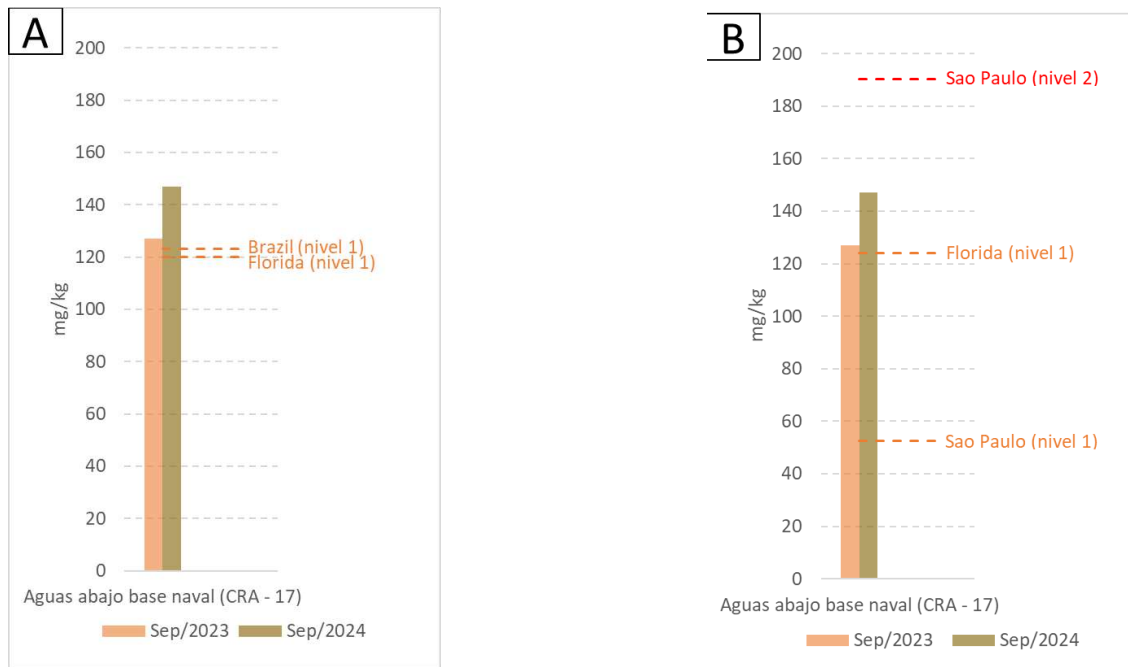


Figure -34 : Zinc concentration at INVEMAR monitoring site, compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B).

Copper (Cu)

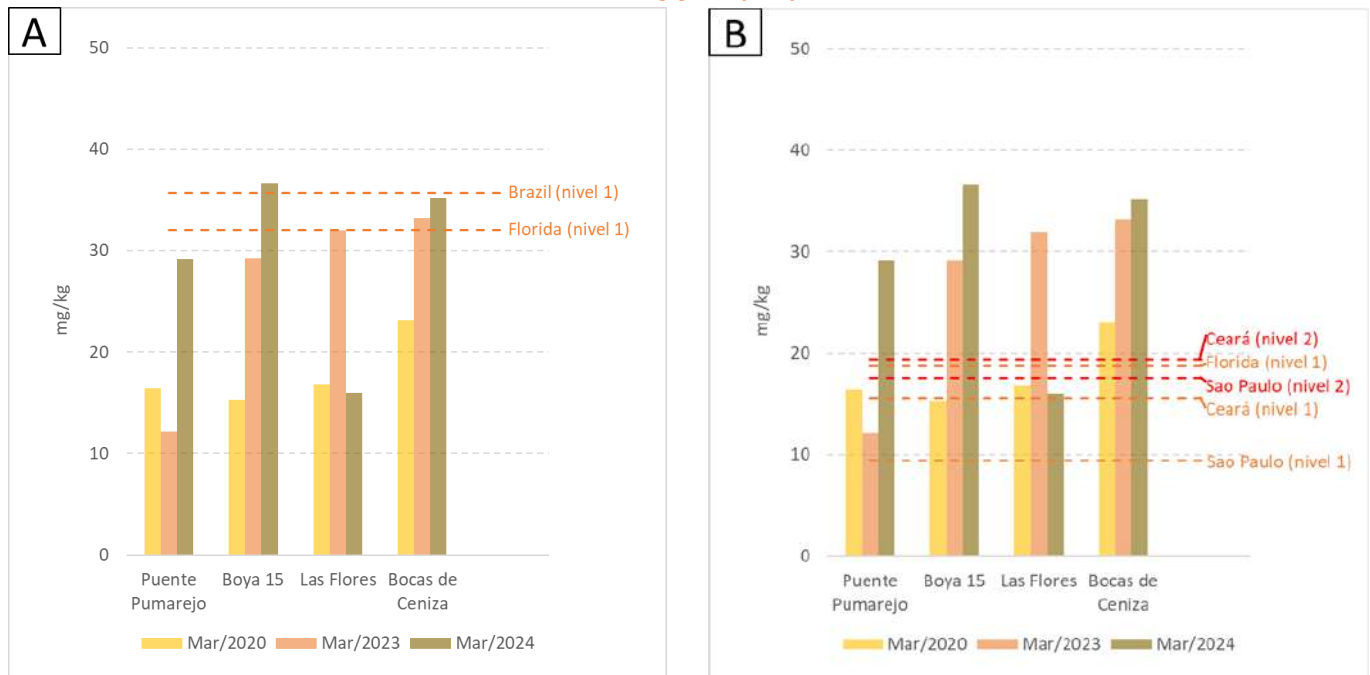


Figure -35 : Copper concentration at Cormagdalena monitoring sites, compared with threshold values for freshwater ecosystems (A), and with threshold values for coastal ecosystems (B).

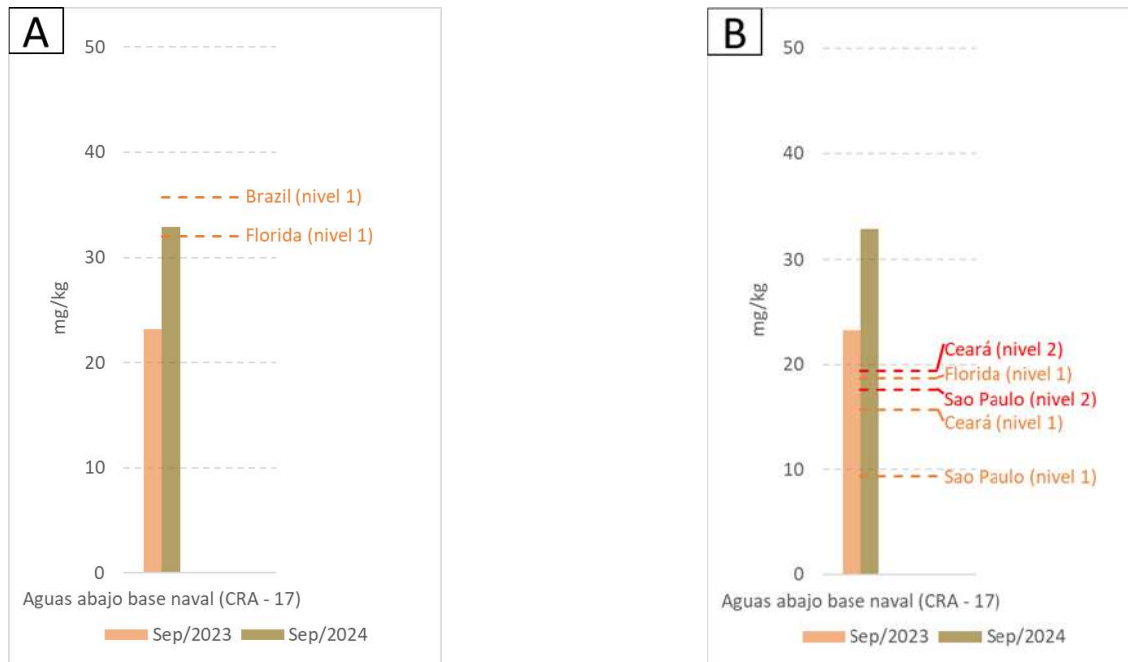


Figure -36 : Copper concentration at the INVEMAR monitoring site, compared with the threshold values for freshwater ecosystems (A), and with the threshold values for coastal ecosystems (B).

Chromium (Cr)

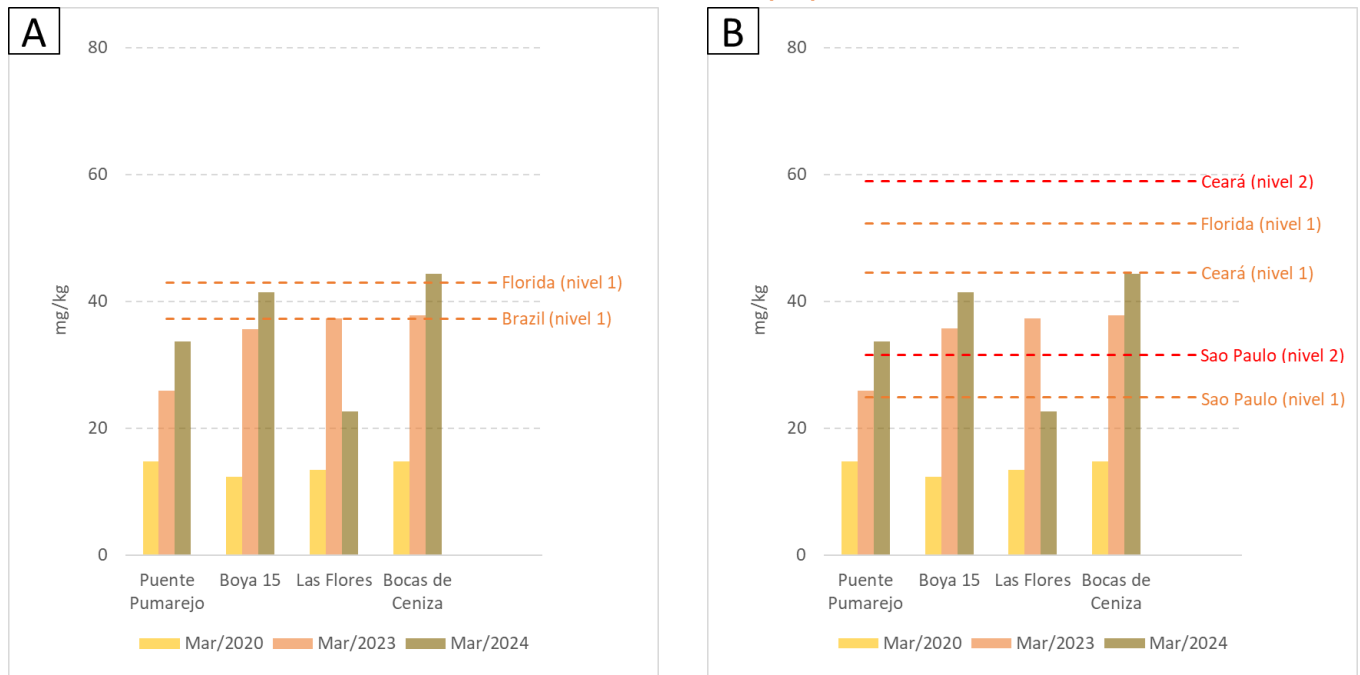


Figure -37 : Chromium concentration at Cormagdalena monitoring sites, compared with threshold values for freshwater ecosystems (A), and with threshold values for coastal ecosystems (B).

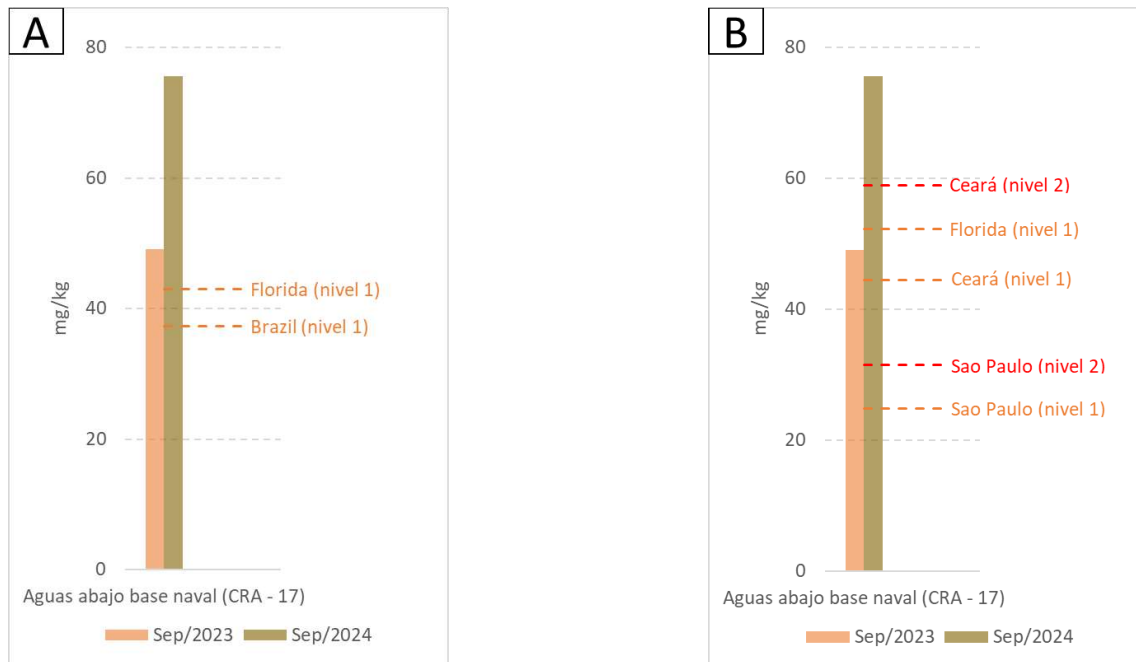


Figure -38 : Chromium concentration at the INVEMAR monitoring site, compared with the threshold values for freshwater ecosystems (A), and with the threshold values for coastal ecosystems (B).

Mercury (Hg)

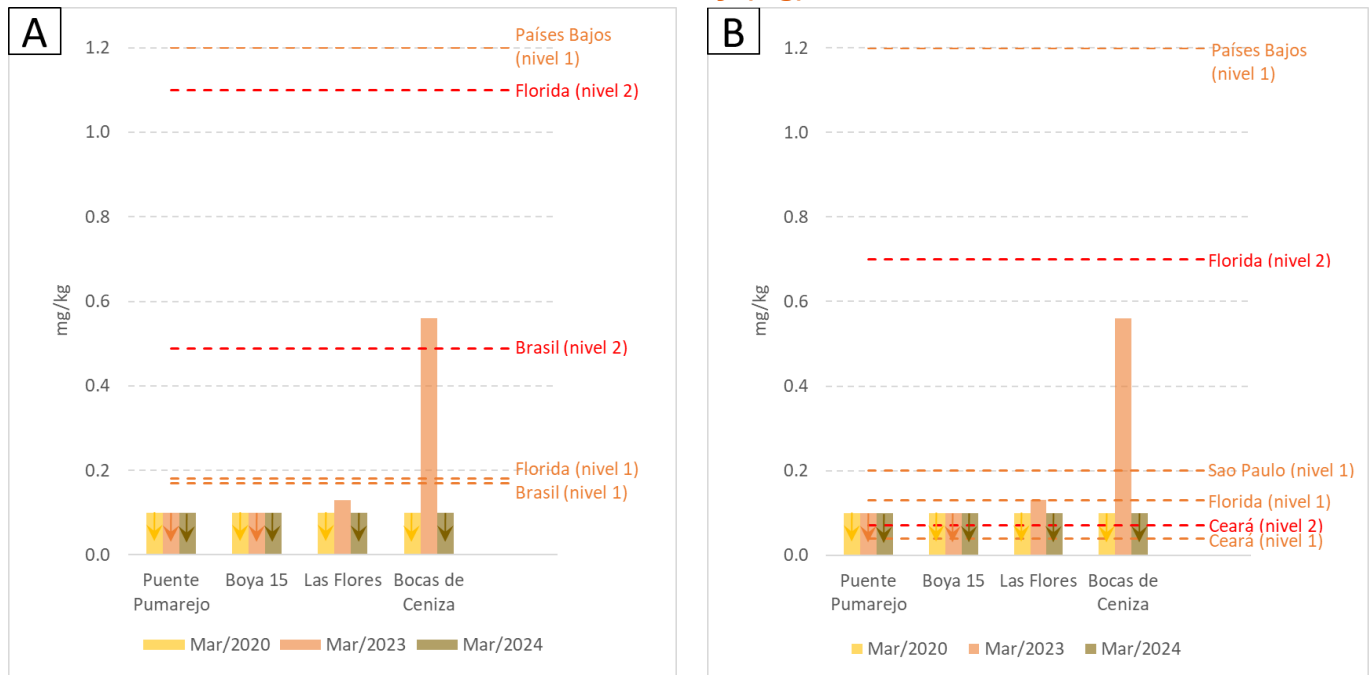


Figure -39 : Mercury concentration at Cormagdalena monitoring sites, compared with threshold values for freshwater ecosystems (A), and with threshold values for coastal ecosystems (B). Inverted arrows indicate values below the limit of quantification of the laboratory spectrometry device.

