Pollution Toolkit
Part 1

A Guide for Pollution Assessment & Monitoring in Coastal Ecosystems

A guide for pollution assessment & monitoring in coastal ecosystems

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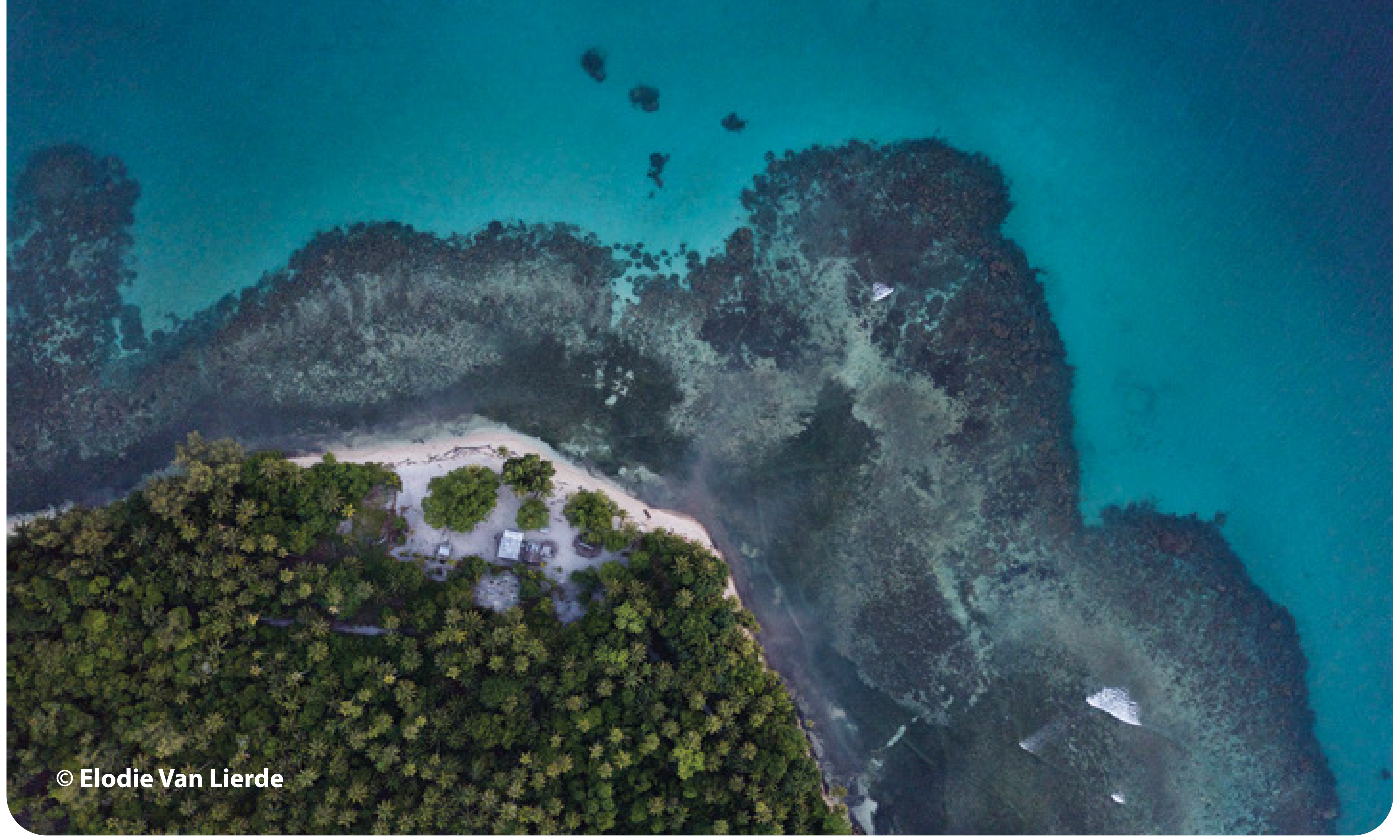
Purpose of the document

This guide is intended for users who are interested in assessing and monitoring coastal and marine pollution to understand their own systems, to inform management, decision-making, policy effectiveness, or compliance in coastal and marine ecosystems. It is not a detailed laboratory or field guide, but an overall guide for readers to assess the state of coastal and marine pollution in their areas, identify assessment and monitoring approaches and methods that could provide the necessary information to motivate action or initiate change, and help with the selection of monitoring parameters. This document is accompanied by multiple technical documents that provide more details on methodologies to help guide selection.

This guide can be used to help you identify what is needed at the very beginning of diagnosing pollution problems in your area or to provide more specific guidance on program design. The information is presented both as standalone sections or can be read as a series of sequential steps. Depending on where you are in your journey, some sections may be more relevant than others, and you may not necessarily need to follow them in a sequence. We have also outlined some example approaches to answer common questions related to coastal and marine pollution (**Section 10**), and have provided a Frequently Asked Questions section (**Section 11**). We hope the information presented here helps you to better protect coastal and marine ecosystems from pollution.



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Glossary

Bioaccumulation: A process of accumulation of chemicals in an organism that takes place if the rate of intake exceeds the rate of excretion (Chojnacka, 2010).

Bioindicators: Living organisms that can be used to assess the state or condition of an ecosystem as a result of disturbances or alterations caused by pollution, due to their known capacity to rapidly respond to changes in the environment (Parmar et al., 2016).

Blackwater: A waste stream from toilets that is the mixture of urine, feces, flush water, and cleansing materials (e.g. toilet paper).

Contaminant: A substance introduced at a given location or a naturally occurring substance that is present at levels above typical concentrations (Chapman, 2007).

Contaminants of emerging concern: Substances that, due to their increasingly widespread and continuous use, toxicity, and persistence in the environment, are of more recent concern (León & Bellas, 2023).

Greywater: Water generated from washing food, clothes, and dishware, as well as from bathing, but not from toilets. It can contain organic matter, pharmaceutical and personal care products, microplastics, and traces of feces and pathogens (e.g., from washing diapers) (Tilley et al., 2014).

Endocrine disruptors: Natural or human-made chemicals that may mimic, block, or interfere with the body's hormones, which are part of the endocrine system. At least 1,000 chemicals have been identified as potential endocrine disruptors (NIEHS, 2024a).

Fecal sludge: Excreta collected via non-sewered sanitation systems, such as pit latrines, leach pits, and septic tanks (SuSanA, 2018).

Indicator: A physical, chemical, or biological measure that points to the presence of specific environmental conditions or pollutants (DES, 2018).

Leachate: Any liquid that, in the course of passing through solid matter, extracts soluble or suspended solids, or any other component of the material through which it has passed, including contaminants.

Legacy contaminants: Pollutants that can persist in groundwater for long periods of time, whose presence may be recorded for many years after management interventions have been implemented.

Parameter: The specific pollutant that is measured to assess pollutant type presence or concentration.

Persistent organic pollutant (POP): A diverse group of long-lasting chemicals that resist degradation and can accumulate in the environment and within living organisms. Due to their persistence, they can travel long distances, bioaccumulate through the food chain, and may pose significant risks to human and ecosystem health, including through toxicity and disruption of endocrine systems (Stockholm Convention, 2020).

Pharmaceutical & personal care products: A diverse group of chemicals that include all drugs (both prescription and over-the-counter medications) and non-medicinal consumer chemicals, such as fragrances (musks) in lotions and soaps, ultraviolet filters in sunscreens, and ingested chemicals like caffeine or sucralose (US EPA, 2013; Osuoha et al., 2023).

Pollutant: A contaminant able to produce adverse biological effects in living beings (Chapman, 2007).

Spatial variation: The differences in physical location or space.

Temporal variation: Changes over time (days, months, years).

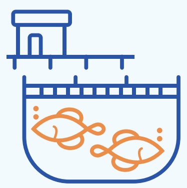
1. Water pollution overview

1.1 Sources of pollution

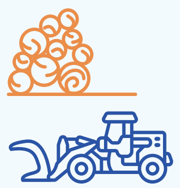
Water pollution in coastal and marine environments can come from a variety of anthropogenic (human) activities (**Table 1**). These activities produce characteristic groups of pollutants (**Fig. 1**), cause a wide variety of impacts, and can be influenced by many environmental factors, including soil type, geological features, terrain, and rainfall patterns. Chemical pollutants, including the >140,000 that humans have synthesized, are often additionally categorized according to their persistence in the environment and their toxicity or impacts to people and environments (Naidu et al., 2021).

Common activities that result in pollution of the aquatic environment

Agriculture: The application of pesticides, synthetic fertilizers, manure, and human waste as part of agricultural activities can release a variety of pollutants into waterways. Intensive soil tillage and deep ploughing causes large losses of sediment, nutrients, pesticides, and heavy metals. Irrigation practices may lead to the leaching of salts contained in soils and drainage increases the concentration of soluble soil components in water (WHO, 2016).



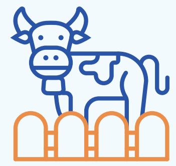
Aquaculture & fisheries: These activities produce wastes such as fish excreta and uneaten food, including medicated feed, as well as pharmaceutical products used to treat or suppress illnesses. Use of livestock manure, synthetic fertilizers, and human waste is a common practice to increase fish yields in pond aquaculture. Different types of pesticides are used to prevent or reduce disease, aquatic vegetation, and the presence of other organisms (WHO, 2016).



Deforestation & land-clearing: These activities destabilize soil causing erosion, with slash-and-burn land clearing and intensive logging causing greater impacts (WHO, 2016). Logging on steep slopes increases soil erosion, while logging close to water bodies increases the amount of mobilized soil that enters them (Wenger et al., 2018). Biomass burning to clear land can substantially elevate the quantity of nutrients that enter coastal environments through atmospheric deposition (Sundarambal et al., 2010).

Domestic wastewater: Domestic wastewater includes waste from both sewered and non-sewered sanitation sources. It typically consists of blackwater and greywater. The risk to human and ecosystem health associated with domestic wastewater depends on its quality, and whether it is treated, partially treated, or raw. Fecal sludge from non-sewered systems also poses a risk if not properly treated and disposed of (Pistocchi et al., 2022; Tilley et al., 2014; WHO, 2016).

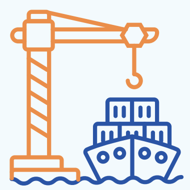
Landfills: Landfills and open dumps lead to leachate formation, which can carry various pollutants to the surrounding soil, surface water, and groundwater. Waste composition is an important factor in determining the pollutants present in the leachate, but commonly include organic matter, inorganic salts, heavy metals, micro- and nanoplastics, and other industrial pollutants (Amano et al., 2021; Economist Impact, 2022).



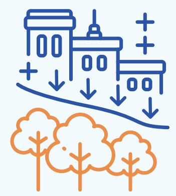
Livestock & invasive animals : Manure generated by livestock and invasive mammals enters water bodies via direct defecation or surface runoff. Pathogens from manure pose a threat to both human and ecosystem health. Antibiotics and other pharmaceuticals used in livestock care can be major sources of pollution, and promote the rise of antibiotic-resistant bacteria. Intensive grazing near rivers erodes river banks and destroys riparian vegetation, facilitating sediment release (WHO, 2016).

Military activities: Pollution can be generated from both routine military operations and emergency or wartime events. The range of typical military pollutants include per- and polyfluorinated substances (PFAS) from fire fighting, hydrocarbons from fuel, metals and polychlorinated biphenyls (PCBs) from equipment, and chemicals from weapons disposal (Fernandez-Lopez et al., 2022; Rodríguez-Eugenio et al., 2018; ; Skalny et al., 2021).

Mining: Mining creates pollution during construction, extraction, and processing activities. Land clearing and excavation mobilizes soil and can unearth naturally occurring heavy metals. Chemical and physical processes required for mineral extraction can cause major pollution issues (Economist Impact, 2022). Pollutants at abandoned or closed mining sites run off into water bodies during rainfall (NOAA, n.d.)



Ports, marinas, & ocean-based industries (e.g., petroleum platforms): Vessels and harbors are a source of wastewater pollution when accessible sanitation facilities or treatment are lacking. Vessel maintenance activities such as antifouling can contribute a wide range of pollutant types to water bodies. Additionally, capital and maintenance dredging in ports and shipping lanes can resuspend benthic sediments, releasing any trapped contaminants. Industries like oil and gas extraction in the ocean can further pollute surrounding waters with heavy metals, hydrocarbons, and radioactive material (Economist Impact, 2022).



Urbanization, including manufacturing, chemical production, industries that support urbanization to occur, industrial wastewater, & stormwater: Fertilizers and pesticides used in urban green spaces can pollute nearby water bodies. Micro- and macro-debris that accumulate in urban areas can be washed into water bodies during rainfall and flooding events. Converting natural land to paved roads that are impervious to water increases the volume of stormwater entering water bodies. Emissions from industrial processes and transportation contribute to water pollution through atmospheric deposition. Industrial wastewater is also a major source of pollution, with the composition depending on the industries in the area (Economist Impact, 2022).

Table 1: Common sources for a range of pollutant types

Pollutants	Agriculture	Aquaculture	Deforestation & Land-Clearing	Domestic Wastewater	Landfills	Livestock & Invasive Mammals	Military Activities	Mining	Ports, Marinas, & Ocean-Based Industries	Urbanization & Industrial Wastewater
Heavy metals	✓			✓	✓		✓	✓	✓	✓
Hydrocarbons			✓	✓	✓		✓	✓	✓	✓
Microbial organisms	✓	✓		✓		✓			✓	✓
Nutrients	✓	✓	✓	✓		✓	✓	✓	✓	✓
Organohalide compounds, organometallic compounds, mineral acids	✓			✓	✓		✓	✓	✓	✓
Organic matter	✓	✓	✓	✓		✓			✓	
Per- & polyfluoroalkyl substances (PFAS)				✓	✓		✓	✓		✓
Pesticides	✓	✓							✓	✓
Pharmaceuticals & personal care products (PPCPs)	✓	✓		✓	✓					
Plastics	✓			✓	✓		✓	✓	✓	✓
Sediments	✓	✓	✓	✓		✓	✓	✓	✓	✓

Fig. 1: Common pollutant types (some pollutants fall into more than one category)

1.2 How do pollutants get into the ocean?

80% of marine pollution originates from the land (NOAA, 2023b). There are several watershed characteristics that influence how much pollution ends up in water bodies, including watershed geomorphology (slope, soil type, and geology) and vegetation cover. Understanding how and when pollution is carried from the land to the sea is a key strategy for prioritizing activities and solutions to mitigate and reduce water pollution impacts to coastal and marine ecosystems.

