UNITED
NATIONS

EP

Distr. LIMITED

UNEP(DEPI)/CAR WG.41/INF.23
09 June 2021

Original: ENGLISH

Fifth Meeting of the Contracting Parties (COP) to the Protocol Concerning Pollution from Land-BasedSources and Activities (LBS) in the Wider Caribbean Region

Virtual, 26 July 2021

Technical Paper on Proposed Criteria for Nutrients Discharges for Domestic Wastewater Effluent

For reasons of public health and safety associated with the COVID-19 pandemic, this meeting is being convened virtually. Delegates are kindly requested to access all meeting documents electronically.

Information Paper on Nutrients Management Guidelines/Standards for Wastewater Discharges into the Wider Caribbean Region

Dr. Hugh Sealy

2021

Centre for Resource Management and Environmental Studies (CERMES)

The University of the West Indies, Faculty of Science and Technology Cavehill Campus, Barbados

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

GLOSSARY

BMP - Best Management Practices

BNR - Biological nutrient removal

BOD - Biological oxygen demand

CARPHA - Caribbean Public Health Agency

CEHI - Caribbean Environmental Health Institute

CEP - Caribbean Environment Programme

Chl*a* - Chlorophyl-a

DIN - Dissolved Inorganic Nitrogen

DIP - Dissolved Inorganic Phosphorus

ENCORE - Elevated Nutrients on Coral Reefs Experiment

F.A.C - Florida Administrative Code

GEF - Global Environmental Facility

GPNM - Global Partnership for Nutrient Management

HABS - Harmful Algal Blooms

IFA- International Fertiliser Association

INI - International Nitrogen Initiative

ICEP - Index of Coastal Eutrophication Potential

INMS T- International Nitrogen Management System

ISO - International Organisation for Standardisation

IWR - Impaired Surface Waters Rule

LA - Load Allocations

LBS Protocol - Protocol Concerning Pollution from Land-Based Sources and Activities to the Convention for the Protection and Development of The Marine Environment of The Wider Caribbean Region

LME - Large Marine Ecosystems

MOS - Margin of Safety

MPCA - Marine Pollution Control Act

NPDES - National Pollution Discharge Elimination System

NUE - Nutrient use efficiency

RAC - Regional Activity Centre

RNPRSAP - Regional Nutrients Pollution Removal Strategy and Action Plan

R.O - Reverse Osmosis

SOCAR - State of the Caribbean Area Report

SS - Suspended Solids

TMDLs - Total Maximum Daily Loads

TN – Total Nitrates

TP – Total Phosphates

UNEP - United Nations Environment Programme

USGS - US Geological Surveys

WBID - Water Body Identification Number

WCR - Wider Caribbean Region

WCS - Wider Caribbean Sea

WLA - Waste load allocation

WQC - Determination of Water Quality Criteria

WWTP - Wastewater Treatment plant

1 INTRODUCTION

The following paper is a result of the recommendation contained in Output 1.1.2 of the Global Environmental Facility (GEF) CREW + Project that The Protocol Concerning Pollution from Land-Based Sources and Activities (LBS Protocol) to the Cartagena Convention, adopted in 1999, should be amended to allow for the adoption of new criteria or standards for domestic wastewater discharges and to increase the reuse of domestic wastewater. It is in this context that this paper focuses on the management and regulation of nutrients (nitrogen and phosphorus) in domestic wastewater discharges into the Wider Caribbean Sea (WCS) and presents a case study for the use of reclaimed water in a water-scarce small island developing state. This information paper has been produced under a short-term consultancy for the United Nations Environment Programme (UNEP) Caribbean Environment Programme (CEP) and Secretariat for the Cartagena Convention and reflects the views of the author only.

1.1 The Problem

Globally, the natural nitrogen and phosphorus cycles have been altered significantly. The concept of "planetary boundaries" was introduced in 2009 (Rockstrom et. al, 2009) and updated in 2015 (Steffen et. al., 2015). The concept of boundaries implies that there are environmental limits within which humans can continue to develop and thrive sustainably. There is a safe zone. In 2009, Johan Rockstrom and 27 other scientists identified 9 processes, at a planetary level, that are critical to maintaining this safe zone. The diagram below (Figure 1.1), reproduced from the 2015 article, indicates that the biogeochemical flows of nitrogen have already exceeded the proposed boundary and phosphorus flows have become high risk[1].

1 The proposed planetary boundary for disruption to the nitrogen cycle both from industrial processes (e.g., Haber Bosch) and intentional biological fixation is 62 Tg N yr^{-1} and for phosphorus flows from freshwater systems into oceans is 11 Tg P yr^{-1}(Steffen et. al., 2015).

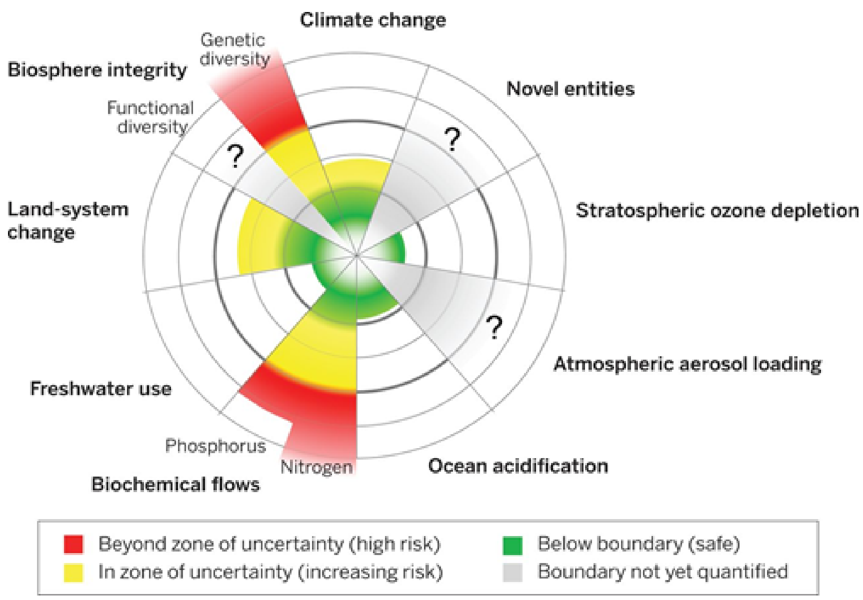

Figure 1.1: The current status of the control variables for seven of the nine planetary boundaries. (Steffen et. al., 2015)

Globally, five key environmental threats from nutrients have been captured under the acronym WAGES:

- Water quality
- Air quality
- Greenhouse gas balance
- Ecosystems and biodiversity
- Soil quality

and illustrated below in Figure 1.2, reproduced from the report entitled "Our Nutrient World" prepared on behalf of the Global Partnership for Nutrient Management (GPNM) and the International Nitrogen Initiative (INI) (Sutton et. al., 2013).