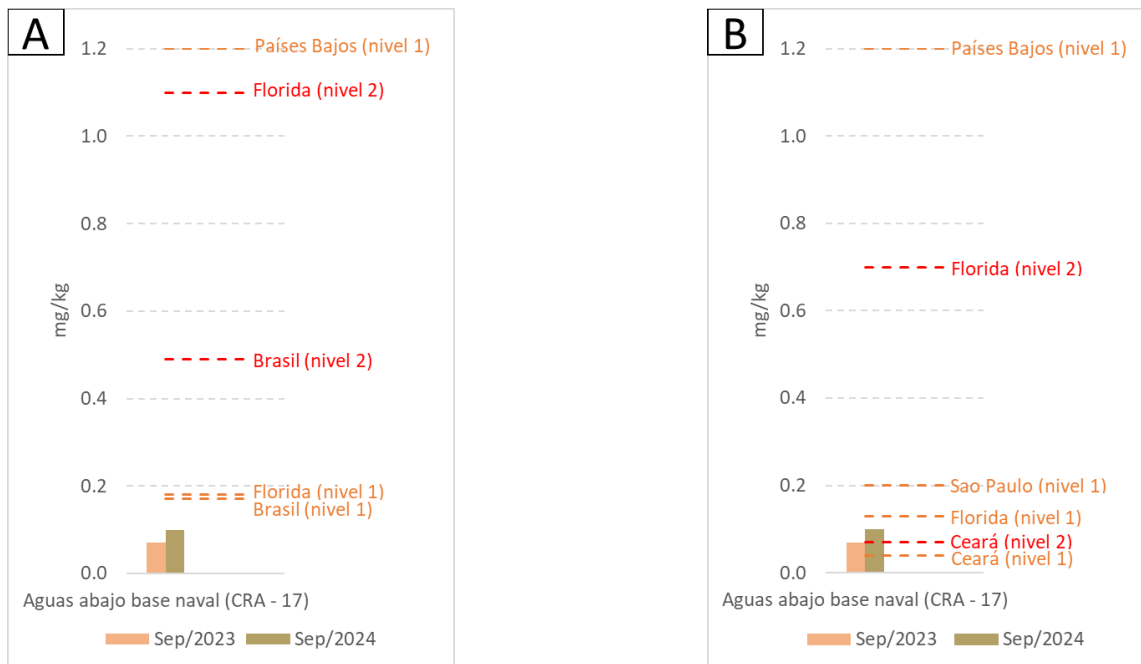


Figure -310 : Mercury concentration at the INVEMAR monitoring site, compared with the threshold values for freshwater ecosystems (A), and with the threshold values for coastal ecosystems (B).

Cadmium (Cd)

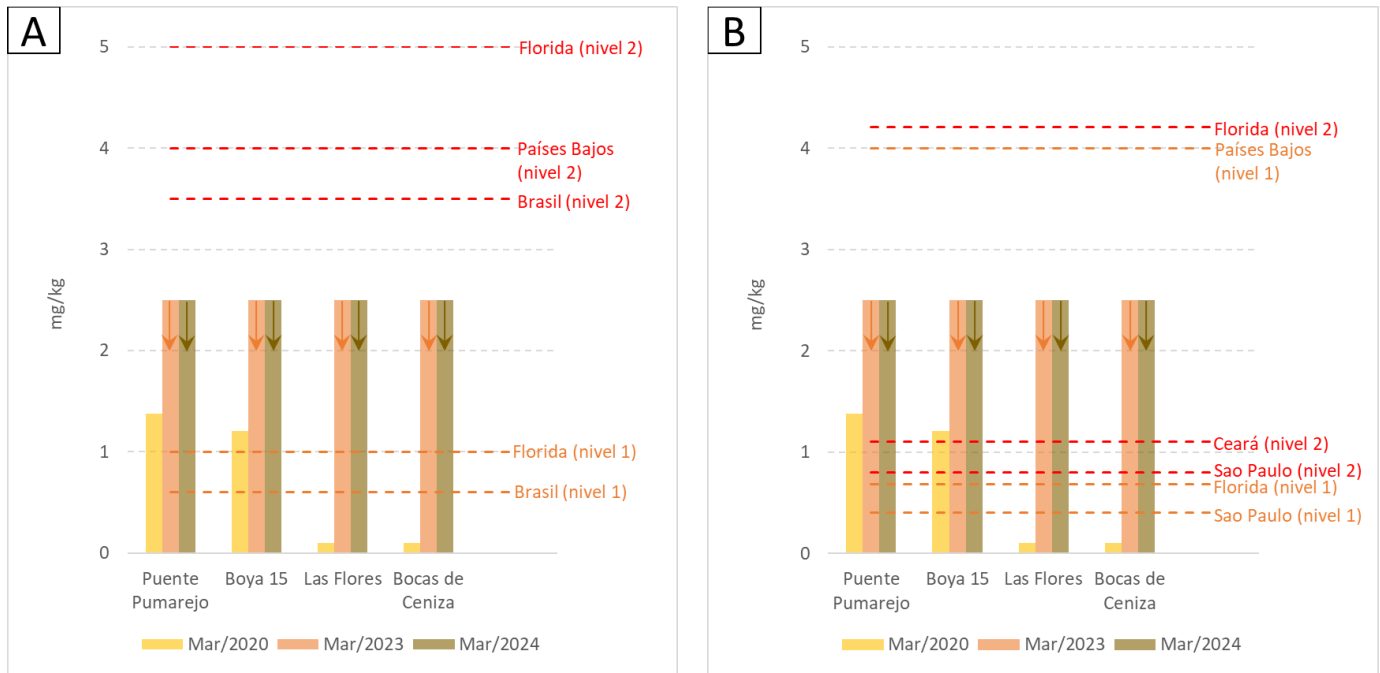


Figure -311 : Cadmium concentration at Cormagdalena monitoring sites, compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B). Downward arrows indicate values below the limit of quantification of the laboratory spectrometry device.

Other mineral substances

Concentrations of other mineral substances are part of the environmental quality report made by Cormagdalena's contractors in March/2024 (these substances were not included in the March/2023 report). The information reported includes only some macronutrients (nitrogen, phosphorus and sulfur), and chlorine (micronutrient for plants). The concentrations of these substances have been determined by other laboratory techniques (Kjeldahl method, colorimetry, spectrophotometry and conductivity).

None of these substances are part of the DCS of Florida, Brazil and the Netherlands (Table -41 of report 2 of this consultancy), nor of the DCS of other countries, and Cormagdalena's contractors do not mention any reference for the interpretation of the concentrations of these substances. An analysis of the information gaps for other mineral substances is presented in section 6.1.2, and due to the absence of SCD for these substances, suggestions are described in chapter 7.

Macronutrients (Nitrogen, Phosphorus, Sulfur)

These three nutrients are of importance in terms of fertility when considering the use of dredged materials as a soil amendment in agriculture. However, just as high concentrations of these nutrients contribute to soil fertility, the use of dredged materials in areas surrounding lentic aquatic ecosystems leads to a risk of eutrophication in these ecosystems.

Nitrogen (N) was determined as total N, from the sum of nitrate, nitrite and Kjeldahl N (organic N + ammonia) concentrations. To interpret the total N contents in terms of fertility for use of the material on dry land, reference was made to the general considerations for interpreting chemical analysis of soils in warm climates, of the Agrology subdirectorate of the Agustín Codazzi Geographic Institute - IGAC (Colombia). While the contents in Puente Pumarejo and Boya 15 are considered high, in Las Flores and Bocas de Ceniza they were medium (Table -33

Table -33 : Total nitrogen contents in Cormagdalena's environmental quality monitoring sites, qualified according to IGAC's general considerations for interpreting chemical analysis of soils in warm climates.

	% de nitrógeno total (Cormagdalena)			
	Puente Pumarejo	Boya 15	Las Flores	Bocas de Ceniza
Mar/2024	0.23	0.26	0.15	0.12

	Bajo (<0.10)
	Medio (0.10-0.20)
	Alto (>0.20)

Phosphorus (P) was determined as total P, and the contents at each Cormagdalena monitoring site are shown in the (Table -34). These contents were determined using a $\text{NaNO}_3/\text{KNO}_3$ fusion technique and colorimetric quantification of Molybdenum Blue, and there is no known reference in the context of Colombia or any other tropical American country to interpret these contents in terms of fertility or risk of eutrophication. As with total N contents, total P contents were highest at Puente Pumarejo and Buoy 15 (Table -34

Table -34 : Total phosphorus contents in Cormagdalena's environmental quality monitoring sites.

	Fósforo total (mg/kg) - Cormagdalena			
	Puente Pumarejo	Boya 15	Las Flores	Bocas de Ceniza
Mar/2024	172.64	138.66	107.73	112.09

As for sulfur (S), Cormagdalena only determined sulfate concentrations, whose values at each Cormagdalena monitoring site are shown in the (Table -35). As for total P, there is no known reference in the context of Colombia or any other tropical American country to interpret these concentrations in terms of fertility or eutrophication risk. In contrast to the total N and P contents, sulfate concentrations were higher in Las Flores and Bocas de Ceniza (Table -35

Table -35 : Sulfate contents in Cormagdalena's environmental quality monitoring sites.

	Sulfatos (mg/kg) - Cormagdalena			
	Puente Pumarejo	Boya 15	Las Flores	Bocas de Ceniza
Mar/2024	63.30	51.10	87.70	79.90

Chlorine

Cormagdalena determined chloride concentrations at each monitoring site, which were higher at Las Flores and Bocas de Ceniza, being considerably higher at the latter site (Table -36). There is no reference in the context of Colombia or any other tropical American country to interpret these concentrations in terms of adequate concentration as a micronutrient for plants, or a concentration that implies a risk of toxicity.

Table -36 : Chloride contents at Cormagdalena environmental quality monitoring sites.

	Cloruros (mg/kg) - Cormagdalena			
	Puente Pumarejo	Boya 15	Las Flores	Bocas de Ceniza
Mar/2024	<20.00	128.57	208.03	688.71

3.2.2 Organic substances

The organic substances that have been determined by the Colombian entities are some polycyclic aromatic hydrocarbons (PAHs) and some pesticides. Concentrations of PAHs were reported by INVEMAR between 2023-24 and by UniCartagena from a sampling conducted in Nov/2013 (Tejeda-Benitez et al., 2018), while pesticides have only been reported by UniCartagena from a sampling conducted in Nov/2014, at a site near the industrial port of Barranquilla (Tejeda-Benitez et al., 2023).

The concentrations of both types of organic substances have been quantified by these entities after extracting the concentrations through different methods (QUEChERS solution, Soxhlet solution and microwave-assisted extraction). After extractions, quantification has been performed by Gas Chromatography coupled to Mass Spectrometry (GC-MS), Gas Chromatography coupled to Triple Quadrapole Tandem Mass Spectrometry (GC-MS/MS), or Gas Chromatography-Mass Selective Detector (GC-MSD). In general, gas chromatography is effective for substances that are thermostable and can vaporize at high temperatures without decomposing, such as pesticides and PAHs. These methods for extracting and quantifying the concentration of pesticides and PAHs are described in the section "About laboratory analytical techniques" at 7.1.2 below.

The following are descriptions of the concentrations of PAHs and pesticides reported by INVEMAR and UniCartagena, and how they compare with the respective DCSs of Florida, Brazil and the Netherlands.

Polycyclic aromatic hydrocarbons (PAHs).

Phenanthrene and Chrysene are the PAHs that have been monitored by INVEMAR and reported by UniCartagena (Tejeda-Benitez et al., 2018), and UniCartagena also reported concentrations of fluoranthene and pyrene. This set of substances corresponds to 31% of the PAHs listed in the Table -41 of report 2 of this consultancy. The reported concentrations of these PAHs have been compared with the Florida and Brazilian thresholds for freshwater and coastal ecosystems. The DCS of PAHs were not been determined for the regions of Ceará and Sao Paulo, therefore the reference DCS for Brazil are the national ones established in CONAMA resolution 454/2012. As for the DCS for the Netherlands, these do not include thresholds for each PAH, but only for the sum of PAHs (See Appendix B of this report, and Table -41 of report 2 of this consultancy).

Phenanthrene

The phenanthrene concentrations reported at the INVEMAR monitoring site were almost the same in Sep/2023 and Sep/2024, and were by far lower than the lowest level-1 threshold for freshwater ecosystems (Brazil -Figure -312 a) and the lowest level-1 threshold for coastal ecosystems (Florida -Figure -312 b). Therefore, it can be assumed that this concentration in the dredged materials would not generate damage if they were dumped in freshwater ecosystems, and that if all the dredged material at this site had this concentration, phenanthrene should not have generated damage to the organisms in the deposition zone.

On the other hand, from the UniCartagena research (Tejeda-Benitez et al., 2018), in Nov/2013 the phenanthrene concentration was 30 µg/kg near the industrial port of Barranquilla, which is slightly lower than the lowest level 1 threshold for freshwater ecosystems (Brazil -Figure -312 a) and much lower than the lowest level 1 threshold for coastal ecosystems (Florida -Figure -312 b). Although this concentration was higher than those reported at the INVEMAR monitoring site in 2023 and 2024, if all the dredged material at this site had had this concentration in Nov/2013, it is quite likely that phenanthrene did not affect harm to organisms in the deposition zone at that time.

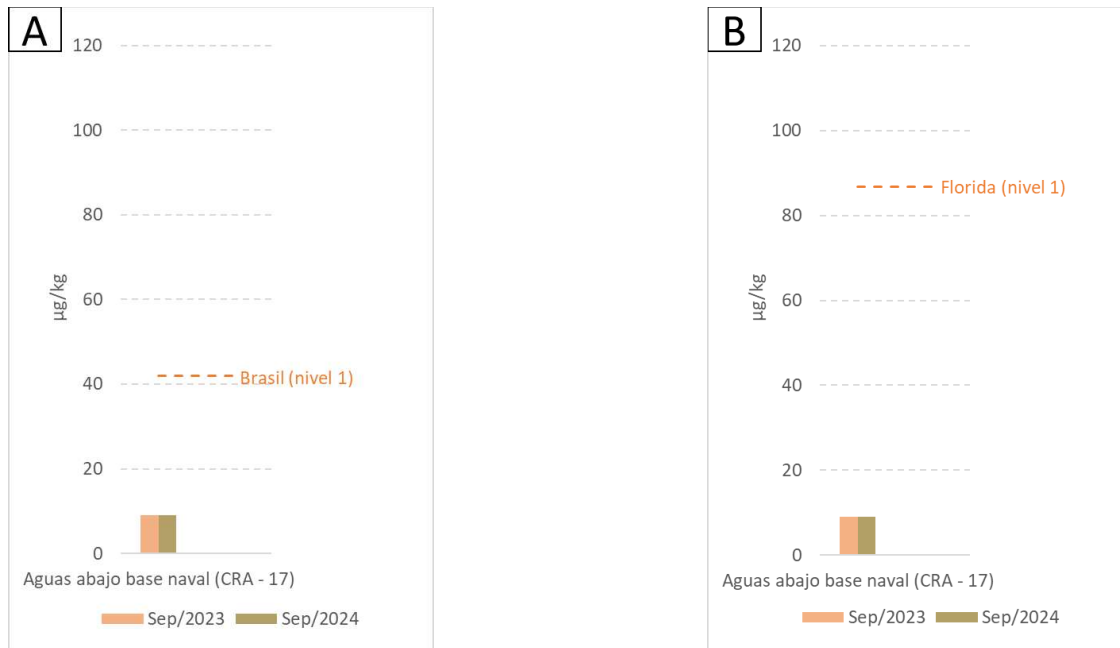


Figure -312 : Phenanthrene concentration at INVEMAR monitoring site, compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B).

Chrysene:

Chrysene concentrations at the INVEMAR monitoring site were only reported in Sep/2024. These concentrations were also by far lower than the lowest Tier 1 threshold for freshwater ecosystems (Brazil -Figure -313 a) and the lowest Tier 1 threshold for coastal ecosystems (Florida -Figure -313 b), as was the concentration reported by UniCartagena in Nov/2013 (Tejeda-Benitez et al., 2018), which was 10 mg/kg. From these comparisons, it can be assumed that if all dredged material at these sites and times had had these concentrations, chrysene should not have generated harm to organisms in the deposition zone, and would not generate harm if discharged into freshwater ecosystems.

