

**Exploring Water Quality and Management
Water Resources and Environmental Monitoring**

ACNA5004

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1. Introduction

Water is vital for human survival, and the survival of life across the planet. Water is used by humans for agriculture, consumption and recreation, as well as to produce food, and fibres for fabrics. Access to water is also a public health issue, as drinking unclean water leads to illness, and water is crucial for sanitation to prevent the spread of disease (United Nations, n.d). As well as supporting human society, all other living organisms around the world depend on water, either directly or indirectly (Sargen, 2019). Even small water bodies provide ecosystem services such as carbon cycling, and are highly biodiverse (Biggs *et al*, 2017).

Water quantity and water quality are two related concepts used to describe water resources. Water quantity refers to the amount of water present in a given area, such as the amount of water in the catchment area of a river. The quantity of water in an ecosystem varies between ecosystems, and often seasonally varies within a single ecosystem, affecting the amounts of available water (OECD, 2015). Knowing the quantity of water present does not reveal how suitable it may be for different purposes such as human consumption or species habitat, however, and for that reason quantity and quality are often measured together to provide a complete picture of the conditions of the area (Boyd, 2019).

The parameters of “good” water quality depend on the context. Quality refers to the characteristics of water, including physical, biological and chemical factors, and how the quality is described will depend on the intended recipients and usage, or role required in an ecosystem (Johnson *et al*, 1997). Water may be of a suitable quality to support living organic life within it, but not of safe drinking quality for humans. Berndtsson (2010), for example, found that green roofs in urban areas may absorb some stormwater runoff, lowering the quantity of water present during potential flooding events, but that the water which is released may contain higher levels of nitrates from fertilisers used on the roofs, which is an alteration to the water quality.

2. Why is water quality important?

There are many forms of pollution that can affect water, and preventing the spread of pollution in water bodies can be complex. This is because water is a universal solvent, which means that substances introduced to it will often dissolve and spread at speed. Pollution can occur in groundwater or surface water, and different water bodies around the world will face different threats (Denchak, 2023).

Polluted, low quality water will have many negative effects on the environment. In Ethiopia, impacts on local water bodies from industrial and agricultural sources, exacerbated by poor enforcement of the water protection laws that are in place, means that access to clean, consistent drinking water is severely limited for much of the population, especially in rural areas. This has led to health issues and birth defects in the population (Talema, 2023). However, it is not just countries considered “developing” that may deal with water quality issues. In the United

States of America, it was found that many water bodies contain multiple contaminants, including heavy metals and pesticides, that are known to be carcinogenic (Warren-Vega *et al*, 2023). Water pollution also damages habitats, and causes illness in organisms living in or alongside it, leading to biodiversity loss (Ogidi & Akpan, 2022).

3. Eutrophication and the Trophic State Index

Polluted water can have many negative effects on the environment around it, and one specific issue triggered by water pollution can be eutrophication. Eutrophication occurs as a result of an excess of nutrients entering the water body. Sources of nutrients can include human sewage and animal waste runoff, as well as runoff containing nutrient fertilisers. These nutrients cause rapid growth of plants and algae in the water, which will grow to the point where they prevent light penetration, and deplete the amounts of dissolved oxygen in the water (European Environment Agency, n.d). The decomposition of algae can lead to the losses of so much dissolved oxygen that “dead zones” are formed, such as in the Gulf of Mexico, and additionally, some algal blooms are toxic to humans or animals (Chislock *et al*, 2013).

To prevent eutrophication from occurring, it is important to have information available about where it has already taken place, areas in the process of becoming eutrophied, and areas of high risk for future eutrophication. This allows a management plan to be developed that is specific to each area, addressing the current status of the water body (Hatton-Ellis, 2016).

Commonly used to quantify the eutrophication levels in water bodies is an environmental index called the Trophic State Index (TSI). This was originally devised by Robert Carlson in the 1970s, and intended to simplify communication of trophic states by the creation of a numerical 0-100 scale on which water bodies can be ranked (Carlson, 1977).

By measuring the total nitrogen, total phosphorus and total chlorophyll *a* present, and using the TSI, it is possible to effectively and consistently track the trophic status of a water body as part of an ongoing restoration plan, ensuring that progress towards goals is being achieved and that damage is not occurring (Poor, 2009). Some studies also use a Secchi disk in conjunction with the TSI to measure water transparency. However, this is a more subjective measurement, and accuracy of readings can be affected by water turbidity (Bowers *et al*, 2020).