In the USA, according to the US Environmental Protection Agency, the primary sources of excess nitrogen and phosphorus are agriculture, stormwater, wastewater, and fossil fuels and the impacts on public health (e.g. air and water quality) and the environment (e.g. forest and soil health degradation, and biodiversity loss due to algal blooms and hypoxia) are described as one of the most widespread and costly environmental issues faced by that nation. Similar impacts, due to the mismanagement of nutrients, are occurring throughout the Wider Caribbean Region (WCR) (UNEP CEP, 2019).

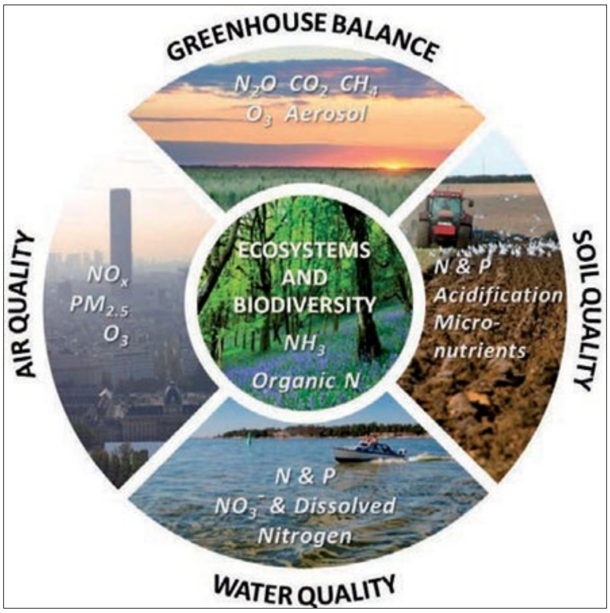

Figure 1.2: Reproduced from Figure ES1 The five key threats of too much or too little nutrients (Sutton et. al. 2013)

By comparing the isotopic ratios of nitrogen-14 with nitrogen-15 in deposited nitrates in ice cores from Greenland, scientists have found a new way to estimate how humans have altered the amount of nitrogen stored in the biosphere, with the most rapid changes correlating with increased fossil fuel combustion (Hastings et. al., 2009). Other research, here in the Caribbean, has shown a decline in nitrogen-15 in sea fans from 1862 – 2005 and has attributed this change in isotopic ratio of nitrogen to *"widespread input of agricultural fertilisers to near-shore coastal waters"* (Baker et. al., 2010).

Phosphate rock is a finite resource and known sources of mined phosphate rock are being depleted whilst demand for phosphorus continues to increase and is expected to double by 2050 (see Figure 1.3 below).

The peaking year for phosphorus production beyond which production will fall due to dwindling reserves is disputed. The International Fertiliser Development Centre believes that we have enough reserves (half of which are in Morocco) for the next 300 – 400 years (IFDC, 2010). The US Geological Surveys (USGS) estimates that, at zero further growth in demand,

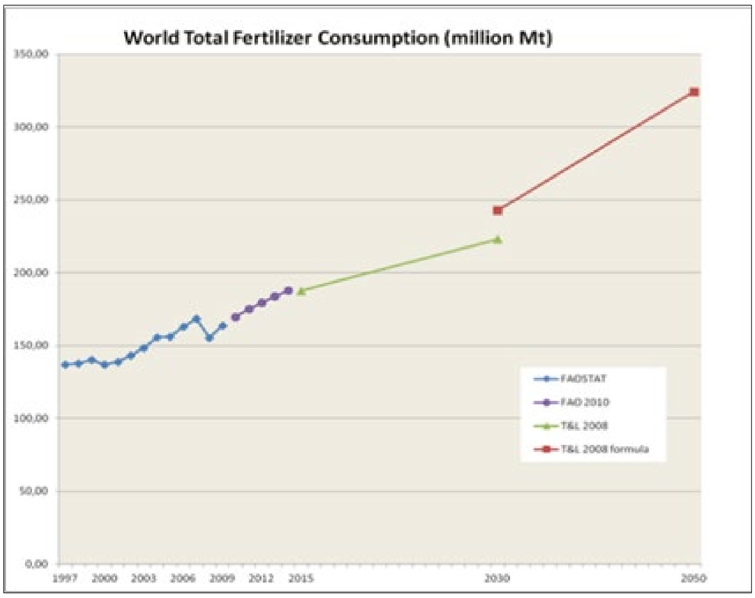

Figure 1.3: Projected Global Fertiliser Production (NPK) by 2050 (Drescher et. al., 2011)

world resources of phosphorus would last another 260 years (Jasinski, 2017). When "peak phosphorus" will occur may be debatable, what is not is that since phosphorus is an essential and finite element, we should seek to conserve the resource.

It is noted that annually over 3 million tonnes of phosphorus are discharged in human urine and faeces, equivalent to 22% of global demand (Mihelcic et. al., 2011)). Struvite, magnesium ammonium phosphate, produced by some bacteria as they breakdown the urea in urine, and the cause of kidney stones, can be used as a slow-release phosphate fertiliser. A detailed discussion of the potential recovery of phosphorus from sewage is beyond the scope of this paper. However, it is noted that a method to efficiently precipitate and recover struvite in wastewater treatment plants has been patented in Norway (NORSOK, 2019) and the Pearl® process is being used to precipitate struvite in a handful of wastewater treatment plants (WWTPs) in the USA and Canada (Schaum, 2018).

Within the Wider Caribbean Region (WCR) (Figures 1.4 and 1.5 below), pollution by nutrients of the wider Caribbean Sea has been assessed recently in the State of the Caribbean Area Report (SOCAR) (UNEP CEP, 2019) by sampling a limited number of sites both insular and continental in the wet season. The SOCAR classifies the waters in the WCR as good, fair or poor based on threshold ranges of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) as the indicators (See Table 1.1). The appropriateness of the parameters and the threshold concentrations used in Table 1.1 are discussed in sections 3.1 and 3.6.

Table 1.1: Threshold Ambient Water Quality Values used for DIN and DIP (UNEP CEP 2019)

Indicator	Status	Continental mg.l^{-1}	Island mg.l^{-1}
DIN	Good	< 0.1	<0.05
	Fair	0.1 to 0.5	0.05 to 0.1
	Poor	>0.5	>0.1
DIP	Good	<0.01	<0.005
	Fair	0.01-0.05	0.005-0.01
	Poor	>0.05	>0.01