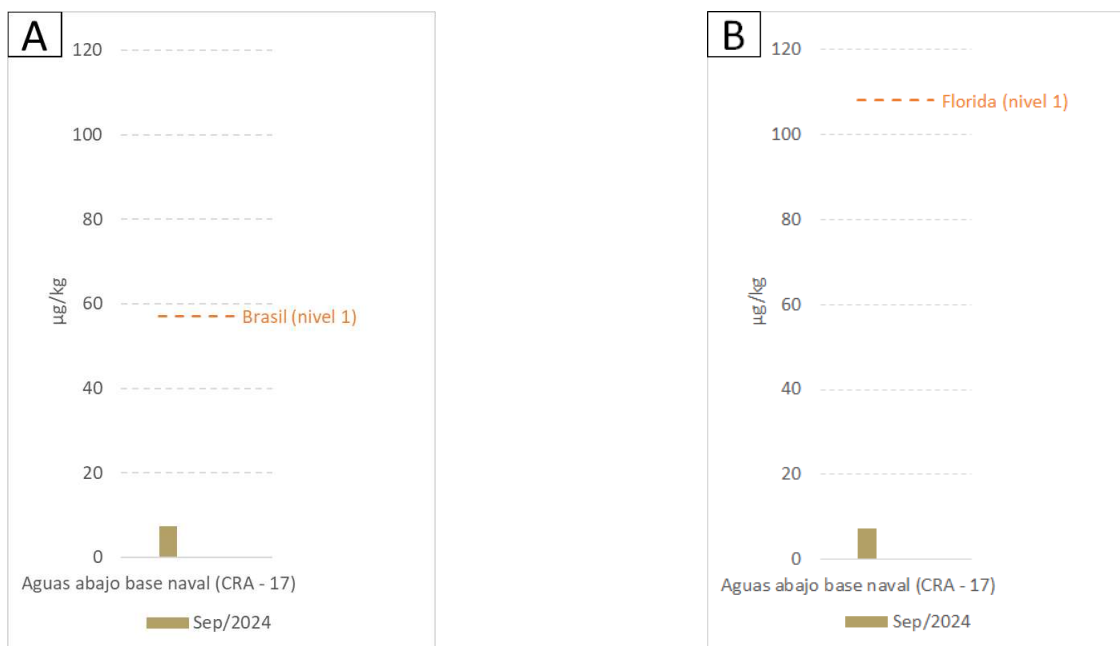


Figure -313 : Concentration of chrysene at the INVEMAR monitoring site in Sep/2024, compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B).

Fluoranthene and pyrene:

UniCartagena also determined from its sampling in Nov/2013 the concentrations of fluoranthene and pyrene (Tejeda-Benítez *et al.*, 2018). The fluoranthene concentration was 30 mg/kg, well below the Florida and Brazil Tier 1 thresholds for freshwater ecosystems (420 and 111 mg/kg respectively), as well as well below the Florida and Brazil Tier 1 thresholds for coastal ecosystems (113 and 600 mg/kg respectively). As for pyrene, its concentration was 10 mg/kg, well below the Florida and Brazil Tier 1 thresholds for freshwater ecosystems (200 and 53 mg/kg respectively), as well as well below the Florida and Brazil Tier 1 thresholds for coastal ecosystems (153 and 665 mg/kg respectively). Therefore, it can be assumed that if all the materials dredged in the access channel had had in Nov/2013 these concentrations of fluoranthene and pyrene, it is quite likely that these compounds did not generate at that time damage to organisms in the deposition zone. And if currently dredged materials had these concentrations of fluoranthene and pyrene, these would not be harmful if used in SbN in freshwater or coastal ecosystems.

Pesticides

The most recent information on pesticide concentrations was reported by UniCartagena from a sampling conducted in Nov/2014 at a site near the port industrial zone (Tejeda-Benitez *et al.*, 2023), and neither INVEMAR nor Cormagdalena have so far reported concentrations of these substances in sediments of the access channel. Of the pesticides mentioned in Table 4-1 of report 2 of this consultancy, UniCartagena determined concentrations of 56% of these substances, which are eight (8) organochlorine pesticides (chlordane, p,p'-DDE, p,p'-DDD, dieldrin, heptachlor, heptachlor epoxide, α -Endosulfan), and one (1) organonitrogen pesticide (atrazine). For these substances, DCSs have been determined for both freshwater and coastal ecosystems in Florida, Brazil or the Netherlands, for chlordane, p,p'-DDE, p,p'-DDD and atrazine, and for heptachlor epoxide there are DCSs only for freshwater ecosystems in Florida. Regarding the SCDs for Brazil, as for PAHs, no pesticide SCDs have been determined for the regions of Ceará and Sao Paulo, so the reference SCDs for Brazil are the national ones established in CONAMA resolution 454/2012.

In addition to the aforementioned pesticides, UniCartagena also determined the concentration of 30 other pesticides, which are organochlorines (10), organophosphates (13), organonitrogenates (3) and organosulfides (4). Of these 30 pesticides, three (3) have thresholds included in the SCD of Florida, Brazil or the Netherlands; these three pesticides are aldrin, disulfoton and endrin. Therefore, adding these three pesticides to the other nine mentioned in the previous paragraph, a description is shared below on how the concentrations of these 12 pesticides were compared to the respective thresholds of Florida, Brazil or the Netherlands, determined so far for them.

The concentration of all 12 pesticides was well below their respective Tier 1 thresholds, while the concentration of atrazine was slightly above the Florida Tier 1 threshold for freshwater ecosystems (Figure -314). So far there is no level 2 threshold for atrazine for these ecosystems in Florida, so it can only be assumed that if the dredged materials currently have this concentration, if discharged to freshwater ecosystems atrazine would generate some harm to organisms.

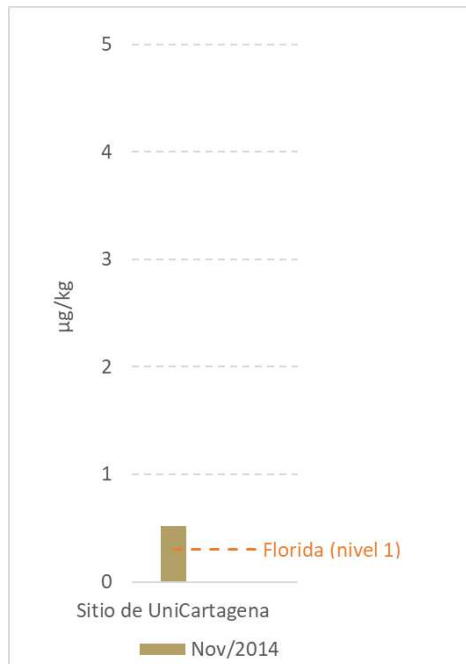


Figure -314 : Atrazine concentration at the UniCartagena sampling site (Nov/2014), compared to threshold values for freshwater ecosystems.

Below, theFigure -315Figure -316Figure -317 andFigure -318 are examples showing how the concentrations of chlordane, p,p'-DDDD, p,p'-DDE and p,p'-DDDT, were well below the level 1 thresholds for Florida, Brazil or the Netherlands, determined so far for these pesticides.

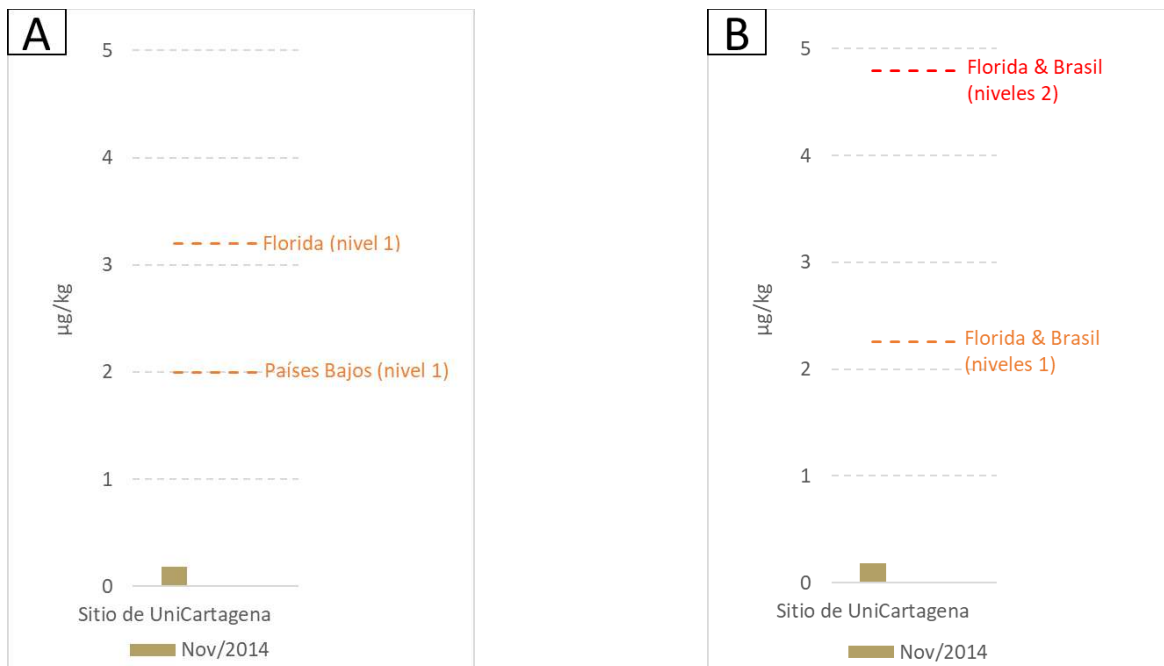


Figure -315 : concentration of chlordane at the UniCartagena sampling site (Nov/2014), compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B).

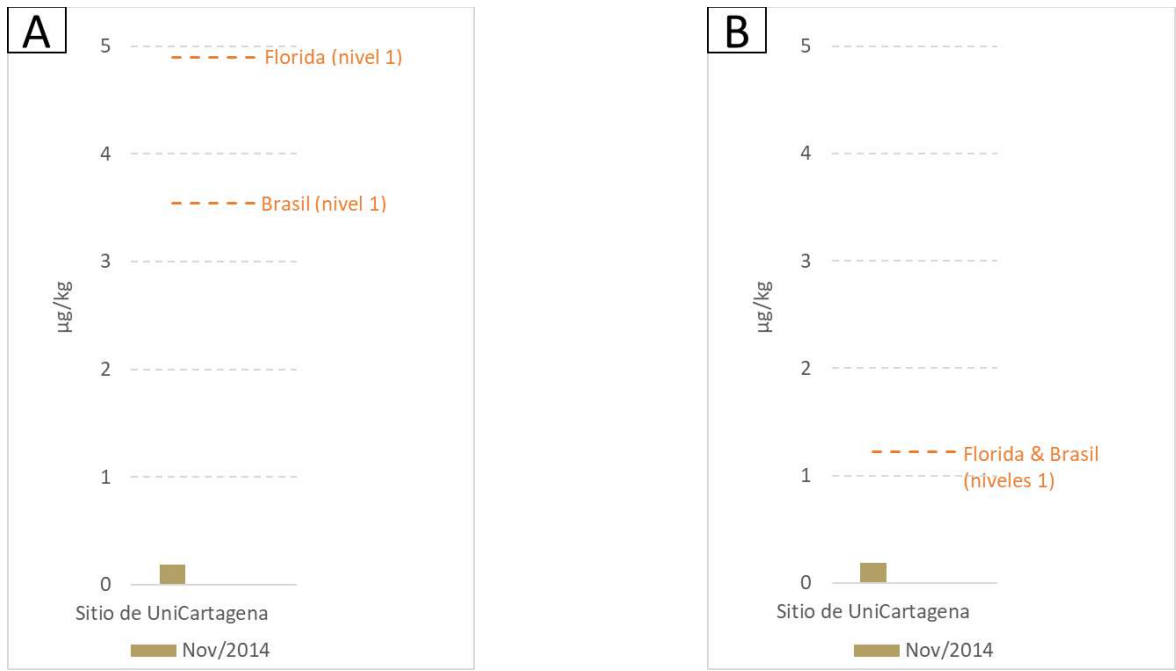


Figure -316 : concentration of p,p'-DDE at the UniCartagena sampling site (Nov/2014), compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B).

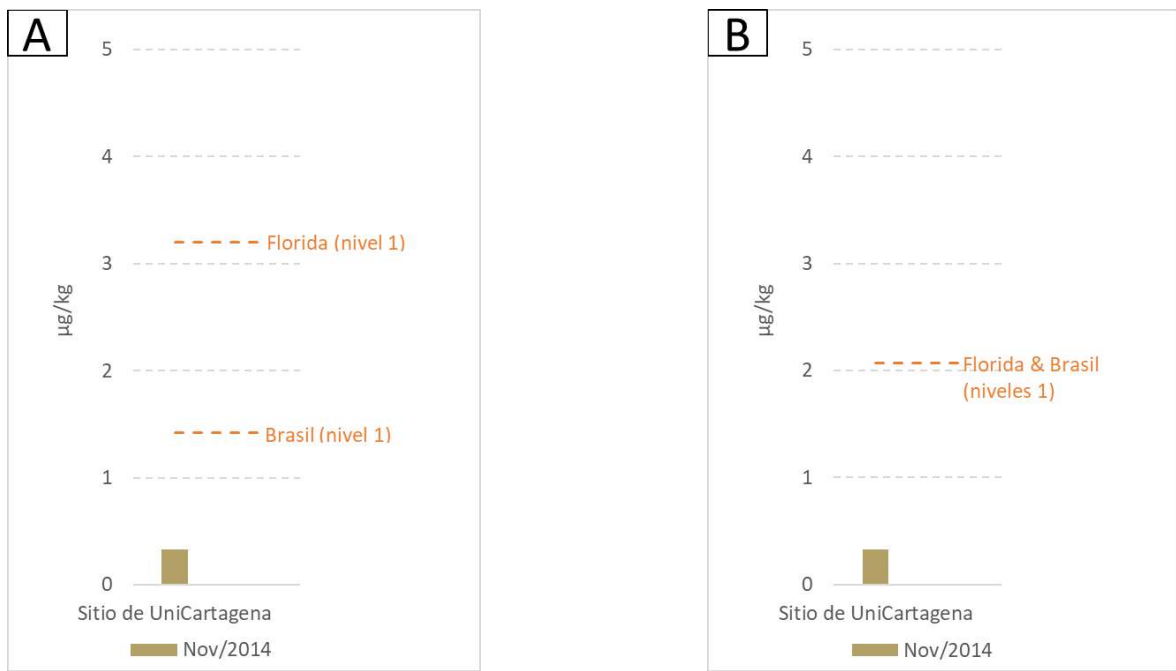


Figure -317 : concentration of p,p'-DDE at the UniCartagena sampling point (Nov/2014), compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B).

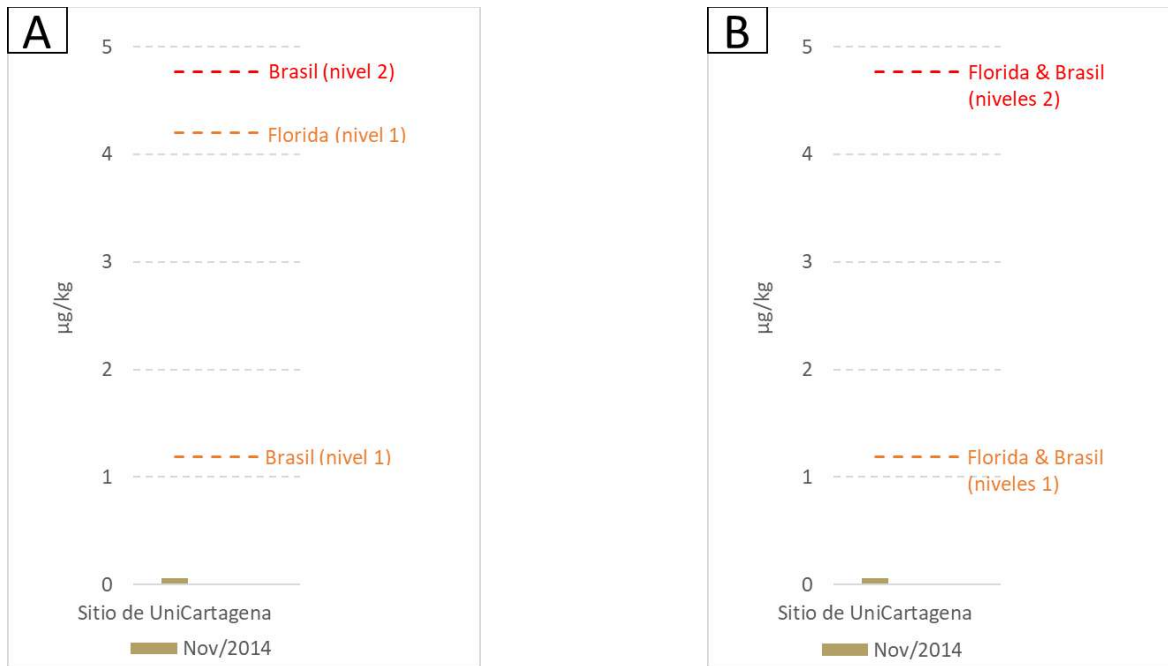


Figure -318 : *p,p'*-DDT concentration at the UniCartagena sampling point (Nov/2014), compared to threshold values for freshwater ecosystems (A), and to threshold values for coastal ecosystems (B).

