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ECOLOGICAL RISK ASSESSMENT OF FRESHWATER SEDIMENTS IN BRAZIL

AVALIAÇÃO DE RISCO ECOLÓGICO EM SEDIMENTOS CONTINENTAIS NO BRASIL

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ABSTRACT

During the past 40 years, ecological risk assessments (ERA) were being performed by different organizations, using different various principles and methods, with little or no communication and inconsistencies between the different many assessment methodologies. Brazil still does not have a regulation based on quality criteria for sediments. Also, ERA approach has only been introduced here, and detailed guidance on how to interpret and apply these frameworks is still generally inadequate. In our paper, ERA framework and its application around the globe is are presented. Also, some promising future directions in ERA are briefly discussed, and critical challenges to future success of this tool in Brazil are identified.

Keywords: ecological risk assessments; toxicity; sediment quality guidelines; weight of evidence.

RESUMO

Durante os últimos 40 anos, avaliações de risco ecológico têm sido aplicadas por diferentes organizações. Utilizando métodos e princípios distintos, essas abordagens geralmente são aplicadas com pouca ou nenhuma comunicação e inconsistências entre si. O Brasil ainda não possui critérios definidos por lei, federal ou estadual, para a avaliação da qualidade de sedimentos. Além disso, as abordagens baseadas em avaliações de risco ecológico para esse fim são recentes no país, sendo essencial a obtenção de mais informações quanto a seus métodos de aplicação e interpretação. Neste estudo, a estrutura das avaliações de risco ecológico e seus métodos de aplicação ao redor do mundo são mostrados. Ainda, ações promissoras e direções futuras em relação à utilização das avaliações de risco ecológico são brevemente discutidas, identificando pontos críticos para o sucesso dessa ferramenta para a avaliação da qualidade de sedimentos no Brasil.

Palavras-chave: análise de risco ecológico; avaliações de risco ecológico; toxicidade; valores-guia da qualidade de sedimentos; pesos de evidência.

INTRODUCTION

Sediments are essential to the functioning of aquatic ecosystems and have long been recognized as the ultimate repository of most of the contaminants discharged into the water bodies. It is widely accepted that sources of contaminants in this environment — such as the organic (polycyclic aromatic hydrocarbons — PAHs, and aliphatic hydrocarbons) and inorganic pollutants (metals and metalloids) — are the result of numerous human activities. Therefore, there is a clear need for continued scientific dialogue around the ecological risk that these sediment contaminants might pose to the aquatic biota.

The environmental quality and disposal options for sediments dredged from navigational channels have been judged by use of some combination of physical, chemical, and biological analyses for over 40 years, being that the earliest regulatory interest in sediments dates back to the 1960s, with the London Dumping Convention. This was subsequently followed up in the 1970s with the work *Ecological evaluation of proposed discharge of dredged material into ocean waters: implementation manual for Section 103 of Public Law 92-532*, by the U.S. Army Corps of Engineers (EEL, 1973).

Since the 1980s, ecological risk assessment (ERA) is increasingly seen as a way to integrate science, policy, and risk management to address sediment contamination around the world. It is a process that evaluates the likelihood or probability for adverse ecological effects occurring as a result of exposure to contaminants or other stressors. It comprises a framework for gathering data and evaluating their sufficiency for decision-making (ENVIRONMENTAL CANADA AND ONTARIO MINISTRY OF THE ENVIRONMENT, 2008).

The current state of the science in ERA is predicated on the use of the sediment quality triad (SQT) in a weight of evidence (WOE) approach (SIMPSON *et al.*, 2005). Consisting initially of three lines-of-evidence (LOE) — chemical, ecotoxicological and ecological —, this approach is usually applied within a tiered system. E.g., information from each LOE is collected at each tier following a stepwise cost-effective process. The SQT is not restricted to only three LOE and can incorporate additional data, such as bioaccumulation/biomagnification, toxicity identification evaluation (TIE), contaminant body residue (CBR) analyses, and sediment stability.

Despite the power of this tool to inform environmental management decisions, the practice has not reached its full potential, since there is little experience with applying the framework outside the United States. Although a number of countries (Australia/New Zealand, Canada, the Netherlands, and the United Kingdom) have developed or promulgated regulatory or procedural approaches to risk assessment, only a few have developed formal guidance documents for performance of ERA. In Brazil, for instance, ERA has only been introduced, but detailed guidance on how to interpret and apply these frameworks — especially in continental areas — is generally inadequate.

Therefore, our paper attempts to cover the state-of-the-art system-based models prevailing over the ERA activities. First, a retrospective look at the concepts and characteristics of ERA is given. Then ahead we review the ERA framework tiered approach that has been developed and applied around the globe in the past decades. Based on this review, future perspectives and some key issues in the fields of ERA — especially in continental areas of Brazil — are provided in the last section.

ECOLOGICAL RISK ASSESSMENT: A BRIEF INTRODUCTION

According to Suter (2008), the ERA, as with other human enterprises, should be understood as a product of its history. In particular, the current practice of ERA results from blending two historical streams: risk assessment and ecological assessment. This account addresses the history of ERA in the context of its institution of origin, the United States Environmental Protection Agency (U.S. EPA).

In 1981, the U.S. EPA commissioned the Oak Ridge National Laboratory aiming to develop and apply ERA methods. From an analogy to the cancer risks estimates made by human health assessments, it was assumed that ERA should also estimate probabilities of clearly defined effects, while addressing all relevant levels of biological organization. These two assumptions guided development and publication of a set of probabilistic methods for assessment of risks to organisms, populations and ecosystems (SUTER *et al*., 2003).

Then, in 1983, the framework of the National Research Council (NRC) and the tools initially developed for the quantification of human health risks have subsequently been extended to other environmental problems including ERA, in the report *Risk assessment in the Federal Government: managing the process* (commonly referred to as the *Red Book*). It recommended development of assessments for non-human or ecological endpoints and also suggested that risk assessment should not only estimate probabilities of clearly defined effects, but follow a standard methodological approach based on an explicit framework (NRC, 1983).

Considering a conceptual framework for the identification and assessment of risks to human health, the NRC created a process comprising the following four stages:

1. Hazard identification: which chemicals are important and why?;
2. Exposure assessment: fate and transport of chemicals, who might be exposed and how?;
3. Toxicity assessment: determining the numerical indices of toxicity for computing risk;
4. Risk characterization: estimating the magnitude of risk and the uncertainty of the estimate.