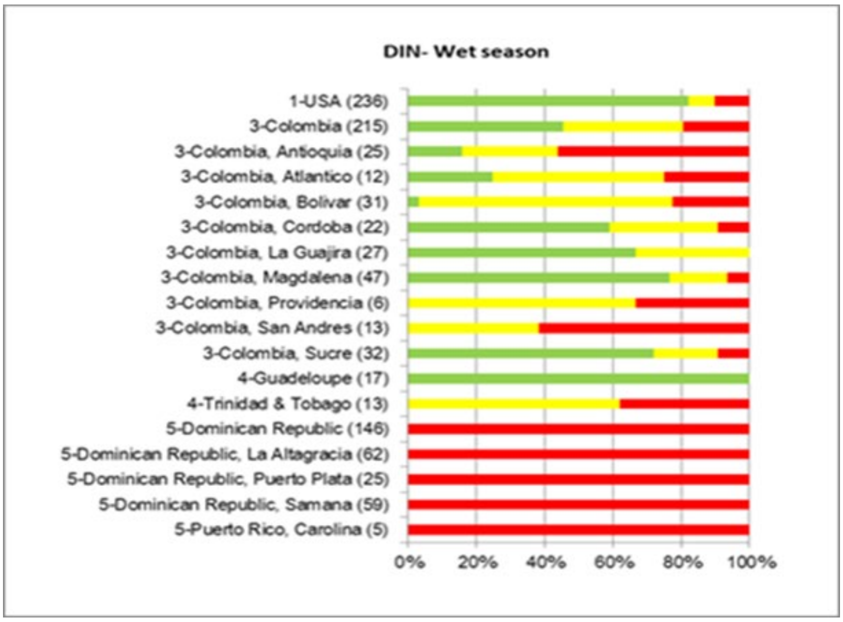

Figure 1.4: Dissolved Inorganic Nitrogen Status in WCR (UNEP CEP 2019)

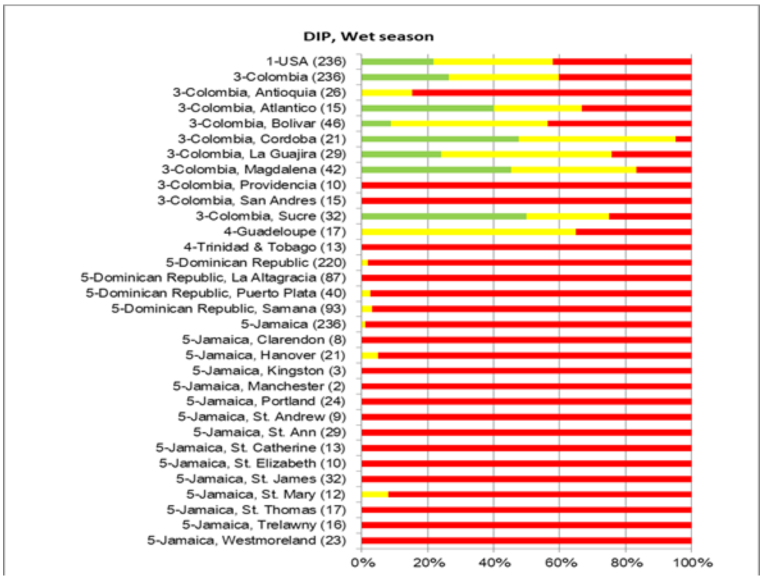

Figure 1.5: Dissolved Inorganic Phosphorus in the WCR (UNEP CEP 2019)

Recognising the limitations of the data sets represented in Figures 1.4 and 1.5 above, it can still be argued that the limited data would appear to indicate a higher than desirable frequency of "poor" conditions for DIN and in particular DIP at the monitored sites within the WCR. Whether or not the Caribbean Sea can be characterized as nitrogen-limited (i.e., there is usually sufficient phosphorus present, but nitrogen is the limiting factor in creating the conditions to allow for algal blooms[2]), Figures 1.4 and 1.5 would suggest that the discharges of both nitrogen and phosphorus need to be better managed.

As evidenced in Chapter 3 of the Regional Nutrients Pollution Removal Strategy and Action Plan (RNPRSAP) approximately 164 hypoxic zones have been reported within the WCR and the frequency of harmful algal blooms (HABS) has increased. It is noted that the occurrence of HABS (80% of which are caused by dinoflagellates in the LAC region) can be influenced by a number of factors including warmer sea temperatures, increasing ocean acidity, the ratio of nitrogen and phosphorus loads (Redfield ratio), deoxygenation and the amount of silica discharged (Neil, 2005) (Gilbert, 2020) (RNPRSAP in press).

In a response to the global impacts of nitrogen pollution including climate change, air pollution and biodiversity loss, the UN launched a Global Campaign on Sustainable Nitrogen Management in 2019 and set the target of halving nitrogen waste by 2030. Another response

---

2 *The role of the presence of silica is noted.*

to the "nutrient challenge" is the Global Partnership on Nutrient Management established under the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA). These and other global and regional frameworks are discussed briefly in section 2.0.

1.1.1 Contribution of Wastewater Discharges to Nutrient Pollution in the WCR

Wastewater discharges account for approximately 10 % of the nutrient load into the WCR, see Figure 1.6 below, reproduced from Chapter 1 of the RNPRSAP.

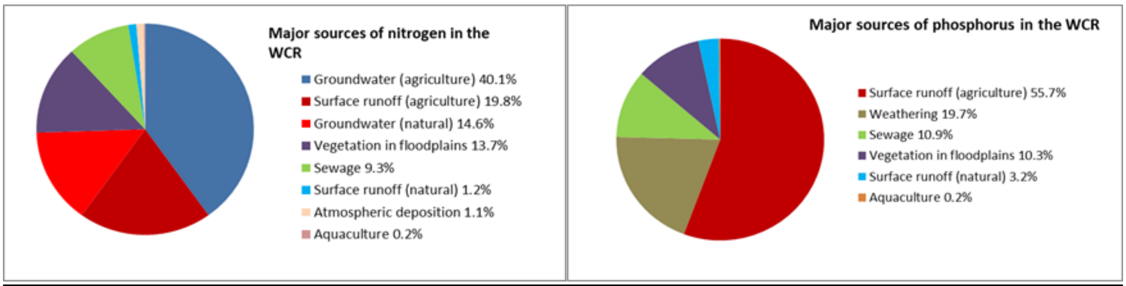

Figure 1.6: Major Sources of Nitrogen and Phosphorus in the WCR -base year 2000. (RNPRSAP, in press)

There may be some variation in the percentage contribution of domestic wastewater (sewage) to overall nutrient loads across sub-regions of the WCR. Those regions/countries with less intensive agriculture and with dense coastal populations, including transient tourists, may have higher contributions from sewage.

A study conducted in 2015 in Barbados used Gorgonian sea rods *(Eunicea Flexuosa)* and over 40 species of macroalgae collected, as bio-indicators, from the south and west coasts of the island. Samples were taken and nitrogen isotope analyses were conducted. The study concluded that *"sewage sources of nitrogen dominate along the south and much of the west coast of the island."* (Baird, 2017).

Therefore, it would appear to be prudent to seek to manage nutrient inputs into the WCR from both agriculture and sewage and the focus of this paper is on the latter.

1.2 Importance of Nutrient Discharge Standards

According to the International Organisation for Standardisation (ISO), standards help answer the question: What is the best way of doing this? Standards allow for setting targets and goals and allow for objective review of the adequacy of effort. A good environmental standard is enforceable and effective in protecting the aspect of the environment it is meant to protect.