For both mineral and organic substances, the DCS from Florida and Brazil are comparable in order of magnitude, and we can assume that the DCS from the Netherlands are not applicable to Colombia. Therefore, for the next chapters, the DCS of the Netherlands are not taken into account.

4 Chemical quality of sediments in the depositional zone near the access channel to the port area of Barranquilla.



Chapter 4 - Executive Summary

This short chapter describes information on the chemical quality of sediments in the marine depositional zone where dredged materials are dumped in the access channel. The information was reported by the Consorcio Dragado Puerto de Barranquilla 2024 - 2025 (2025), which was contracted by the CRA (Corporación Autónoma Regional del Atlántico).

This information was determined from a sampling conducted in Feb/2025, and as for the concentrations of substances for which thresholds are included in the SCD for coastal ecosystems of Florida and Brazil, the concentrations of seven heavy metals are included. While the mercury concentration was reported as a value below a limit of quantification of 2.00 mg/kg, the concentrations of the other heavy metals are presented in the Table -41 and compared with the mentioned thresholds.

Table -41 Heavy metal concentrations in sediments of the marine deposit zone, compared with DCS thresholds for coastal ecosystems of Florida and Brazil (Source: Consorcio Dragado Puerto de Barranquilla 2024 - 2025, 2025).

	Florida (EEUU)		Zona de depósito	Ceará (Brasil)		Zona de depósito	Sao Paulo (Brasil)		Zona de depósito
	Nivel 1	Nivel 2	Feb-25	Nivel 1	Nivel 2	Feb-25	Nivel 1	Nivel 2	Feb-25
Zn	124.00	271.00	53.00	543.00	603.00	53.00	52.60	190.20	53.00
Cu	18.70	108.00	44.00	15.60	19.40	44.00	9.40	17.60	44.00
Cr	52.30	160.00	20.00	44.50	59.00	20.00	24.90	31.50	20.00
Cd	0.68	4.21	1.40	N/A	1.10	1.40	0.40	0.80	1.40
Ni	15.90	42.80	15.29	20.20	24.10	15.29	10.80	14.60	15.29
Pb	30.20	112.00	25.70	24.00	47.30	25.70	6.70	16.60	25.70

< Nivel 1
 Entre niveles 1 y 2
 > Nivel 2

Compared to the concentrations at the access channel monitoring sites in 2024, in 2025 the sediments of the deposition zone presented lower concentrations of zinc (Zn) and chromium (Cr), and copper (Cu) was higher (concentration above the level 2 thresholds of Ceará and Sao Paulo, Brazil). As for cadmium (Cd) and lead (Pb), in this study the consortium was able to quantify the concentrations more accurately; Cd was also higher than the level 2 thresholds of Ceará and Sao Paulo (Brazil), and although the concentration of Pb was higher than that of the access channel monitoring sites, the harmfulness of this concentration in the deposition area is questionable. Similarly, although the Ni concentration was slightly lower than that of the INVEMAR monitoring site in the access channel, as it is above the Sao Paulo level 2 threshold, doubt arises as to how harmful the concentration could be in the deposition zone.

Regarding organic compounds, the same consortium only reported the concentration of total hydrocarbons in the marine deposit area. This concentration was reported as a value below a limit of quantification of 0.01 mg/kg, which is much lower than the level 1 thresholds for total PAHs in the Florida, Ceará and Sao Paulo SCD for coastal ecosystems.

On the other hand, the state of the hydrobiological community in the water of this deposit zone was also reported by the Consorcio Dragado Puerto de Barranquilla 2024 - 2025 (2025), based on sampling carried out in Feb/2025. This community was characterized by the following: 1) 25 phytoplankton morphospecies (average density of 252.09 ind/L, and dominance of *Thalassionema sp*, which is common in cold and turbulent waters); 2) 16 zooplankton morphospecies (average density of 249.31 ind/m³, and 86.3% dominance of arthropods); 3) 12 fish species, of which the dominant ones were the mojarra (*Eugerres plumieri*), the striped mullet (*Mugil incilis*), and the big-headed rockcod (*Larimus breviceps*).

5 Discussion of the substances of greatest concern



Chapter 5 - Executive Summary

This chapter presents a discussion of the substances of greatest concern, among those for which Colombian entities have reported concentrations in sediments of the access channel and the marine deposit zone.

The key points of this chapter are:

- Mineral substances:
 - Heavy metals and arsenic: from the available information it can be assumed that Cu and Cd are of greatest concern in the marine deposition zone, and are likely to be of concern if materials dredged in the access channel are spread in other coastal/marine areas. For the other heavy metals, there is uncertainty about their level of concern, as information on their concentration in the access channel has not been sufficiently representative, is not up to date, or has not been accurately quantified.
 - Other mineral substances: It was not possible to evaluate information on other inorganic substances reported by Cormagdalena, due to the absence of DCS for these substances, so it is not yet possible to determine which of these substances are of concern.
 - Organic substances:
 - Polycyclic aromatic hydrocarbons (PAHs): The frequency and density of sampling do not allow conclusions to be drawn.
 - Pesticides: Of what was identified from sampling in 2014, only the concentration of atrazine was above the Tier 1 threshold for freshwater ecosystems in Florida. However, given that Colombia ranked first worldwide in 2022 in pesticide use per area of crops (FAO, 2024), new information is needed to assess pesticide concentrations.
-

5.1 Mineral substances

5.1.1 Heavy metals and arsenic

Zinc (Zn), copper (Cu), chromium (Cr), mercury (Hg), cadmium (Cd), lead (Pb) and nickel (Ni), are the heavy metals whose concentrations in sediments were recently reported (in 2024 by Cormagdalena or INVEMAR contractors, in the access channel, and in 2025 by the Consorcio Dragado Puerto de Barranquilla 2024 - 2025, in the deposition area). Since of the reports at the four Cormagdalena monitoring sites, those at "Las Flores" were much lower than at the neighboring sites, and therefore unreliable, the information on heavy metal concentrations at this site is not taken into account in this discussion. In addition, the concentrations of the heavy metals mentioned were much lower than the Netherlands Tier 1 thresholds, so this discussion focuses on comparisons with the DCSs of Florida and Brazil.

Zn, Cu and Cr concentrations were accurately determined in both the access channel and the deposition zone. Compared to the SCDs for freshwater ecosystems, the concentrations of these three metals at Puente Pumarejo were below the level 1 thresholds, while at all other sites they were at most between the level 1 and 2 thresholds of the Florida or Brazil SCDs (closer to level 1). On the other hand, compared to the DCSs for coastal ecosystems, at all monitoring sites Zn and Cr concentrations were at most between the level 1 and 2 thresholds of the DCSs of one or two regions (closer to level 1); meanwhile, Cu concentrations were above the level 2 thresholds of Ceará and Sao Paulo (Brazil). Therefore, if Zn, Cr and Cu concentrations are similar in all dredged materials, they would be of moderate concern for spreading the materials in freshwater ecosystems. And for dumping the materials in coastal ecosystems, Zn and Cr would be of moderate concern, but Cu of higher concern. It should be noted that these applications of dredged materials in freshwater or coastal ecosystems correspond with the potential use of the materials in SbN.

Regarding the concentrations of mercury (Hg), cadmium (Cd) and lead (Pb) reported in 2024 by Cormagdalena and INVEMAR contractors, as long as they continue to be reported as values below the limits of quantification (LOQ) of the spectrometry devices, it is not possible to determine which of these metals are of concern. Hg was accurately quantified only at the INVEMAR monitoring site, but the data from this site alone do not allow conclusions to be drawn about risks of Hg contamination throughout the access channel. On the other hand, although the concentrations of Cd and Pb were reported at the Cormagdalena monitoring sites as values below the quantification limits, the concentrations accurately quantified in the deposition zone allow us to consider that Pb would be of moderate concern and Cd of greater concern at this site.

Regarding silver (Ag) and arsenic (As), which have been reported only by UniCartagena at a site near the Industrial Port area in Nov/2013 (Tejeda-Benítez et al., 2018), the report at a single site, and even more so from that date, also does not allow conclusions to be drawn as to whether the concentrations of these substances are of concern. Likewise, there is uncertainty as to whether nickel (Ni) is of concern, as it has only been reported at the INVEMAR monitoring site and in the deposition area, with concentrations above only one of the three level 2 reference thresholds for coastal ecosystems (Sao Paulo).

In summary, from the available information it can be assumed that Cu and Cd are of most concern in the deposition zone, and are likely to be of most concern if materials dredged in the access channel are spread to other coastal/marine areas. For the other heavy metals, there is uncertainty about their degree of concern, as information on their concentration in the access channel has not been sufficiently representative, is not up to date, or has not been quantified with certainty.

5.1.2 Other mineral substances

In terms of toxicity risk, it was not possible to evaluate the information on other mineral substances reported by Cormagdalena, due to the absence of DCS for these substances, so it is not yet possible to determine which are of concern. Considerations for these other mineral substances are described in section 6.1.2 (Information Gaps).

5.2 Organic substances

5.2.1 Polycyclic aromatic hydrocarbons (PAHs)

Phenanthrene and chrysene are the most recently reported PAHs by INVEMAR in Sep/2024, and flouranthene and pyrene were reported by UniCartagena from sampling in Nov/2013 (Tejeda-Benitez et al., 2018). Regardless of the

sampling dates, one report per substance at the same location does not allow conclusions to be drawn as to whether the concentrations of these substances are of concern, relative to the materials dredged along the access channel. The low concentration of total hydrocarbons reported in the deposition area by the Consorcio Dragado Puerto de Barranquilla 2024 - 2025, allows us to assume that PAHs are probably not of concern in the access channel, but this needs to be verified.

5.2.2 Pesticides

Of the 12 pesticides reported by UniCartagena (Tejeda-Benitez et al., 2023), for which thresholds are included in the DCSs of Florida, Brazil or the Netherlands, the concentrations of 11 were below the reference level 1 thresholds; only the concentration of atrazine was above the level 1 threshold for Florida freshwater ecosystems. From this it can be assumed that at the time of sampling (Nov/2014), none of these pesticide concentrations were of concern, and that atrazine may have generated some harm to organisms at the sampling site (near the industrial port of Barranquilla).

However, the concentration of atrazine and possibly the concentrations of other of these 12 pesticides, and even those of the other 27 pesticides reported by UniCartagena, could also be of concern. After FAO (2024) reported that globally Colombia was in 2022 the 9th country with the highest pesticide use, and the highest user per cropped area, it can be assumed that some pesticide residues in dredged materials could be harmful to organisms when discharged into freshwater and coastal ecosystems.

In addition, as UniCartagena determined the pesticide concentration from a sample collected in November, it is also necessary to take into account that November is part of a rainy period and therefore a period of higher river flow. Therefore, this condition could influence in having lower levels compared to those found at the end of dry periods (March and September).

Therefore, to verify if there are pesticides of higher concern, it is necessary to obtain new pesticide concentration data, ideally in March or September. Recommendations for evaluating these new data, as part of a comprehensive sediment chemical quality assessment, are mentioned at 7.1 .

5.3 Reliability of data

If the information described in chapter 3 were taken as a reference to define the risk of contamination from dumping dredged materials in the deposition area, or from using these materials in SbN, the decision would be biased. Cormagdalena, INVEMAR and UniCartagena have conducted their sediment samplings at an unknown depth, which apparently are superficial samplings, and it must be taken into account that in dredging activities the removed material corresponds to a depth interval of 50-100 cm.

Therefore, in order to verify the risk of contamination, it is necessary to elaborate an exhaustive evaluation, representative of the sediments that are dredged. This is particularly relevant considering that some hazardous substances, such as heavy metals, persistent organic compounds (e.g., pesticides and industrial chemicals), and hydrocarbons from industrial, agricultural, municipal and mining activities, end up passing into the marine environment through surface and groundwater. These contaminants can accumulate in marine organisms, affect human health and deteriorate ecosystems .¹⁰

Recommendations for conducting this assessment are provided at 7.1

¹⁰ [Pollution of the sea: application of nuclear techniques | IAEA](#)

6 Information gaps to assess the chemical quality of sediments in the access channel to the port of Barranquilla.



Chapter 6 - Executive Summary

This chapter presents an analysis of the information gaps for evaluating the chemical quality of sediments in the access channel to the port of Barranquilla. In general, these gaps correspond to substances whose concentrations have not been determined, are not updated, or have not been accurately quantified due to the quantification limits of laboratory devices.

It is advisable to conduct further investigations, applying higher sampling density and frequency to close information gaps and contamination uncertainties.

- Mineral substances:
-

- In determining the suitability for beneficial uses of dredged material, other substances to consider include cobalt, molybdenum, antimony, ammonia, phosphate, sulfides, iron (Fe), cyanide (free or complex) and thiocyanates, among other optional ones. These are especially important when the sediments to be used are incorporated into freshwater or coastal ecosystems. For some of these substances there are no thresholds in the SCD of Florida, Brazil and the Netherlands, and it is suggested to determine thresholds for Colombia.
- In sediments where high concentrations of organic matter are a result of anthropogenic contamination, high concentrations of dissolved ammonia and sulfides in these sediments may be considered substances of concern.
- Organic substances:
 - Polycyclic aromatic hydrocarbons (PAHs): it is suggested to extend the investigation with other PAHs.
 - Pesticides: The substances commonly used in pesticides in Colombia are mancozeb, 2,4-D, glyphosate, paraquat, imidacloprid and chlorpyrifos. Therefore, the analysis of these substances could be considered.

Other data required for this type of evaluation are granulometry, organic carbon content and pH. In addition, the abundance of coliforms and emerging contaminants such as PFASs could also be studied.

6.1 Mineral substances

6.1.1 Heavy metals and metalloids

Just as UniCartagena determined As, Ag and Ni concentrations, it is necessary that these substances also be determined by the Colombian institution that will monitor sediment quality to determine the suitability for beneficial uses of the dredged material. In addition, other heavy metals that could also be of concern are cobalt (Co) and molybdenum (Mo); of these two elements it is necessary to keep in mind that while Mo is highly soluble in seawater, Co is less toxic in this saline environment. In addition, another metalloid to consider is antimony (Sb).

To test whether all the heavy metals and metalloids mentioned in this report are of concern, it is suggested to include them in a comprehensive sediment chemical quality assessment, for which recommendations are described in section .7.1

6.1.2 Other mineral substances

Regarding macronutrients, although the concentrations of total nitrogen, total phosphorus and sulfates have been determined by Cormagdalena contractors (section "Other mineral substances" in numeral 3.2.1), in terms of risk of eutrophication¹¹ and subsequent release of toxins by certain algae in lentic ecosystems, the concentrations of ammonia, phosphate and hydrogen sulfide are of concern. MacDonald (1994) mentioned that variables such as ammonia and hydrogen sulfide have the potential to affect benthic organisms, and that concentrations of these compounds should be part of site-specific sediment quality assessments. Subsequently, MacDonald et al. (2003) mentioned that ammonia and hydrogen sulfide concentrations in sediment pore water are high priority quality indicators.

In sediments in which high concentrations of organic matter are the result of anthropogenic contamination, high concentrations of dissolved ammonia and sulfide in these sediments may be considered substances of concern. Such concentrations can be toxic and have effects on benthic ecology (Simpson et al., 2013). This could be the case in Colombia, where not all wastewater is treated and part of it accumulates in the Magdalena River, hence the need to verify the state of ammonia, phosphate and sulfide contamination.

When considering the potential use of dredged materials as a soil amendment in agriculture, other macronutrients to be determined are potassium (K), calcium (Ca) and magnesium (Mg), which are referred to as exchangeable bases.