Land-based pollution can be transported into the ocean in a variety of ways (**Fig. 2**). They include:

1. **Surface runoff:** The transport of pollutants via surface runoff is linked to the hydrological dynamics of watersheds and the nature of the pollutants themselves. It involves the mobilization of contaminants from various land-based sources and activities. These contaminants are then conveyed by river systems as they progress from upstream headwaters through estuaries and into coastal waters.
2. **Flood events:** Beyond normal surface runoff, seasonal and episodic flood events play a substantial role in transporting pollutants from the land to the sea. During such events, the volume and velocity of river discharge significantly increase. This surge in water flow can entrain and transport various pollutants in larger amounts. The high velocity of a flooding river can also disperse pollutants farther into the ocean than normal river flow can.
3. **Groundwater:** Contamination of groundwater occurs through leaching and infiltration of pollutants from landfills, septic systems and pit latrines, and other subsurface sources. Over time, this polluted groundwater may resurface in rivers and estuaries, eventually introducing contaminants into coastal ecosystems. The composition of the underlying geological strata, hydrogeological properties, and the nature of the contaminants all influence this transport pathway.
4. **Atmospheric deposition:** Atmospheric deposition is the process by which gases and particulate matter in the atmosphere settle onto terrestrial and aquatic surfaces. It serves as a vector for introducing contaminants into ecosystems. Pollutants, including heavy metals such as mercury, excess nutrients, industrial emissions, and airborne microplastics, can be deposited directly into water bodies or onto land and subsequently washed into water bodies.
5. **Stormwater:** Stormwater runoff acts as a conduit for urban pollution to reach coastal waters. In urban environments, stormwater can pick up a wide array of contaminants, such as oil and grease, heavy metals, and debris, and it is often untreated. This pathway is influenced by factors such as land use, impervious surfaces, and the efficiency of stormwater management practices.
6. **Domestic & industrial wastewater outfalls:** The release of partially treated and untreated wastewater directly into coastal waters is a significant source of pollution. The impacts of this pollution are contingent on the volume and composition of wastewater discharges, the level of treatment, and the dilution and dispersion processes in the receiving marine environment.
7. **Soil erosion & sediment transport:** Soil erosion from deforested, agricultural, or construction sites can carry sediments laden with pollutants into rivers and streams, which then transport these sediments to the ocean.

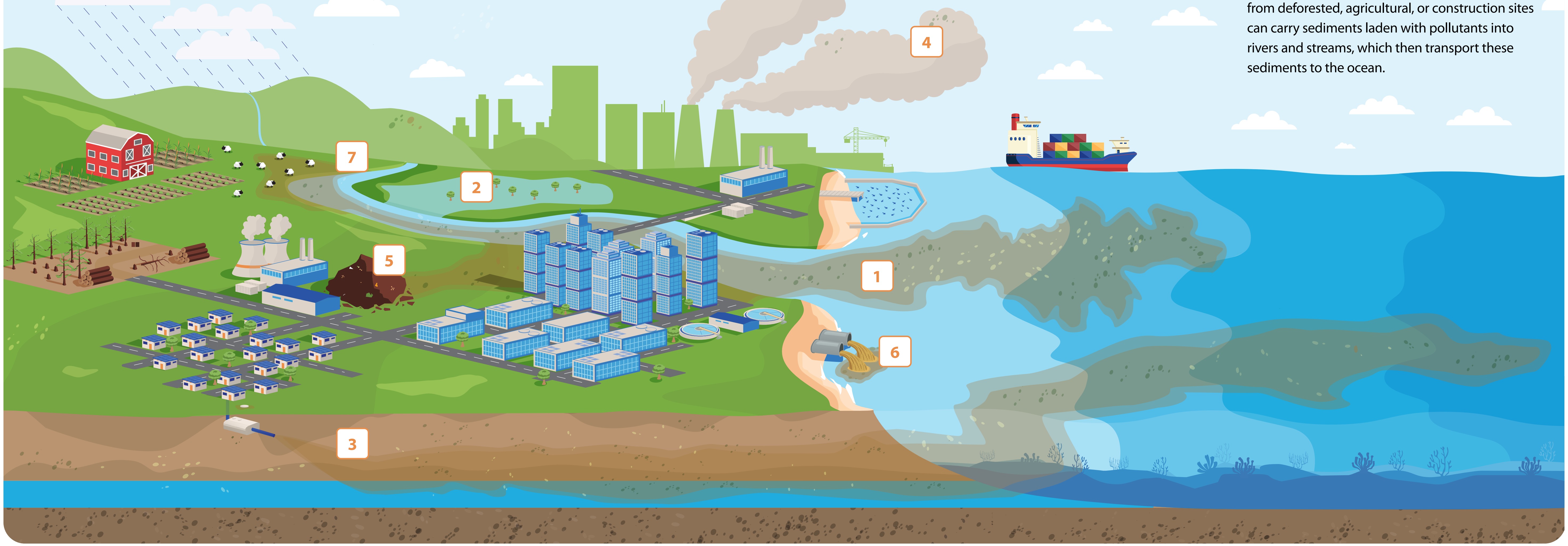


Fig. 2: *A variety of pollution transport pathways from land to coastal ecosystems*

2. Introduction to pollution assessment, monitoring, & evaluation

There are a wide variety of situations and conditions where concerns about coastal and marine pollution and its impact on human and ecosystem health will arise. To address these concerns it is important to understand the source and scale of the pollution problem, which in turn will help prioritize the actions required to mitigate the pollution issue. In order to identify how best to manage pollution, there is a need for robust data collection and data analysis to inform decision making for the most appropriate responses. Assessment and monitoring of coastal pollution is essential to track natural and anthropogenic change, identify the sources of pollution, and ensure responsible stewardship and management of the use of coastal and marine ecosystems that can be impacted by pollution.

Assessment

An initial assessment (described in **Section 3**) or a more targeted study to help identify the type, extent, and impact of pollution.

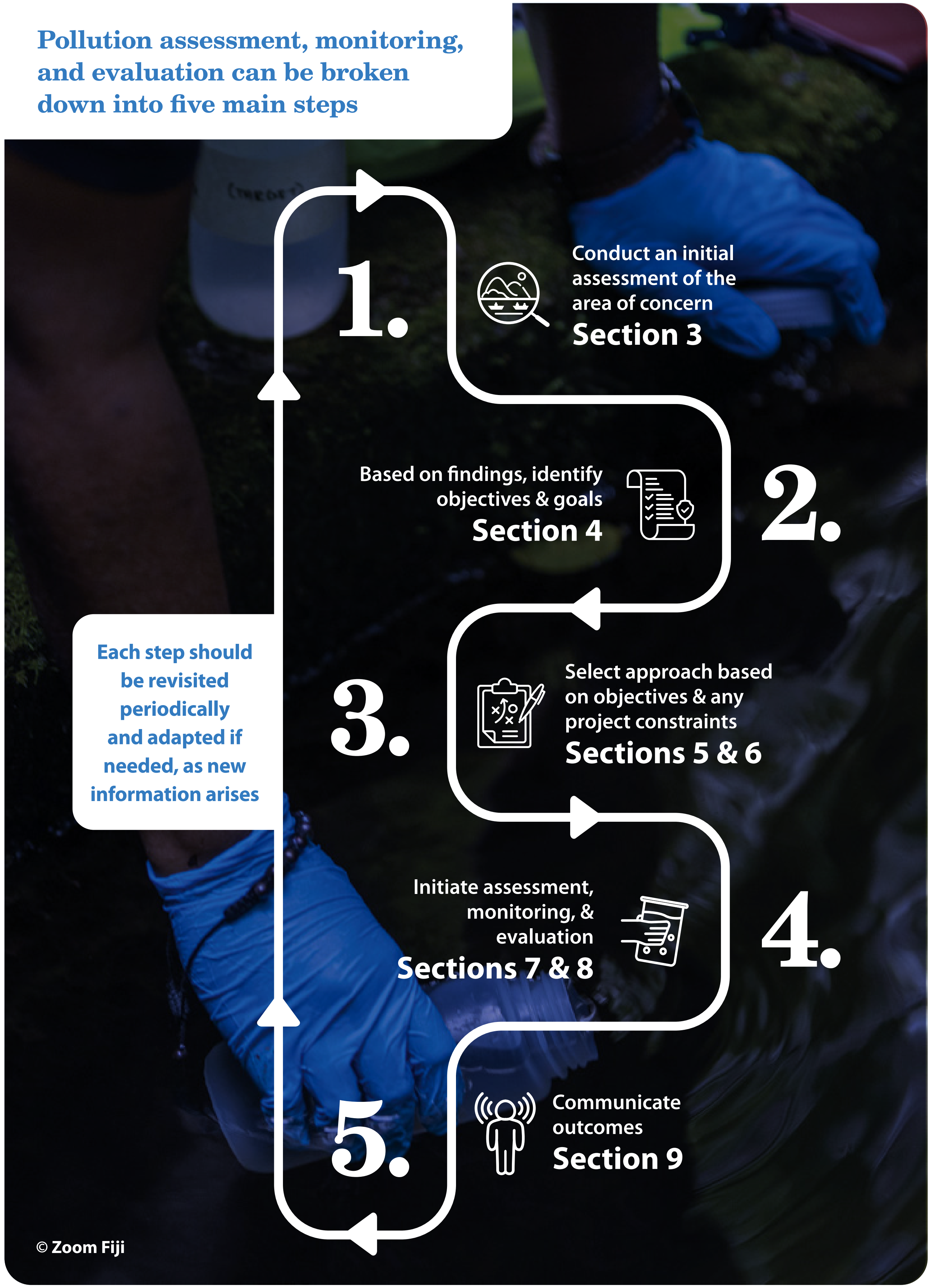
Monitoring

The routine collection of data to establish baselines and to track changes through time in response to concerns around pollution impacts.

Evaluation

Tracking the responses of water quality and other pollution indicators to management interventions, to identify impact and to inform adaptive management actions.

Assessment involves activities that can measure the source, extent, and impact of the issue, **monitoring** measures the variability of pollution and the effectiveness of actions, and evaluation involves the interpretation of that information. Whilst there are many different ways to approach the assessment and monitoring of coastal pollution, it should be adaptive, allowing for adjustments and refinements as your understanding of the issues grows.



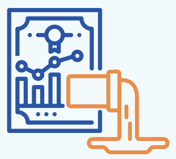
3. Getting started: initial assessment

The scale, extent, and concerns about the pollution problem will be a key driver in the types of assessment and monitoring that are required. Implementing an effective program or project to assess coastal and marine pollution can often be expensive, time-consuming, and complex. **It is critical to understand what information is needed for different partners to initiate action, motivate change, or track pollution and its impacts through time.**

Therefore, prior to investing in an assessment and monitoring program, an initial assessment of the potential sources, type, extent, and impact of pollution should be performed. This involves gathering, reviewing, and analyzing existing information. **Importantly, this assessment should be completed before deciding on your approach (or approaches) to assessing and monitoring the coastal pollution issue.**

Existing (and accessible) information is a very important part of your pollution assessment. There are many valuable local, national, and global datasets that can also be used to understand the sources, type, extent, and impact of coastal pollution.

Preliminary data gathering, using a wide range of existing data sources can provide information on...


The activities that are responsible for generating pollution.


The prevalence of pollution generating activities.


The spatial and temporal dimensions of the pollution issue (linked to the scale of the impact).


The likely pathway that connects sources of pollution to the coastal and marine areas of concern.


The primary pollutant types of concern.


The key individuals, organizations, and partners that are responsible for generating pollution, impacted by pollution, are responsible for its mitigation.


Any management, policies, legislation, regulations, and compliance mechanisms that are in place.


Data gaps that need to be addressed through a more targeted assessment.

The initial assessment can be broken down into three categories

Who

Who are the key communities and organizations involved?

What

What are the sources of water pollution, and are there any existing policies, legislation, or regulations in place to manage it?

Where

Where are the pollution generating activities occurring, and where in the coastal and marine environment are pollutants ending up?

Partner, community, & stakeholder mapping should focus on identifying four main groups

- The people **Responsible for the pollution.**
- The people **Affected by pollution.**
- The people **Able to mandate and enforce change.**
- The people **Responsible for pollution management.**

Who

The initial assessment can be quite short or more detailed, depending on information needs, and it can include one or a combination of the following components

Desktop assessment – Mapping & collecting existing data

- Land-use and land cover mapping.
- Collation of existing data, such as government reports, scientific publications, research studies, etc.
- Wastewater and stormwater systems and infrastructure mapping.
- Regulatory, policy, and management assessment, and gap analysis.
- Partner, community, and other stakeholder identification.

Physical inspection

- Examination of infrastructure, e.g., presence of leaking pipes.
- Observations of water and coastal areas for signs of pollution.
- Locating main sources of pollution.

Formal and informal discussions with key informants & community members

- Are there concerns regarding pollution?
- Are there practices that could cause pollution?

What & Where

Once you have collated all of the existing data, it is important to analyze and interpret the information to understand what it is indicating with regards to the sources, type, extent, and potential impacts from pollution. This step is **key to identifying data gaps and developing a pollution assessment and monitoring program that can best address the information needs required to initiate action or motivate change**.

To get you started, in **Appendix 1** we have outlined a number of questions to guide you on your initial assessment of existing information.

After going through these questions, you should be able to identify the following:

1. The location and scale of the area of interest.
2. The main concerns or questions about pollution in the area of interest.
3. The main data gaps that need to be filled to guide decision-making for pollution management.
4. The information partners and communities need to initiate action or motivate change in attitudes and actions.

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4. Defining goals, objectives, & targets

Coastal pollution assessment, monitoring, and evaluation aims to gather the data needed to protect the environment from negative biological and ecological impacts caused by pollution (Altenburger et al., 2015).

However, good monitoring programs are not just exercises in data collection. Setting appropriate goals, objectives, and targets is an essential requirement to help guide the data collection and analysis.

Goals

The higher level ambitions for your area and the outcomes you are trying to achieve, which may be met through multiple activities associated with improving water quality across watersheds and coastal and marine environments.

Example goals for your area

- Protect and maintain thriving aquatic ecosystems.
- Preserve the resources those systems provide to society.
- Safeguard human health.

There are likely to be existing goals in your area related to the conservation of coastal ecosystems and protection of ecosystem services that may benefit from some aspects of pollution management. Your assessment, monitoring, and evaluation program must provide the information and knowledge needed to guide decision-making around achieving stated goals.

Objectives

Specific statements of outcomes you are trying to achieve through pollution management, which will support your broader goals. Objectives can be both numerical and or narrative statements*.

A clearly stated management objective is needed for planning a coastal pollution assessment, monitoring, or evaluation program. Until you have this, you will not be able to fully address the more detailed questions around how to design and execute the program outlined in **Sections 5-7**.

Example management objectives

- Water quality in coastal systems should not harm or impact the coastal ecosystem.
- Recreational swimming areas comply with water quality regulations for safe swimming.
- Pollutant concentrations remain within water quality guidelines.
- Nutrient pollution loads are reduced to historic ambient levels.

Examples of scientific questions that could be addressed to inform management objectives

- Is agricultural pollution negatively impacting seagrass meadows?
- How do different pollutant concentrations vary in space and time?
- What are the main sources of nitrogen pollution in the area?

*** If there was limited information available during your initial assessment, you will likely have to undertake a more targeted scientific assessment to fully understand the pollution challenges in your area prior to setting more specific management objectives. In this case, your program objectives will be more focused on the scientific questions you are trying to answer rather than management objectives. However, even if this is the case, it is still critical to have clearly stated scientific questions that relate to broader management objectives and goals. Otherwise, you risk collecting additional information that cannot be used to inform management.**

Here are some questions to guide you in identifying both your management objectives & questions through targeted scientific assessments

- What is your desired end-state?
- What is currently stopping the desired end-state from occurring?
- What threats are you trying to quantify and mitigate?
- Do you need to demonstrate a long-term change?
- Are you abiding by or trying to meet international goals?
- Do you have requests from project partners, community members, and other stakeholders on mitigating particular threats or achieving specific outcomes?
- Are there policy targets or legal regulations you are required to meet?
- Are you obliged to meet the conditions of an Environmental Impact Assessment?