4. Calculating Trophic States

To calculate the trophic state of a water body, the concentrations of certain nutrients must be known. There are different nutrient variables that can be measured, and the equations used will vary based upon ratios of nutrients found, so sampling regime should be carried out prior to calculations, to indicate the most appropriate methods (Carlson, 2007). Shown below (table 1) are the quantities of chlorophyll a, total phosphorus and total nitrogen, listed as hypothetical samples from five different lakes.

Table 1: Lake water sample data.

Lake Water Sample	Chlorophyll a (mg/l)	Total phosphorus (mgP/l)	Total nitrogen (mgN/l)
A	0.6	0.005	0.10
B	10	0.04	0.70
C	160	0.34	5.6
D	120	0.96	2.8
E	25	0.22	7.8

The first step is to determine the ratio of total nitrogen to total phosphorus in each lake. This determines which equations (see table 2) must be used to complete the calculation correctly.

Table 2: TSI equations (Lake County Water Authority & USF Water Institute, 2023a).

1.	$TSI_{(chl\ a)} = 16.8 + [14.4 \times \ln(chl\ a)]$
2.	$TSI_{(TP)} = 18.6 \times [\ln(TP \times 1000)] - 18.4$
3.	$TSI_{(TN)} = 56 + 19.8 \times \ln(TN)$
4.	$TSI_{2(TP)} = 10 \times [2.36 \times \ln(TP \times 1000) - 2.38]$
5.	$TSI_{2(TN)} = 10 \times [5.96 + 2.15 \times \ln(TN + 0.001)]$

If the concentrations of phosphorus and nitrogen present in the lake samples are roughly equal, this is referred to as being “balanced”. If the concentrations are unequal, it will be described as “limited”. If the amount of nitrogen is lower than phosphorus, it is nitrogen limited, and vice versa. This is because the lack of the nutrient is a limiting factor in the growth of plants (Oldroyd & Leyser, 2020).

If the ratio of total nitrogen (TN) and total phosphorus (TP) is between 10-30, the lake is considered balanced. If the ratio is higher than thirty, it is phosphorus limited. If the ratio is lower than 10, it is nitrogen limited. Some of the lakes sampled above are balanced, and some are limited (see table 3).

Table 3: Nutrient ratios.

Balanced	Limited
Lake A: TN/TP = 20	Lake D: TN/TP = 2.9
Lake B: TN/TP = 17.5	Lake E: TN/TP = 35.4
Lake C: TN/TP = 16.4	

For balanced samples, equations one, two and three should be used. For limited samples, equations one, four and five should be used instead. Using these equations it is possible to calculate the TN, TP and chlorophyll *a* levels of each sample (see table 4).

Table 4: Equation results.

Lake Sample	Equations Used	Results
A	1, 2, 3	Chlorophyll <i>a</i> = 9.4 TP = 11.5 TN = 10.4
B	1, 2, 3	Chlorophyll <i>a</i> = 49.9 TP = 50.2 TN = 48.9
C	1, 2, 3	Chlorophyll <i>a</i> = 89.8 TP = 90.0 TN = 90.1
D	1, 4, 5	Chlorophyll <i>a</i> = 85.7 TP = 138.2 TN = 81.7
E	1, 4, 5	Chlorophyll <i>a</i> = 63.1 TP = 103.4 TN = 103.7

Using a final set of equations to average these results based on the limiting nutrient, the TSI score can be calculated (see table 5).

Table 5: Final stages of TSI calculation (Lake County Water Authority & USF Water Institute, 2023b).

Lake Sample	Equation Used	Results
A	Balanced $TSI = \{TSI_{(chl\ a)} + [TSI_{(TN)} + TSI_{(TP)}] / 2\} / 2$	12.7
B	Balanced $TSI = \{TSI_{(chl\ a)} + [TSI_{(TN)} + TSI_{(TP)}] / 2\} / 2$	83.8
C	Balanced $TSI = \{TSI_{(chl\ a)} + [TSI_{(TN)} + TSI_{(TP)}] / 2\} / 2$	89.9
D	Nitrogen Limited $TSI = [TSI_{(chl\ a)} + TSI_{2\ (TN)}] / 2$	83.7
E	Phosphorus Limited $TSI = [TSI_{(chl\ a)} + TSI_{2\ (TP)}] / 2$	83.2

These results can then be matched to the TSI ranking table (table 6).