¹¹ The state of a body of water that is excessively enriched with nutrients, resulting in excessive growth of plants and algae. This overgrowth can disrupt the ecosystem, leading to excessive growth of harmful (toxin-releasing) algal blooms, oxygen depletion and even fish kills.

On the other hand, other micronutrients to consider are iron (Fe), manganese (Mn), and boron (B), which in high concentrations can also be of concern in freshwater ecosystems, coastal ecosystems and agricultural land. Cormagdalena has reported in water of the access channel iron concentrations considerably higher than the threshold of resolution 0883/2018, so it is assumed that the concentration of iron in sediments may be of concern. In addition, other mineral substances for which concentrations remain to be determined are cyanide and thiocyanates.

6.2 Organic substances

6.2.1 Polycyclic aromatic hydrocarbons (PAHs)

In addition to the PAHs that have been monitored by INVEMAR, it is suggested that the concentrations of the other PAHs mentioned in Appendix B be determined. To verify whether PAHs are of concern in the sediments of the access channel, it is suggested that the PAHs in this Appendix B be included in a comprehensive assessment of the chemical quality of the sediments, for which recommendations are described in section .7.1

6.2.2 Pesticides

In addition to the pesticides that were reported by UniCartagena from a sampling conducted in Nov/2014 (Tejeda-Benitez et al., 2023), it is suggested to determine the concentration of the other pesticides mentioned in Appendix B. In addition, it is necessary to take into account that according to IDEAM (2023), the active ingredients mostly used in Colombia are mancozeb, 2,4-D, glyphosate, paraquat, imidacloprid and chlorpyrifos. However, the SCD of Florida, Brazil and the Netherlands do not include thresholds for these pesticides, so Colombia must determine the respective thresholds.

To verify whether the pesticides reported by UniCartagena in Nov/2014 are of concern in the sediments of the access channel, and to know whether the other suggested pesticides are also of concern, it is suggested to include at least the pesticides mentioned in Appendix B, in a comprehensive sediment chemical quality assessment, for which recommendations are described in Section .7.1

Other Organics and Tributyltin

Other organic compounds such as aromatics, chlorobenzenes, chlorophenols, polychlorinated biphenyls (PCBs), other chlorinated hydrocarbons, and other organic substances could also be of concern in the sediments of the access channel. In general, these compounds come from fuels, industrial solvents, detergents, disinfectants, dyes, paints, insulation products, wood preservation products, and products used to make plastics and synthetic chemicals. In addition, another substance that could be of concern is tributyltin (TBT), which is an organometallic compound hazardous to marine animals due to its high bioavailability in salt water in contrast to fresh water.

It is suggested that all of the above compounds be determined to be of concern, and could also be included in a comprehensive sediment chemical quality assessment, recommendations for which are described in section .7.1

6.3 Additional information needed to assess sediment quality

6.3.1 Granulometry, organic matter content, pH and cation exchange capacity.

Granulometry, or more specifically clay content, as well as organic matter content, are sediment characteristics that influence the bioavailability of most mineral substances. This is because clay and organic matter have negative electrical charges, especially at high pH in the case of organic matter and regardless of pH in the case of clay, and to such negative charges the mineral substances present are attached as cations (Simpson and Batley, 2016; Blume et al., 2016; Garavito, 2024). Given that this fraction of attached substances is the one considered reactive, or potentially bioavailable, it is relevant to make the determination of clay and organic matter contents, as well as sediment pH.

According to the above, for future sediment grain size determinations it is suggested to distinguish clay, silt, sand and gravel particles, respectively as sizes <0.002 mm, between 0.002 and 0.063 mm, between 0.063 and 2 mm, and >2 mm (Simpson & Batley, 2016). Regarding the distinction of sand, silt and clay contents, it is suggested to first remove

the organic matter by combustion of the sample, then isolate the gravel by passing the sample through a 2 mm sieve, and subsequently apply a gravimetric method for texture determination to the material passing through this sieve. This method can be the Bouyoucos method (NTC 6299:2018), or for greater accuracy in the determination, the pipette method is applied (ISO 11277:2020), which is also applied in Colombia.

Additionally, taking into account that the sum of negative charges of clay and organic matter is known as the Cation Exchange Capacity - CEC (Simpson and Batley, 2016; Blume et al., 2016; Garavito, 2024), this is a characteristic that also needs to be determined by laboratory test (NTC 5268:2014), in order to evaluate the bioavailability of most metals and arsenic.

6.3.2 Mineralogy of clays

The information on clay types and their composition (mineralogy) is relevant for the following. On the one hand, it allows knowing the total content of each mineral substance of concern (metals and arsenic), in order to relate this content to that of the potentially bioavailable fraction. When the sediment has a high clay content, it is necessary to assess the risk of long-term release of metals and arsenic of concern, in addition to the potentially bioavailable fraction, due to chemical weathering¹² of the clay. The degree of this weathering depends on the climate, water conditions and the presence of biological agents, of the environment where the material is present (Blume et al., 2016; Garavito, 2024).

On the other hand, it is necessary to take into account that the type of clay has an effect on its degree of expansion and contraction. If the predominant clay type is kaolinite, it is more susceptible to compact in humid environments, while if smectite clay predominates, it is more susceptible to contract or expand depending on its humidity level (Blume et al., 2016; Garavito, 2024). According to the above, when the sediment has high clay content, the determination of the type of clay is required to determine the viability of various uses of the dredged material.

6.3.3 Other information to consider

Abundance of fecal coliforms

Not all domestic wastewater in the Magdalena River basin is treated, and in 2024 Cormagdalena and INVEMAR reported abundances of total coliforms in water from their access channel monitoring sites, which were higher than the permissible limit of 1000 individuals per 100 ml (limit in recreational water bodies, according to article 2.2.3.3.3.9.7. of Colombian decree 1076/2015). Based on the above, the abundance of coliforms in sediment pore water could be of concern for uses of dredged materials in freshwater ecosystems, where humans are likely to be in contact with the water. Based on the above, a proposal for cases where fecal coliform abundance in sediment pore water needs to be assessed is presented in section 3.2.2 of Report 4 of this consultancy.

Emerging contaminants

Emerging contaminants include pharmaceuticals, microplastics, PFASs and synthetic nanoparticles. Following the development of nanotechnology in the 21st century, the synthesis of sub-100 nm particles for a variety of uses has been undertaken. While some of these nanoparticles (NPs) are organic and their by-products are non-toxic, some NPs containing silver (Ag), gold (Au) or copper (Cu), may be toxic. More research is needed on the environmental effects of these NPs, which are present in some electronic devices, cosmetics, and other products, and have been used as antimicrobial agents in pesticides, sportswear, and food packaging (Tortella et al., 2024; Altammar, 2023; Garcia-Torra et al., 2021).

As for microplastics, they can be of different polymeric compositions, sizes and shapes, and some polymers contain additives that leach out over time (e.g., plasticizers, flame retardants or stabilizers). Due to the presence of microplastics in air and water, they have entered the food chain, and while some academics claim that the potential risks to human health remain poorly defined, others have reported that microplastics cause endocrine disruption and metabolic disorders, such as obesity and diabetes (Marcharla et al., 2024; Brouwer et al. 2023). In Colombia, microplastic density has been monitored by INVEMAR only in coastal tourist beaches, with the support of MinAmbiente. INVEMAR has reported microplastics of size between 1-5000 µm, taking them into account as a factor

¹² Decomposition of rocks and minerals by chemical reactions with water, air and biological agents.

of environmental degradation, caused mainly by inadequate disposal and management of liquid and solid waste (INVEMAR-CRA, 2024).

On the other hand, domestic wastewater includes pharmaceutically active compounds (PhACs), which can also accumulate in sediments and organisms. These PhACs cause serious harm to human health and aquatic organisms, including endocrine disruption, disruption of thyroid and other hormones, and disruption of fish reproduction. In Colombia, the Universidad de la Costa and the Central Unit of Valle del Cauca have reported concentrations of several PhACs in rivers and coastal ecosystems; these PhACs include naproxen, ibuprofen, caffeine, and estrogens (Guzman-Tordecilla et al, 2025; Buitrago-Gonzalez et al., 2024), and illicit drugs have also been reported (Buitrago-Gonzalez et al., 2024).

As for PFASs (per- and polyfluoroalkyls), these have been used in the chrome plating process, in the treatment of textiles, carpets and paper, and as compounds in paints, food packaging, flame retardant foams and non-stick cookware. These substances are considered persistent organic pollutants, which cause health problems such as liver damage, thyroid disease, obesity, fertility problems and cancer .¹³

As for thresholds for the emerging pollutants mentioned, only PFASs have been included in a Dutch regulation, and no thresholds have been determined in the other countries. If there is interest in implementing thresholds for these compounds in Colombian CSD, research is needed to determine the toxicity risk caused by each compound.

¹³ <https://quimicos.minambiente.gov.co/wp-content/uploads/2024/09/Sin-titulo.pdf>

7 Recommendations for evaluating the chemical quality of sediments in dredged areas of Colombian seaports and establishing sediment quality guidelines.



Chapter 7 - Executive Summary

For the dredging area of each maritime port zone, it is recommended that an exhaustive evaluation of the chemical quality of sediments be carried out, in order to verify which of the substances reported so far by Colombian entities are of concern, and to determine which of the other substances mentioned in Appendix F are also of concern. Subsequently, the information generated can be used as a basis for determining the specific SCD for each Colombian maritime port area.

The main key points of this chapter are:

- A thorough assessment of the chemical quality of the sediment is recommended to verify which substances are of concern both in the channel and in the deposition zone.
 - Sampling: In general, it is suggested to consider four variables for sediment sampling: 1) # of sampling sites and their distribution; 2) depth intervals to be characterized; 3) # of subsamples required to collect a composite sample representative of each depth interval; 4) # of replicates per sampling site, to account for within-site variability through statistical analysis.
 - Analytical techniques: each analytical technique has its own strengths and limitations, so the choice of method depends on the specific analytical objectives. Factors such as the compounds of interest, their physicochemical properties, such as volatility, and the desired sensitivity for the compound analyzed, play an important role in the analytical decision-making process. In addition, application-specific requirements must also be taken into account, and cost considerations are a constraint in some cases.
-

7.1 Comprehensive sediment chemical quality assessments to verify which substances are of concern in the sediments of maritime port areas.

In order to verify which substances are of concern not only in the access channel to the port of Barranquilla, but also in the dredged areas of the other maritime ports of Colombia, it is suggested that comprehensive sediment quality assessments be prepared. For these evaluations, it is suggested that the concentrations of the substances mentioned in Appendix F be determined. Subsequently, once the information is obtained, while there are still no thresholds for sediments in Colombia, the concentration of each substance can be compared with the Florida thresholds, both for freshwater ecosystems (Appendix B) and for coastal ecosystems (Table 4-1 of report 2 of this consultancy).

It is suggested to temporarily use the Florida thresholds because in the American continent there are officially only thresholds for the USA and Canada, and of these countries the state of Florida is the one that has the most similar environmental conditions to those of Colombia. As for the Brazilian thresholds, those for freshwater ecosystems are adopted from US and Canadian thresholds, and those for coastal ecosystems were proposed by universities. Although the latter are considered valid methods, they have not been officially implemented by any Brazilian authority, so it is better not to use Brazilian thresholds as a temporal reference in Colombia.

After comparing the information generated by Cormagdalena, INVEMAR and UniCartagena on sediment quality in the access channel to the port of Barranquilla, it can be considered that this comparison is biased, due to possible differences in sampling methods, and differences in laboratory methods applied by each entity. Since the Cormagdalena and INVEMAR reports do not mention details on the sampling method, it is necessary that such information be described in future reports. According to the above, in order to elaborate comprehensive sediment quality assessments, it is necessary to first define a methodology, for which the following are recommended criteria to be considered for sediment sampling and the application of laboratory analytical techniques.

7.1.1 Recommendations for sediment sampling

While INVEMAR and UniCartagena have characterized the quality of the sediments in order to evaluate the state of health of the marine-coastal and freshwater ecosystems, Cormagdalena's objective has been to verify whether its contractors in charge of maintenance dredging activities are complying with their environmental management plan. The depth range of the samples taken by these entities is unknown, and it is generally inferred that they correspond to surface samples. In contrast to this, considering the current interest in determining whether the dredged materials can be used for beneficial uses, it is necessary to take into account that dredging is carried out to a depth of 50-100 cm, and it is suggested that a sampling method be applied to obtain representative information from this dredging depth, including the necessary information on stratification.

In general, it is suggested to consider four variables for sediment sampling: 1) # of sampling sites and their distribution; 2) depth intervals to characterize; 3) # of subsamples needed to collect a composite sample representative of each depth interval; 4) # of repetitions per sampling site, to account for within-site variability through statistical analysis.

As it is necessary to obtain information on sediment quality representative of the depth that a dredge reaches (50-100 cm), it is suggested to apply a sampling method that allows to extract sediments at least up to 50 cm depth, from which sub-samples can be taken. For this purpose, some researchers have obtained their subsamples from sediments extracted using a multicore tool or an Ekman box sampler. While the multicore extracts sediment in 3-4 plastic tubes¹⁰, the Ekman box sampler extracts sediment in the box, and some of that material is extracted in plastic tubes (Figure - 71).

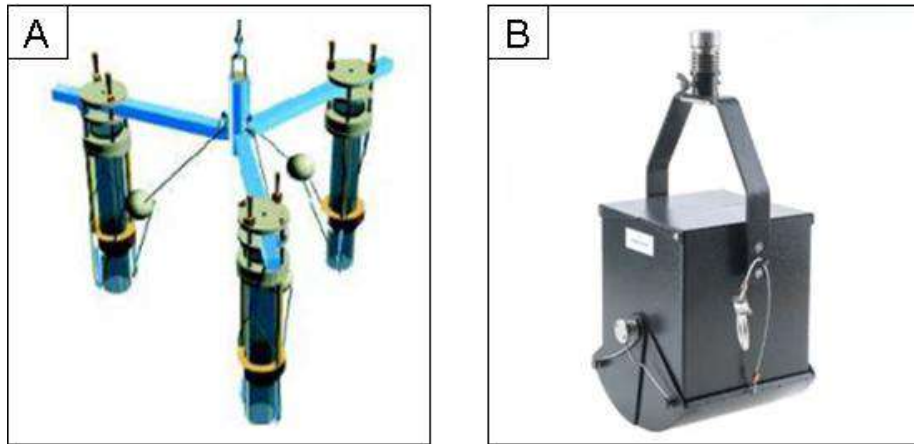


Figure -71 : (A) Multi-core tool (Source: IDEAM & INVEMAR, 2021); (B) Ekman box sampler (Source: environmental-expert.com). See also UIC Sediment Coring aboard the R/V Lake Guardian (Multicore Tool) and TDI-Brooks Box Coring (Ekman Box Sampler).

The Van Veen grab is another tool that can be used to extract sediment, but is useful when the interest is to obtain subsamples at shallower depths. The multicore tool is the most accurate technology for sampling at greater depths, but this technology requires a higher investment than the Ekman box sampler.

Once the sediment has been extracted in the plastic tubes, 2 cm thick subsamples can be extracted at the depth intervals of interest (e.g., 0-2 cm and 40-42 cm). To obtain each composite sample, the # of subsamples depends on the # of tubes used in the sampling, and the investigator can decide whether to perform replicates at each sampling site, to account for within-site variability by statistical analysis (at least three replicates). As for the number and distribution of sampling sites, the investigator can determine this by taking into account the extent and shape of the study area.

7.1.2 Recommendations on laboratory analytical techniques

Laboratory analytical techniques encompass a wide range of methods designed to detect specific substances and quantify their concentration. Previously, it is required to extract the fraction of interest from the sample. For the extraction of any heavy metal or metalloid, the extraction of the "reactive concentration" (also called "potentially bioavailable concentration") is necessary to assess the chemical quality of the sediment. This extraction is performed by laboratory chemical digestion with an acid solution. The techniques applied to determine the reactive concentration of heavy metals and arsenic reported by Colombian entities, except for mercury (Hg), have been the $\text{HNO}_3+\text{H}_{(2)}\text{O}_2$ solution (Cormagdalena; Tejada-Benitez et al., 2018), microwave-assisted acid digestion¹⁴ (INVEMAR), and Aqua regia (Tejada-Benitez et al., 2016). In recent years, Aqua regia has been considered to extract more than the reactive concentration, so it is suggested to use the solution $\text{HNO}_3+ \text{H}_{(2)}\text{O}_2$. Regarding Hg, considering its volatility, it is suggested to extract its reactive concentration by means of controlled heating in an oxygen decomposition furnace, a technique that has been applied by INVEMAR. Regarding the techniques applied for the extraction of organic compounds from sediment samples, these are outlined in the Table -71

Table -71 : Summary of extraction techniques used by Cormagdalena, INVEMAR and UniCartagena contractors to extract organic compounds.