The *Red Book* provided key concepts that impelled the investigators at Oak Ridge National Laboratory to develop a framework similar to the one for human health, but more suited to assessment of ecological risk. Based on this framework, the U.S. EPA proposed, in 1992, an initial methodological guidance for managing contaminated industrial sites. This framework extended the NRC and Oak Ridge National Laboratory frameworks by describing the process in detail and showing how it could be applied to a broad range of situations (U.S. EPA, 1992).

Following a certain number of works, this guide was improved to become *Guidelines for Ecological Risk Assessment* (U.S. EPA, 1998), which has now become the reference around the world regarding ERA. Referring to the generic framework and guidelines proposed by the U.S. EPA, ERA is defined as "a process that evaluates the likelihood that adverse ecological effects may occur or are occurring to ecosystems exposed to one or more stressors" (U.S. EPA, 1998). Since then, this guide has been revised by many countries and adapted to manage their polluted sites.

THE ECOLOGICAL RISK ASSESSMENT FRAMEWORK

An ERA is a rigorous scientific process used to quantify the magnitude of risk attributable to a single stressor or a combination of stressors at a specific location. The end goal of this process is to enable the risk managers to identify, prioritize, and manage the associated risks. This framework is appropriate for sites where the costs and/or ecological impacts of remediation are likely to be large relative to the cost of assessment. Remediation costs or other risk management may ultimately be much lower using a risk-based approach compared to an approach based on comparison of contaminant concentrations to sediment quality guidelines (SQGs).

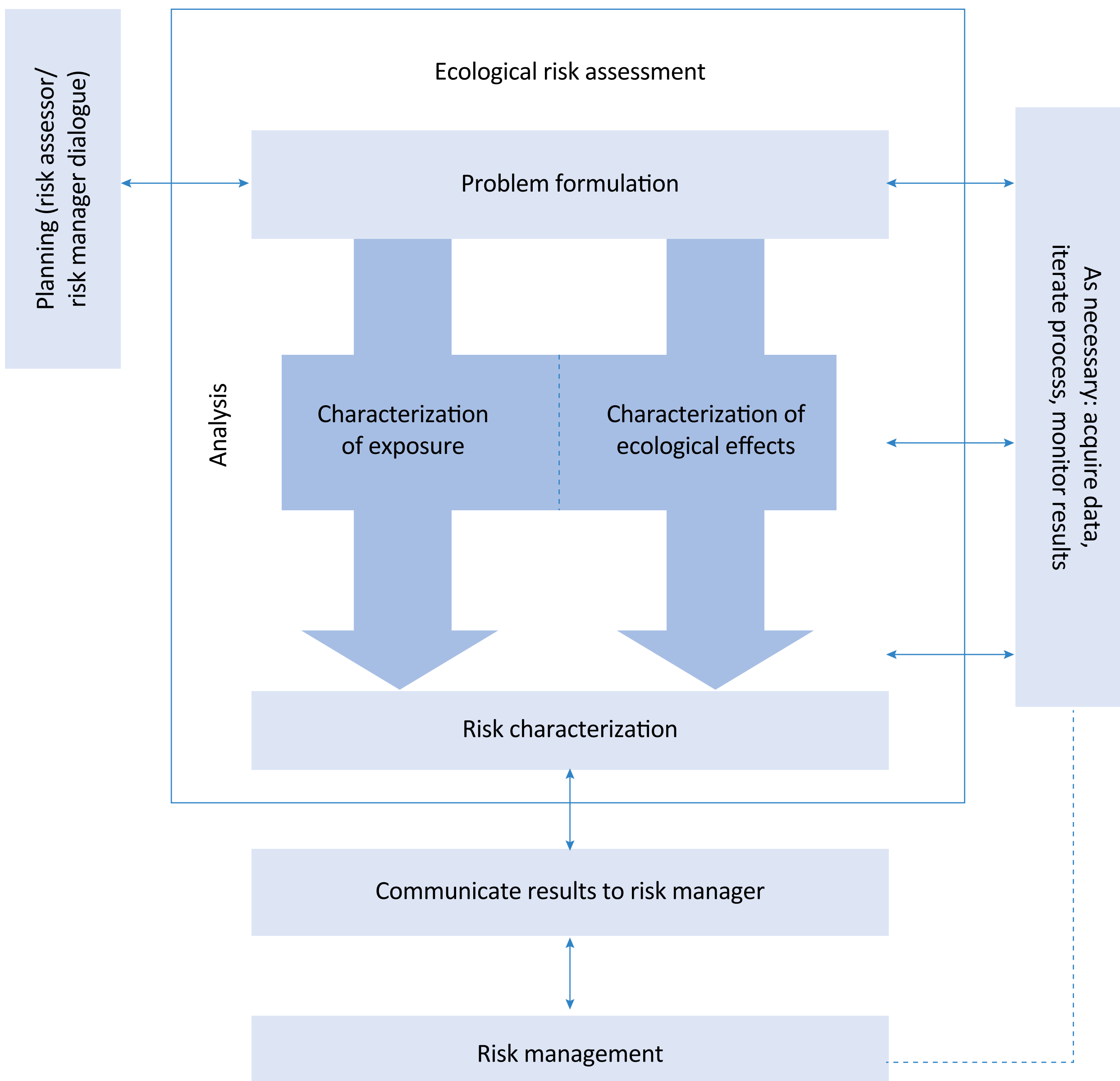
The key to success was the realization by the architects of ERA that risk assessment is a process and not a specific set of data collection techniques or analytical methods (BARNTHOUSE, 2008). Because situations to which an ERA may be applied can vary greatly in scope and complexity, an iterative, tiered approach is often employed. Use of a tiered approach, with expert review between tiers, helps ensure more efficient use of resources, and that limited resources are continually re-focused on an ever-narrowing number of increasingly significant stressor – receptor interactions.

As showed by Figure 1, the ERA approach typically involves tree main phases:

1. Problem formulation determines the questions that are to be asked during the risk assessment process;

2. Analysis assessment details the biological effects of the stressor under examination. Simultaneously, the exposure potential of the material to the critical biological group is calculated as part of an exposure assessment;
3. The determination of the likelihood (statistical probability) of an effect is formalized as risk characterization.

This format was originally proposed for human health risk assessment and has to be modified for ERA.



Fonte: U.S. EPA (1998).

Figure 1 – General ecological risk assessment overview.

The risk management decision based on ERA provides scientific evaluation of ecological risks that are typically rated from high to low. This allows to make rapid decisions, so that immediate remediation actions can be focused on receptors with the highest risks. The main steps of ERA and procedure are as follows ahead.