Once you have identified your goals and objectives, it is important to set targets for how you will meet those objectives**. **Setting targets will ensure that you are collecting the relevant data at the appropriate spatial and temporal scales.**

Target

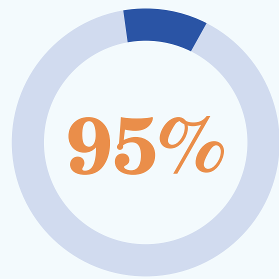
A target is an indicator established to determine how successful you are at achieving an objective.

Good assessment, monitoring, & evaluation targets should be

- Specific
- Measurable
- Achievable
- Results oriented
- Realistic & attainable
- Time-bound
- Inclusive
- Equitable

Example targets

By 2030, nitrogen loads entering coastal environments are reduced by **50%.**



95% of the *Enterococcus* sample measurements must fall within acceptable standards for human health to achieve safe swimming status by 2025.

The current measures of water quality bioindicators must be maintained on coral reefs within **1 km** of the proposed development site throughout the duration of construction.

**** Setting targets will be less relevant if you are still undertaking baseline scientific assessments. We suggest you use this guide iteratively, so once you have the results from your baseline assessments, you can focus more on setting specific management objectives and targets.**

In summary

If you still require additional information that will be collected through targeted scientific assessments, working with relevant partners to discuss broader management goals and objectives will help you design data collection so that the information can be used to guide management. If you are implementing management interventions to address pollution, having clear objectives and targets will ensure you are collecting the data needed for monitoring and evaluation at the appropriate spatial and temporal scales.

5. Deciding on your approach for data collection

There are many approaches to assess and monitor water pollution, and any given question or concern regarding pollution may be answered through several different approaches. The selection of the most appropriate approach or the mixture of approaches will depend on the type of pollution problem, the temporal and spatial scale of the problem, available budget, staff and technical expertize required, and the type of information that is needed. Selecting the appropriate approach ensures that the available resources (e.g., time, personnel, etc.) are used in the most cost-effective and efficient way to obtain the necessary information. Having the right data will help inform decisions regarding the best course of action to manage or mitigate a pollution issue.

We have broken down the different approaches to pollution assessment and monitoring into seven broad categories.

Biotic and abiotic sampling for further assessments

The collection of organisms, organism tissues, or sediments to assess the bioaccumulation of a pollutant within the tissue of an organism, physiological and anatomical abnormalities or deformities, changes in a system through time, and in some cases, sources of pollutants.

Direct, in-situ water quality measurements, observations, & samples

The collection of water samples that are analyzed at a laboratory or with a water quality testing kit, as well as in-situ measurements taken with an instrument, passive sampler, or data logger.

Ecological monitoring of bioindicators

In-situ monitoring of pollution-specific bioindicators to assess the impact of pollution or management on ecosystems (Gibson et al., 2000; Zaghloul et al., 2020).

Indigenous & local knowledge

Dynamic bodies of integrated, holistic, social and ecological knowledge, practices, and beliefs pertaining to the relationship of living beings, including people, with one another and with their environments. Indigenous and local knowledge is grounded in territory, is highly diverse, and is continuously evolving through the interaction of experiences, innovations and various types of knowledge (written, oral, visual, tacit, gendered, practical and scientific). Such knowledge can provide information, methods, theory, and practice for sustainable ecosystem management (IPBES, 2017).

Quantitative modeling

The use of hydrodynamic, ecological, predictive, or statistical models to assess the extent and magnitude of a pollution problem; to clarify the dynamics of complex connections between the sources of pollution and the impacts on ecosystems; and to evaluate the efficacy of proposed management interventions or proposed developments.

Remote sensing with satellite data

The use of satellite and airborne sensors to classify types of pollutants and their sources across large scales, based on their optical signature.

We have developed detailed factsheets about each approach. Each approach sets out elements you need to consider to decide whether an approach is suitable to generate the information you need, based on the specific characteristics of the problem you aim to understand and the resources available to conduct an assessment. One or multiple approaches can be used based on your particular data needs.

A combination of these approaches can be integrated into a **long-term monitoring and evaluation program (see Section 7.3)**. This is a permanent, long-term program that collects data to monitor, assess, and track change. Typically, long-term monitoring programs are developed to track changes in a coastal or marine system and to assess compliance against national or international regulations, thresholds, or standards. Long-term monitoring programs should align with objectives and goals around ecosystem or human health.

Factsheets to the pollution assessment approaches

To decide on the best approach or approaches to generate the information you need with the resources that are available, there are three main considerations that need to be evaluated:

1. **Information needs**
2. **Trade-offs among different approaches**
3. **Project logistics & constraints**

After going through this section, you should be able to identify the following:

1. The different approaches that could be implemented to collect the required data and information.
2. The trade-offs between the various approaches with regards to the type of information generated and some additional requirements for acquiring it.
3. The project logistics and constraints in place that will influence the pollution assessment and monitoring approaches that could be implemented.

In **Section 10**, we also go through some examples of how you would use different approaches in combination to collect the data that are needed.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5.1 Information needs

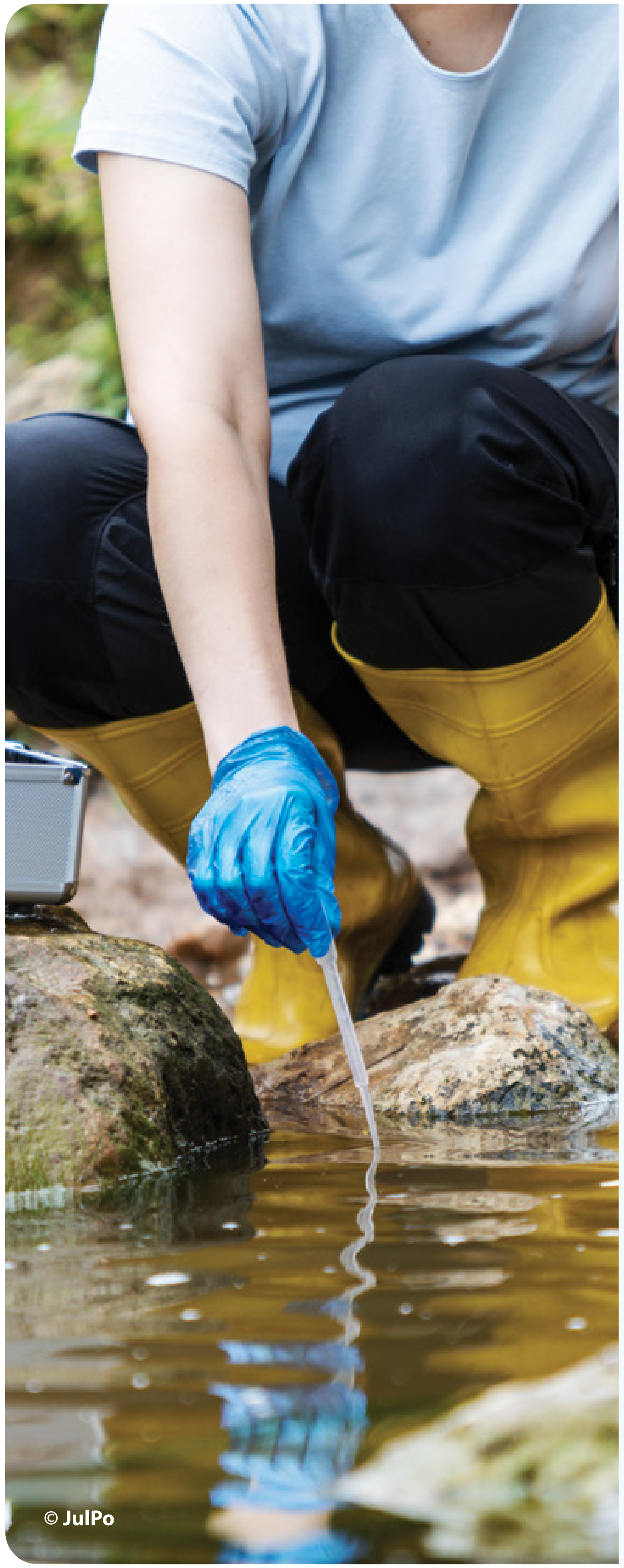
From your initial assessment (**Section 3**) and your goals, objectives, and target setting (**Section 4**), you should now know the type of information that you need to collect during a targeted scientific assessment or for monitoring and evaluation of management interventions. If there is not a direct recipient of the information being collected, you should engage the partners and communities identified in **Section 3** first to build support for the project.

On the following page, we have identified several common questions that people often have regarding coastal pollution and provide guidance on the approaches that are most appropriate for answering them. It is not always necessary to undertake every approach that could be used to answer your question, so the information should be used to guide you on what types of approaches could be used.

Which approaches could be used to collect the required data and information?

Do you need to...

	Biotic Abiotic	Ecological Monitoring	Direct, In-Situ	Indigenous & Local Knowledge	Quantitative Modeling	Remote Sensing
Identify potential or specific polluting activities?				●	●	●
Identify pollution loads reaching the coast?			●		●	
Identify specific parameters or pollutant types in the environment?	●		●		●	●
Identify the spatial extent of pollution in coastal and marine environments?	●	●	●	●	●	●
Determine if coastal and marine environments are meeting water quality standards?			●			●
Identify the specific source(s) of a pollutant in the environment?	●		●		●	
Identify which areas are most polluted?	●	●	●	●	●	●
Determine if there are species, ecosystem, or fisheries impacts?	●	●		●		
Determine if there are risks to human health, that could threaten recreational activities?	●		●	●		
Track historic changes in pollutant loads,sources, and ecosystem condition?	●			●	●	●
Track changes in pollutant loads, sources, and ecosystem condition in response to changing land-use?		●	●	●	●	●
Predict the fate of pollution and impacts on ecosystem condition in response to changing land-use?					●	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5.2 Factors to consider for each approach

Based on the information outlined in **Section 5.1**, you can see that for most of the questions related to pollution assessment and monitoring, there are multiple approaches that you can use. The information in **Table 2** should help guide you on the best approach or approaches to use, based on your information needs, the objectives you are trying to meet, the time-frames of the project, and the levels of funding you have available.

Depending on your context and your objectives, one approach might be more appropriate than another. For instance, some approaches are much more accurate in measuring pollutant concentrations, while other approaches allow for data to be collected in a cost-effective way across much greater spatial and temporal scales. We refer to these as your **data characteristics**.

For each approach, it's not only important to think about the characteristics of the data being collected, but you also need to consider some of the requirements for collecting data, such as the resource requirements for data collection, e.g., laboratory facilities, transportation, or sampling materials; the expertise required for data collection and analysis; and whether any specialized equipment is required. We refer to these as your **data requirements**. In **Table 2** we go through a series of factors related to both **data characteristics** and **data requirements** that are important to consider for different approaches. We highlight how each approach compares against each other. For each approach, we are assuming the same level of financial resources are being put into data collection. For example,with remote sensing, one can access data over very large spatial scales and the cost of collecting remote sensing information at regional versus national scales is not that different. However, while it is possible to collect water samples across large spatial scales, scaling up from a regional to national scale for site-level work would require significant increases in the levels of funding.

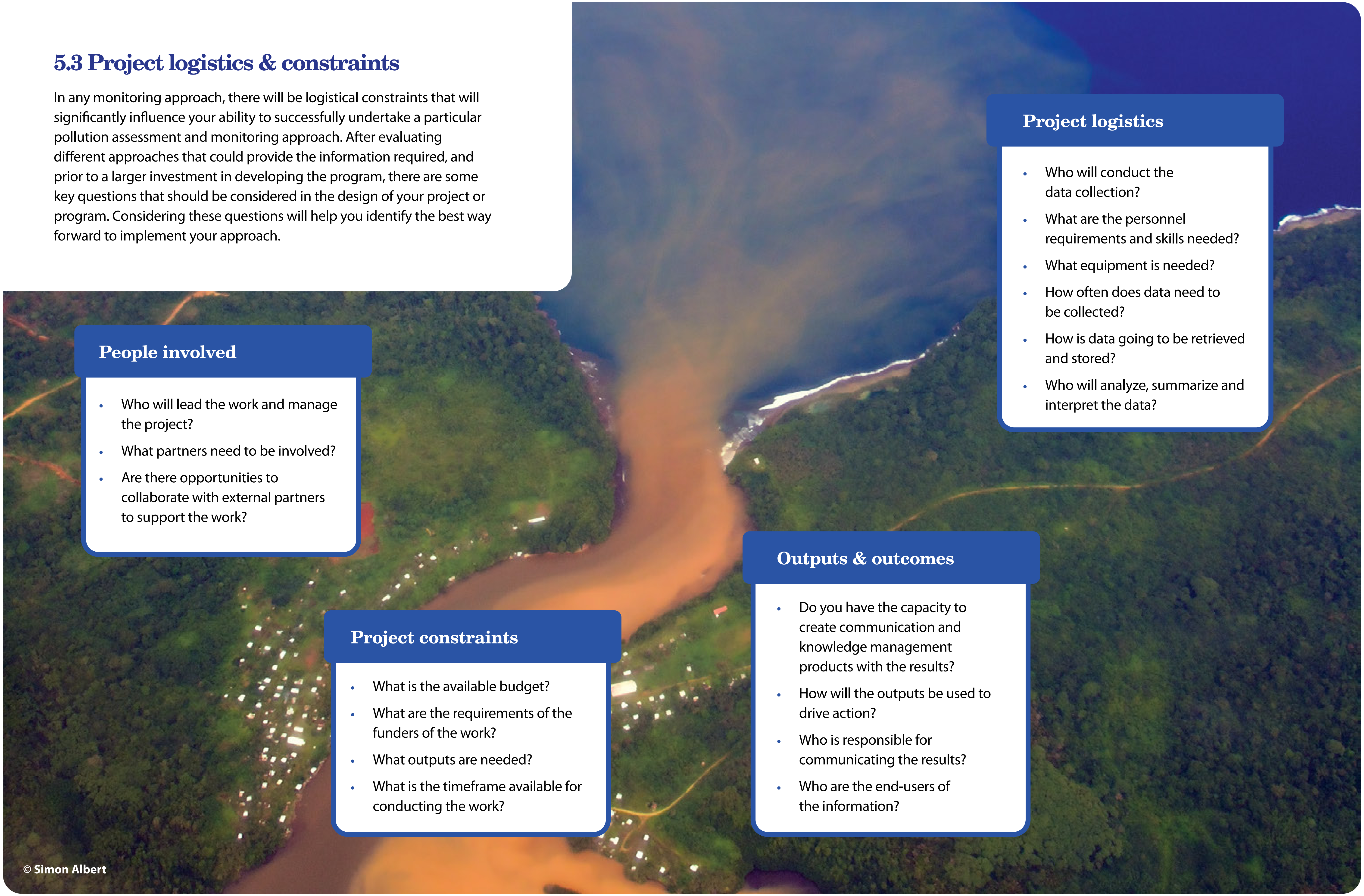
Table 2: How different approaches compare across various factors when cost & effort are the same

More symbols in the **data characteristics** columns means that an approach will give you more accurate measurements of a pollutant, or data, on a greater spatial or temporal scale. More symbols in the **data requirements** columns means that more resources, subject matter expertise, and/or specialized equipment are required for that approach.