So how does the LBS Protocol currently seek to regulate the problem of nutrients? The relevant general obligations of Parties, as described in Article III, are reproduced below (empathises by the author):

- Each Contracting Party shall, in accordance with its laws, the provisions of this Protocol, and international law, take appropriate measures to prevent, reduce and control pollution of the Convention area from land-based sources and activities, using for this purpose the **best practicable means** at its disposal and **in accordance with its capabilities.**

- Each Contracting Party shall develop and implement appropriate plans, programmes and measures. In such plans, programmes and measures, each Contracting Party shall adopt effective means of preventing, reducing or controlling pollution of the Convention area from land-based sources and activities on its territory, including the use of **most appropriate technology** and management approaches such as integrated coastal area management.

Note the use of terms like "best practicable means", "in accordance with its capabilities" and "most appropriate technology"[3], which would appear to be a recognition of the different capacities and cultures of the contracting Parties and imply an inherent philosophy of the use of technology-based standards (see Section 3.4).

Other relevant articles in the current LBS Protocol are:

- Article V - Contracting Parties shall promote cooperation …..

3 The LBS Protocol defines most appropriate technology as the best of currently available techniques, practices, or methods of operation to prevent, reduce or control pollution of the Convention area that are appropriate to the social, economic, technological, institutional, financial, cultural and environmental conditions of a Contracting Party or Parties

    - identify and approach potential sources of financing for projects necessary to implement this Protocol.
- Article VI - Each Contracting Party shall formulate and implement monitoring programmes, as appropriate, in accordance with the provisions of this Protocol and relevant national legislation. Such programmes may, inter alia:
    - (a) systematically identify and assess patterns and trends in the environmental quality of the Convention area; and
    - (b) assess the effectiveness of measures taken to implement the Protocol.
- Article XII - The Contracting Parties shall submit reports to the Organisation …..
    - The Scientific, Technical and Advisory Committee shall use the data and information contained in these national reports to prepare regional reports

There are also relevant clauses in the annexes. For example:

- Annex 1
    - Domestic sewage is a priority source category
    - Nitrogen and phosphorus compunds are primary pollutants of concern
- Annex II
    - The Contracting Parties, when developing sub-regional and regional source-specific effluent and emission limitations and management practices pursuant to Article IV of this Protocol, shall evaluate and consider the following factors: …..
        - Total quantity (units discharged, for example, per year or per day)
        - Alternative Production, Waste Treatment Technologies or Management Practices
            - (a) Recycling, recovery and reuse opportunities
- Annex III
    - Each Contracting Party shall:
    - (a) Consistent with the provisions of this Annex, provide for the regulation of domestic wastewater discharging into, or adversely affecting, the Convention area;
    - (b) To the extent practicable, locate, design and construct domestic wastewater treatment facilities and outfalls such that any adverse effects on, or discharges into, Class I waters, are minimised;

- (c) Encourage and promote domestic wastewater reuse that minimises or eliminates discharges into, or discharges that adversely affect, the Convention area;
- (d) Promote the use of cleaner technologies to reduce discharges to a minimum, or to avoid adverse effects within the Convention area; and
- Develop plans to implement the obligations in this Annex, including, where appropriate, plans for obtaining financial assistance.
- 2. Each Contracting Party shall be entitled to use whatever technology or approach that it deems appropriate to meet the obligations specified in Part C of this Annex.

The LBS Protocol specifies for household systems:

- Each Contracting Party shall strive to, as expeditiously, economically and technologically feasible, in areas without sewage collection, ensure that household systems are constructed, operated and maintained to avoid contamination of surface or ground waters that are likely to adversely affect the Convention area
- Household systems include, but are not limited to, septic tanks and drain fields or mounds, holding tanks, latrines and bio-digesting toilets.

In the apparent absence of political will or economic capacity to sewer populations, it could be argued that more focus is needed on smaller on-site treatment technologies that remove/recover nutrients within the WCR. Annex 1V of the protocol seeks to regulate agricultural non-point sources of pollution (the largest source of nutrient pollution) by:

- Making it mandatory for all Parties to formulate policies, plans and legal mechanisms
- Education, training and awareness programmes
- The development and promotion of economic and non-economic incentive programmes to increase the use of best management practices

There is no attempt in the LBS Protocol to set any numerical/quantitative standards to regulate nutrient pollution from non-point sources. Nutrient use efficiency (NUE) or nutrient management standards are now being applied in some jurisdictions (Virginia Department of Conservation and Recreation, 2014) and being promoted by the Food and Agricultural Organisation in animal production (FAO, 2012).

There are no quantitative standards in the LBS Protocol to regulate the amount of nutrients in wastewater discharges into the WCR. Annex III of the Protocol at section 3 (a) states the following:

"Each Contracting Party shall take into account the impact that total nitrogen and phosphorus and their compounds may have on the degradation of the Convention area and, to the extent practicable, take appropriate measures to control or reduce the amount of total nitrogen and phosphorus that is discharged into, or may adversely affect, the Convention area."

One could argue that the language above represents a qualitative standard. The word "*shall*" implies a mandatory obligation on each Party. It could also be argued that in the absence of clear scientific knowledge about the public health impacts or aquatic ecotoxicology of a substance or a group of substances, one should be cautious about setting a quantitative standard (either end-of-pipe or ambient) unless that standard was zero.

The problem arises as to how would it be determined that the amount of nitrogen and/or phosphorus discharged by individual polluters "*may adversely affect the Convention area*"? How would compliance be determined using only a qualitative standard? The regulator would need to prove, in each individual case, that the particular discharge caused harm to the receiving environment.

The status quo is an already problematic aggregate level of nutrient pollution from domestic discharges, which are likely to increase as populations increase in the region. The qualitative or narrative approach used to date in the LBS Protocol to manage nutrient discharges from both point and non-point sources has not apparently had the desired effect. It is posited that the introduction of quantitative nutrient discharge standards will be easier to enforce.

It is further posited that the presence of numerical standards for parameters like suspended solids (SS) and biological oxygen demand (BOD) in the LBS Protocol has provided a clear target for designers and operators of wastewater treatment plants and that those targets are achievable through the use of what is now conventional and widely available technology (See Barbados Case Study at Section 5.0). It can be argued that nitrogen removal technology from domestic wastewater (less so phosphorus removal) has also now become conventional.

Therefore, it is recommended that Annex III of the LBS protocol be amended to provide for quantitative limits (loads and/or concentrations) for nitrogen and possibly for phosphorus in domestic wastewater discharged into the WCR.

2 EXISTING RELEVANT GLOBAL AND REGIONAL FRAMEWORKS AND INITIATIVES

This section of the paper attempts to briefly summarise some of the major global and regional frameworks and initiatives which are relevant to a review of the nutrient management strategy for domestic wastewater discharges in the WCR.

2.1 Global Initiatives

- The Sustainable Development Goals (SDGs)

Replacing the Millennium Development Goals in September 2015, the SDGs are the new global targets for 2030. The SDGs provide a framework for sustainable development within which are guiding aspirations for nutrient management. Many of the 17 SDGs are relevant to global nutrient management including SDGs 1, 2 ,3 ,6 ,7, 8, 11, 12, 14, 15 & 17.