PROBLEM FORMULATION PHASE

The problem formulation is a systematic planning step for identifying the major factors to be considered in a particular assessment. It provides the foundation for the entire ERA (U.S. EPA, 1998). A robust problem formulation outcome will greatly assist assessors, managers, and interested parties in identifying the most logical risk-management options for protecting human health (NRC, 2009). This section summarizes the chemical, physical and biological characteristics of study areas, identifies the stressors and endpoints derived from stakeholder's values, and defines risk regions. These decisions will guide the type of data and information that need to be gathered and help to identify knowledge gaps.

According to U.S. EPA (1998), the problem formulation phase results in three products:

- Assessment endpoints that adequately reflect management goals and the ecosystem they represent;
- Conceptual models that describe key relationships between a stressor and assessment endpoint or between several stressors and assessment endpoints;
- An analysis plans.

A key component of the problem formulation stage is defining an assessment endpoint to determine what ecological entity is important to protect. Such ecological entity can be a species, a community, or even an ecosystem. Once the entity has been identified, the next step is to determine what specific attribute(s) of the entity is potentially at risk and important to protect. This provides a basis for measurement in the risk assessment.

Once assessment endpoints are chosen, a conceptual model is developed to provide a visual representation (a map, flow chart, or schematic) of hypothesized relationships between ecological entities and the stressors to which they may be exposed, accompanied by a written description of this process and of the risk questions. These models should include information about the source, stressors, receptors, potential exposure, and predicted effects on the assessment endpoint. The Figure 2 illustrates an example of a conceptual model.

The analysis plan is the final stage of problem formulation. During analysis planning, risk hypotheses are evaluated to determine how they will be assessed using available and new data. The plan includes a delineation of the assessment design, data needs, measures, and methods for conducting the analysis phase of the risk assessment.

ANALYSIS PHASE

Analysis is a process that examines the two primary components of risk, exposure and effects, and their relationships between each other and ecosystem characteristics. The objective is to provide the ingredients necessary for determining or predicting ecological responses to stressors under exposure conditions of interest. The analysis phase incorporates both exposure assessment and ecological effects assessment:

- Exposure assessment: data gathering and analysis phase focused on determining exposure concentrations or rates not associated with adverse ecological effects, or focused on actually characterizing the presence or absence of adverse effects to ecological resources at a site;
- Ecological effects assessment: data gathering and analysis phase geared towards quantifying relevant exposure concentrations for ecological resources of concern at a site.

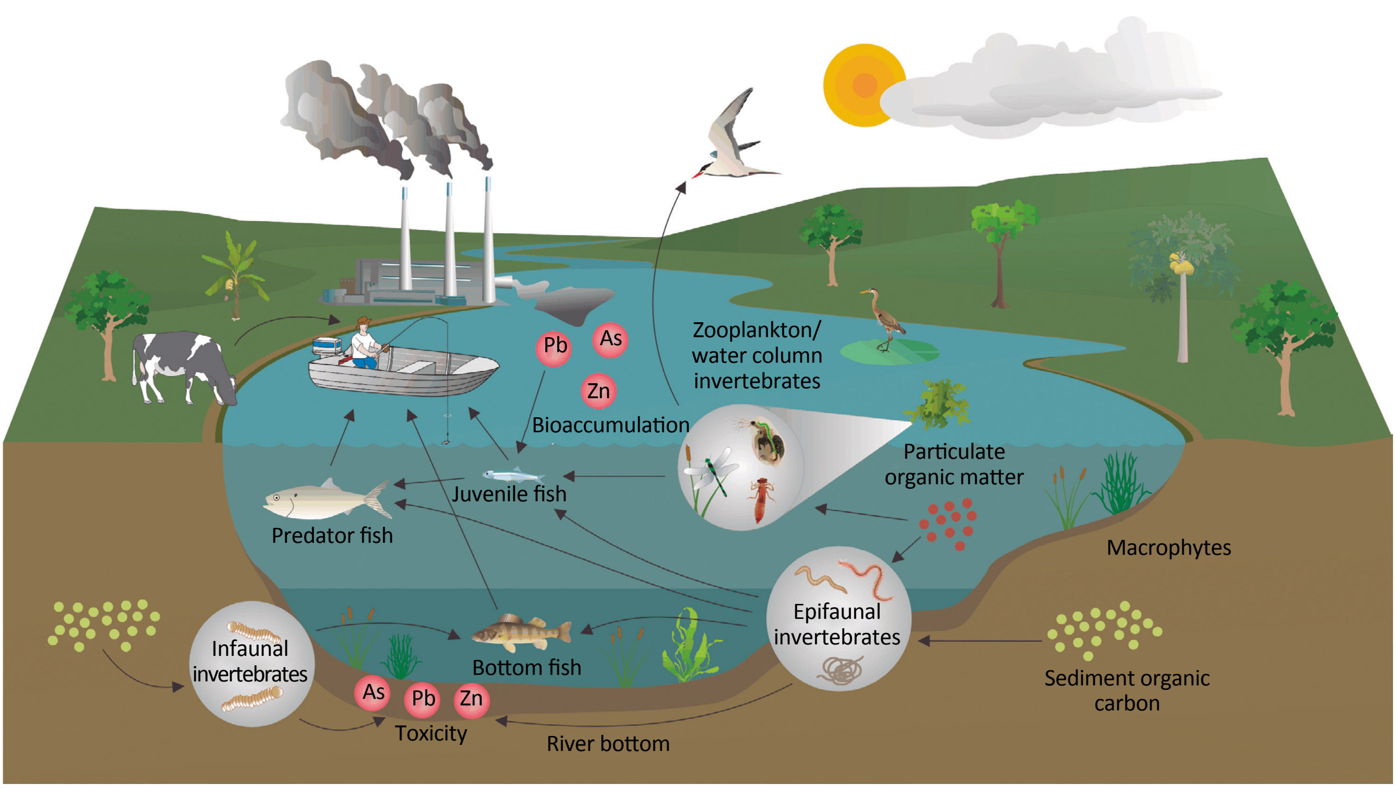
The data and models used for exposure assessment depend in part on the types of effects that are expected and are most relevant for decision making; the data and models used for effects assessment depend in part on the expected spatial and temporal exposure patterns. Together, exposure and effects assessment provide the scientific foundation for the risk assessment.

RISK CHARACTERIZATION PHASE

Risk characterization is the final phase of an ERA. It is the culmination of all work done during the previous phases. During risk characterization, the assessor uses the results of analysis to estimate the risk posed to ecological entities. The assessor then describes the risk, indicating the overall degree of confidence in the risk estimates, summarizing uncertainties, citing evidence supporting the risk estimates, and interpreting the adversity of ecological effects.