Data Characteristics				Data Requirements		
Accuracy in Measuring a Pollutant	Spatial-Scale of your Data	Temporal Scale		Resource Requirements	Specialized Equipment Required	Subject Matter Expertise
■■	■	■	Biotic abiotic	■■■	■■■	■■■
■	■■	■	Ecological monitoring	■■■	■	■■
■■■	■	■	In-situ	■■■	■■■	■
■	■	■■	Indigenous & local knowledge	■■	■	■
■■	■■	■■	Modelling	■	■■	■■■
■■	■■■	■■■	Remote sensing & spatial analysis	■	■■	■■■

5.3 Project logistics & constraints

In any monitoring approach, there will be logistical constraints that will significantly influence your ability to successfully undertake a particular pollution assessment and monitoring approach. After evaluating different approaches that could provide the information required, and prior to a larger investment in developing the program, there are some key questions that should be considered in the design of your project or program. Considering these questions will help you identify the best way forward to implement your approach.



People involved

- Who will lead the work and manage the project?
- What partners need to be involved?
- Are there opportunities to collaborate with external partners to support the work?

Project constraints

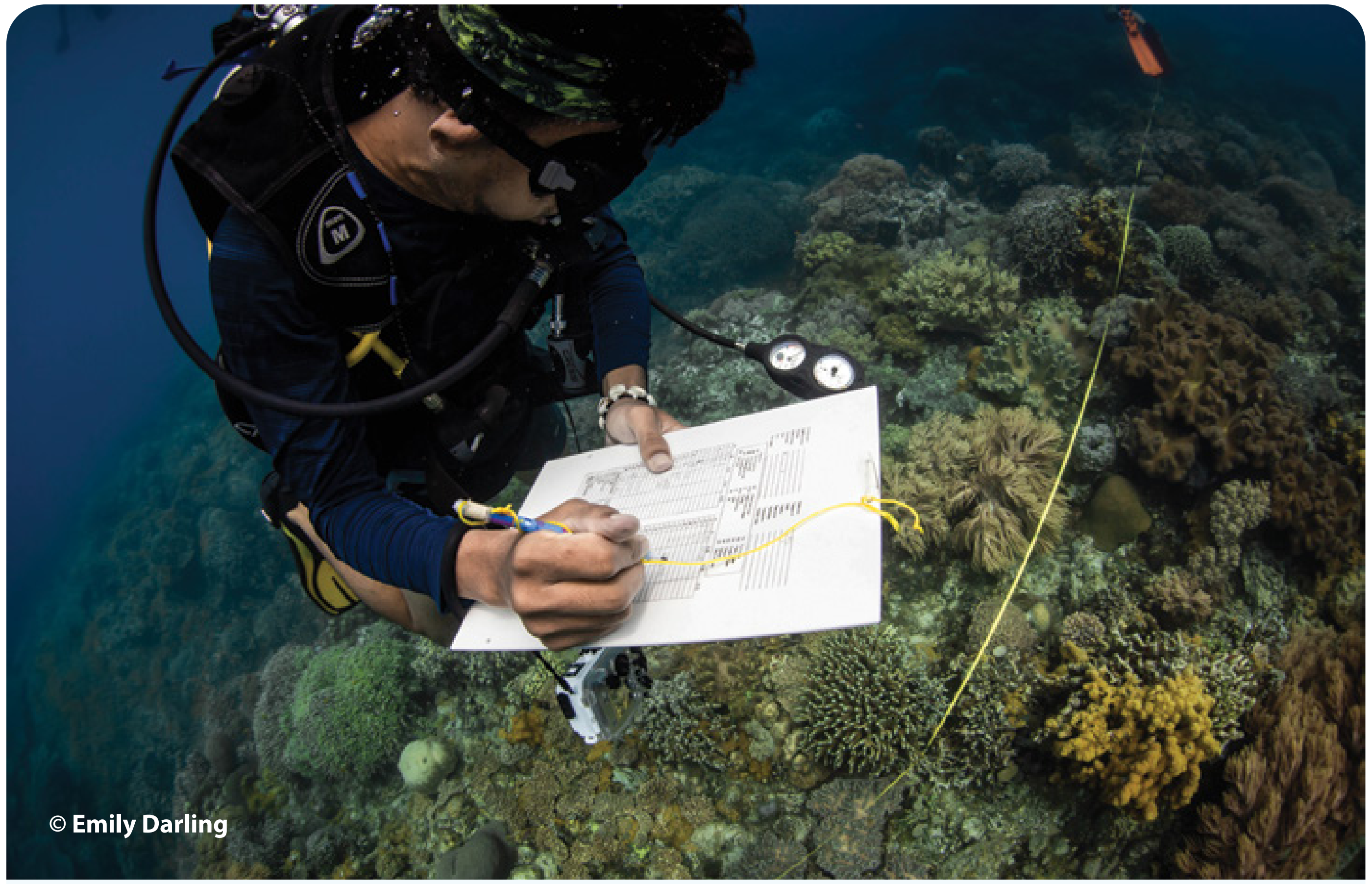
- What is the available budget?
- What are the requirements of the funders of the work?
- What outputs are needed?
- What is the timeframe available for conducting the work?

Outputs & outcomes

- Do you have the capacity to create communication and knowledge management products with the results?
- How will the outputs be used to drive action?
- Who is responsible for communicating the results?
- Who are the end-users of the information?

Project logistics

- Who will conduct the data collection?
- What are the personnel requirements and skills needed?
- What equipment is needed?
- How often does data need to be collected?
- How is data going to be retrieved and stored?
- Who will analyze, summarize and interpret the data?



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6. Collection of in-situ information

Some of the most common queries about pollution assessment and monitoring are around collecting direct, in-situ measurements, observations, and samples. This section answers many of those common questions and provides guidance on: identifying relevant parameters to measure, depending on the type of pollution that needs to be measured, selecting methods to use to collect in-situ information, and developing the most appropriate sampling and experimental design.

After going through this section, you should be able to identify the following:

1.

A selection of the most appropriate parameters that could be measured to help answer your objectives/questions.

2.

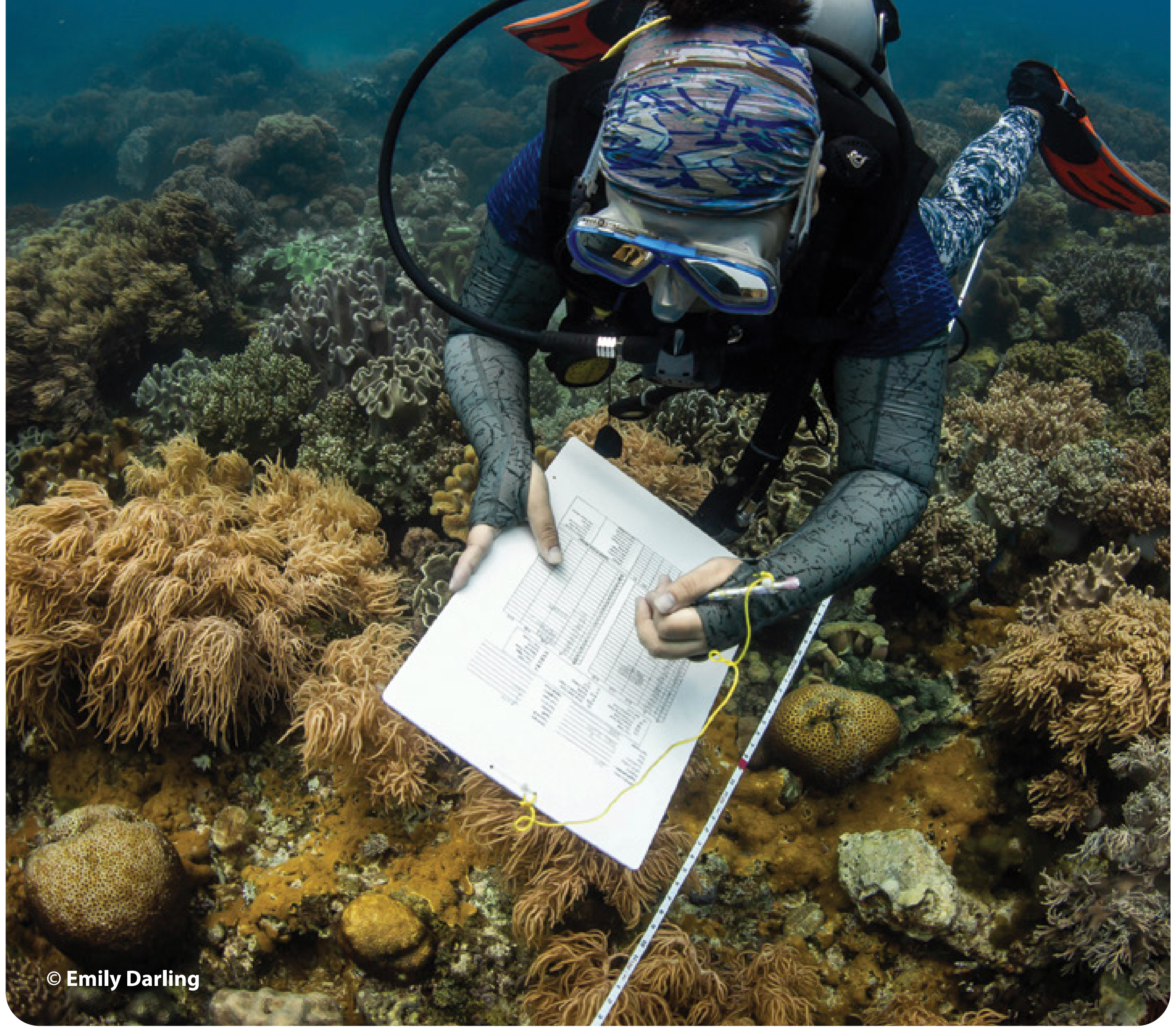
The methods available to you based on your objectives, moderated by logistic constraints & available resources.

6.1 What to measure

Different land uses, activities, and industries produce specific groups of pollutants (**Table 1**). Some pollutants are specific to particular industries, such as a pesticide used in agriculture, while others may be generated by multiple types of land-use, such as nutrients. For many pollutant types, there are a range of water quality parameters and indicators that can be measured (**Fig. 3**).

A parameter is defined as the specific pollutant that is measured to assess pollutant type presence or concentration, e.g., nitrate...

An indicator is defined as a physical, chemical, or biological measure that points to the presence of specific environmental conditions or pollutants, e.g., chlorophyll a.



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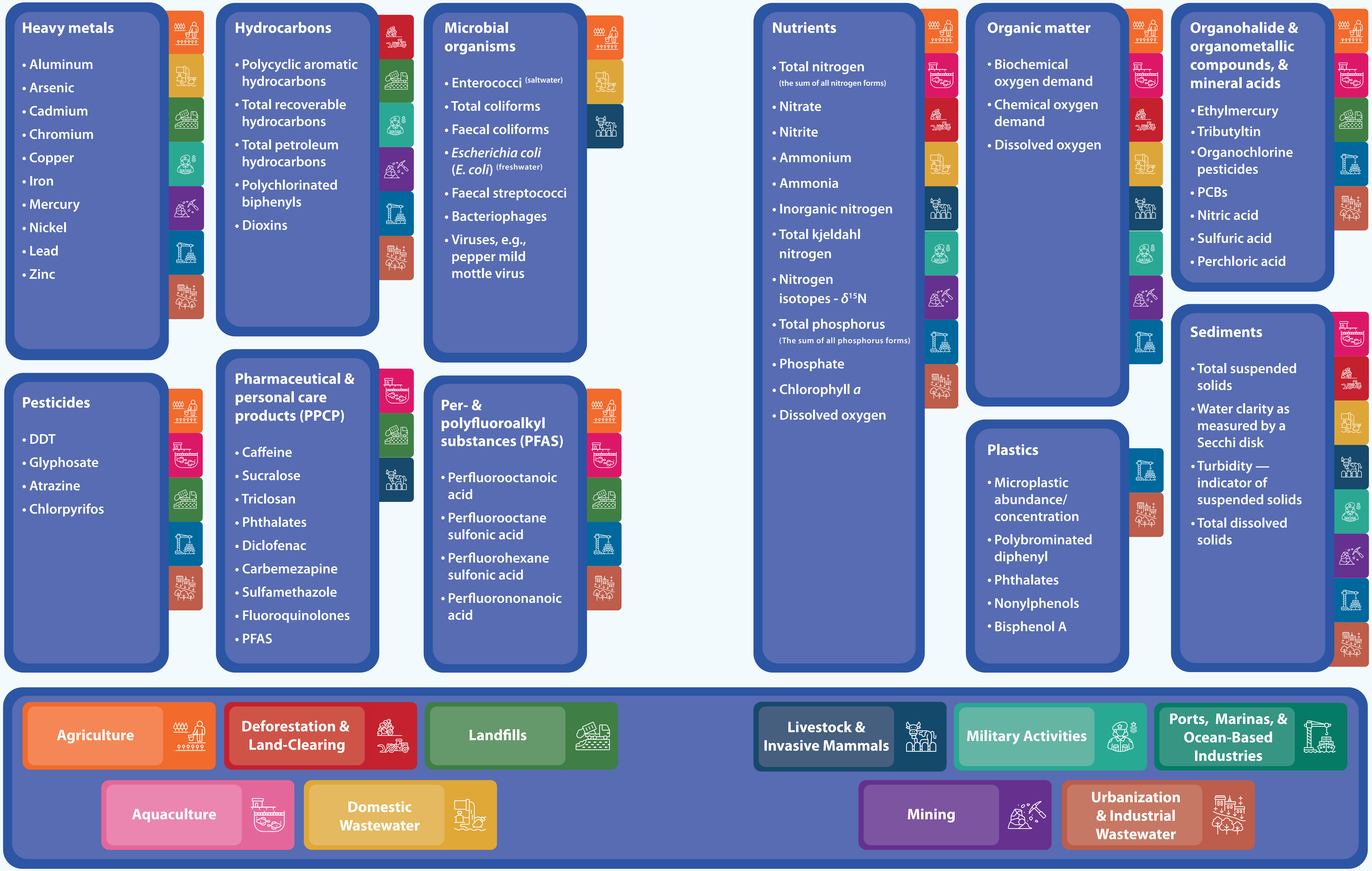

Fig. 3: *Examples of common parameters and indicators that can be measured to assess different pollution types*

With all pollutants

Beyond the specific parameters of interest, it is important to record data on **temperature**, **pH**, and **salinity**, as this information will provide important context to your results. For example, salinity levels will give an indication of the type of waterbody you are working in, with levels from **0–5 indicative of a freshwater** environment, **5–30 indicative of a estuarine** environment (and typically highly variable given tide and salinity ranges), and greater than **30 indicative of estuarine waters merging into marine, offshore waters**.

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Specific advice on the best parameters to select is context-dependent and beyond the scope of this guide. However, **this guide presents some of the broader considerations that can help you with decision-making around the best parameters to select**.

Do you need information on a specific parameter in the environment, or are you tracking one specific type of pollution?

Answer: Some parameters for particular pollutant types can be measured with many kinds of equipment, like water quality testing kits or data loggers, and can be more easily measured at laboratory facilities, without the need for specialized equipment. If you are more interested in categorizing a pollution type, e.g., nutrient pollution, rather than a specific parameter, e.g., ammonia, consider selecting a method that is less expensive, and logistically easier to use. However, this may also be influenced by the degree of certainty required and the concentration level. If you are trying to point towards a specific source (e.g., a golf course that uses a specific pesticide), then measuring a parameter that is a reliable indicator for a specific pollutant source makes more sense. If you do have information on the type of industry that is connected to the pollution issue, much of the preliminary information on pollution can be accessed through literature and can help with developing your monitoring to test for a specific pollutant.