SDG 6, in particular target 6.3[4], clearly calls for an increase in the numbers of domestic wastewater treatment systems, the minimization of discharges of nutrients (hazardous chemicals) from these systems and increased emphasis on water reclamation. SDG 12 speaks to sustainable consumption and production, which implies movement towards a more circular economy and in the case of nutrients, more efficient use and recovery. Targets 12. 4 and 12.5 call for the environmentally sound management of chemicals throughout their lifecycle and reduction in waste generation.

2.2 Global Partnership on Nutrient Management

In 1995, in a global effort to counter the effects of land-based pollution of the marine environment, The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) was adopted by 108 countries[5].

In 2009, at the United Nations Commission for Sustainable Development (UNCSD), it was agreed that a coordinated global response was required to what has been termed the *"nutrient*

---

4 *By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally*."(UNDESA)

5 https://www.unep.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/governing-global-programme

challenge", which could be defined as *"how to reduce the amount of excess nutrients in the global environment, consistent with global development" or how to produce more food and energy with less pollution."* - http://www.nutrientchallenge.org.

As a result, under the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), the Global Partnership on Nutrient Management (GPNM)was formally launched on May 6, 2009. The GPNM is a platform for governments, inter-governmental organisations, non-governmental organisations, the private sector, and academia to create an agreed agenda to combat the nutrient challenge. Support is provided by the governments of the USA, Netherlands, Italy, Germany, EU, the International Fertiliser Association (IFA), the International Nitrogen Initiative (INI), and the UN Food and Agricultural Organisation (FAO). The UNEP Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (UNEP GPA) acts as the secretariat for the GPNM (IISD, 2009) (Sutton et al., 2013).

The objectives of the GPNM include:

- catalysing strategic advocacy
- acting as a knowledge platform
- enhancing capacity
- mainstreaming nutrients in the sustainable development agenda

A Caribbean platform to drive action at a regional level was launched in 2013 in partnership with the Institute for Marine Affairs of Trinidad and Tobago and the Secretariat of the Cartagena Convention, Caribbean Environment Program Regional Coordination Unit[6].

Within the UN, a resolution for sustainable nitrogen management was adopted at the fourth session of the UN Environment Assembly in March of 2019 and later that year, in a joint effort between UNEP and the INI, the International Nitrogen Management System (INMS) supported the development of the Colombo Declaration on Sustainable Nutrient Management. The Colombo Declaration calls for the halving of nitrogen waste globally from all sources of nitrogen pollution[7]. Global Wastewater Initiative

6 *https://sustainabledevelopment.un.org/partnership/?p=7426*

7 *https://www.unep.org/news-and-stories/press-release/colombo-declaration-calls-tackling-global-nitrogen-challenge*

The UNEP GPA has also launched the Global Wastewater Initiative to promote good wastewater management practices and to promote wastewater as a valuable resource rather than as waste. One of the focal areas of the GWI is *"contributing to the development and implementation of joint pilot projects to demonstrate and adopt measures enabling nutrients to be removed from wastewater"*[8].

Expected outcomes from the GWI include:

- Improved synergy among stakeholders including scientists, NGOs, the private sector, governments, and international organizations for more effective wastewater management
- Healthier ecosystems and improved human well-being
- Increased opportunities and benefits realized and concerted national and international efforts to embed effective wastewater in national development plans
- Enhanced knowledge generation, sharing, and utilization for better wastewater management
- Enhanced recognition of wastewater as a resource and an opportunity by decision-makers and stakeholders
- Increased utilization of the 3R approach worldwide
- Enabled complementarities between the GW^2I and relevant Conventions and other international instruments, action plans, initiatives, and activities
- Systematic publication of scoping papers and global assessments on emerging wastewater issues
- Increased mobilization of resources to address wastewater challenges.

2.3 Regional Initiatives

Relevant regional initiatives include the:

- Regional Seas Strategic Directions
- Cartagena Convention and the LBS Protocol
- Caribbean Large Marine Ecosystem Project ($CLME^+$) Strategic Action Programme; and the
- Regional Nutrients Pollution Reduction Strategy and Action Plan (RNPRSAP).

8 https://www.unep.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/global-wastewater-initiative

Beginning in 2004, every 4 years, UNEP has formulated Regional Seas Strategic Directions (RSSD). Since 2015, the Regional Seas Programme has prioritized assistance to countries seeking to achieve SDG 14 (sustainable use of oceans). The latest round of strategic directions (2021 – 2024) are currently being finalized (UNEP, 2021). The previous RSSD (2017 – 2020) had as its Strategy #1 - *"Reduce marine pollution of all kinds in line with the SDG Goal 14.1"*. One of the actions identified to help achieve Strategy 1 was to *"raise the visibility of relevant pollution issues at all levels and facilitate science-policy interactions.."* (UN Environment 2016). However, there appears to be little specific mention of, or direction provided for, nutrients management in domestic wastewater in the previous RSSD

The Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region (WCR) or Cartagena Convention was adopted in 1983 and entered into force in 1986. The Convention has spawned three protocols, which are listed below, with the year they entered into force in parentheses:

- Oil Spills Protocol (1986)
- Specially Protected Areas and Wildlife Protocol (SPAW) (2000)
- Land-based Sources of Marine Pollution Protocol (LBS) (2010)

A regional coordinating unit (UNEP-CAR/RCU) was established in 1986 in Jamaica to act as a Secretariat for the Convention and its protocols, and each protocol is served by at least one Regional Activity Centre (RAC). The RACs for the LBS Protocol are:

- Cuba - Centre of Engineering and Environmental Management of Coasts and Bays
- Trinidad & Tobago - Institute of Marine Affairs

Annex III of the LBS Protocol provides end-of-pipe (effluent) standards for domestic wastewater discharges I into either Class1 or 2 waters in the WCR (see Table 2.1 below).

Table 2.1: LBS Protocol Effluent Limitations for Domestic Wastewater Discharges into the WCR

Parameter	Effluent Limit Class 2 Waters	Effluent Limit Class 1 Waters
Total Suspended Solids	150 mg/l*	30 mg/l*
Biochemical Oxygen Demand (BOD_5)	150 mg/l	30 mg/l
pH	5-10 pH units	5-10 pH units
Fats, Oil and Grease	50 mg/l	15 mg/l
Floatables	not visible	
Faecal Coliform (Parties may meet effluent limitations either for faecal coliform or for E. coli (freshwater) and enterococci (saline water).)	NA	Faecal Coliform: 200 mpn/100 ml; or a. E. coli: 126 organisms/100ml; b. enterococci: 35 organisms/100 ml
* Does not include algae from treatment ponds		

There are no effluent limitations for nutrients in Table 2.1, although nitrogen and phosphorus are identified as primary pollutants of concern in Annex I; and in Annex III Contracting Parties are required to: *"take into account the impact that total nitrogen and phosphorus and their compounds may have on the degradation of the Convention area and, to the extent practicable, take appropriate measures to control or reduce the amount of total nitrogen and phosphorus that is discharged into, or may adversely affect, the Convention area"*.