Type of substance(s)	Extraction technique	Advantages of the technique	Disadvantages of the Technique	Measuring Entity (Source of data)
Pesticides	QUEChERS ¹⁵	- Minimal use of solvents	- Not suitable for all samples - Used more for practical screening than for quantification	UniCartagena - Tejada-Benitez et al. (2023)

¹⁴ With HNO_3+HF solution, or $\text{HCl}+\text{H}_{(2)}\text{O}_2$ solution.

¹⁵ Fast, easy, inexpensive, effective, resistant and safe.

Type of substance(s)	Extraction technique	Advantages of the technique	Disadvantages of the Technique	Measuring Entity (Source of data)
PAHs and hydrocarbons	Soxhlet	- Effective for solid-liquid extraction - Well established and reliable	- Time consuming - High solvent usage - Shows lower extraction efficiency (compared to microwave-assisted extraction), especially for lighter PAHs	UniCartagena - Tejada-Benitez et al. (2017), and Cormagdalena.
Pesticides and PAHs	Microwave-assisted extraction	- Faster extraction process - Lower solvent usage compared to Soxhlet. - Best performance for organochlorine pesticides. ¹⁶	- Requires specialized equipment - May not be suitable for all sample types	INVEMAR

After extraction, a wide range of analytical methods can be used to quantify the concentration of substances in sediments. Depending on the analytical methods, different limits of detection (LOD) and limits of quantification (LOQ) can be achieved. LODs represent the lowest concentration of substances above which the presence of the substance can be reported, with quantification being of low accuracy, whereas the limit of quantification (LOQ) represents the lowest concentration above which the substance can not only be reliably detected, but also accurately quantified. Therefore, it is imperative to have a clear understanding of LODs as well as LOQs, as the interpretation of low concentration data can become uncertain and lead to erroneous conclusions. Furthermore, depending on the characteristics of the compound of interest, different analytical techniques can be used; for example, for heavy metals, flame AAS (atomic absorption spectrometry) or ICP-MS (inductively induced plasma mass spectrometry) are suitable, whereas, for volatile compounds, such as many pesticides or some PAHs, GC-MS (gas chromatography-mass spectrometry) is appropriate. In the Table -72 the advantages and disadvantages of the analytical techniques used to quantify the concentrations reported by the Colombian entities are presented.

Table -72 : Summary of analytical techniques used by contractors Cormagdalena, INVEMAR and UniCartagena.

Type of pollutants measured	Analytical method(s)	Analytical Method Advantages	Disadvantages Analytical Method	LOD ^v	LOQ ^v	Typical Units ^v	Entity that has used the technology
Some heavy metalsn (Cr, Ni, Pb, Zn, Cd and Cu)	Atomic absorption spectrometry (AAS), using flame.	- Highly selective ⁱ - Easy to operate with simple sample preparation - Cost-effective (CAPEX and OPEX)	- Single element analysis (one element at a time) - Chemical interferences ^{(i) (iii)} (i)	2-500 µg/L ^(17,18,19,20)	20-5000 µg/L ^{((14.) (15) (.) (16) (.) (17) (i))}	µg/L	INVEMAR and Cormagdalena
Arsenic and other heavy metals (Cr and Ag)	Inductively coupled plasma mass spectrometry (ICP-MS).	- High sensitivity ^{iv} (ultra-trace detection, so the LOD is very low).	- Spectral interference - High cost (CAPEX and OPEX)	5-20 ng/L ^(15, 16, 17)	50-200 ng/L ^(15, 16, 17)	ng/L	UniCartagena - Tejada-Benitez et al. (2018).

¹⁶ Zondo, S., & Mahlambi, P. (2025). Comparison of soxhlet and microwave-assisted extractions efficiency for the determination of herbicides in soil and maize crop: Cumulative and health risks assessment. *Environmental and Food Safety Journal*. <https://doi.org/10.1002/efd2.177>

¹⁷ U.S. Environmental Protection Agency (n.d.). Method 7000B: *Flame atomic absorption spectrophotometry*. In *Test methods for evaluating solid waste, physical/chemical methods (SW-846)*. Retrieved from <https://www.epa.gov/hw-sw846>

¹⁸ Cs Analytical (n.d.). *Comparison of atomic spectroscopy techniques and the advantages of ICP-MS vs. AA & ICP-OES*. Retrieved December 9, 2025, from <https://csanalytical.com/comparison-atomic-spectroscopy-techniques-advantages-icp-ms-vs-aa-icp-oes/>

¹⁹ Tyler, G. (n.d.). *ICP-OES, ICP-MS and AAS techniques compared* [PDF]. Jobin Yvon S.A.S., Horiba Group. Retrieved December 9, 2025, from https://www.horiba.com/fileadmin/uploads/Scientific/Downloads/OpticalSchool_CN/TN/ICP/ICP-OES_ICP-MS_and_AAS_Techniques_Compared.pdf

²⁰ Agilent Technologies (n.d.). *GFAAS vs ICP-MS vs ICP-OES*. Retrieved December 9, 2025, from <https://www.agilent.com/en/product/atomic-spectroscopy/gfaas-vs-icp-ms-vs-icp-oes>.

Type of pollutants measured	Analytical method(s)	Analytical Method Advantages	Disadvantages Analytical Method	LOD ^v	LOQ ^v	Typical Units ^v	Entity that has used the technology
		- Multi-element analysis					
PAHs	Gas chromatography followed by mass spectrometry (GC - MS).	- High sensitivity.	- Sample volatility: limited to compounds that can be vaporized without decomposition.	1-10 ng/L (SIM mode) ²¹	10-300 ng/L	ng/L	UniCartagena - Tejeda-Benitez et al. (2018) and INVEMAR
Pesticides (organic chlorine and others).	Gas chromatography followed by tandem mass spectrometry (GC-MS/MS).	- Higher selectivity and sensitivity compared to GC-MS	- Higher cost and complexity compared to single MS due to additional MS column	0.1-1 ng/L ²²	1-10 ng/L	ng/L	UniCartagena - Tejeda-Benitez et al. (2018).

- i. Focuses on measuring the absorption of specific wavelengths by atoms, which reduces the probability of overlapping signals from other elements.
- ii. Chemical interference occurs when components of the sample matrix interact with the analyte, preventing efficient atomization or altering its absorption signal, leading to inaccurate measurements
- iii. (It analyzes mainly surface layers, which limits its ability to assess bulk composition and makes it sensitive to surface contaminants).
- iv. Sensitivity in analytical chemistry refers to the ability of an analytical method or instrument to reliably detect and measure small amounts or low concentrations of a substance in a sample
- v. (Limits of detection and quantification can vary significantly depending on the element or analyte, the specific method, instrument configuration, and sample matrix conditions. The values provided are typical practical ranges for aqueous analysis under standard conditions) (However, LOQ (limit of quantification) is usually 3 to 10 times the LOD) (Limit of Detection)²³.

The selection of an analytical technique is highly dependent on the specific requirements of the analysis, such as the type of sample, the analyte of interest, and the desired sensitivity to conform to the established standard and its compound-specific threshold. As presented in the tables above, a number of analytical and extraction techniques have been used to detect and quantify a wide diversity of compounds.

- Flame atomic absorption spectroscopy (flame AAS) is suitable for trace metal analysis in liquids, but is limited to the detection of a single element, making analysis of multiple elements time consuming.
- Inductively coupled plasma mass spectrometry (ICP-MS) offers exceptional sensitivity for trace-level quantification, although it is expensive and complex.
- Gas chromatography plus mass spectrometry (GC-MS) excels in the analysis of volatile organic compounds with high sensitivity, although it is limited to volatile compounds only.
- Gas chromatography plus tandem mass spectrometry is more sensitive than GC-MS because it has an additional MS column, but it is also more expensive and complex.

Another technology that can be used to quantify the concentration of mineral elements in sediments, after extraction of the reactive concentration, is X-ray fluorescence (XRF). This technology is ideal for rapid analysis, detects several elements and is cheaper than ICP-MS. However, for trace-level quantification or for complex samples, XRF is not sufficiently accurate and sensitive compared to spectrometric techniques such as ICP-MS. Recently, a new technology called monochromatic XRF, which is cheaper than ICP-MS and has similar quantification capabilities, has been offered on the market and has been used in Colombia by entities such as Agrosavia and CIAT.

²¹ Thermo Fisher Scientific. (n.d.). Technical Note TN10431: *GC-MS detection limits in SIM mode for environmental analysis*. Thermo Fisher Scientific. Retrieved from <https://www.thermofisher.com>

²² Agilent Technologies. (n.d.). *Mass spectrometry guide: GC-MS and GC-MS/MS sensitivity and quantitation performance*. Agilent Technologies. Retrieved from <https://www.agilent.com>

²³ CORESTA (2020). *Guide No. 28: LOD/LOQ for determination of metals*. Retrieved December 9, 2025, from https://www.coresta.org/sites/default/files/technical_documents/main/Guide-No28_LODLOQ-for-Determination-of-Metals_Nov20.pdf

In conclusion, each analytical technique has its own strengths and limitations, so the choice of method depends on the specific analytical objectives. Factors such as the compounds of interest, their physicochemical properties, such as volatility, and the desired sensitivity for the compound analyzed, play an important role in the analytical decision-making process. However, it is recommended that analytical techniques selected in the future require a minimum limit of quantification below the Tier 1 thresholds established in the sediment quality guidelines used as a reference. Finally, application-specific requirements must also be taken into account, and cost considerations are a constraint in some cases.

7.2 Recommendations for establishing sediment quality guidelines for each maritime port zone in Colombia.

The researchers who proposed site-specific SCDs for the coasts of the Ceará and Sao Paulo regions (Brazil) suggested that these SCDs could be adopted by the state as a reference point for environmental quality assessments (Moreira et al. 2021; 2022). Based on the above, Colombia can similarly establish DCS for the dredging area of each maritime port zone, this work being coordinated by MinAmbiente, with the participation of INVEMAR and some universities, and involving the Regional Autonomous Corporations. It is important to emphasize what was mentioned in reports 1 and 2 of this consultancy, about the influence of pH and the clay and organic matter contents of the sediments, on the bioavailability of substances, and therefore on the toxicity risks. Given the variability of these conditions per site, it is suggested that, based on empirical evidence, thresholds be determined for each maritime port area, in relation to the environment where each beneficial use of dredged material is made. For this determination of thresholds, information on pH and clay and total organic carbon contents in sediments of each port area is required, in order to normalize the concentrations of metals, mineral and organic substances, according to the variability of texture, organic matter and cation exchange capacity. In order to apply this normalization, it is then necessary to apply criteria from the equilibrium partitioning approach.

Similar to the criteria applied by Moreira et al. (2021; 2022), including toxicity tests with the burrowing amphipod *Tiburonella viscana*, in Colombia UniCartagena has evaluated the chemical quality of sediments in sites of the Magdalena River, including criteria from toxicity tests with the nematode *Caenorhabditis elegans* (Tejeda-Benitez et al., 2026; 2018; 2023). Therefore, UniCartagena has potential to contribute to research aimed at the determination of thresholds specific to Colombia. On the other hand, toxicity identification and assessment tests can be used to confirm whether ammonia or sulfides in sediments are of risk when making uses of dredged materials in lentic aquatic ecosystems.

7.3 Recommendation for monitoring sediment chemical quality, aimed at determining what beneficial uses dredged materials are valid for .

For uses of materials from maintenance dredging, periodic evaluations are recommended to ensure that the level of sediment contamination since the last dredging cycle (PIANC, 1992). Once the DCS for the dredged areas of the Colombian seaports have been determined, in relation to the uses of the dredged materials, the monitoring of the physical and chemical quality of the sediments can be performed once or twice a year (e.g., at the end of the dry seasons, in March and September²⁴). These times are suggested considering two aspects 1) that with such climatic conditions the sampling work can be performed more easily; 2) that considering the lower river flows tributary near each marine port area, the concentrations of substances in the sediments are expected to be higher compared to those of rainy periods. Therefore, the most worrisome concentrations can be determined at the end of dry periods, and the most suitable time to monitor the Barranquilla access channel is in March, which is the month prior to maintenance dredging.

²⁴ However, it is necessary to assume that at present there is uncertainty about climatic conditions, influenced by the El Niño and La Niña phenomena in the case of countries near the Pacific Ocean.

If there is interest in monitoring more frequently, taking into account the requirements mentioned in the previous paragraphs, it is necessary to determine whether the available budget allows for more frequent monitoring. Additionally, in the event that unusual contaminant discharges are reported (e.g., oil spills upstream), it is necessary to add additional sediment characterization to the usual sediment monitoring.

8 References

- Altammar KA (2023). A review on nanoparticles: characteristics, synthesis, applications, and challenges. *Frontiers in Microbiology, Volume 14-2023*.
- Blume HP, Brümmer GW, Fleige H, Horn R, Kandeler E, Kögel-Knabner I, Kretzschmar R, Stahr K, & Wilke BM (2016). *Scheffer/Schachtschabel: Soil science*. Berlin and Heidelberg: Springer-Verlag.
- Bravo D, Leon-Moreno C, Martínez CA, Varón-Ramírez VM, Araujo-Carrillo GA, Vargas R, Quiroga-Mateus R, Zamora A, & Rodríguez EAG (2021). The First National Survey of Cadmium in Cacao Farm Soil in Colombia. *Agronomy, 11(4)*, 761.
- Brouwer H, van Oijen FLN, & Bouwmeester H. (2023). Chapter 40 - Potential human health effects following exposure to nano- and microplastics, lessons learned from nanomaterials. In M. E. Knowles, L. E. Anelich, A. R. Boobis, & B. Popping (Eds.), *Present Knowledge in Food Safety* (pp. 590-605). Academic Press.
- Buchman MF (2008). Screening Quick Reference Tables (SQuiRTs), NOAA OR&R Report 08-1. Office of Response and Restoration Division, National Oceanic and Atmospheric Administration. Seattle WA.
- Buitrago-González ME, Sánchez-Pinto JD, Martínez-Martina M, Rodríguez-Correa AM, Virviescas-Ospina MJ & Santacoloma-Londoño S (2024). Emerging Pharmaceutical Pollutants in Colombian Watersheds and Environmental Management Measures. *Journal of Hunan University (Natural Sciences), 51(10)*.
- Barranquilla Canal Study Consortium (2020). Environmental study for the improvement of the infrastructure and navigation of the Barranquilla Port access channel to the PIMSA Sector.
- Consorcio Dragado Puerto de Barranquilla 2024 - 2025 (2025). Hydrobiological and sedimentological study on the area of final disposal of sediments. 73 p.
- Cormagdalena (2007). Atlas Cuenca Del Río Grande de la Magdalena. 283 p.
- Cormagdalena. Cormagdalena Contractors' Reports 2023 and 2024.
- FAO (2024). Pesticides use and trade: 1990-2022. FAOSTAT Analytical Brief 89.
- Garavito F (2024). *Chemical properties of soils*. Instituto Geográfico Agustín Codazzi (IGAC), Bogotá, Colombia.
- García-Torra V, Cano A, Espina M, Ettcheto M, Camins A, Barroso E, Vazquez-Carrera M, García ML, Sánchez-López E, & Souto EB (2021). State of the Art on Toxicological Mechanisms of Metal and Metal Oxide Nanoparticles and Strategies to Reduce Toxicological Risks. *Toxics, 9(8)*, 195.
- Gonzalez Cano WT & Kim K (2022). How to Achieve Sustainably Beneficial Uses of Marine Sediments in Colombia. *Sustainability 14(22)*, 14821.
- Guzmán-Tordecilla M, Elles Pérez C, Ramos de la Hoz Y, Castillo Ramírez M, Medina Altahona J, Garzón Rodríguez C, Burgos Nuñez S, Paternina Uribe R, Enamorado Montes G, Jiménez Vergara E, Urango Cardenas I, Escobar Delgado L, Ortega Pardo K & Díaz Hernández L. (2025). Environmental quality and emerging pollutants: a look at the Mallorquín and Arroyo León swamp. Editorial Universitaria de la Costa, S.A.S.
- IDEAM (2023). National Water Study 2022. Institute of Hydrology, Meteorology and Environmental Studies (IDEAM). 512 p.
- IDEAM & INVEMAR. 2021. Protocolo de Monitoreo y Seguimiento del Agua. Bogotá, D. C.. 631 p.

INVEVAR. Marine Environmental Information System (SIAM) - Microdata Search - Thematic.
<https://siamexplorer.invevar.org.co/microdatos/tematica>

INVEVAR (2003). Manual de técnicas analíticas para la determinación de parámetros fisicoquímicos y contaminantes marinos (aguas, sedimentos y organismos). INSTITUTO DE INVESTIGACIONES MARINAS Y COSTERAS José Benito Vives De Andrés - INVEVAR. 148 p.