Do you need to identify the specific source of a pollutant type in the environment, which could have multiple sources?

Answer: Many pollutant types come from multiple sources, such as nutrient pollution from agricultural runoff or domestic wastewater (Table 1). If you are trying to identify the specific source, consider selecting a parameter unique to that source, such as a pharmaceutical or personal care product or a human-associated microbial organism to assess wastewater pollution, rather than a parameter with multiple sources like total nitrogen (**See FAQs on how to do this**).

Does the country where you are working have water quality or wastewater discharge standards?

Answer: Many countries have water quality or wastewater discharge guidelines and/or standards that list limits for specific parameters. These parameters may not be the ones that have the clearest link to human and ecosystem health (Burkepile et al., 2019). However, it often makes sense to measure parameters that are listed in standards instead of or in addition to other parameters of interest so you can report on the state of pollution in relation to any policies or regulations in place.

Do you need to determine if there are risks to coastal and marine ecosystems?

Answer: The known relationship between some pollutant parameters and their impacts on coastal ecosystems is much more well-established than for others. Therefore, selecting a parameter with a clear link to ecosystem health will provide more information on risks to ecosystems from pollution (Burkepile et al., 2019). However, establishing a clear relationship between pollution and the impact on the ecosystem can be difficult and may require long-term monitoring using multiple approaches , including ecological monitoring of bioindicators, and selection of sites including both non-impacted and impacted areas.

Do you need to determine if there are risks to human health?

Answer: There are guidelines for human health when it comes to recreational bathing or consumption of seafood. Therefore, if you want to understand if there are any risks to human health due to pollution, you need to select a parameter that has known human health consequences or is a proxy for human health and is listed in human health guidelines (see **Question 4** in **Section 10**). Consider also assessing bioaccumulation of pollutant types of concern for human health in common fishery species (see **Factsheets on Approaches to Assessing and Monitoring Coastal Pollution**).

What are the conditions under which you are collecting samples?

Answer: If you need to ship samples, carry them on planes, or are far from a laboratory, you need to think about any chemicals involved in sample preservation, holding times in between collection and analysis, whether the sample needs to be kept cold or frozen, and whether it requires specialized equipment for analysis (see **Section 6.2** for more information).

6.2 How to measure pollutants

Once you have narrowed down your list of parameters that you might want to measure, you need to think about how you are going to measure them. There are many ways to collect water quality information. These can range from the very simple activity of taking a water sample for analysis at a monthly frequency to complex, automated collection of data by deployed equipment. We have broken down the different methods for direct, in-situ water quality measurements, observations, and samples into six broad categories:

1 Manual water sampling for laboratory analysis

Collection of a water sample by a person, for its analysis in laboratories.

2 Automated water sampling for laboratory analysis

Automatic collection of samples by deployed equipment, where the water samples are retrieved and analyzed in a laboratory.

3 Automated measurements with a data logger/sensor

The measurement and recording of pollutants over time, through the use of sensors or probes that are deployed.

4 Passive sampling

Collection of pollutants through the deployment of a material in water or sediments that accumulates organic compounds for a defined period of time, followed by retrieval and analysis in a laboratory.

5 Manual water sampling and analysis with a water quality testing kit

Collection of a water sample by a person, for its on-site analysis with a water quality testing kit.

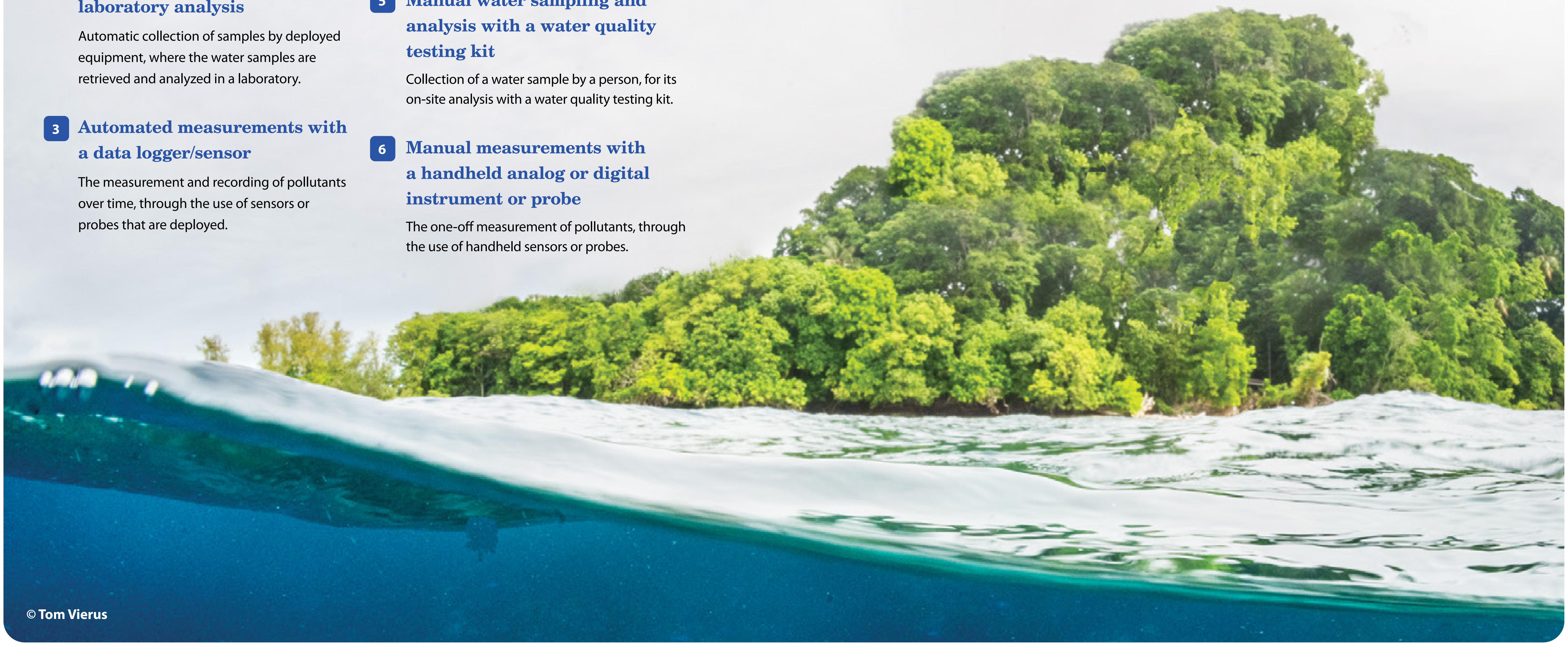
6 Manual measurements with a handheld analog or digital instrument or probe

The one-off measurement of pollutants, through the use of handheld sensors or probes.

We have compiled detailed information about each method with the different elements you need to consider to decide whether a particular method is suitable to generate the information you need, based on the specific characteristics of the problem you aim to understand and the resources available to conduct an assessment.

It is important to highlight that multiple methods can be used based on your particular data needs.

Technical information on methods for direct, in-situ water quality measurements, observations, and samples.



The selection of the method/s to collect data are dictated by information needs and logistic constraints. Often, decision-making is more related to budget constraints or longer-term goals. As described in more detail in the factsheets, the different methods to collect in-situ information all have their pros and cons, and it will be up to you to ultimately decide on what factors are most important.

However, there are some constraints that **make certain methods impossible for different contexts**. We highlight the most common constraints and provide guidance on available options you could use in these instances (**Fig. 4**).

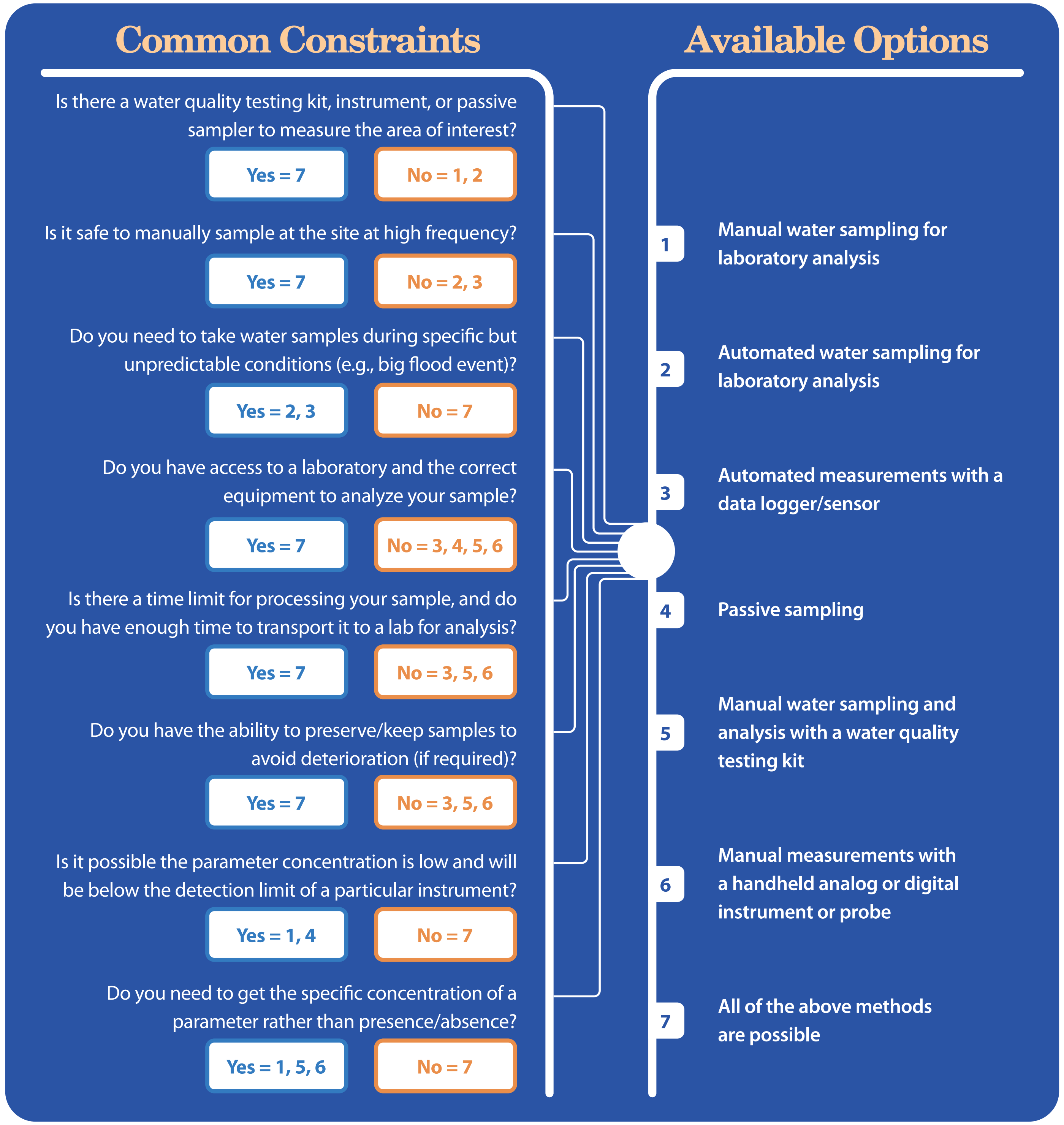


Fig. 4: *Common constraints and the available options*

What next?

Once you have a better understanding of the methods that are available to you, there will be additional factors to consider, which will help you select the best method. When making your selection, you should think about your information needs, the objectives you are trying to meet, the time-frames of the project, and the levels of funding you have available.

In **Table 3**, we go through a series of factors related to the characteristics of the data you can collect with different methods. For each method, we are assuming the same level of financial resources are being put into data collection. For example, each water sample collected for laboratory analysis must be paid for, so more frequent collection incurs a greater cost than taking measurements with a handheld instrument, where there is not a cost associated with each measurement.

Table 3: Different factors to consider for each in-situ data collection method

More symbols means that a method can measure more pollution parameters, will give you more accurate measurements of a pollutant, or allow for data collection on a greater spatial or temporal scale.

	No. of Pollution Parameters Able to be Measured	Accuracy in Measuring a Pollutant	Temporal Scale	Spatial Scale
1 Manual water sampling for laboratory analysis	■■■	■■■	■	■■
2 Automated water sampling for laboratory analysis	■	■■	■■	■
3 Automated measurements with a data logger/sensors	■	■■■	■■■	■
4 Passive sampling	■■	■■	■■■	■
5 Manual water sampling and analysis with a water quality testing kit	■■	■	■■	■■
6 Manual measurements with a handheld analog or digital instrument or probe	■	■■	■■	■■■

7. Site selection & sampling frequency

7.1 Selection of sampling sites

The selection of appropriate sampling sites is an important component of pollution assessment and monitoring because you need to make sure that you are sampling in areas that allow you to meet your objectives*. For instance, if you are trying to understand how tourism impacts pollution, you need to sample in areas where there is tourism activity as well as in areas without tourism, or with much lower levels. Your initial assessment (**Section 3**) plays a key role in deciding on sampling sites, because it should provide information, such as:

- Sources of pollution, such as the location of urban areas or polluting activities.
- The location of streams and rivers, and in some cases locations of groundwater seeps.
- Hydrodynamic (i.e., currents, waves, and mixing) conditions in coastal environments.