Possible revision of the LBS Protocol to better manage nutrient pollution from domestic wastewater is the focus of this paper and the Protocol is discussed in detail in subsequent sections.

The CLME$^+$ Strategic Action Programme (2015 – 2025)[9] (SAP) sets out a 10-year strategy to sustainably manage the shared living marine resources of the Caribbean and North Brazil Shelf large marine ecosystems (LME). It should be noted that unlike the Cartagena Convention the CLME+ does not contain the Gulf of Mexico LME. Using an ecosystem-based approach, the SAP identified 3 types of marine ecosystems within the CLME+:

- Reefs and associated systems
- Pelagic ecosystems
- Continental shelf ecosystems

9 https://www.clmeproject.org/sap-overview/

The CLME+ SAP is heavily oriented towards vital marine species conservation and has six strategic actions for the protection of the marine environment. The first strategic action, which seeks to enhance regional governance arrangements is perhaps the most relevant to nutrient management in wastewater. Sub actions under Strategy 1 seek to inter alia, enhance:

- Regional institutional coordination
- mainstreaming of lessons learned
- compliance and enforcement capacity,
- data management,
- monitoring, assessment and reporting

Increasing monitoring and compliance capacity within the region will be particularly important if the current and proposed standards, for nutrient management in the LBS Protocol, are to be effectively enforced.

Finally, a relevant and recent regional initiative, supported by CLME+, is the Wider Caribbean Regional Nutrients Pollution Reduction Strategy and Action Plan (RNPRSAP). The goal of the RNPRSAP is *"To establish a collaborative framework for the progressive reduction of impacts from excess nutrient loads on priority coastal and marine ecosystems in the WCR."*

Included within the objectives of the RNPRSAP are to assist in defining regional standards and criteria for nutrient discharges (effluent standards for nitrogen and phosphorus) into the WCR and to recommend ambient coastal water quality standards for nutrients[10], using an Index of Coastal Eutrophication Potential (ICEP) as an indicator. The impact of both the indicator parameters (DIN & DIP) and the values chosen are discussed in section 3.6.

The following best management practices for nutrient management in domestic wastewater have been recommended by the authors of the RNPRSAP:

- Nature-based solutions in combination with hard engineering
- Recovery of nitrogen and phosphorus
- Reuse of treated sanitation waste

Comment: The review of the relevant global and regional initiatives, conducted as part of this study, has shown an evident, mounting, international and regional response to the nutrients challenge. This paper is meant to complement the regional effort and in particular, the

10 http://gefcrew.org/carrcu/LBSSTAC5/Presentations/Re_Nutr_Poll_Red_Strat.pdf

RNPRSAP, by evaluating some of the factors that could or should influence nutrient discharge standards for wastewater treatment plants, from the perspective of an engineer with practical experience in the design and operation of sewerage systems in the region.

3 PRINCIPLES AND APPROACHES TO MANAGING WASTEWATER STANDARDS IN THE WCR

This section of the paper seeks to present the principles and approaches that could be applied to wastewater management in the WCR. It is suggested that, inter alia, the following principles should apply:

3.1 The Precautionary Principle

The Precautionary Principle – *"the lack of certainty regarding the threat of environmental harm should not be used as an excuse for not taking action to avert that threat"* (IUCN, 2007). The precautionary principle is embedded in, inter alia:

- The Rio Declaration 1992 Principle 15
- Convention on Biological Diversity 1992, Preamble
- Framework Convention on Climate Change 1992, Article 3.3
- UK Biodiversity Action Plan, 1994, para 6.8
- Convention on International Trade in Endangered Species of Wild Fauna and Flora, Resolution Conf 9.24 (Rev CoP13)
- Cartagena Protocol on Biosafety to the Convention on Biological Diversity 2000

The LBS Protocol does not specifically mention the precautionary principle. However, there is the obligation of a Contracting Party to conduct an Environmental Impact Assessment (Article VII) if it *"has reasonable grounds to believe that a planned land-based activity on its territory, or a planned modification to such an activity, which is subject to its regulatory control in accordance with its laws, is likely to cause substantial pollution of, or significant and harmful changes to, the Convention area."*

Applying the precautionary principle to a revision of the LBS Protocol, in the context of nutrient measurement, may oblige a recognition that a safe level of nitrogen/nitrates in water (fresh or marine) may not have been adequately determined to date, given the divergent results of various studies on this subject. For example, from a public health perspective, one new study has appeared to find a statistically significant increase in risk to colon and rectal cancer at nitrate concentration as low as 3.87 mg NO_3-NO_3/l (0.87 mg-NO_3-N/l) as compared to the WHO guideline for infant methemoglobinemia of 50 mg NO_3-NO_3/l or 11.3 mg NO_3-N/l (Schullehner et al., 2018).

The marine nearshore environmental assets with the greatest economic value for many insular members of the WCR - coral reef ecosystems - also appear to be amongst the most sensitive marine receptors. A study conducted on the effects of nitrates on two species of corals (*Porites porites & Montastrea annularis)* collected from fringing reefs off the west coast of Barbados found that even at a concentration of 1 micromole per litre (0.014 mg NO_3-N/l) the rate of skeletal growth of the corals was impacted (Marubini and Davies, 1996).

In contrast, mixed regression models were used to analyse a number of physical and human factors that could impact on the concentration of DIN at the base of 34 watersheds on the island of Tutuila, America Samoa and produce exceedance criteria. Biological data and the exceedance criteria were then used to recommend a 0.1 – 0.15 mg/l benchmark for DIN to protect the coral reefs surrounding the Pacific island (Houk et al., 2020).

Others argue that a critical examination of both field and laboratory data including the Elevated Nutrients on Coral Reefs Experiment (ENCORE) fails to show that the concentrations of nutrients found at studied sites could affect the physiology of the corals or be the sole or main cause of widespread change in coral-algal abundance. They argue that other drivers, including – abundance and preferences of grazers, temperature stress, sedimentation stress and diseases can be significant causes of coral mortality and algal cover (Szmant, 2002)

This lack of certainty also implies that the application of any new standards should be closely monitored and regularly reviewed. It necessitates a sense of humility when setting regulatory policy and acknowledgement of the need for all policy decisions to be guided by the best science and to be evidence-based.

3.2 Prevention is better than cure

Prevention is better than cure is an axiom that when applied to waste management focuses on reducing the amount and toxicity of the wastes generated. It is a reminder that nutrients management in domestic wastewater should not only address treatment technologies and end-of-pipe discharge standards. Efforts should also be made to reduce both the flow rates of wastewater discharges and the concentrations of nutrients entering the wastewater treatment plant (WWTP).