Risks are estimated by integrating exposure and stressor–response profiles using a wide range of techniques. To reduce uncertainty, risk characterization generally builds the final risk estimates upon different lines of evidence, using a weight-of-evidence (WOE) approach. Lines of evidence may include laboratory studies (e.g., bioassays), ecological field investigations, model predictions, and comparison of point estimates or distributions of exposure and effects data. Agreement among different lines of evidence increases confidence in the conclusions of the risk assessment (BURTON *et al.*, 2002).

Completing risk characterization allows risk assessors to clarify the relationships between stressors, effects, and ecological entities and to reach conclusions regarding the occurrence of exposure and the adversity of existing or anticipated effects. A good risk characterization will restate the scope of the assessment, express results clearly, articulate major assumptions and uncertainties, identify reasonable alternative interpretations, and separate scientific conclusions from policy judgments.



FCSI: Federal Contaminated Sites Inventory.

Figure 2 – Example of a conceptual model for bioaccumulation/biomagnification of metals from sediment through an aquatic food chain to fish, birds, and humans.

ECOLOGICAL RISK ASSESSMENT AROUND THE WORLD

A general overview of the ERA framework and tools from North America, United Kingdom, Australia/New Zealand, and developing countries, i.e., Brazil, were considered. Overall, the ERA approach followed by the U.S. EPA (described previously) is best used when performing hazard identification and prospective risk assessment. The approaches adopted by the U.K. and Australia/New Zealand follow the precautionary principle and are conservative approaches to hazard identification and risk assessment.

Although risk assessment is undertaken in various ways in other countries, the following section focuses on where formal guidance is currently available. A general observation is that access to documentation about ERA and its regulatory uses is variable between those places, making the application and consistent review of the issues difficult. In developing countries, such as Brazil, ERA is either adopted from the U.S. EPA, or formal risk are completely lacking.

United States

The U.S. EPA's framework and guidelines, used to conduct assessments over the past two decades, have been and continue to be a robust and useful foundation upon which to build the information needed to support decision making for ecological resources. According to the Committee on Environment and Natural Resources (CENR, 1999), the vast majority of ERA by the U.S. EPA has been in three areas:

- Premanufacture notification (PMN) under the Toxic Substances Control Act (TSCA);
- Chemical or pesticide registration under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA);
- Contaminated waste sites under either the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or the Resource Conservation and Recovery Act (RCRA).

Generally, ERA for pesticide registration are prospective estimates based on single active ingredients and use sites and follow an iterative four-tiered approach (HOPE, 2006). The vast majority of ERA is directed at PMNs and contaminated waste sites, with the latter having proved a most fruitful area for the evolution of the science and practice of ERA (STAHL *et al.*, 2005). ERA techniques, but not necessarily the complete framework, have also been applied to invasive species (ORR *et al.*, 1993), agroecosystems, and ecosystems management (LANDIS, 2005).

Besides the ERAs framework, U.S. EPA has developed guidance for designing a data collection plan to support study goals (U.S. EPA, 2000), which should be consulted during the problem formulation phase of ERA. The U.S. EPA also published guidance on developing ecological assessment endpoints that analyzed the rationale for selecting various levels of biological organization as endpoints for risk-management decision making (U.S. EPA, 2003). The decision to use organism-level or population-level endpoints in assessing ecological risk should be made in the problem-formulation stage of an ERA.

In early 2004, the U.S. EPA staff published a report, *An examination of EPA risk assessment principles and practices*, that presented current U.S. EPA risk assessment principles and practices (U.S. EPA, 2004). Carried out by a broad group of agency staff representing headquarters and the regional offices, the paper goals are to present a different perspective on several significant technical positions taken by the agency and to highlight key technical areas where further dialogue, research, and scientific analysis will help advance the state of agency practice. According to U.S. EPA, this type of review provides an accessible starting point for external review, analysis, and feedback regarding agency practices and rationales. Paralleling or subsequently following the U.S. EPA example, many nations (Canada, Australia/New Zealand, the Netherlands, and the United Kingdom) developed similar frameworks to assess ecological risk; structurally, the most significant differences comprise the extent of stakeholder involvement and the degree of inclusion of management processes.

Canada

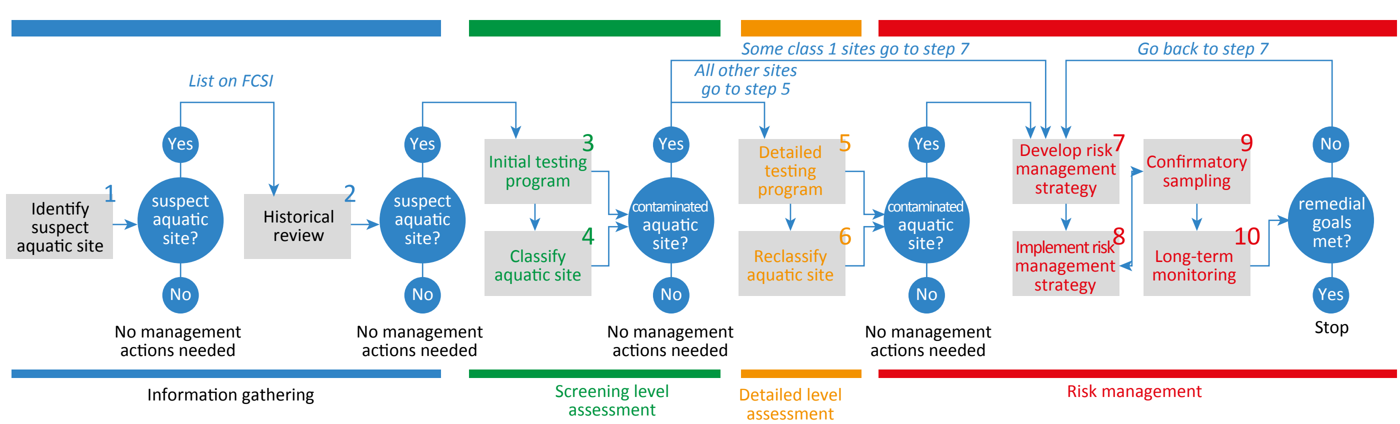
The basic framework for ERA in Canada has been provided by Environment Canada (1994) and elaborated upon numerous books (SUTER, 1993; LANDIS, 2005). As a part of its National Contaminated Sites Remediation Programme, Environment Canada produced *A framework for ecological risk assessment at contaminated sites in Canada: review and recommendations* (ENVIRONMENT CANADA, 1994). This report is a review of ERA methods and recommends an approach to promote consistency in site assessment and remediation in Canada. Canadian ERA framework is composed by exposure assessment, receptor characterization, hazard assessment, and risk characterization, and is compatible with US tiered approaches and is particularly useful in that many of the regulatory factors that pervade US literature.