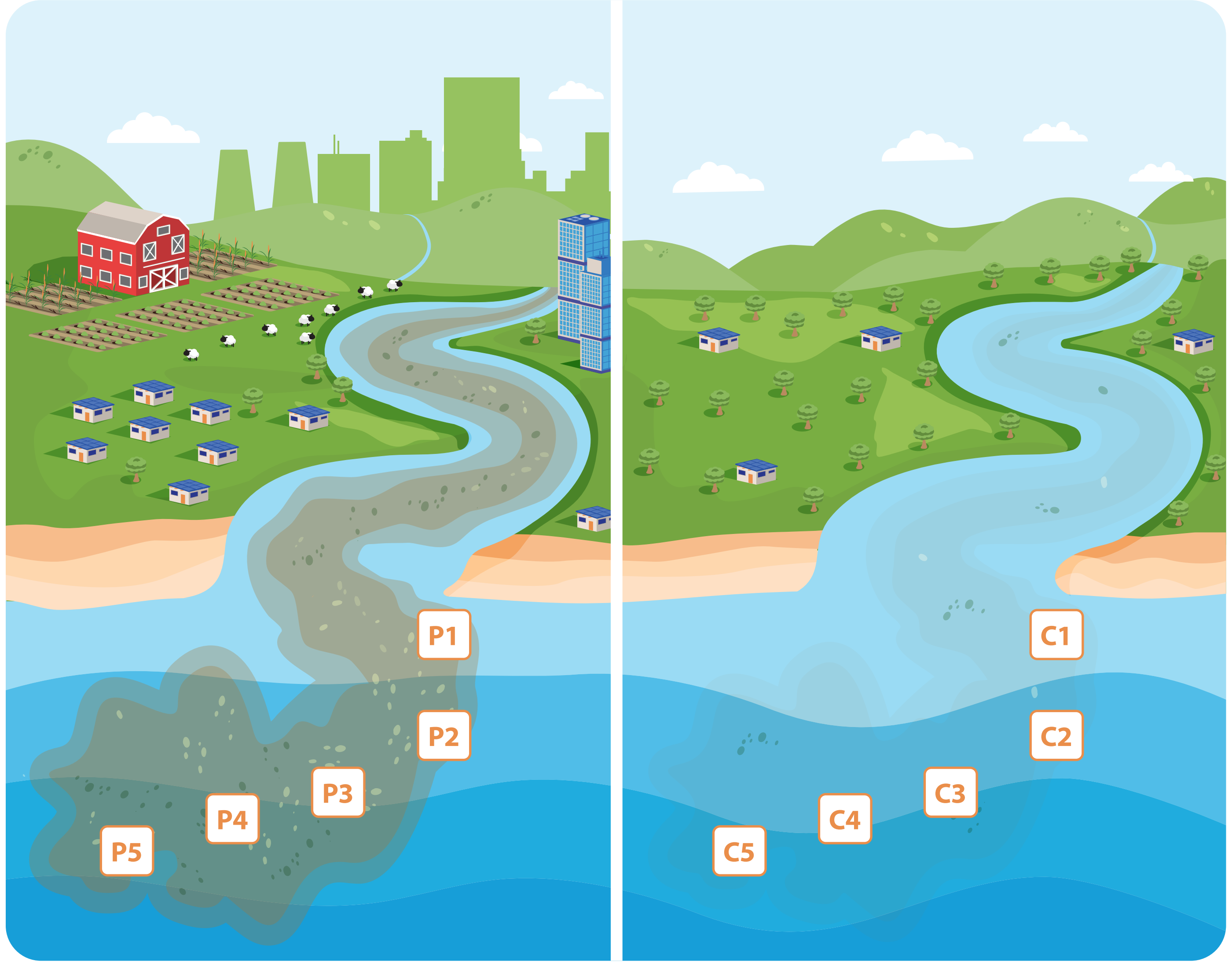


***Fig. 5:** Example of sampling from inshore to offshore at a polluted and control site*

** If water samples are going to be collected for compliance purposes, please refer to the conditions specified by environmental authorities of the area of interest.*

Optimally, monitoring should be implemented across a series of sites arranged along a gradient extending from the pollution source, following the path of pollutant transport and dispersal (**Fig. 5**). Sampling in this way can identify both the presence of pollutants and their spatial distribution.

When selecting control sites for your study, it is crucial to ensure that these sites differ from the impacted sites only in terms of the specific impact you intend to monitor. For example, if the focus is on assessing the impact of pollution, your control sites should be similar to the impacted sites in all aspects except for the level of pollution and/or the presence of the activity that generates the pollution. This principle holds true across various environmental gradients, such as inshore to offshore. Therefore, inshore sites affected by pollution should be compared with inshore sites experiencing less or no pollution (**Fig. 5**). Similarly, offshore sites in areas impacted by pollution should be juxtaposed with offshore sites in cleaner areas. This is because water quality and ecosystem condition will vary naturally across inshore to offshore gradients. Carefully selected control sites play a pivotal role in isolating the effects of pollution from natural environmental variability, thereby ensuring the validity and reliability of your study's findings.

Additional considerations when selecting sampling sites:

- Fixed sampling sites allow for consistent repetition and comparison over time.
- They should be located in areas safe to access and accessible under most weather conditions.
- The distance between sites will be determined by the level of mixing conditions. In areas that are well-mixed, sampling sites can be more separated from each other.
- Permits and approvals may be required to access certain areas such as protected areas or private property. Remote locations and difficult terrain may require special considerations regarding transport, safety, and appropriate equipment.
- Transporting equipment, personnel, and samples are important elements for a successful sampling plan. These elements need to be taken into account when selecting a sampling site.

7.2 Frequency of measurements

Water sampling frequency is determined by the type of information you need, the nature and specific attributes of the water body, and the variability of parameters of interest in time and space (The ASEAN Secretariat, 2008). Infrequent data collection can result in a poor representation of water quality changes and patterns in a given system, leading to potentially inaccurate reporting and management.

There are statistical methods, such as a power analysis, which can be used to design a statistically-robust pollution assessment and monitoring program (Harcum & Dressing, 2015; Spooner et al., 2011).

Here, we highlight several factors to consider and rules of thumb regarding sampling frequency

1. If your system has distinct types of variability, e.g., a rainy season, particular wind patterns, or large tidal fluctuations, you need to sample across all kinds of conditions to be able to assess natural variability, whether human activities are changing this variability, or if your system is exceeding water quality standards.
2. Monthly sampling is considered appropriate for characterizing a water body over a long period of time, but to detect finer variations, weekly sampling would be better.
3. If you have a distinct wet and dry season, try to sample as close as possible to the first flush (i.e., right after the first large rainfall event), with repeated sampling during flooding events and throughout the wet season.
4. If you are monitoring a pollution event, e.g., algal blooms, oil spills, unsafe levels of a pollutant due to storms or flooding, you will need to monitor daily to a few times a week to track it.
5. To reduce the risk of Type II errors (i.e., false negatives), **sample size needs to be increased as much as possible and sampling should be as frequent as possible.**. The more variability in your system, the more samples you have to take. While there is no minimum or maximum number of samples that should be taken, **statisticians will often use 30 as the number of samples that can show variability correctly in the dataset.** This is the minimum number of standards used in the US to establish a baseline for regulatory purposes.
6. Opt for collecting information on fewer parameters if it means you can take more samples of one parameter.
7. If there are established, or internationally recognized sampling protocols for your question or concern, follow the guidance in those protocols on frequency (see Question 4 in **Section 10** for some examples).
8. Adherence to regulatory standards is crucial for compliance and environmental management. The selected sampling frequency must align with regulatory guidelines to ensure the data's validity and acceptance.
9. If you are monitoring multiple sites, you need to sample at similar conditions (e.g., high tide) to avoid errors due to system variability.
10. If you have limited resources but need to establish a baseline, consider undertaking a rapid assessment method with more frequent analysis over a very short time frame (e.g., a month) and repeated in the wet and dry season.

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7.3 Long-term monitoring & evaluation

When tracking progress towards management objectives and targets or monitoring development activities to ensure compliance with regulations, it is important to implement a long-term **monitoring and evaluation (M&E) program**, which will influence the type of approaches and methods you select, as well as the frequency of sampling.

Long-term M&E is essential for assessing and responding to environmental changes from management or development, and a crucial component of adaptive management of coastal and marine systems (Australian Government Initiative, n.d.a). Effective long-term monitoring involves data collection before, during, and after project implementation or development, while evaluation systematically assesses intervention design, implementation, and outcomes for learning and accountability. A well implemented M&E program can assess whether policy implementation has been successful and can identify factors that led to successful or unsuccessful implementation.

Factors for success

- Clear **program objectives and targets** and a design aligned with original goals (**see Sections 4-7**).
- Sustained funding to support long-term, systematic monitoring, data hubs, and data interface systems.
- Ability to collect long-term data in systems with multiple pressures.
- Sampling, field logistics, and personnel are in place to continue a long-term monitoring program.
- Ability to statistically analyze long-term data.
- Ability to track changes, trends, and variability with confidence.
- Multiple levels of engagement across many partners, communities, and other stakeholders.
- Agreement between relevant parties to respond to the outcomes of the monitoring and evaluation.
- Monitoring programs linked to policy implementation.

External resources with more information

- Reichelt-Brushett, 2023
- Sukhotin & Berger, 2013

8. Quality control & data management

8.1 Sample quality assurance & quality control

Quality assurance and quality control (QA/QC) are a very important part of pollution assessment and monitoring because there are a lot of steps from sampling to analysis where error can be introduced. The specific quality control measures will depend on the equipment being used and the parameter being measured, but we highlight below some elements you need to consider along the way.

Before sampling

- Make sure you know the specific sampling protocols needed for each parameter being measured.
  - If sending samples to a laboratory, ensure you are collecting and preserving the samples in accordance with the laboratory's protocols.
  - If using a testing kit or digital instrument, make sure you are following the manufacturer's protocols.
  - Double-check that your instrument or water quality testing kit can be used in the salinity conditions of your water body.
  - Double-check that the unit of measurement is the correct one for your needs and compatible with existing monitoring programs in your area, if relevant.
- If collaborating with other agencies for water quality monitoring, make sure procedures for data collection are compatible with yours.
- If you need to capture a specific event, i.e., the first flush of the wet season, make sure all of your sampling equipment and field logistics are in place in advance, so that you can mobilize quickly.
- Make sure that collection of data is consistent throughout the duration of the project or program to ensure compatibility.
- If you need to transport samples to a laboratory, make sure you are able to maintain proper storage conditions (e.g., keeping them frozen) the entire way.
- If flying with samples or if they need to be shipped, double check with the airline and the shipping company that you can ship specific preservatives and have the appropriate customs forms checked and completed. Many countries have strict guidelines for import and export of water and sediment samples that need to be checked prior to any movement of samples.
- Ensure you have calibrated your water quality testing kit or instruments according to manufacturers' protocol, especially if you have not used it in awhile. (see question 7 in **Section 11**).
- If you are sending samples to a laboratory, double check their QA/QC protocols and ensure that their analytical instruments have been properly calibrated. This can be done through checking laboratory records.
- If you are using a water quality testing kit, make sure you have enough reagents for the samples you are collecting, that you are storing reagents correctly, and that they are within their use-by date.

Things to check

- [ ] Do samples need to be collected in specific containers (e.g., dark bottles)?
- [ ] Do the sampling containers need a specific type of preparation (e.g., acid-washed)?
- [ ] What volumes are required?
- [ ] Do they require a specific way of sampling (e.g., minimizing exposure to air)?
- [ ] Do samples need to be filtered?
- [ ] Do samples need a preservative?
- [ ] Do samples need to be kept at a specific temperature during transport and storage?
- [ ] What are the holding times for samples?
- [ ] Is all of your equipment properly calibrated?
- [ ] Are all of your reagents within their use-by date?

During sampling

- Ensure you have a field safety plan.
- Bring blank samples with you as a way to check if contamination of water samples occurs throughout the sampling process and during transport.
- Bring the protocol requirements for every parameter with you.
- Ensure you have all of the sampling equipment you need, including preservatives.
- Label sample jars with a unique identifier before sample collection.
- Wear gloves to avoid contaminating water samples.
- Refrain from eating, smoking, or having a boat engine running while working with water samples. Exhaust gases and cigarette smoke can contaminate samples.
- Ensure samples are securely fastened and consider wrapping lids with parafilm to avoid loss or contamination.
- Collect replicate samples for each parameter at each sampling location/depth.
- For instruments, values should be recorded 3 times at each location/depth.


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Sample Processing & Analysis

- Follow the Standard Operational Procedure (SOP) for sampling and analysis. If no SOP exists, ensure compliance with the actions listed below.
- Follow safety procedures at every step, including field and laboratory. Be safe at all times, and carefully consider the safety of yourself and the sampling team prior to any sample processing and analysis.
- Document all weather conditions, survey staff, and vessel information.
- Document sample collection information on both paper and electronic forms.
- Ensure that you associate a unique id with each individual sample that can be tracked through sample processing and analysis.
- Ensure that samples collected in the field are stored correctly, such as freezing samples immediately after field processing if freezing is required.
- Once samples are returned to the lab, check that all field samples and unique ids are matched with the sample sheet.
- Check latitudes and longitudes recorded against each sample.
- Ensure that sites with multiple samples are matched in both field log sheets and electronic data records.
- Check with laboratory staff that the field notes, survey sheets, geographical information, and sample numbers are correct, understood, and checked by both the field staff and laboratory staff.
- Store samples as required, or initiate laboratory analysis procedures if samples are to be analyzed immediately.

8.2 Documentation standards & data management

It is important to have written procedures for all activities related to the collection, processing, analysis, reporting, and tracking of water quality data. This documentation should be available to field and laboratory personnel.

For the best quality data, documentation of field and laboratory activities should follow these guidelines:

- Data should be documented directly, promptly, and legibly.
- Enter in "long-form" rather than "wide-form" as this will make data analysis much easier (The Data School, 2022).
- All reported data must be uniquely traceable to the raw data through sample identification numbers that are on each sample as labels, and recorded in the field and laboratory log books.
- Field notes should be reviewed as soon as possible to ensure they are clear and complete, and make any necessary corrections. Then, they should be scanned, and data entered into a digital database with a copy of the file in a different location.
- All data reduction formulas (such as dilutions) must be documented and include the initials of the data collector.
- The process of documentation must be clearly stated, including standards and guidelines to stick to for management of metadata and appropriate data storage.
- Use standardized terms, units, and classifications.
- Incorrect data should be removed from the dataset before use, especially if intended to be used for regulatory purposes.
- Ensure that data correction is based on appropriate procedures, is justifiable, and that original values are retained somewhere.
- It is essential to store all collected data in multiple locations for redundancy and safety. At a minimum, data should be backed up in a secure cloud storage service in addition to local storage solutions.

All original data records should include, as appropriate

- ☐ A description of the data collected (e.g., parameters, value, unit of measurement).
- ☐ The sampling depth.
- ☐ Units of measurement, unique sample identification (ID).
- ☐ Site ID and description.
- ☐ Auxiliary data (e.g., weather conditions, wind speed).
- ☐ Name of the person collecting the data.
- ☐ Name of the organization(s) conducting sample collection and analysis.
- ☐ Date and time of data collection.
- ☐ Filtration, preservation, and storage information, including volume of sample.
- ☐ Date and location of sample processing.
- ☐ Method used to process samples, including the make and model of the equipment used and reagents used.

9. Analysis & communication of data

Once all of the pollution data in your area of interest is collected, it will need to be analyzed, interpreted, and communicated to relevant project partners, community members, and other stakeholders. Information users need to be fully informed about the scope and results of the project or program and how the findings can be used for decision-making on how best to manage coastal pollution.

Analysis

In the analysis step, the data available are analyzed to look for trends and hotspots that can indicate water quality problems. Then, the information needs to be interpreted given the specific conditions of the place. For instance - given local knowledge of the place, what are likely sources of impairment? Was the timing or place of the sample the reason that values are high or low? How do the values compare with local or government standards?

Communication

After there is some consensus about what the data are showing, communicating this interpretation involves creating the graphics, maps, and language that are tailored to the project partners, community members, and other stakeholders that will decide or influence management options and/or behavior change.