Upstream of the WWTP, wastewater minimization policies could include:

- Water use efficiency – e.g. low flush toilets, low flow shower heads and faucets, water efficient washing machines and dish washers
- Separate stormwater - stop the use of combined sewers, prevent/reduce stormwater infiltration into the sewerage system, disconnect illegal drainage connections to the sewers.
- Public education and regulation – ban in-sink grinders, installation and maintenance of grease traps, ban phosphorus in detergents

Finally, when the wastewater does arrive at the WWTP, application of the principle requires efforts to reuse the treated water (circular economy) and/or recover or remove as much of the nutrients as possible before final disposal to the WCR.

3.3 The Polluter Pays Principle

The Polluter Pays Principle is the 16th of 27 principles enunciated in the Rio Declaration on Environment and Development (UNCED, 1992). The principle is recognized in national laws (e.g. US Clean Water Act, Clean Air Act, and Resource Conservation and Recovery Act) and by the European Union in the Treaty on the Functioning of the European Union. The principle is also captured by what is now referred to as Extended Producers Responsibility being promoted by the Organisation for Economic Cooperation and Development (OECD) and others.

The World Bank in a background paper to its 2019 publication – From Waste to Resource - Shifting paradigms for smarter wastewater interventions in Latin America and the Caribbean, stated the following; *"The "polluter pays" principle dictates that utilities should pay the cost of residual pollution abatement connected with their discharges."* The consultants for the World Bank used biochemical oxygen demand (BOD) to define a "unit of pollution" as 1 kg/l of BOD and estimated the cost of abatement at US$1.17/unit (World Bank, 2019). It may be informative to attempt to estimate the cost of a "unit of nutrient pollution" entering or leaving a WWTP.

The Mogden Formula has been used by water utilities in the UK to set charges for effluent from various industries.

Trade Effluent Charge = R + [(V + Bv) or M] + B(Ot/Os) + S(St/Ss)
R = receiving charge
V = primary treatment charge
Bv = biological treatment charge
M = ocean discharge charge

B = biological oxidation charge
Ot/Os = chemical oxidation demand measurement
S = primary sludge disposal charge
St/Ss = measurement of total suspended solids

It is not surprising that in the Mogden Formula, volume, oxygen demand and suspended solids are the parameters used to determine the charges applied by the wastewater utility to the generator of the wastewater entering the sewerage system. These are the parameters that are commonly regulated and impact on the cost of operating the treatment plant. Methods used to determine trade effluent charges, like the Mogden Formula, could be modified to incorporate the nutrient load. If nutrient concentrations/loads in the effluent from a WWTP were regulated, it is likely that the operator would seek to pass on those costs of nutrient removal/recovery.

Should the polluter pays principle apply to the Parties to the Cartagena Convention and its protocols? If yes, how would wide disparities in the level of development and capacity of Parties be considered? For example, using the San Diego/Tijuana border as a case study on transboundary hazards related to wastewater treatment, it is argued that in cases where there is a significant difference in the political and economic circumstances of the neighbouring parties (in this case USA and Mexico) other cost-burden principles may be more applicable than the polluter pays principle (Fischhendler, 2007).

The income level of a household is unlikely to significantly impact the nutrient load in the sewage discharged from that household. However, the household income level directly impacts its ability to pay for the capital, operating and maintenance (O&M) costs of nutrient removal. The state may decide to subsidise the true costs. In Israel, the State owns all water resources and management is centralized. In 2006, the Water Law there was amended to introduce the principle of full cost recovery for both water provision and wastewater treatment and called for the substitution of the use of reclaimed wastewater for freshwater in agriculture. In 2010, tertiary standards for wastewater treatment were introduced and WWTP began removing nitrogen and phosphorus. As a result, the domestic sector pays significantly more for water than do farmers and 85% of agricultural water demand is met with reclaimed effluents (OECD, nd).

If it is agreed that the three principles above are accepted internationally, then how should they be applied to the focus of this paper - nutrient management in WWTPs in the WCR? Both the precautionary and prevention principles would appear to imply that the recommended standards for and/or revisions to the LBS Protocol need to err on the side of caution and be as effective as possible. Effectiveness being defined as the percentage reduction in nutrient load from WWTP discharges into the WCR achieved after the regulatory intervention.

The effectiveness of the new regulation will be the product of the stringency of the regulation and the degree of compliance/enforcement achieved. Neither high compliance with a weak standard nor low compliance with a strong standard will be effective. It may be concluded that if numerical (quantitative) discharge standards are recommended, the standards should be as stringent as possible but constrained by the recognition of the respective current capabilities of the member states. It could also be concluded that any recommended standards should be reviewed regularly to determine their effectiveness and considering changing circumstances.

The polluter pays principle speaks not only to disincentivising potential polluters, but also to the financial sustainability of the proposed revisions to the Protocol. Besides the setting of standards, building an effective regulatory framework to control nutrient discharges and/or wastewater and biosolids reuse will require many of the smaller states in the region to substantially increase their educational, training, monitoring, analytical and enforcement capacities. It is recommended that these administrative and regulatory costs to the state are partially, but perhaps not fully recovered from the owners/operators of the WWTPs. The rationale being that the regulation of the wastewater sector benefits more than those connected to the sewerage system if it results in a healthier coastal marine environment.

Whilst there may be consensus on the principles just discussed, those discussed in the following sections (3.4 – 3.7) are not universally accepted, with different jurisdictions using their own preferred approaches or combinations of approaches.

3.4 Performance and Technology-based Standards

Is there a difference between a performance standard and a technology-based standard? In theory, a performance standard is technology-neutral, it doesn't care about what treatment technology is applied, it focuses on the output quality. In practice, the regulatory agency would usually gather information on the best available technologies within the economic capacity of the industry and base the performance standard on that information.

For example, the US EPA, under its National Pollutant Discharge Elimination System (NPDES), uses several levels of control (technology-based) to regulate industrial wastewater discharges, including the following:

- Best Practicable Control Technology Currently Available (BPT)
- Best Conventional Pollutant Control Technology (BCT)
- Best Available Technology Economically Achievable (BAT)
- New Source Performance Standards (NSPS)
- Best Management Practices (BMPs)

WWTPs owned by the state of municipality or what are called publicly owned treatment works (POTWs) must comply with secondary treatment or equivalent standards for BOD, TSS and pH. There do not appear to be any quantitative technology-based effluent limitations (TBELs) for nutrient discharges from POTWs under the NPDES.

The following definition of wastewater treatment levels was used by the UK Department for Environment, Food and Rural Affairs in 2012 (DEFRA, 2012)

- **Preliminary treatment** – to remove grit and gravel and screening of large solids.
- **Primary treatment** – to settle larger suspended, generally organic, matter.
- **Secondary treatment** – to biologically break down and reduce residual organic matter.
- **Tertiary treatment** – to address different pollutants using different treatment processes.

The European Union Urban Waste Water Treatment Directive – 91/271/EEC specifies a minimum of secondary treatment for urban wastewater discharges (from agglomerations with greater than 10,000 population equivalent) but also allows for primary treatment into "less sensitive areas" in estuaries and coastal waters if studies show no adverse impacts. It is noted that after conducting comprehensive studies, the UK gradually reduced the number of less sensitive designations and by 2012 had none (DEFRA, 2012).