The Canadian Environmental Protection Act of 1999 provides a legislative framework to deal with toxic substances in the environment (HOPE, 2006). Under the act, environmental (ecological) risk assessments are carried out by Environment Canada, with the objectives of determining whether a substance is toxic, as defined by the act, and of providing scientific support for the determination.

In 2008, the *Canada-Ontario decision-making framework for assessment of Great Lakes contaminated sediment* was prepared by Peter Chapman (Golder Associates) with the Sediment Task Group on behalf of Environment Canada and the Ministry of the Environment and Climate Change under the Canada-Ontario Agreement (ENVIRONMENT CANADA AND ONTARIO MINISTRY OF THE ENVIRONMENT, 2008). The purpose of this document was to provide a decision-making framework for contaminated sediments explicitly based on ERA principles, and which also has applications to contaminated sediments in other areas (e.g., freshwater, estuarine and marine). The framework is conceptually divided into a series of seven steps and six decisions that correspond to different ERA tiers.

Three years later, the Island Marine Aquatic Sites Working Group developed the final guidance for assessing, classifying, and managing federal aquatic sites funded by the Federal Contaminated Sites Action Plan (FCSAP) (CHAPMAN, 2011). This framework, elaborated for the Island Marine Aquatic Sites Working Group subcommittee of the inter-departmental Contaminated Sites Management Working Group (CSMWG), is based on the CSMWG (1999) 10-step process for terrestrial contaminated sites (*A federal approach to contaminated sites*), and provides an objective, transparent, consistent and scientifically rigorous framework for identifying and addressing contaminated aquatic sites, focusing on the sediment.

The 10-step FCSAP risk-based framework (Figure 3) is iterative and sequential in both scope and de-



Source: Environmental Canada (2013).

Figure 3 – Canadian framework for assessing and managing contaminated aquatic sites.

cision points (the latter comprise simple ‘’yes’’ or ‘’no’’ criteria). It is intended to be sufficiently prescriptive to standardize the decision-making process while still allowing for necessary site-specific flexibility. There are four tiers: information gathering; screening level assessment; detailed level assessment; and risk management (including monitoring). It has five decision points and three routes of exposure (water column, sediment, contaminant transfer).

A Decision-Making Framework (DMF) for the FCSAP (ENVIRONMENTAL CANADA, 2013) was latter published. This guidance outlines the specific activities and requirements for addressing federal contaminated sites in Canada. This framework (Figure 4) was developed to provide a common approach to managing contaminated sites for which the federal government is responsible, but does not replace the FCSAP 10-step process; rather, it is a complementary guide to assist federal custodians in managing their contaminated sites.

Australia and New Zealand

In October 2000, the Australia and New Zealand Environment Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) released “Interim” guidelines for sediment quality as part of the revised *Australian and New Zealand guidelines for*

Step 1: identify suspect site

Step 2: historical review

Step 3: initial testing program

Step 4: classify site (optional)

Step 5: detailed testing program

Step 6: re-classify site

Step 7: develop remediation/risk management strategy

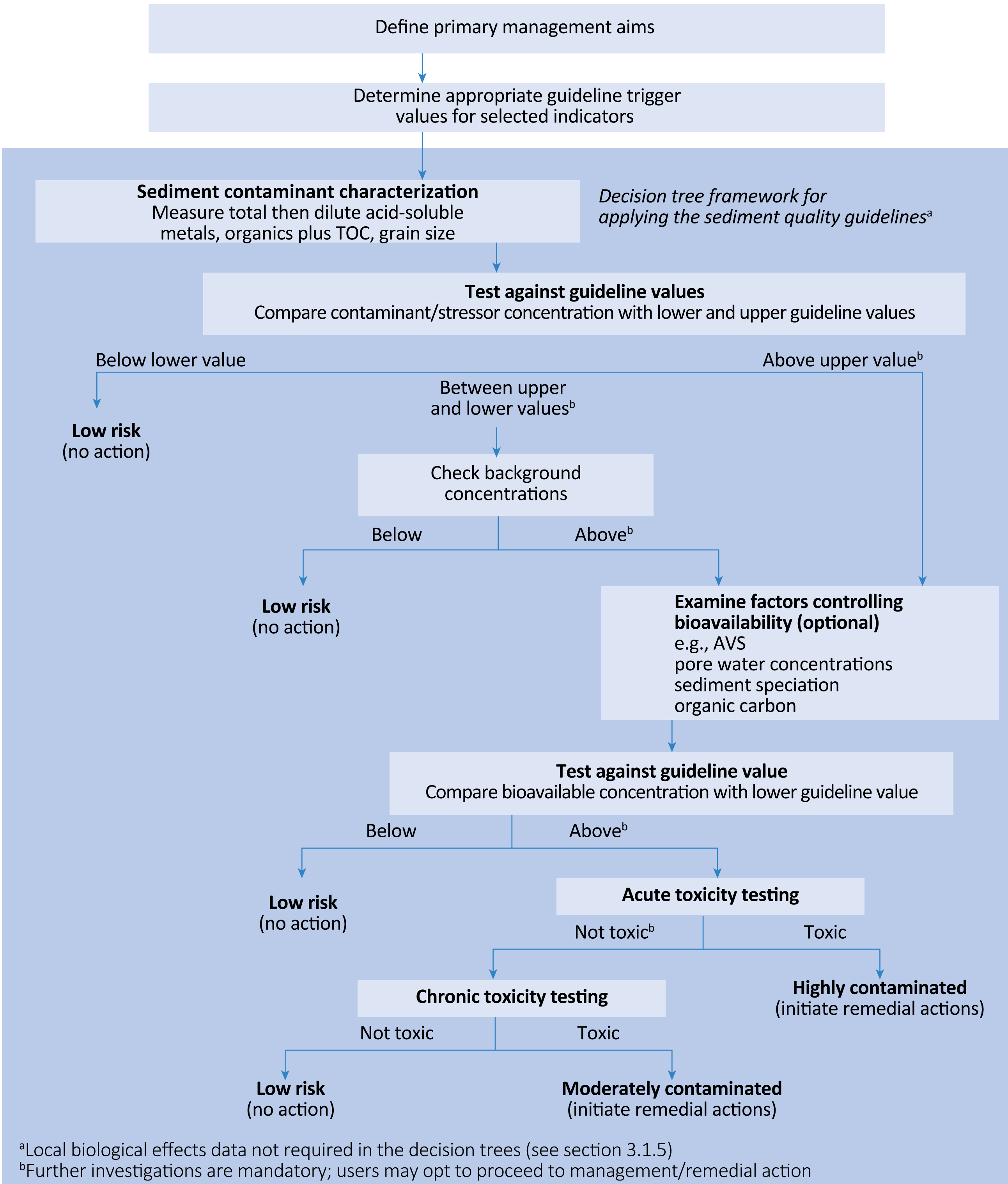
Step 8: implement remediation/risk management strategy

Step 9: confirmatory sampling and final report

Step 10: long-term monitoring (if required)t

Source: Environmental Canada (2013).