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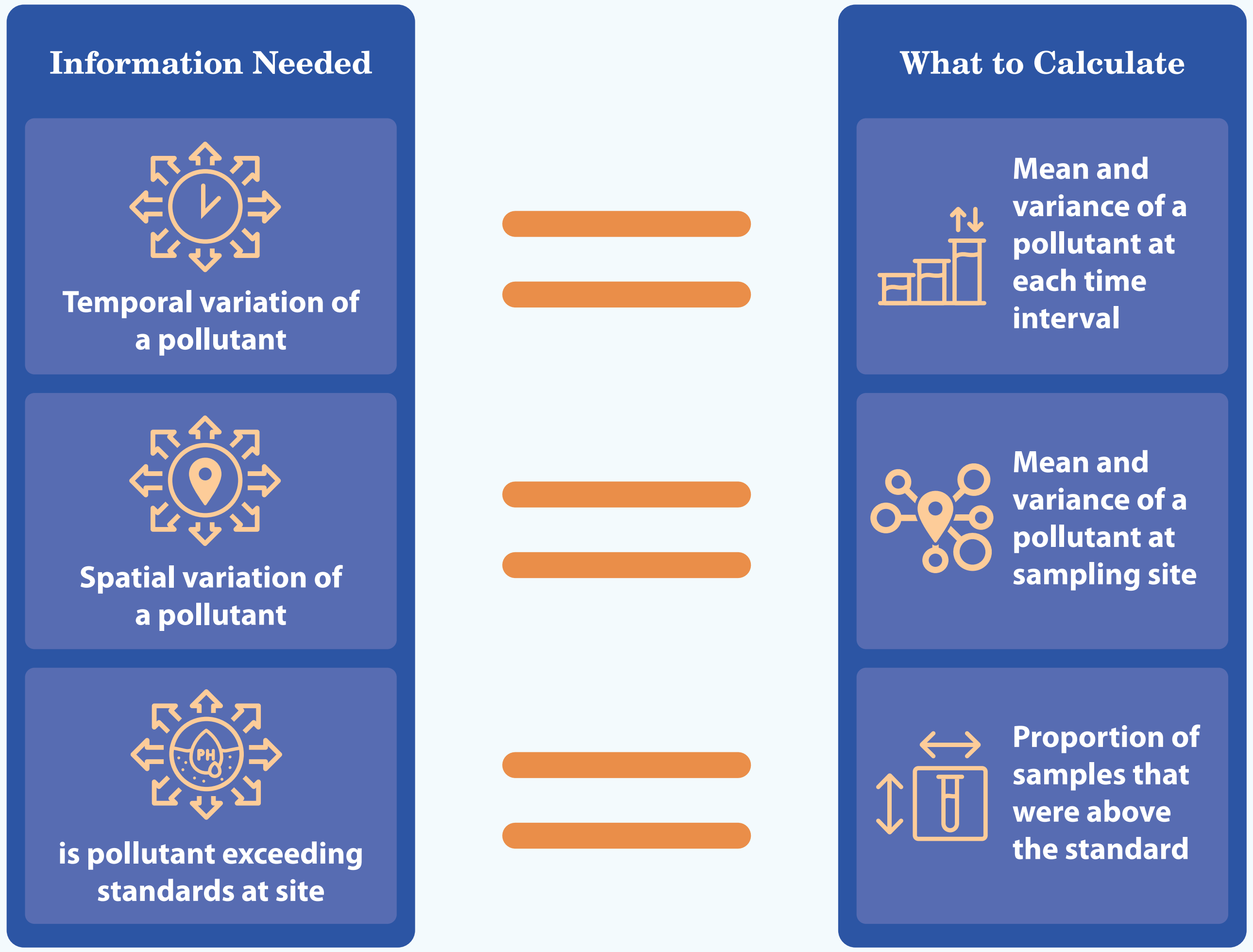
9.1 Techniques for analysis — Is there a spatial trend? a time-based trend?

One notable challenge in analyzing water quality data is the inherent complexity of it, where multiple sources can simultaneously influence the pattern of water quality concentrations. Additionally, the range of natural variability can obscure or conflate the data, making it challenging to distinguish anthropogenic impacts from natural variability.

The first steps of analysis are to calculate **descriptive/ summary statistics** and to **visualize the data**. It can be hard to see patterns or anomalies in your data by looking at a spreadsheet. Common descriptive statistics include proportions, means, medians, totals, variance, standard deviations, and standard errors.

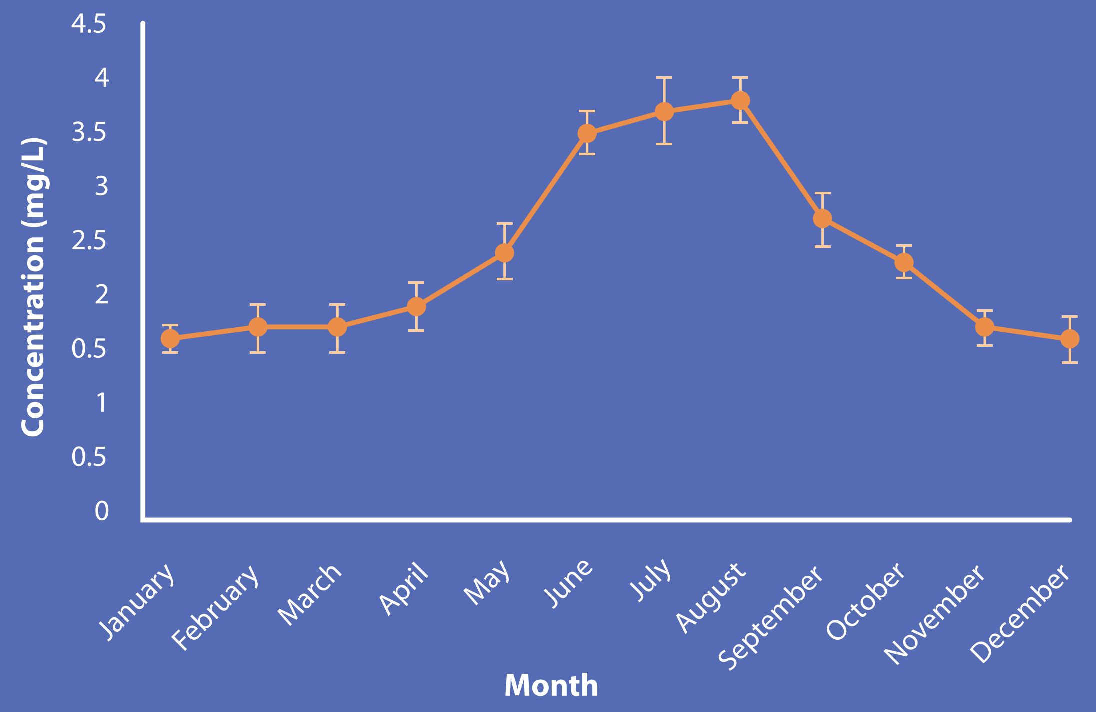
Descriptive statistics can be calculated in different ways, depending on the information you need. For example:

- If you want preliminary information on the **temporal variation of a pollutant**, calculate the mean and variance of a pollutant at each time interval.
- If you want preliminary information on the **spatial variation of a pollutant**, calculate the mean and variance of a pollutant at a sampling site.
- If you want preliminary information **on whether a pollutant is exceeding water quality standards at different sites**, calculate the proportion of samples that were above the standard.

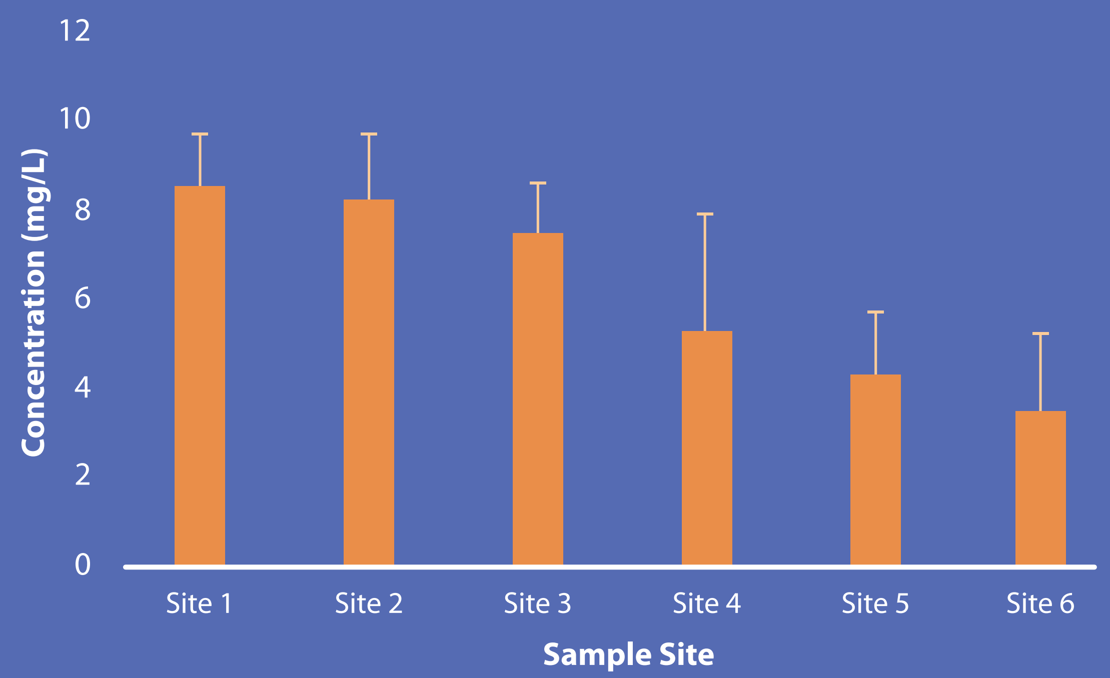


Here are some common ways to visualize this water quality data

What is the temporal variation of a particular pollutant?



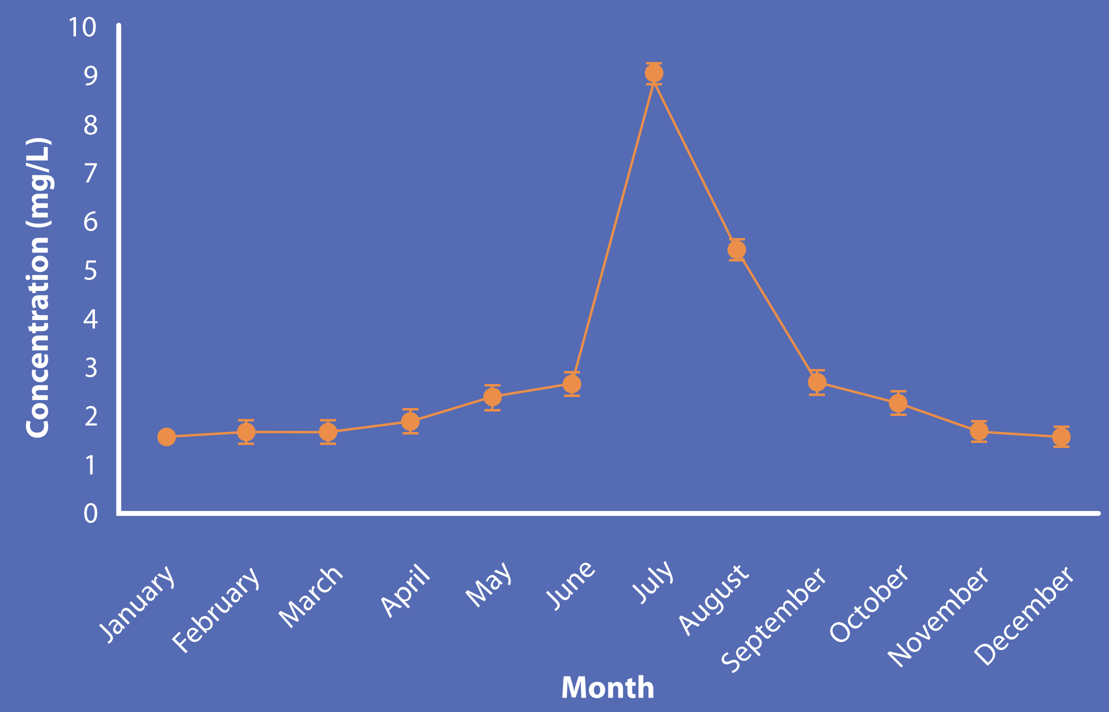
What is the spatial variation of a particular pollutant?



Is a particular pollutant exceeding water quality standards?

Data visualization can also be a very good way to identify anomalies that indicate a change in the system that you maybe didn't observe initially. For instance, in the below graph, there is a big spike in the concentration of the pollutant of concern. Further investigation could reveal that there was a major rainfall event just prior to the spike in the concentration, which suggests that it may be driving the observed change in the data*.

*If you cannot find an explanation for anomalies in your data, go back to the original data sheets to double check that all values were entered correctly.



Although descriptive statistics and data visualization are an important preliminary tool for investigation and can be a good way to communicate complex information to project partners, community members, and other stakeholders, oftentimes, more **advanced statistical analysis** are essential for distinguishing anthropogenic impacts from background fluctuations and quantifying the significance of observed patterns.

Statistical tests can be used to determine whether a **predictor variable**, such as land-use, distance from pollutant source, or a management intervention, has a statistically significant relationship with an **outcome variable**, like pollutant concentration or bioindicator prevalence or to estimate the difference between two or more groups.

Statistical significance

The observed data or differences among data are not the result of chance and can be attributed to a specific cause.

- For example, there was a statistically significant difference between rainfall and pollutant concentrations, indicating that more rainfall led to greater concentrations of the pollutant.

Defining what types of analysis you want to perform or the types of evaluation you are interested in needs to be done prior to collecting any information, so that you can design an appropriate project or program that will yield the required data.

There are a wide variety of resources available to help you identify which statistical test is right for you (Australian Government Initiative b-e, n.d.; Meals & Dressing, 2005; Scribbr, n.d.).

9.2 Communication

Communicating the results of your project or program to project partners, community members, and other stakeholders is arguably the most important part of the work. It requires careful consideration to ensure clarity and understanding. Below, we share some general tips on what to consider as you begin to design your communication plan.

Understand your audience & tailor communication

- Think about the background and motivations of your four groups identified in **Section 3** and tailor your communication to match their level of knowledge and interest.

Keep messages clear & simple

- Use plain language and avoid technical jargon. When you need to use it, define any technical terms or acronyms.
- Clearly articulate main messages and key takeaways.
- Practice your presentation with colleagues or individuals unfamiliar with the subject to make sure it is clear.

Utilize visual aids & compelling storytelling

- Incorporate visual aids like graphs and charts to support clear communication. The initial data visualization discussed in **Section 9.1** could be used, if the story is clear.
- Frame data within a compelling narrative using real-world examples.

Use multiple formats & provide context

- Present information in various formats (text, visuals, verbal).
- Explain the relevance of data in the broader context, connecting findings to potential impacts on project partners, community members, and other stakeholders.

Share resources & follow up

- Provide supplementary materials, references, or links for interested parties who want to delve deeper into the data.
- Ensure accessibility to additional resources for further understanding.
- After the initial communication, follow up with project partners, community members, and other stakeholders to address any lingering questions.
- Offer ongoing support for understanding and interpretation.

Prioritize information & foster dialogue

- Highlight the most important information first and present data logically.
- Encourage questions and discussions to maintain an open dialogue.

Stay transparent

- Acknowledge uncertainties and limitations in the data.
- Be honest about what is known and what is still being researched.

There are a lot of great examples of the different approaches used by existing water quality monitoring programs and many use multiple styles:

- DES, 2020
- Heileman UNEP/CEP et al., 2019.
- Save the Sound, n.d.
- Seqwater, n.d

10. Examples of common questions & approaches

Q1. Are there banned substances present?

Approach to use

Direct, in-situ water quality measurements, observations, and samples.

Methods to use

Passive sampling and manual water sampling for laboratory analysis.