INVEVAR (2024). Diagnosis and Evaluation of Marine and Coastal Water Quality in the Colombian Caribbean and Pacific. Cusba, J, Obando, P and Espinosa, L (Eds). Monitoring Network for the Conservation and Protection of Marine and Coastal Waters of Colombia - REDCAM: INVEVAR, MinAmbiente, CORALINA, CORPOGUAJIRA, CORPAMAG, CRA, CARDIQUE, CARSUCRE, CVS, CORPOURABÁ, CODECHOCÓ, CVC, CRC and CORPONARIÑO. Final Technical Report 2023, Santa Marta. 177 p.

INVEVAR-CRA (2024). Generation of technical-scientific information to support the environmental management of the regional autonomous corporation of Atlántico- CRA in the coastal zone of the department of Atlántico. 194 p.

MacDonald DD (1994). *Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Volume 1: Development and Evaluation of Sediment Quality Assessment Guidelines*. Report prepared for Florida Department of Environmental Protection. Tallahassee, Florida. 140 p.

MacDonald DD, Ingersoll CG, Smorong DE, Lindskoog RA, Sloane G & Biernacki T. (2003). Development and evaluation of numerical sediment quality assessment guidelines for Florida inland waters. MacDonald Environmental Sciences Ltd., United States Geological Survey and Florida Department of Environmental Protection. 150 p.

Marcharla E, Vinayagam S, Gnanasekaran L, Soto-Moscoso M, Chen WH, Thanigaivel S, & Ganesan S. (2024). Microplastics in marine ecosystems: A comprehensive review of biological and ecological implications and its mitigation approach using nanotechnology for the sustainable environment. *Environmental Research*, 256, 119181.

Moreira LB, Braga Castro Í, Fillmann G, Peres TF, Cavalcante Belmino IK, Sasaki ST, Taniguchi S, Bicego MC, Marins RV, Drude de Lacerda L, Costa-Lotufo LV, & de Souza Abessa DM (2021). Dredging impacts on the toxicity and development of sediment quality values in a semi-arid region (Ceará state, NE Brazil). *Environmental Research*, 193.

Moreira LB, Choueri RB, & de Souza Abessa DM (2022). A consensus-based approach for the development of Site-specific Sediment Quality Values in an SW Atlantic region (São Paulo State, Brazil). *Journal of Hazardous Materials Advances*, 7.

Moreno-Madriñán MJ, Rickman DL, Ogashawara I, Irwin DE, Ye J & Al-Hamdan MZ (2015). Using remote sensing to monitor the influence of river discharge on watershed outlets and adjacent coral Reefs: Magdalena River and Rosario Islands, Colombia. *International Journal of Applied Earth Observation and Geoinformation*, 38, 204-215.

Rahman Z & Singh VP (2019). The relative impact of toxic heavy metals (THMs) (arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. *Environmental Monitoring and Assessment*, 191, 419.

Restrepo JD, Kjerfve B, Hermelin M, & Restrepo JC (2006). Factors controlling sediment yield in a major South American drainage basin: the Magdalena River, Colombia. *Journal of Hydrology*, 316(1), 213-232.

Restrepo JD & Syvitski JPM (2006). Assessing the Effect of Natural Controls and Land Use Change on Sediment Yield in a Major Andean River: The Magdalena Drainage Basin, Colombia. *AMBIO: A Journal of the Human Environment*, 35(2), 65-74.

Colombian Geological Service. Geochemical Atlas of Colombia Version 2020, 2018, and 2016.
<https://www2.sgc.gov.co/sgc/mapas/Paginas/AtlasGeoquimico.aspx>.

Simpson SL & Batley GB (2016). *Sediment quality assessment: A practical guide*. 2nd edition. CSIRO Publishing. Clayton South - Australia. 359 p.

Tejeda-Benitez L, Flegal R, Odigie K, & Olivero-Verbel J (2016). Pollution by metals and toxicity assessment using *Caenorhabditis elegans* in sediments from the Magdalena River, Colombia. *Environmental Pollution*, 212, 238-250.

Tejeda-Benítez, L, Noguera-Oviedo K, Aga DS, & Olivero-Verbel J (2018). Toxicity profile of organic extracts from Magdalena River sediments. *Environmental Science and Pollution Research*, 25(2), 1519-1532.

Tejeda-Benítez L, Noguera K, Aga D, & Olivero-Verbel J (2023). Pesticides in sediments from Magdalena River, Colombia, are linked to reproductive toxicity on *Caenorhabditis elegans*. *Chemosphere*, 339.

Tortella G, Rubilar O, Fincheira P, Parada J, Caixeta de Oliveira H, Benavides-Mendoza A, Leiva S, Fernandez-Baldo M & Seabra AB (2024). Copper nanoparticles as a potential emerging pollutant: Divergent effects in the agriculture, risk-benefit balance and integrated strategies for its use. *Emerging Contaminants*, 10(4), 100352.

Appendices

Appendix A – Contents of gravel, sand and silt + clay

Reports from Cormagdalena before dredging, and in monitoring of sediments physicochemical quality of Cormagdalena and INVEMAR (Calculations from data of Cormagdalena, and data reported by INVEMAR-CRA).

6.	Sector	7.	Institution (activity)	8.	Year-Month	9.	Reported Km or Km interval	10.	Silt+Clay%	11.	Sand%	12.	Gravel%		
13.	I	14.	Cormagdalena (chemical quality monitoring)	15.	2023-03	16.	K1+000 (Bocas de Ceniza)	17.	94.1	18.	5.9	19.	0.0		
				20.	2023-06	21.	K1+000 to K2+000	22.	1.6	23.	98.4	24.	0.0		
				26.	2023-06	27.	K1+000 to K2+000	28.	65.9	29.	34.1	30.	0.0		
				31.	2023-08	32.	K0+000 to K2+000	33.	97.0	34.	3.0	35.	0.0		
				36.	2023-08	37.	K0+000 to K2+000	38.	83.6	39.	16.4	40.	0.0		
				41.	2023-08	42.	K0+000 to K2+000	43.	94.1	44.	5.9	45.	0.0		
				46.	2023-10	47.	K0+500 to K2+000	48.	94.7	49.	5.0	50.	0.3		
				51.	2023-12	52.	K1+000 to K2+000	53.	86.3	54.	13.7	55.	0.0		
				56.	2023-12	57.	K0+000 to K2+000	58.	41.3	59.	58.3	60.	0.4		
				61.	Cormagdalena (chemical quality monitoring)	62.	2024-03	63.	K1+000 (Bocas de Ceniza)	64.	86.9	65.	13.1	66.	0.0
				67.	Cormagdalena (report before dredging)	68.	2024-05	69.	K0+000 to K2+000	70.	10.6	71.	89.4	72.	0.0
						73.	2024-05	74.	K1+000 to K2+000	75.	76.5	76.	23.5	77.	0.0
						78.	2024-05	79.	K0+000 to K2+000	80.	94.7	81.	5.3	82.	0.0

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF MARINE
SEDIMENTS DRAINED IN COLOMBIA, INCLUDING NATURE-BASED
SOLUTIONS.

6.	Sector	7.	Institution (activity)	8.	Year- Month	9.	Reported Km or Km interval	10.	Silt+Clay%	11.	Sand%	12.	Gravel%
				83.	2024- 07	84.	K0+400 to K0+500	85.	29.6	86.	70.2	87.	0.2
				88.	2024- 07	89.	K0+400 to K1+160	90.	3.1	91.	96.9	92.	0.0
93.	II	94.	Cormagdalena (chemical quality monitoring)	95.	2023- 03	96.	K7+500 (Las Flores)	97.	94.2	98.	5.8	99.	0.0
		100.	Cormagdalena (report before dredging)	101.	2023- 10	102.	K2+000 to K4+000	103.	96.7	104.	3.3	105.	0.0
		106.	Cormagdalena (chemical quality monitoring)	107.	2024- 03	108.	K7+500 (Las Flores)	109.	72.5	110.	27.5	111.	0.0
112.	III	113.	Cormagdalena (chemical quality monitoring)	114.	2023- 03	115.	K15+000 (Boya 15)	116.	84.7	117.	15.3	118.	0.0
		119.	INVEMAR (chemical quality monitoring)	120.	2023- 09	121.	K9+000 (Base naval – 17)	122.	54.1	123.	45.7	124.	0.2
		125.	Cormagdalena (report before dredging)	126.	2023- 10	127.	K11+000 to K15+000	128.	6.0	129.	93.8	130.	0.2
		131.	Cormagdalena (chemical quality monitoring)	132.	2024- 03	133.	K15+000 (Boya 15)	134.	96.6	135.	3.4	136.	0.0
		137.	INVEMAR (chemical quality monitoring)	138.	2024- 09	139.	K9+000 (Base naval – 17)	140.	74.1	141.	25.7	142.	0.2
143.	IV	144.	Cormagdalena (chemical quality monitoring)	145.	2023- 03	146.	K22+000 (Puente Pumarejo)	147.	23.6	148.	76.4	149.	0.0
		150.	Cormagdalena (report before dredging)	151.	2023- 06	152.	K19+300 to K21+000	153.	10.8	154.	89.2	155.	0.0
		156.	Cormagdalena (chemical quality monitoring)	157.	2024- 03	158.	K22+000 (Puente Pumarejo)	159.	89.2	160.	10.8	161.	0.0

Appendix B – Thresholds for freshwater ecosystems from SQGs of Florida, Brazil and the Netherlands

			Florida (USA)	Brazil	The Netherlands	Florida (USA)	Brazil	The Netherlands
Category 1	Category 2	Substance	Level 1	Level 1	Level 1	Level 2	Level 2	Level 2
Mineral substances	Trace metals (mg/kg)	Cadmium (Cd)	1.00	0.60	-	5.00	3.50	4.00
		Chromium (Cr)	43.00	37.30	-	110	90	120.00
		Cobalt (Co)	50.00	-	-	-	-	25.00
		Copper (Cu)	32.00	35.70	-	150.00	197.00	96.00
		Lead (Pb)	36.00	35.00	-	130.00	91.30	138.00
		Mercury (Hg)	0.18	0.17	-	1.10	0.49	1.20
		Molybdenum (Mo)	-	-	-	-	-	5.00
		Nickel (Ni)	23.00	18.00	50.00	49.00	35.90	50.00
		Silver (Ag)	1.00	-	-	2.20	-	-
		Zinc (Zn)	120.00	123.00	-	460.00	315.00	563.00
	Metalloids (mg/kg)	Antimony (Sb)	-	-	4.00	-	-	-
		Arsenic (As)	9.80	5.90	-	33.00	17.00	29.00
	Other mineral substances (mg/kg)	Cyanide (free)	-	-	3.00	-	-	-
		Cyanide (Complex)	-	-	5.50	-	-	-
		Thiocyanates	-	-	6.00	-	-	-
Organometallics (µg/kg dry weight, 1% OC)	Tributyltin (as Tin) -							
	TBT	-	-	150.00	-	-	-	
Organic substances	Aromatics (mg/kg)	Benzene	-	-	0.20	-	-	-
		Ethylbenzene	-	-	0.20	-	-	-
		Toluene	-	-	0.20	-	-	-
		Xylenes (total)	-	-	0.45	-	-	-
		Styrene (vinylbenzene)	-	-	0.25	-	-	-
		Fenol	-	-	0.25	-	-	-
		Cresols (total)	-	-	0.30	-	-	-
	Polycyclic Aromatic	Acenaphthene	6.70	6.71	-	89.00	88.90	-

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF MARINE
SEDIMENTS DRAINED IN COLOMBIA, INCLUDING NATURE-BASED
SOLUTIONS.

			Florida (USA)	Brazil	The Netherlands	Florida (USA)	Brazil	The Netherlands	
Category 1	Category 2	Substance	Level 1	Level 1	Level 1	Level 2	Level 2	Level 2	
Organic substance s	<i>Hydrocarbons (PAHs, in µg/kg)</i>	Acenaphthylene	5.90	5.87	-	130.00	128.00	-	
		Anthracene	57.00	46.90	-	850.00	245.00	-	
		Fluorene	77.00	21.20	-	540.00	144.00	-	
		Naphthalene	180.00	34.60	-	560.00	391.00	-	
		2-Methylnapthalene	-	20.2	-	-	201.00	-	
		Phenanthrene	200.00	41.90	-	1200.00	515.00	-	
		Total Low Molecular Weight PAHs	-	-	-	-	-	-	
		Benz(a)anthracene	110.00	31.90	-	1100.00	782.00	-	
		Benzo(a)pyrene	150.00	31.90	-	1500.00	230.00	-	
		Chrysene	170.00	57.10	-	1300	862.00	-	
		Dibenz(a,h)anthracen e	33.00	6.22	-	140.00	43.00	-	
		Fluoranthene	420.00	111.00	-	2200.00	2355.00	-	
		Pyrene	200.00	53.00	-	1500.00	875.00	-	
		Total High Molecular Weight PAHs*	-	-	-	-	-	-	
		Total PAHs*	-	-	-	-	-	-	
	PAH	1600.00	1000.00	-	23000.00	4000.00	9000.00		
	<i>Polycyclic Aromatic Hydrocarbons (PAHs, in µg/kg)</i>	<i>Monochloroethene (vinyl chloride)</i>	Monochloroethene (vinyl chloride)	-	-	0.10	-	-	-
			Dichloromethane	-	-	0.10	-	-	-
			1,1-dichloroethane	-	-	0.20	-	-	-
			1,2-dichloroethane	-	-	0.20	-	-	-
			1,1-dichloroethylene	-	-	0.30	-	-	-
			1,2-dichloroethylene (sum)	-	-	0.30	-	-	-
			Dichloropropanes (sum)	-	-	0.80	-	-	-
Trichloromethane (chloroform)			-	-	0.25	-	-	-	
1,1,1-trichloroethane			-	-	0.25	-	-	-	
<i>Volatile Chlorinated hydrocarbons (mg/kg)</i>									

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF DRAGED MARINE SEDIMENTS IN COLOMBIA, INCLUDING NATURE-BASED SOLUTIONS.

			Florida (USA)	Brazil	The Netherlands	Florida (USA)	Brazil	The Netherlands
Category 1	Category 2	Substance	Level 1	Level 1	Level 1	Level 2	Level 2	Level 2
Organic substances		1,1,2-trichloroethane	-	-	0.30	-	-	-
		Trichloroethylene (Tri)	-	-	0.25	-	-	
		Tetrachloromethane (Tetra)	-	-	0.30	-	-	
		Tetrachloroethylene (Per)	-	-	0.15	-	-	
	Chlorobenzenes (mg/kg)	Hexachlorobenzene	20.00	-	-	240.00	-	0.04
		Chlorobenzenes (sum)	-	-	2.00	-	-	
	Chlorophenols (mg/kg)	Pentachlorophenol	-	-	-	-	-	0.02
		Total chlorophenols	-	-	0.20	-	-	
	Polychlorinated Biphenyls (PCBs) - (µg/kg)	Total PCBs	60.00	34.10	-	680.00	277.00	140.00
	Other chlorinated hydrocarbons	Monochloroanilines (sum) (mg/kg)	-	-	0.20	-	-	-
		Chloronaphthalene (sum) (mg/kg)	-	-	0.07	-	-	-
		PCDD/PCDF (ng tox eq/kg)*	-	-	-	-	-	-
	Organochlorine pesticides (µg/kg)	Aldrin	-	-	-	-	-	1.30
		Chlordane	3.20	-	2.00	18.00	-	-
		p,p'-DDD	4.90	3.54	-	28.00	8.51	-
		p,p'-DDE	3.20	1.42	-	31.00	6.75	-
		p,p'-DDT	4.20	1.19	-	63.00	4.77	-
		Total DDT	5.30	-	-	570.00	-	-
		Dieldrin	1.90	2.85	-	62.00	6.67	8.00
		Drins (sum)	-	-	-	-	-	15.00
		α-endosulfan	-	-	-	-	-	2.1
Endrin		2.20	2.67	-	210.00	62.40	3.50	
Gamma HCH (Lindane)		2.40	0.94	-	5.00	1.38	3.00	

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF MARINE
SEDIMENTS DRAINED IN COLOMBIA, INCLUDING NATURE-BASED
SOLUTIONS.