Table 6: TSI states (Saetang & Jakmunee, 2021).

TSI	Trophic Status	Description
0–40	Oligotrophic	Clear water, low nutrient content
40–50	Mesotrophic	Water moderately clear, medium level of nutrient
50–80	Eutrophic	High algal blooms, high nutrient content, decreased oxygen
80–100	Hypereutrophic	Highest algal blooms, highest nutrient content

Comparing the results of Table 5 to the ranking scale provided in Table 6, there are several different trophic statuses present across the samples. Sample A is oligotrophic, whereas samples B, C, D and E are all ranked as the low end of hypereutrophic.

5. The Water Framework Directive

Water quality monitoring is important for collecting data that can be used in policy decisions to improve water management and prevent water quality degradation. Different countries often have different water management legislation in place (Khan & Charles, 2022). As many rivers are transboundary, an integrated management approach between countries that share catchment areas and watercourses is necessary to ensure good water quality at all points of a river.

The Water Framework Directive (WFD) is a piece of primary legislation created by the European Union in 2000. It covers groundwater and surface water, and aims to protect water from pollution by setting regulatory standards for certain pollutants, and requiring members to set their own Environmental Quality Standards (European Commission, n.d). This legislation is implemented via the production of river basin management plans from local environment authorities, identifying risk areas and pressures that the water bodies in that area are facing.

In Wales, there are three water river basin districts that each have their own management plan. These are the Severn district, the Dee district and the Western Wales district. Both the Severn and Dee districts are both partially in England, and the Severn district management is led by the Environment Agency. The Dee district and the Western Wales district are both managed by Natural Resources Wales (Natural Resources Wales, 2023). The WFD was transposed into domestic law, so this means it is still valid post the United Kingdom leaving the European Union (*The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017*).

6. Why Monitor Water Quality?

Reasons for monitoring the quality of water include:

- Ensuring drinking water is safe for human consumption, as dangerous substances can be identified and eliminated prior to drinking.
- Supporting ecosystem conservation and restoration. If the quality of a water body is not known, it can be hard to measure degradation that has already occurred or may occur in the future. In Hong Kong, there was a lack of data about the quality of rivers next to various developing cities, so identifying if damage was taking place was challenging until baseline data was collected (Ho *et al*, 2020). It also allows restoration progress to be tracked.

- Allowing pollution events to be recorded and tracked, exposing pollution sources. Particularly dangerous contaminants can be identified, and hazardous interactions between substances can be predicted (Altenburger *et al*, 2019).
- Fresh water sources can be groundwater or surface water, and many areas depend on a mixture of sources for their drinking water, such as Malaysia. Monitoring both of these sources of water is vital to prevent drinking water and water used for sanitation being contaminated by industry or agriculture who may be competing for the same water resources (Razman *et al*, 2022).
- The climate crisis is putting increasing stress on water bodies by leading to raised temperatures, raised salinity levels and increased severe weather events, and having data on quality conditions allows management plans to be developed to maintain high water quality and mitigate damage (Behmel *et al*, 2016).

7. Types of Water Monitoring

The WFD requires water quality monitoring to be carried out and reported in the form of river basin management plans to demonstrate that water quality standards are being met. A river basin, watershed or catchment area are all terms for the water that drains into a particular water body, such as a river. These basins can be large, such as the Amazon river and its tributaries, which in 2021, drained an area of almost seven million square kilometres (Alves, 2023). The way a water basin is managed strongly affects the water body that is fed by it, and can have large effects on the ecological, social and economic factors in the area (Narenda *et al*, 2021).

Because of the large area that the WFD covers, it recognises that there are many different types of water body covered by it and that member states have different amounts of baseline environmental data, and identifies three primary forms of monitoring to support the collection of water quality data (European Commission, 2003). These are known as surveillance monitoring, investigative monitoring and operational monitoring (see figure 1).

- Surveillance monitoring is a long term form of monitoring. Instead of focusing on individual sites, a number of sites in a catchment area will be monitored to provide representative data to extrapolate out to provide an estimate of the quality of the whole catchment. This is used to establish baseline water quality data where member states do not already have it, and to confirm that quality standards are being upheld (World Health Organisation, 2022).
- Operational monitoring is another long term form of monitoring, but focused on specific sites that are identified as being at risk of pollution events. This may be a river flowing through a heavily urbanised area, or an area where investigative monitoring has needed to be carried out after point source pollution incidents (Olding, 2004).
- Investigative monitoring is carried out when a pollution incident is known to have occurred, or when surveillance monitoring is revealing unexpected results that are not explainable with current data. This will be carried out at particular areas of concern, and

may be especially important for catchment areas that have multiple pressures, such as tourism impact combined with agricultural and industrial impacts (Postigo, 2021).