Figure 4 – The 10-step Decision-Making Framework (DMF) for the Federal Contaminated Sites Action Plan (FCSAP).



TOC: total organic carbon; AVS: acid volatile sulfide.
Source: ANZECC; ARMCANZ (2000).

Figure 5 – Decision tree for the assessment of contaminated sediments

fresh and marine water quality (ANZECC; ARMCANZ, 2000). According to Simpson *et al*. (2005), at the time, these represented the latest in international thinking. However, in recognition that the science underpinning these guidelines required improvement, the guidelines were termed "interim" with the intention being that they would be significantly revised in the future. The interim guidelines involved a tiered, decision-tree approach (Figure 5), in keeping with the risk-based approach introduced in the water quality guidelines.

Following this framework, the total concentrations of contaminants are compared to sediment quality guideline (SQG) values, termed trigger values (TVs). If the contaminant concentrations exceed the TVs, further investigations should be initiated to determine whether there is indeed an environmental risk associated with the exceedance (BATLEY; SIMPSON, 2008). The framework then recommended the consideration of contaminant bioavailability and toxicity testing to demonstrate the presence or absence of an unacceptable impact (ANZECC; ARMCANZ, 2000). The interim framework has been widely applied in both Australia and New Zealand to make informed decisions about sediment ecosystem health. However, these applications have also highlighted the weaknesses in the interim framework and are currently being reviewed and updated (WARNE *et al*., 2014).

Since 2000, considerable advances have occurred worldwide in the science underpinning sediment quality assessment. These have included the use of WOE approaches, the development of new toxicity tests, the recognition of limitations in some TVs and the development of TVs for contaminants for which no values currently exist, as well as additional information on contaminant bioavailability and uptake pathways (SIMPSON *et al*., 2005).

The actual ANZECC/ARMCANZ framework revision is being coordinated by the Australian Department of Sustainability, Environment, Water, Population and Communities. The revision will be evolutionary in nature reflecting the latest scientific developments and a range of stakeholder desires. According to Warne *et al*. (2014), key changes will be: increasing the types and sources of data that can be used; working collaboratively with industry to permit the use of commercial-in-confidence data; increasing the minimum data requirements; including a measure of the uncertainty of the trigger value; improving the software used to calculate trigger values; increasing the rigor of site-specific trigger values; improving the method for assessing the reliability of the trigger values; and providing guidance of measures of toxicity and toxicological endpoints that may, in the near future, be appropriate for trigger value derivation.

The United Kingdom

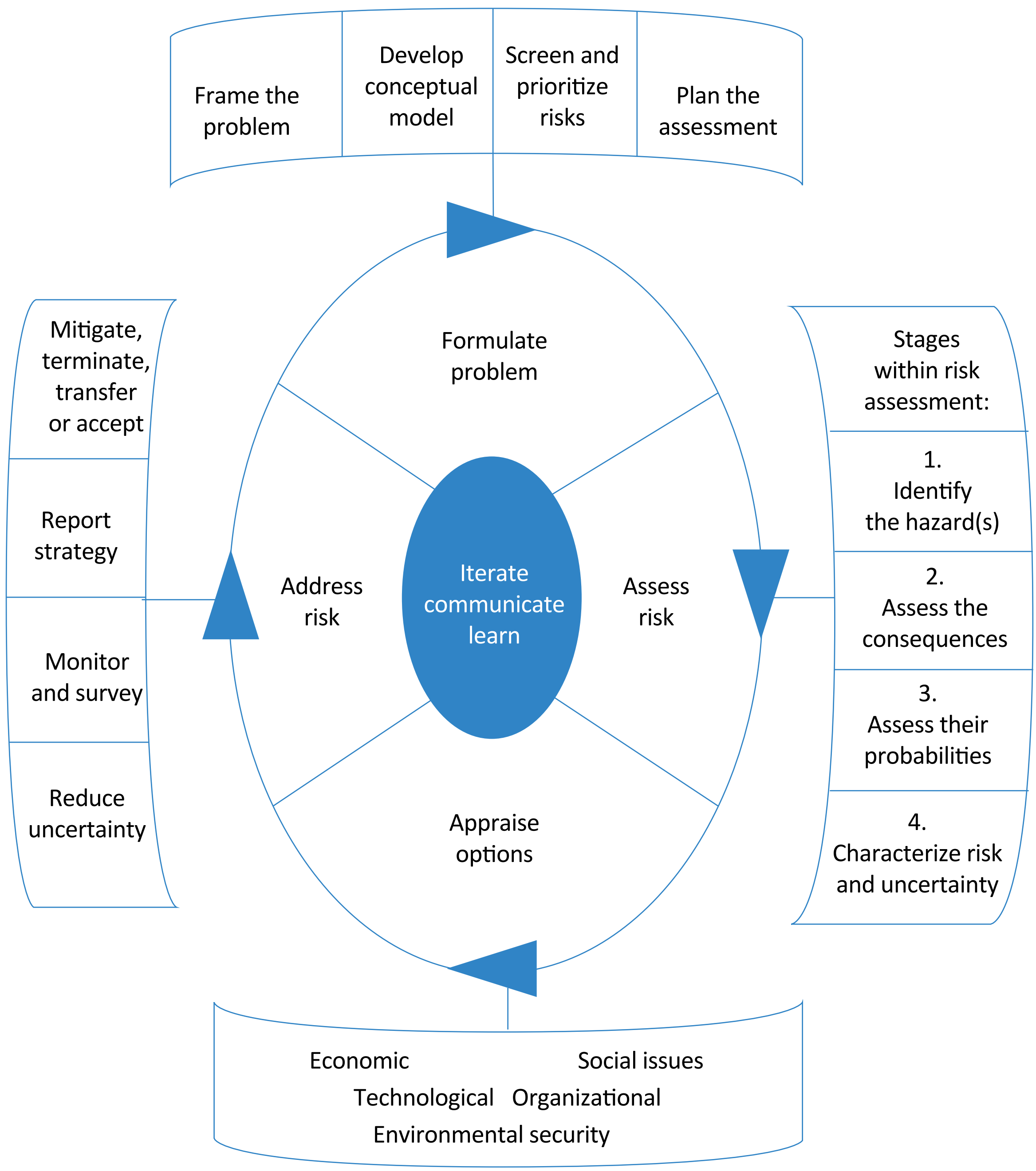
The use of ERA has received growing prominence in the United Kingdom (UK) since the early 1990s, in part as a response to the explicit requirements of recent environmental legislation. An original set of guidelines was published in 1995 by the Department of the Environment (DOE) (ENVIRONMENT CANADA, 1995). In 2000 the Department of the Environment Transport and the Regions (DETR), the Environment Agency (EA), and the Institute of Environment and Health (IEH) published the *Guidelines for Environmental Risk Assessment and Management* (DETR, 2000).