			Florida (USA)	Brazil	The Netherlands	Florida (USA)	Brazil	The Netherland s
Category 1	Category 2	Substance	Level 1	Level 1	Level 1	Level 2	Level 2	Level 2
Organic substance s		Total HCH (Alfa, Beta, Gamma)	-	-	-	-	-	10.00
		Heptachlor	-	-	-	-	-	4.00
		Heptachlor epoxide	2.50	-	-	16.00	-	4.00
		MCPA	-	-	550.00	-	-	-
		Toxaphene	0.10	-	-	32.00	-	-
	<i>Organo- phosphorus pesticides (µg/kg)</i>	Azinphos-ethyl	0.02	-	-	-	-	-
		Azinphos-methyl	0.06	-	7.50	-	-	-
		Diazinon	0.38	-	-	-	-	-
		Malathion	0.67	-	-	-	-	-
		Proxim	0.06	-	-	-	-	-
		Pyrazophos	0.02	-	-	-	-	-
	<i>Organo- nitrogen pesticides (µg/kg)</i>	Atrazine	0.30	-	35.00	-	-	-
		Simazine	0.34	-	-	-	-	-
	<i>Organo- sulphur pesticides (µg/kg)</i>	Disulfoton	0.30	-	-	-	-	-
	<i>Organo- carbamate pesticides (µg/kg)</i>	Carbaryl	-	-	150.00	-	-	-
		Carbofuran	-	-	17.00	-	-	-
	<i>Other organic substances (mg/kg)</i>	Asbestos	-	-	-	-	-	100.00
		Cyclohexanone	-	-	2.00	-	-	-
		Bis(2-ethylhexyl) phthalate (DEHP)	180.00	-	-	2600.00	-	-
		Diethyl Phthalate	630.00	-	-	-	-	-
		Di-n-butyl Phthalate	-	-	-	43.00	-	-
		Pftalates (sum)	-	-	0.25	-	-	-
		Mineral oil	-	-	-	-	-	1250.00

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF DRAGED MARINE SEDIMENTS IN COLOMBIA, INCLUDING NATURE-BASED SOLUTIONS.

			Florida (USA)	Brazil	The Netherlands	Florida (USA)	Brazil	The Netherlands
Category 1	Category 2	Substance	Level 1	Level 1	Level 1	Level 2	Level 2	Level 2
		Pyridine			0.15			
		Tetrahydrofuran			0.45			
		Tetrahydrothiophene			1.50			
		Tribromomethane (bromoform)			0.20			

Appendix C – Substance contents by Cormagdalena

Substance contents measured by contractors of Cormagdalena, in March/2023 and March/2024 (values in orange are quantification limits, and the substances mentioned are only those included in SQGs of Florida, Brazil or The Netherlands).

			Puente Pumarejo		Boya 15		Las Flores		Bocas de Ceniza		
Category 1	Category 2	Substance	2023	2024	2023	2024	2023	2024	2023	2024	
Mineral substances	Trace metals (mg/kg)	Cadmium (Cd)	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	
		Chromium (Cr)	25.90	33.70	35.69	41.40	37.31	22.60	37.76	44.30	
		Cobalt (Co)	-	-	-	-	-	-	-	-	-
		Copper (Cu)	12.16	29.15	29.22	36.66	31.94	15.98	33.22	35.18	
		Lead (Pb)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
		Mercury (Hg)	0.10	0.10	0.10	0.10	0.13	0.10	0.56	0.10	
		Molybdenum (Mo)	-	-	-	-	-	-	-	-	
		Nickel (Ni)	-	-	-	-	-	-	-	-	
		Silver (Ag)	-	-	-	-	-	-	-	-	
		Zinc (Zn)	66.32	112.09	117.19	150.38	111.59	72.25	110.95	121.94	
		Metalloids (mg/kg)	-	-	-	-	-	-	-	-	
	Other mineral substances (mg/kg)	-	-	-	-	-	-	-	-		
Organometallics (µg/kg dry weight, 1% OC)		-	-	-	-	-	-	-	-		
Organic substances	Aromatics (mg/kg)	-	-	-	-	-	-	-	-		

Appendix D – Substance contents measured by INVEMAR

Substance contents measured by INVEMAR in September/2023 and September/2024 (values in orange are quantification limits, and the substances mentioned are only those included in SQGs of Florida, Brazil or the Netherlands).

			Aguas Abajo Base Naval (CRA - 17)	
Category 1	Category 2	Substance	2023	2024
Mineral substances	Trace metals (mg/kg)	Cadmium (Cd)	12.50	12.50
		Chromium (Cr)	49.10	75.60
		Cobalt (Co)	-	-
		Copper (Cu)	23.20	32.90
		Lead (Pb)	15.00	16.50
		Mercury (Hg)	0.07	0.10
		Molybdenum (Mo)	-	-
		Nickel (Ni)	75.00	16.50
		Silver (Ag)	-	-
		Zinc (Zn)	127.00	147.00
		Metalloids (mg/kg)	-	-
	Other mineral substances (mg/kg)	-	-	-
Organometallics (µg/kg dry weight, 1% OC)		-	-	-
Organic substances	Aromatics (mg/kg)	-	-	-
	Polycyclic Aromatic Hydrocarbons (PAHs, in µg/kg)	Acenaphthene	-	-
		Acenaphthylene	-	-
		Anthracene	-	-
		Fluorene	-	-
		Naphthalene	-	-
		2-Methylnaphthalene	-	-
		Phenanthrene	9.08	8.99
		Total Low Molecular Weight PAHs	-	-
		Benz(a)anthracene	-	-
		Benzo(a)pyrene	-	-

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF MARINE
 SEDIMENTS DRAINED IN COLOMBIA, INCLUDING NATURE-BASED
 SOLUTIONS.

			Aguas Abajo Base Naval (CRA - 17)	
Category 1	Category 2	Substance	2023	2024
Organic substances	Polycyclic Aromatic Hydrocarbons (PAHs, in µg/kg)	Chrysene	-	7.39
		Dibenz(a,h)anthracene	-	-
		Fluoranthene	-	-
		Pyrene	-	-
		Total High Molecular Weight PAHs*	-	-
		Total PAHs	-	-
	Volatile Chlorinated hydrocarbons (mg/kg)	-	-	-
	Chlorobenzenes (mg/kg)	-	-	-
	Chlorophenols (mg/kg)	-	-	-
	Polychlorinated Biphenyls (PCBs) - (µg/kg)	-	-	-
	Other chlorinated hydrocarbons	-	-	-
	Pesticides (µg/kg)	-	-	-
	Other organic substances (mg/kg)	-	-	-

Appendix E – Substance contents measured by UniCartagena

Substance contents measured by UniCartagena (Tejeda-Benitez et al., 2016; 2018; 2023), from samplings done in Nov/2013 and Nov/2014 (values in orange are quantification limits, and the substances mentioned are only those included in SQGs of Florida, Brazil or the Netherlands).

			Nearby the industrial port area of Barranquilla	
Category 1	Category 2	Substance	2013	2014
Mineral substances	Trace metals (mg/kg)	Cadmium (Cd)	2.02	-
		Chromium (Cr)	52.70	-
		Cobalt (Co)	9.48	-
		Copper (Cu)	26.90	-
		Lead (Pb)	16.80	-
		Mercury (Hg)	0.12	-
		Molybdenum (Mo)	-	-
		Nickel (Ni)	26.80	-
		Silver (Ag)	0.40	-
		Zinc (Zn)	99.00	-
	Metalloids (mg/kg)	Antimony (Sb)	-	-
		Arsenic (As)	8.54	-
	Other mineral substances (mg/kg)	-	-	-
Organometallics (µg/kg dry weight, 1% OC)	-	-	-	
Organic substances	Aromatics (mg/kg)	-	-	-
	Polycyclic Aromatic Hydrocarbons (PAHs, in µg/kg)	Acenaphthene	-	-
		Acenaphthylene	-	-
		Anthracene	-	-
		Fluorene	-	-
		Naphthalene	-	-
		2-Methylnaphthalene	-	-
		Phenanthrene	30.00	-
		Total Low Molecular Weight PAHs	-	-
		Benz(a)anthracene	-	-

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF MARINE
SEDIMENTS DRAINED IN COLOMBIA, INCLUDING NATURE-BASED
SOLUTIONS.

Organic substances	<i>Polycyclic Aromatic Hydrocarbons (PAHs, in µg/kg)</i>	Benzo(a)pyrene	-	-
		Chrysene	10.00	-
		Dibenz(a,h)anthracene	-	-
		Fluoranthene	30.00	-
		Pyrene	10.00	-
		Total High Molecular Weight PAHs*	-	-
		Total PAHs	-	-
	<i>Volatile Chlorinated hydrocarbons (mg/kg)</i>	-	-	-
	<i>Chlorobenzenes (mg/kg)</i>	-	-	-
	<i>Chlorophenols (mg/kg)</i>	-	-	-
	<i>Polychlorinated Biphenyls (PCBs) - (µg/kg)</i>	-	-	-
	<i>Other chlorinated hydrocarbons</i>	-	-	-
	<i>Organo-chlorine pesticides (µg/kg)</i>	Aldrin	-	BDL
		Chlordane	-	0.18
		p,p'-DDD	-	0.19
		p,p'-DDE	-	0.33
		p,p'-DDT	-	0.06
		Total DDT	-	-
		Dieldrin	-	BDL
		Drins (sum)	-	-
		α-endosulfan	-	0.08
		Endrin	-	BDL
		Gamma HCH (Lindane)	-	-
		Total HCH (Alfa, Beta, Gamma)	-	-
		Heptachlor	-	0.03
	Heptachlor epoxide	-	0.01	
	<i>Organo-chlorine pesticides (µg/kg)</i>	MCPA	-	-
Toxaphene		-	-	

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF DRAGED MARINE SEDIMENTS IN COLOMBIA, INCLUDING NATURE-BASED SOLUTIONS.

Organic substances	<i>Organo-phosphorus pesticides (µg/kg)</i>	Azinphos-ethyl	-	-
		Azinphos-methyl	-	-
		Diazinon	-	-
		Malathion	-	-
		Proxim	-	-
		Pyrazophos	-	-
	<i>Organo-nitrogen pesticides (µg/kg)</i>	Atrazine	-	0.52
		Simazine	-	-
	<i>Organo-sulphur pesticides (µg/kg)</i>	Disulfoton	-	BDL
	<i>Organo-carbamate pesticides (µg/kg)</i>	Carbaryl	-	-
		Carbofuran	-	-
	<i>Other organic substances (mg/kg)</i>	-	-	-

Appendix F - Priority Substances for Sediment Quality Monitoring and for the Determination of Colombia's Own Thresholds

According to the criteria mentioned in reports 1 and 2 of this consultancy, and in this report, the priority substances are mentioned below to determine their concentrations in sediment quality monitoring, and for the determination of their own thresholds in Colombia.

Category 1	Category 2	Substance	Priority substance for...		Comments
			Comparison with Florida thresholds (USA)	Determination of Colombia's own mbrals	
Mineral substances	Metals (mg/kg)	Cadmium (Cd)	X	X	
		Cobalt (Co)	X	X	For coastal applications only
		Copper (Cu)	X	X	
		Chromium (Cr)	X	X	
		Mercury (Hg)	X	X	
		Molibdeno (Mo)	N/A	X	For freshwater applications only
		Nickel (Ni)	X	X	
		Silver (Ag)	X	X	
		Lead (Pb)	X	X	
		Zinc (Zn)	X	X	
	Metaloides (mg/kg)	Antimony (Sb)	N/A	X	
		Arsenic (As)	X	X	
	Other minerals (mg/kg)	Ammonia	N/A	X	For freshwater applications only
		Cyanide	N/A	X	
		Phosphates	N/A	X	For freshwater applications only
Sulfides and sulphates		N/A	X	For freshwater applications only	
Organometallic (µg/kg dry weight, 1% OC)		Tributyltin (as tin) - TBT	N/A	X	Especially for applications in coastal areas
Organic substances	<i>Polycyclic aromatic hydrocarbons (PAHs, in µg/kg)</i>	Acenaphthene	X	X	
		Acenaphthylene	X	X	
		Anthracene	X	X	
		Fluorene	X	X	
		Naphthalene	X	X	

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF DRAGED MARINE SEDIMENTS IN COLOMBIA, INCLUDING NATURE-BASED SOLUTIONS.

Organic substances	<i>Polycyclic aromatic hydrocarbons (PAHs, in µg/kg)</i>	2-Methylnaphthalene	X	X	
		Phenanthrene	X	X	
		Benz(a)anthracene	X	X	
		Benzo(k)fluoranten	X	X	
		Benzo(a)pyrenean	N/A	X	
		Chryseno	X	X	
		Dibenz(a,h)anthracene	X	X	
		Fluoranthene	X	X	
		Indene(1,2,3-cd) pyrene	N/A	X	
		Pyrene	X	X	
	<i>Chlorobenzenes (mg/kg)</i>	Chlorobenzenes (total)	N/A	X	
	<i>Chlorophenols (mg/kg)</i>	Chlorphenols (total)	N/A	X	
	<i>Polychlorinated biphenyls (PCBs) - (µg/kg)</i>	PCBs (total)	X	X	
	<i>Organochlorine pesticides (µg/kg)</i>	2,4-D	N/A	X	Of high concern in Colombia
		Chlordane	X	X	
		p,p'-DDD	X	X	
		p,p'-DDE	X	X	
		p,p'-DDT	X	X	
		DDT total	X	X	
		Dieldrin	X	X	
		Endrin	X	X	Florida Thresholds for Freshwater Only
		Heptachlor epoxide	X	X	Florida Thresholds for Freshwater Only
		Lindano (Gamma (HCH))	X	X	
	<i>Organophosphate pesticides (µg/kg)</i>	Azinfos-etil	N/A	X	
		Azinophis-methyl	N/A	X	
Clorpirifos		N/A	X	Of high concern in Colombia	
Diazinon		N/A	X		
Glyphosate		N/A	X	Of high concern in Colombia	

TECHNICAL AND POLICY ADVICE ON BENEFICIAL USES OF MARINE
 SEDIMENTS DRAINED IN COLOMBIA, INCLUDING NATURE-BASED
 SOLUTIONS.

		Malathion	N/A	X	
		Proxim	N/A	X	
		Pyrazophone	N/A	X	
	<i>Organo-nitrogenous pesticides (µg/kg)</i>	Atrazine	X	X	Florida Thresholds for Freshwater Only
		Imidacloprid	N/A	X	Of high concern in Colombia
		Simazina	N/A	X	
	<i>Organosulfur pesticides (µg/kg)</i>	Disulfoton	X	X	Florida Thresholds for Freshwater Only
	<i>Bipyridyl pesticides (µg/kg)</i>	Paraquat	N/A	X	Of high concern in Colombia
	<i>Organocarbamate pesticides (µg/kg)</i>	Carbaril	N/A	X	
		Carbofurano	N/A	X	
		Mancozeb	N/A	X	Of high concern in Colombia

Appendix G – Abbreviations and acronyms

Abbreviation	Description
Comagdalena	Corporación Autónoma Regional del Río Grande de la Magdalena (“Río grande de la Magdalena” is how Spanish people called the Margdalena River during the colonial period).
INVEMAR	Instituto de Investigaciones Marinas y Costeras “José Benito Vives de Andreis”
NbS	Nature-based solution(s)
SQGs	Sediment quality guidelines
UniCartagena	Universidad de Cartagena (and associate researchers from foreign universities)

* For other abbreviations that appear in the document but not often, in the English version the translated full name of the entity/regulation is mentioned in English, and the abbreviation corresponds to that of the name in Spanish.

Colophon

POLICY AND TECHNICAL ADVICE ON BENEFICIAL USES OF DREDGED MARINE SEDIMENTS IN COLOMBIA, INCLUDING NATURE-BASED SOLUTIONS.
ASSESSMENT OF THE QUALITY OF DREDGED MARINE SEDIMENTS IN THE PORT AREA OF BARRANQUILLA.

The project "Policy and technical advice on beneficial uses of dredged marine sediments in Colombia, including nature-based solutions" is part of the collaboration between the Government of the Netherlands, through the Partners for Water program, and the Colombian Ministry of Environment, the National Planning Department (DNP) and the Ministry of Transport. The project was executed by a consortium formed by Arcadis, Fundación Herencia Ambiental Caribe, JESyCA and Netics, together with governmental entities from both Colombia and the Netherlands.

AUTHORS

Juan David Carranza (Fundación Herencia Ambiental Caribe)
Jorge Gaitán (JESyCA)
Tiago Jurriens Piccoli (Arcadis)

OUR REFERENCE

: 1

DATE

January 30, 2026

STATUS

Final

VERIFIED BY

Martijn Onderwater
Technical Manager, Arcadis B.V

Jip Koster
Soil researcher

PUBLISHED BY

Jeroen Klooster
Project Manager, Arcadis B.V



Netherlands Enterprise Agency



Government of the Netherlands