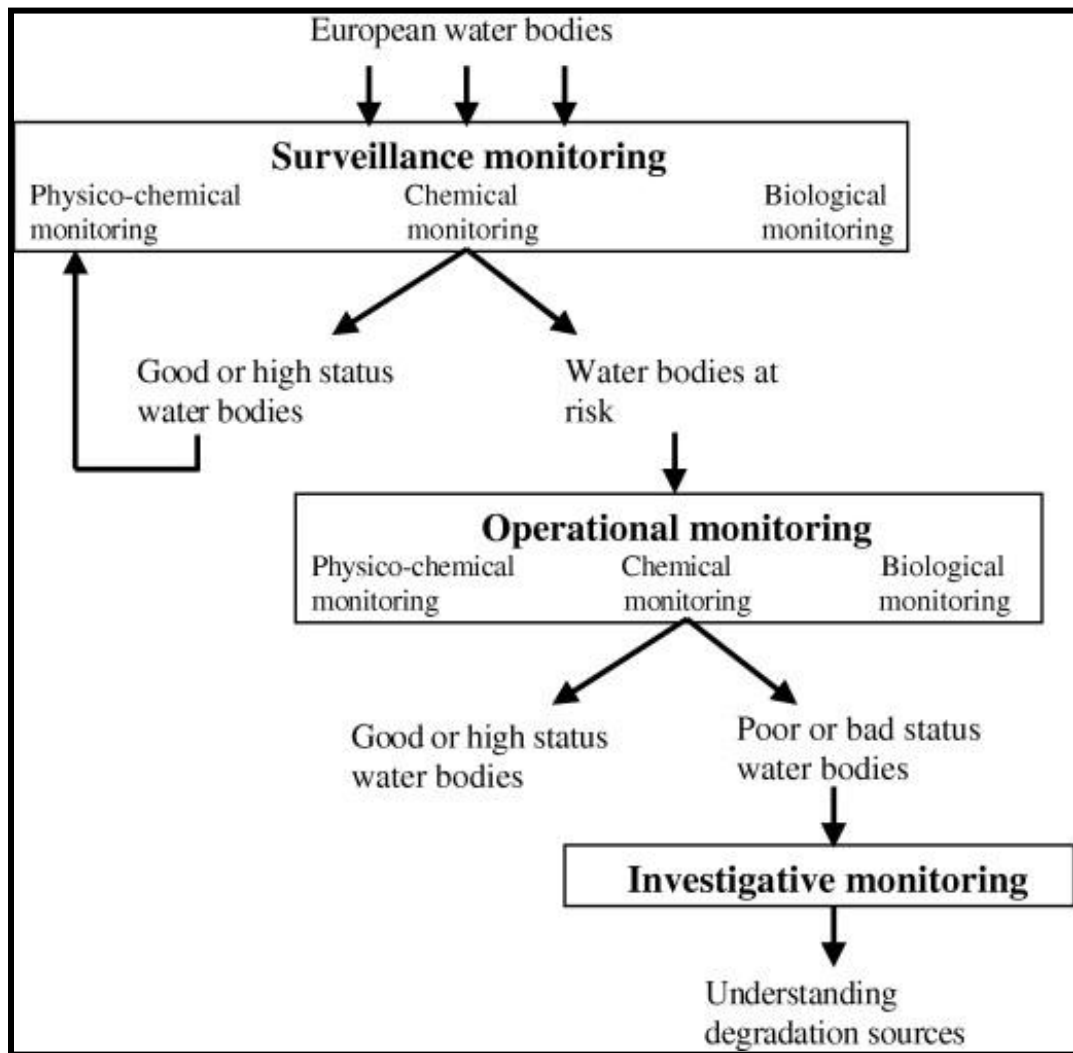


Figure 1: Types of Monitoring (Sanchez & Porcher, 2009).

8. River Data (See Figure 2)

FIGURE 2: RIVER ILSTON

Results of Kick Sampling

KICK SAMPLING

Standing in the river and kicking the bed while holding a net upright downstream (Davies, 2022). We kick sampled for 3 minutes per sample.