In 2011, the Department for Environment, Food and Rural Affairs (DEFRA) developed the *Green Leaves III*, the latest and revised edition of the *Guidelines for Environmental Risk Assessment and Management*, which supersede the earliest versions. This revision brings the guidelines in England and Wales in line with current thinking in the field of environmental risk management (GORMLEY *et al*., 2011).

A cyclical framework for environmental risk management is provided to offer structure in what would otherwise be a complex array of considerations for the decision-maker (Figure 6). The framework also offers a mechanism through which the process of ERA and management can be explained to stakeholders, and acts as a valuable *aide-mémoire* to multidisciplinary teams conducting risk assessment. This framework identifies four main components of risk assessment:

- Formulating the problem;

- Carrying out an assessment of the risk;
- Identifying and appraising the management options available;
- Addressing the risk with the chosen risk management strategy.



Source: Gormley *et al.* (2011).

Figure 6 – The cyclical framework for environmental risk assessment and management in the United Kingdom.

CURRENT REGULATORY ENVIRONMENTAL PROGRAMS AND ENVIRONMENTAL RISK ASSESSMENT IN BRAZIL

Brazilian current regulatory programs

In Brazil, since 1986, the protection of freshwater, estuarine and marine waters against pollution has been based on the Resolution no. 20 from the National Council for the Environment (CONAMA, 1986). On May 13, 2011, CONAMA issued Resolution no. 430, on the conditions and standards of effluent discharges to address wastewater treatment systems and industrial dischargers. Resolution no. 430 amends the existing effluent standards of Resolution no. 357/2005, which also extends to the classification and ecological management of water bodies (CONAMA, 2005; 2011).

Resolution no. 430 establishes standards for the discharge of effluents from sanitary sewers, which consists of residential, commercial and publicly collected liquid wastes and may include some industrial discharges (CONAMA, 2011). Wastewater treatment systems that discharge directly into the ocean through submarine pipes are subject to a distinct set of standards. For industrial pollution sources, this resolution imposes a new regime of obligatory self-monitoring and testing. The requirements include collection of samples by trained professionals and testing of samples by laboratories specially accredited by the National Institute of Metrology, Standardization and Industrial Quality (INMETRO).

On December 28, 2009, following three years of debate, CONAMA issued Resolution no. 420, establishing federal standards for the environmental management of contaminated sites. The resolution provides state and municipal environmental agencies with a framework of guidelines for the management of site remediation programs. It also contains monitoring and reporting requirements that may apply to Brazilian facilities. Subject to implementation by state agencies, all facilities with the potential to pollute may be required to institute soil monitoring programs and submit technical reports on the results with each renewal of their environmental licenses (CONAMA, 2009).

The core of the new federal standards is a multi-stage process under which potentially contaminated sites are to be identified, investigated, classified, remediated and monitored. Responsible parties must submit to the appropriate environmental agency a plan that addresses:

- The control and elimination of the sources of contamination;
- The current and future use of the area;
- An evaluation of risks to human health;
- Intervention alternatives considered technically and economically viable;
- A monitoring program;
- Costs and timeframes for implementing the intervention alternatives.

The resolution also creates technical criteria for use by environmental agencies, setting reference values for contaminants and procedures for determining the analytical methods to be employed by state environmental agencies. The Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) is also directed to create a National Database of Contaminated Sites using information obtained by the state agencies.

Environmental agencies of each Brazilian state should list the different soils in their territory and establish reference values (backgrounds) until 2013, providing crucial information to identify contaminated areas and carry out intervention actions. Until now, states such as São Paulo (CETESB, 2005), Pernambuco (BIONDI, 2010), and Minas Gerais (COPAM, 2010) already carried out studies for soil reference values.

Juchen *et al*. (2014) compared the local background concentrations for trace elements in two different sets of soils from the states of Paraná and Rio Grande do Sul, south region of Brazil. The authors concluded that the trace element levels may vary from location to location, especially due to different classes of soils and/or parent materials. Poleto and Gonçalves (2006) reported that the specificity of each reference value is also clear when comparing the thresholds established by different guidelines.

In 2005 the São Paulo Environmental Agency (CETESB, 2005) published *Guiding Values for Soils and Groundwater in the State of São Paulo*, including quality reference values (QRV) obtained from background concentrations of trace elements in soils from the state. As well as QRVs, CETESB proposed prevention and intervention values, above which heavy metal levels indicate potentially polluted soil and a potential risk to human health. Quality reference values for soils in Brazil and other individual states are given in Table 1.

Regarding sediment quality assessment, Brazil still does not have regulation based on quality criteria for sediments. However, given the contamination of reservoirs, rivers, estuaries and coastal areas, sediment quality evaluation started to receive more attention from scientists over the last two decades, as a means to promote conservation and remediation criteria. According to Poleto *et al*. (2009), new studies of urban sediments should provide a means of formulating management strategies focused on the way in which polluted sediment is transported in the urban environment, particularly from the perspective of Brazilian cities.

In the São Paulo state, sediment quality has been monitored by CETESB since 2002. A comprehensive and systematic study of sediment was needed, because some studies have indicated that several rivers and reservoirs in the state have relatively high concentrations of contaminants at levels likely to affect the benthic community. However, one of the biggest issues regarding sediment quality assessment in Brazil is that most of the laboratory tests has been standardized for regions of temperate climate, which imposes some constraints for apply this frameworks in tropical areas, especially for *in situ* testing.

Brazilian sediment quality criteria to orientate dredged material management are given by the Resolution no. 454/2012 from CONAMA, but such values were established based on the American and Canadian SQGs and do not consider the toxicity tests and the contaminant bioaccumulation (CONAMA, 2012). Some examples of the quality reference values for metals in dredged materials are given in Table 2.