Experimental design considerations

- Sampling should occur for at least one year to capture seasonal variations (but would typically need to be more frequent).
- Passive samplers have a range of days to months, so frequency of sampling is dependent on the specific passive sampler used.
- Manual water sampling should happen in routine intervals over the course of the year.
- Assessment against predetermined thresholds may need longer term and sustained collection of data.
- A cost effective approach may be to deploy one passive sampler in combination with in-situ samples.
- However, the best practice approach (dependent on funding) would be a multi-year program, in-situ sampling alongside passive samplers deployed over the same period.
- Multiple data points would provide higher data resolution, and multiple samples across time would provide increased confidence in assessing banned substances.

Considerations for sampling & analysis

- Water and sediment sample analysis will be dependent on the type of banned substance.
- Unknown substances may need a suite of environmental chemical analysis.
- Data from passive samplers and manual water sampling should be assessed against thresholds, either national (if known) or internationally accepted thresholds and/or guidelines.
- Longer term data would allow you to track compliance with accepted water quality standards.

Additional resources

- Nicolaus et al., 2016
- Smith et al., 2012
- Warne et al., 2023

Q2. Is the water body meeting water quality standards for ecosystem health?*

Approaches to use

Direct, in-situ water quality measurements, observations, and samples; remote sensing and spatial analysis; ecological monitoring of bioindicators.

**You can use a similar approach to understand the natural variability of water pollution in time and space, which is a precursor to setting water quality standards for ecosystem health.*

Direct, in-situ methods to use

Manual water sampling for laboratory analysis.; manual water sampling and analysis with a water quality testing kit; manual measurements with a handheld analog or digital instrument or probe, automated measurements with a data logger/sensor.

Experimental design considerations

- Number of sites will be dependent on the variability within the waterbody. An offshore area with stable water quality may only need 1 site whereas a large intertidal estuarine system will need 3 to 4 sites to cover variability over the salinity range.
- Depending on the pollutant of interest, monthly manual water sampling can be supported with automated measurements with data loggers or manual sampling and analysis with a water quality testing kit.
- Digital instruments and water quality testing kits will need to be properly calibrated and validated to ensure they are accurately reporting pollution concentrations (see **Question 7** in **Section 11**).
- If the pollutant has a spectral signature that can be quantified using remote sensing with satellite imagery, then remote sensing over a larger area can support discrete, in-situ measurements.
- Ecological monitoring of bioindicators at exposed and control sites will provide information on ecosystem impacts, which can indicate that water quality is impacting ecosystem health.
- A cost effective approach may have limited manual sampling coupled with automated sampling with deployed data loggers.
- A best practice approach (dependent on funding) would include a multi-year program, in-situ measurements, and remote sensing with satellite imagery.
- Monitoring of bioindicators should occur ideally twice a year during different seasons, but could be once a year to be cost-effective.
- Multiple data points would provide higher data collection, but care needs to be taken on the integration and data analysis of multiple different data sources.

Considerations for sampling & analysis

- Typically, water quality standards are set for seasonal or annual statistical measurements (e.g., means, median or percentiles). However, a reporting period may range from 5–10 years. Data must be routinely collected, analyzed, and assessed according to the requirements of the water quality standards.

Additional resources

- Bean et al., 2017
- Devlin & Haigh, 2020
- Great Barrier Reef Marine Park Authority, 2023

Q3. Is the source of fecal contamination animal or human?

Approaches to use

Direct, in-situ water quality measurements, observations, and samples; biotic and abiotic sampling for further assessments.

Direct, in-situ methods to use

Manual water sampling for laboratory analysis.

Biotic & abiotic sampling method to use

Stable isotope analysis.

Experimental design considerations

- Sample directly from potential effluent if it is visible.
- Sample from pollution source outwards (see **Fig. 5**).
- The number of sites and frequency of sampling will be defined by the extent of the fecal contamination problems. For example, a small number of septic systems discharging into coastal waters will require more frequent sampling to ensure detection than if the source is a large sewage treatment plant with a regularly discharging outfall.

Additional resources

- Dafouz et al., 2018
- Gourmelon et al., 2021
- Meals et al., 2013a
- Minh et al., 2020
- Sauvé et al., 2012
- Symonds et al., 2018

Considerations for sampling & analysis

- A best practice approach to confirm whether fecal pollution is human in origin is to undertake microbial source tracking through genetic analyses. This could be conducted on a water sample collected during manual water sampling. This can be expensive.
- A cost-effective approach would be to take water samples for human-specific pharmaceutical or personal care products, such as caffeine, which would indicate the presence of domestic wastewater.
- Nitrogen stable isotope analysis of ^{15}N:^{14}N (denoted as $\delta^{15}N$)in macroalgae can provide information if there is nitrogen sourced from domestic wastewater (see factsheet on Approaches for Assessing and Monitoring Pollution).

Q4. Is the water safe for aquaculture, fishing, or recreational activities?

Approaches to use

Direct, in-situ water quality measurements, observations, and samples; Biotic and abiotic sampling for further assessments.

Direct, in-situ methods to use

Manual water sampling for laboratory analysis; passive sampling.

Abiotic & biotic sampling method to us

Bioaccumulation of pollutants; histological assessments; stable isotope analysis.

Experimental design considerations

- Unlike the previous questions in this section, many places have monitoring protocols in place to assess human health risks from polluted water, including what should be measured, the frequency of measurements, and how to designate an area as safe. There are also international guidelines on how to assess human health risks from polluted water.
- If your monitoring data is being used to create health advisories, ensure you are following international best practice for conducting human health risk assessments.(see below for some examples).
- In general, if conducting event sampling (e.g., a spill or harmful algal bloom), sampling daily to multiple times a week is recommended.
- Routine, weekly sampling of recreational beaches is advised.

Additional resources

- Environment Protection Authority Victoria, 2023
- Schmitt et al., 1999
- U.S. EPA, 2019
- U.S. Food and Drug Administration, 2019
- WHO, 2010
- WHO, 2021

Considerations for sampling & analysis

- Passive samplers could be used to detect contaminants (See **Question 1**).
- Histological assessments on organisms can indicate if there are impacts to fishery and aquaculture species.
- Assessing bioaccumulation of contaminants can indicate if an organism is safe for consumption.

Q5. Have management interventions changed pollution loads and dispersal?

Approaches to use

Direct, in-situ water quality measurements, observations, and samples; remote sensing and spatial analysis; and quantitative modeling.

Direct, in-situ methods to use

Manual water sampling for laboratory analysis; manual water sampling and analysis with a water quality testing kit; imanual measurements with a handheld analog or digital instrument or probe; automated measurements with a data logger/sensors.

Experimental design considerations

- Requires an integrated watershed to coast (ridge to reef) program where information on land-use and agricultural interventions are monitored via modelling or remote sensing and spatial analysis and are then connected to load monitoring and downstream coastal systems.
- In-situ sampling requires sites within watersheds, associated with variable land-use, sites within river systems to monitor riverine pollutant loads, and sites in the coastal system to monitor pollution dispersal.
- The use of automated data loggers to measure pollution parameters and flow will significantly improve pollution load estimates (Meals et al., 2013b).
- Remotely sensed satellite data can provide critical, long-term information on land use change and pollutant extent in the marine environment (plume mapping).
- Quantitative models can estimate changes in pollution loads and dispersal with land-use change and the implementation of management interventions.
- A cost effective approach would be to conduct a preliminary assessment of water quality with in-situ sampling to understand the variability in the system, which can inform the minimum number of samples required to test for long-term change.
- Modelling pollutant loads reaching the coast and their dispersion into the environment can provide information on relative change. Small-scale, but more frequent sampling of key variables can significantly improve model accuracy (Hutley et al., 2020).
- A best practice approach (dependent on funding) would be a multi-year program, with a mix of a watershed-to-coast, in-situ data collection, remote sensing using satellite data, and quantitative models to assess and report on the impact of management interventions.

Considerations for sampling & analysis

- Monitoring of land-use change can be assessed through the tracking of positive interventions and the percent of best management practices in place within a particular industry (e.g., sugarcane farming).
- River monitoring and pollutant load assessment can be reported as annual means, accounting for seasonal variability.
- Coastal water quality health can be assessed through a series of indicators (annual means, seasonal means) against a pre-established threshold.
- Plume mapping and modelling of pollutant load estimates and dispersion can be reported as annual % area exposed to specific conditions or concentrations.

Additional resources

- Meals et al., 2014
- Meals & Dressing, 2008
- Great Barrier Reef Marine Park Authority, 2023
- DES, 2023
- OSPAR Commission, n.d.

11. Frequently asked questions

How many different parameters should I measure?

Answer: This will depend on what your objective is and if you need to quantify specific pollutants. As a general rule though, when selecting parameters to measure, opt for fewer parameters and more samples per parameter.

How can I identify the difference between agricultural pollution and domestic wastewater pollution?

Answer: If both agricultural pollution and wastewater pollution are likely to be present, there are a few options available. The first option would be to collect water samples and test for wastewater or agricultural pollution specific indicators such as caffeine or a pesticide that is in use in the area, which can indicate which of the respective sources are reaching the area of interest. Second, collecting samples of an organism, such as macroalgae, and conducting nitrogen stable isotope analysis can be used to infer the likely contribution of each source, because wastewater pollution and agricultural pollution have different ratios of ^{15}N:^{14}N (denoted as $\delta^{15}N$) (DES, 2018; Duprey et al., 2019; Risk et al., 2009). Third, water samples or sediment samples could be collected for microbial source tracking- a genetic analytical technique that can differentiate between fecal waste from humans and fecal waste from mammals (Gourmelon et al., 2021). If human fecal matter is present, it indicates that wastewater pollution is present. However, none of these techniques can tell you which pollution source is having a larger impact. If you have sites that are predominantly polluted by domestic wastewater and sites predominantly polluted by agricultural pollution, you could combine the sampling techniques above with ecological monitoring of bioindicators to assess relative impacts of each pollutant type compared to each other and to a control site. All of these options have pros and cons, specific requirements, and vary in cost, so a thorough assessment of the different approaches is recommended.

How do I figure out what detection level my equipment needs to measure my water quality parameter of interest?

Answer: This will depend on the environment or ecosystem and the parameter you are trying to measure, but in general, the further you are away from the source, the lower the concentration of your parameter will be. Your initial assessment (**Section 3**) and your selection of a sampling method (**Section 6.2**) should include assessments of previous studies to see the ranges of concentrations of the parameter of interest that have been previously recorded in similar environments. . As a rule of thumb, always try to use test kits and instruments with the lowest detection level possible. to reduce the risk of Type II errors (i.e., false negatives). Typically, test kits will not be sensitive enough to measure very low concentrations of pollutants, though this technology is improving rapidly.

How many samples can I take before I know I have a baseline?

Answer: According to guidance from the U.S. Environmental Protection Agency, for regulatory purposes in the US, 30 samples are needed before a designation can be made.

Should I use a water quality testing kit or a multi-parameter digital instrument?

Answer: **Assuming that both types measure your parameter of interest in the right salinity conditions** and are within your budget, there are a couple of additional factors you should consider when making this decision: 1) how many sites you want to measure, 2) how frequently you plan to measure within a particular project or program, and 3) the limits of detection. Since water quality testing kits require reagents for each test conducted, the more samples you take, the more expensive it becomes. A multi-sensor instrument might cost more initially, but over time could end up being the more economical choice if you intend to take a lot of samples. Additionally, reagents have a limited shelf-life so if you are not planning to take frequent samples, you may need to purchase new reagents multiple times during a sampling program, which could become expensive.

How do I ensure accuracy in my water quality testing kit or sensors on instruments or data loggers?

Answer: *For water quality digital instruments or probes*, it is important to conduct regular, routine calibration using standard solutions that have known concentrations of a parameter. This is to ensure they continue to accurately measure parameters. It is best to calibrate instruments using standard solutions in the range of values expected to be encountered in the field. Water quality instruments should be calibrated before the start of each sampling trip, checked daily if on an extended trip, and checked at the end of the trip.For water quality testing kits, it is important to validate and calibrate them before use to ensure the outputs are reliable and consistent, especially when you are using them because you are unable to take water samples and send them to a laboratory. This can be done by conducting a side-by-side comparison analysis with equipment in a trusted laboratory, using equipment that is up-to-date with its calibration and other manufacturer requirements. Tests could be conducted with standard solutions or with field samples collected from sites that are expected to have a range of concentrations for the parameter of interest. If using field samples for this, you must use the same processing and preservation methods for the samples for each unit. These validation tests should be completed at the same time, to ensure comparability The results of the validation tests can also be used to calibrate water quality testing kit results with laboratory results, if there is a consistent difference between the two methods.

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Appendix 1: Questions to guide you on your initial assessment of existing information

1. **What are the potential sources of pollution in the area of interest?**
   a. What activities are occurring in the watershed that could generate pollution, and what are their spatial extent?
   b. Are there particular pollution generating activities that are of most concern?
   c. Are the concerns related to pollution due to lack of infrastructure, e.g., inadequate sanitation infrastructure and systems (see Wenger et al., 2023 for more details on how to assess this)?
   d. Have land-use or population estimates changed recently or are they expected to change in the near-future?
   e. Have there been any observations of erosion, livestock, or feral mammals in or near water bodies, or loss of vegetation?
   f. How close to water bodies are pollution-generating activities occurring?
   g. Are there domestic or industrial wastewater outfalls that discharge into water bodies?
   h. Do the sources of pollution cross jurisdictional boundaries?
   i. Are there human health concerns related to drinking water quality?

2. **What are the watershed characteristics?**
   a. What is the vegetation type and extent in the watershed?
   b. Is there any riparian vegetation along streams and rivers?
   c. Are there soil or geology types that are more prone to erosion or groundwater infiltration?
   d. What are rainfall patterns like?
   e. Do rivers flow year-round or seasonally?

3. **What are the characteristics of the coastal & marine environment?**
   a. What ecosystems are present?
   b. What are the hydrodynamic conditions in the area?
   c. Is the area of interest sheltered or exposed?
   d. Are there coastal aquaculture sites, fishing grounds, tourism areas, or marine protected areas present?
   e. Are there concerns for human or ecosystem health related to marine pollution?

4. **Given the pollution-generating activities in the watershed and its characteristics, what pollutants could be reaching coastal and marine environments (Table 1)?**
   a. Are there particular pollutants of most concern that are likely to be present?
   b. Are there multiple pollution generating activities that could be creating the same types of pollution?

5. **Is there any ongoing management of pollution?**
   a. Are there any active pollution management programs in the area of interest? Note that there could be terrestrial restoration initiatives that will have a net-positive effect on pollution even if it is not the goal of the program.
   b. Are there any policies or legislation in place to address water pollution, such as wastewater discharge standards, water quality guidelines, regulatory bans on hazardous substances, best practice management guidelines or policies for industries operating in watersheds, etc.?

6. **Are there records of past pollution events?**
   a. Are there records of past changes to water quality e.g., a flooding event, oil spills?
   b. Have there been any observations of changes in water color, texture, smell, or clarity that suggest pollution in the coastal waters?
   c. Are there records of past ecosystem impacts from pollution, e.g., eutrophication events, algal blooms, or fish kills?
   d. Are there records of past human health impacts from pollution, e.g., beach closures or contaminated seafood?

7. **Who are the key interested parties?**
   a. Who is responsible for generating pollution?
   b. Is pollution coming from private land?
   c. Is pollution being generated from non-point source activities that the government should be regulating?
   d. Are there any watershed management groups active in the area of interest?
   e. Are there individuals that are being negatively affected by water pollution?
   f. Who will be needed to facilitate reductions in pollution?
   g. Who can mandate or initiate change?


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