RESULTS

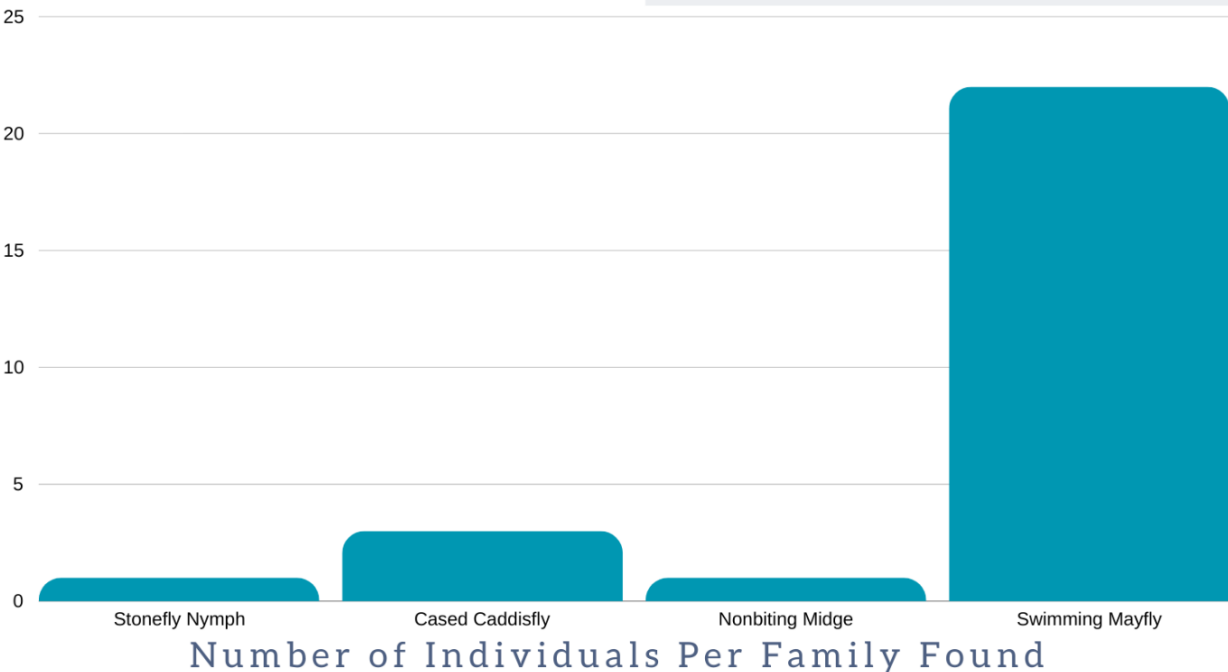
Species from four different families were found:

- Plecoptera (Stoneflies)
- Odontoceridae (Cased Caddisflies)
- Chironomidae (Nonbiting Midges)
- Nesameletidae (Swimming Mayflies).

NET PRIMARY PRODUCTIVITY (NPP)

NPP is influenced by many factors. Plants use chlorophyll and sunlight to grow, so where water transparency is low [such as here or not], NPP will be lowered (Kuehl & Troelstrup, 2013).

High levels of key nutrients like Phospurus increase NPP, as more is able to grow. Low nutrient levels reduce NPP.



9. Conclusion

In this report, a number of tasks have been completed with the aim of investigating water quality and why it is important, the factors that affect it, how it can be measured, and how it can be managed. Water quality is crucial to the health of human society and ecosystem function, but due to lack of information, poor enforcement of protective legislation or the lack of protective legislation altogether, water resources are being exploited and water quality degraded all around the world. Polluted water causes illness in human and non-human populations alike, as well as loss of biodiversity, amenities and livelihoods, and as the climate crisis progresses, the pressures on water resources will intensify further.

Many of the studies discussed have identified the need to be able to consistently and accurately measure water quality as a vital first step in being able to protect and improve polluted water. Legislation such as the Water Framework Directive helps to guide these processes, making use of different kinds of monitoring to ensure a complete set of data is collected, and using indices such as the TSI to help clearly communicate information between communities. As poor water quality can be caused by biological, chemical and physical means, anthropological factors, and is frequently a transboundary issue, it was identified that integrated management approaches will be crucial in ensuring that there is good quality water for generations to come.

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