Ecological risk assessment approaches in Brazil

Despite the existence of effluent discharge, contaminated sites, and water quality standards, ERA approaches have only been introduced in South American countries, and detailed guidance on how to interpret and apply these frameworks is still generally inadequate. Usually, Brazilian studies are carried out based on the U. S. EPA framework.

An advanced search in the Science Direct website using the keywords *ecological risk assessment* and *Brazil* showed an increase in the number of ERA researches

Table 1 – Quality reference values (QRVs) for trace elements of Brazil and regional background values for Pernambuco, São Paulo and Minas Gerais states.

Background [Reference value]	Arsenic (As)	Cadmium (Cd)	Barium (Ba)	Chromium (Cr)	Cooper (Cu)	Nickel (Ni)	Lead (Pb)	Antimony (Sb)	Selenium (Se)	Zinc (Zn)
	mg kg^{-1}d. wt									
Pernambuco (BIONDI, 2010)	0.6	0.6	84	35	5	8.5	12	0.1	0.4	34.5
São Paulo (CETESB, 2005)	3.5	< 0.5	75	40	35	13	17	< 0.5	0.2	60
Minas Gerais (COPAM, 2010)	8	< 0.4	93	75	49	21.5	19.5	0.5	0.5	46.5
Brazil (CONAMA, 2009)	15	1.3	150	75	60	30	72	2	5	300

Source: Conama (2012).

in the last five years, especially in the São Paulo state. From 2005 to 2010, 3,443 results were observed. In the years of 2006, 2007, and 2008, the number of observed papers was 405, 508, and 600, respectively. Since 2010 to the present, 6,735 papers were published, being 1,147, 1,456 and 1,743 for 2012, 2013 and 2014, respectively.

Regarding ERA in Brazil, the QualiSed Project is among the most complete researches developed so far (MOZETO *et al*., 2004). Aiming to develop the technical basis for deriving sediment-quality guidelines that could be applied to the São Paulo state water bodies, the QualiSed Project — a multidisciplinary cooperative project which involved the Federal University of São Carlos (UFSCar), the State University of Campinas (UNICAMP), and CETESB — included, from 2000 to 2003, studies of a series of reservoirs on the Tietê River (São Paulo state), from its headwaters (Billings and Rasgão reservoirs in the most polluted area) and middle Tietê (Barra Bonita and Bariri, moderately degraded reservoirs) to the lower reaches (Promissão, a better-quality water body).

The data collected during the project were used to define an operational scheme or framework for sediment-quality assessment. Analysis of the QualiSed Project database showed that the application of Canadian guidelines does not provide a straightforward evaluation of the sediment quality for the protection of aquatic life. As an alternative, it suggested a program involving an integrated and hierarchic evaluation of sediment quality (AIHQS), in which the ecotoxicological aspects are prioritized. The success of this ERA in particular was the development of the management goals in a collaboration between decision makers, assessors, scientists, and stakeholders; included in the problem formulation; translated into information needs; and then articulated with data-quality objectives.

Sanchez (2012) evaluated the impact of anthropogenic activities in the São Paulo state, more specifically the Lobo Hydrographic Basin, using an ERA approach based on the U.S. EPA framework. Also, the assessment of different lines of evidence (LOE) were carried out by Torres *et al*. (2015) in the Santos Estuarine System (SES) for the evaluation of environmental quality. The WOE approach was applied to compare and harmonize LOEs commonly used in sediment quality assessments and to then classify estuary environments according to both their potential for having adverse effects on the biota and their possible ecological risks. The authors recommended that this kind of approach must be used when evaluating sediment quality in special situations, such as the design of dredging projects in port areas that have a history of sediment contamination.

Table 2 – Quality reference values (QRVs) for dredged materials ($\mu g.g^{-1}$) established by the Resolution no. 454/2012 from National Council for the Environment.

Pollutants		Classification levels of dredged material (in dry weight unit)			
		Freshwater		Saline/Brackish Water	
		Level 1	Level 2	Level 1	Level 2
Metals and arsenic (mg/kg)	Arsenic (As)	5.9[1]	17[1]	8.2[2]	70[2]
	Cadmium (Cd)	0.6[1]	3.5[1]	1.2[2]	9.6[2]
	Lead (Pb)	35[1]	91.3[1]	46.7[2]	218[2]
	Copper (Cu)	35.7[1]	197[1]	34[2]	270[2]
	Chromium (Cr)	37.3[1]	90[1]	81[2]	370[2]
	Mercury (Hg)	0.17[1]	0.486[1]	0.15[2]	0.71[2]
	Nickel (Ni)	18[3]	35.9[3]	20.9[2]	51.6[2]
	Zinc (Zn)	123[1]	315[1]	150[2]	410[2]

[1]Environmental Canada (1995); [2]Long *et al*. (1995); [3]FDEP (1994).

In 2012, World Wide Fund for Nature in Brazil (WWF-BRAZIL, 2012) and The Nature Conservancy (TNC) partnered in order to identify the environmental risks in the Paraguay River Basin using an approach developed by Mattson and Angermeier (2007). This method is based on a multicriteria participatory approach that takes into consideration knowledge of the basin by local stakeholders — an ecological risk index is developed according to the severity of the impacts on ecosystems. The purpose of this study was to identify the status of the ecological components that ensure integrity of aquatic ecosystems in the basin. This assessment provides the governments of the four countries that share the basin (Brazil, Argentina, Paraguay and Bolivia), as well as civil society organizations so that they can develop a climate change adaptation agenda for the Pantanal Wetlands and work to enhancing resilience and minimizing the basin's vulnerability.

In 2000, U.S. EPA has developed guidance for designing a data collection plan to support study goals. A particular guidance should be developed and consulted for Brazil aiming to support the problem formulation and the analysis phase, taken into account the great variability of biomes and its enormous territory. According to Dale *et al*. (2008), ERA case studies should be compiled and developed to provide useful information for developing standards of practice to determine ecological condition. This case studies compilation would also be useful to risk assessors in Brazil considering how to address issues of spatial and temporal scale, geomorphology, quality reference values, and standard toxicity tests.

CONCLUSIONS

ERA is widely used and will continue to be used to protect the environment and prioritize remedial actions around the world. As ERA continues to grow at a phenomenal pace, Brazilian environmental authorities should establish a standard framework for risk assessment in sites posing some risk. Experience can be acquired with the system by testing the U.S. EPA basic approach in practical situations at a number of characteristic sites, aiming to provide important information to help the regular utilization of the risk assessment process to support site restoration and reclamation decisions in Brazil.

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