Conversely, the EC Directive also calls for the designation of some waters that may need special environmental protection as "sensitive areas" and would require tertiary level treatment (e.g. nutrient reduction) for wastewater discharges into these areas. This consideration of both the technology available and the sensitivity of the receiving environment could be considered a best practice.

The LBS Protocol appears to recognise the technological approach to setting standards and defines *"Most Appropriate Technology"* as *"the best of currently available techniques,* *practices, or methods of operation to prevent, reduce or control pollution of the Convention area that are appropriate to the social, economic, technological, institutional, financial, cultural and environmental conditions of a Contracting Party or Parties;"* In a revised Protocol, the use of "most appropriate technology" could be combined with a performance-based approach. Consideration could also be given to encouraging ecosystem-based approaches and nature-based solutions as well as nutrient recovery, where feasible.

3.5 Health-based Standards

The use or inappropriate disposal of raw or inadequately treated sewage can have significant public health consequences. Typical communicable excreta or urine -related diseases (and the pathogens that cause the disease) include diarrhoea (*Escherichia coli)*, cholera (*Vibrio cholerae*), typhoid (*Salmonella typhi*) and schistosomiasis (*Schistosoma* spp) (WHO, 1992). In addition, sewage can also contain chemical toxins, for example heavy metals and persistent organic pollutants that can cause non-communicable diseases. For example, nitrates in drinking water have been targeted by the WHO for causing methemoglobinemia in infants. The WHO conducts "rolling revisions" of its Guidelines for Drinking Water Quality (GDWQ), the latest version maintains the guideline value for nitrate (as NO_3^-) at 50 mg/l (equivalent to 11.3 mg/l NO_3^- - N) and nitrites (as NO_2^-) at 3 mg/l (WHO, 2017).

With respect to health-based standards for wastewater, the WHO has focused on the management of risks associated with reuse. WHO published its first guidelines - *Reuse of effluents: Methods of wastewater treatment and public health safeguards*, in 1973. The WHO updated these guidelines in 1989 with *Health guidelines for the use of wastewater in agriculture and aquaculture* and published a third set of guidelines in 2006: *Guidelines for the safe use of wastewater, excreta and greywater* (WHO, 2006a).

A review of the WHO 2006 guidelines, as part of this study, revealed the following:

- > 10% of the world's population consume food that was irrigated with wastewater.
- The use of wastewater for agriculture and aquaculture is increasing in both developing and developed countries as a result of increasing water stress, population and pollution increase, and a growing recognition of the resource value.
- Source-separated urine, that has been stored for 1 – 6 months, poses low health risks when used in agriculture.
- A health-based performance standard or target of Disability-Adjusted Life Years (DALY) loss of ≤10-6 per person per year is used to set the guidelines for wastewater

reuse. Multiple barriers can be used to achieve the 6-7 log removal of pathogens required to achieve this health-based target

- Table 8.1 in Volume 2 -Wastewater Use in Agriculture looks at the effect of various compounds in the irrigation water on soils, crops and livestock. The discussion on nitrogen and phosphorus is reproduced below in Table 3.1 (WHO, 2006b):

Table 3.1: Effects of Nitrogen and Phosphorus in Wastewater used for Irrigation (WHO 2006b)

Parameter	Concentration in the irrigating water	Soil	Crops	Livestock
Nitrogen	Municipal wastewater with 20–85 mg TN/l	Acidification problems provoked by synthetic fertilizers are not observed	Increases productivity in quantity and quality Depending on soil's content and type of crops, problems can arise above 30 mg N-NO_3/l	No problems reported
	Wastewater with >30 mg/l	No reported effects	Can increase succulence beyond desirable levels, causing lodging in grain crops and reducing sugar content in beets and cane Beyond seasonal needs, may induce more vegetative than fruit growth and also delay ripening	Forage, being the main food for cattle, can cause grass tetany, a disease related to an imbalance of nitrogen, potassium and magnesium in pasture grasses
Phosphorus	Municipal wastewater with 6–20 mg/l	No reported effects	Increases productivity	
	Municipal wastewater with >20 mg/l	No reported effects	Reduce copper, iron and zinc availability in alkaline soils	

It is noted that the impact of runoff or leaching of irrigation water into the groundwater or adjacent surface waters is not considered in Table 3.1 above. It may seem counter-intuitive to seek to remove nutrients from wastewater intended to be reused for irrigation. In the Barbados case study (see Section 5.0), the decision was taken to remove as much of the nutrients as practically possible from the reclaimed water, even if that water is used in the dry season for irrigation and to recharge groundwater aquifers in the wet season. This decision (in consultation with the Ministry of Agriculture) was taken to reduce the risks of damaging some crops and of contaminating the groundwater and adjacent surface waters, which contribute to the nutrient load into the coastal waters containing very sensitive marine receptors – coral reefs. Therefore, whilst the WHO Guidelines for nutrients in reclaimed water intended for use in irrigation should be noted, the guidelines may not be appropriate for some countries.

3.6 Water Quality-based Standards

Another way to establish standards is to consider the effect of the pollutant on the receiving environment or more specifically the designated purpose or use of the receiving environment. The term "fit for purpose" applies. The US EPA describes the process of setting water quality standards as having three components:

- Designation of how the receiving water body is to be used (e.g. recreation, irrigation, drinking water, fish/shellfish/wildlife protection).
- Determination of water quality criteria (WQC) to protect that designated use. These criteria can be quantitative/numeric (e.g. concentrations or loads) or qualitative/narrative (e.g. *"Waters shall be free from toxic pollutants in toxic amounts"*). WQC must:
    - *"be based on sound scientific rationale*
    - *contain sufficient parameters or constituents to protect the designated use*
    - *support the most sensitive designated use of the water body.*" (US EPA, 2017)
- Setting of antidegradation requirements to maintain the integrity of the water body.

It is notable that the US EPA encourages states, territories and authorized tribes to set numeric WQC for both nitrogen and phosphorus (and suggests the use of total nitrogen and total phosphorus as parameters to monitor) to prevent eutrophication and algal blooms; arguing that the paradigm that assumes that primary production is nitrogen-limited in marine waters and phosphorus-limited in freshwaters is oversimplified (US EPA, 2015).

The US EPA publishes a N/P Criteria Progress Map that monitors the implementation of numeric WQC for nitrogen and phosphorus in the various states and territories. A brief review of the map reveals that Hawaii (see Table 3.2 below) has developed a complete set of criteria for N & P for all water bodies. Whereas states like Alabama, Mississippi and Louisiana that discharge into the northern area of the Gulf of Mexico have not yet set numeric discharge standards for any water bodies including coastal waters.

Table 3.2: Selected Nutrient WCQ for the State of Hawaii[11]

Parameter	**Application**	**Criteria Magnitude[12]**
Ammonia	open coastal waters: dry season *(Saltwater)*	2 - 9 µg/l
Ammonia	open coastal waters: wet season *(Saltwater)*	3.5 - 15 µg/l
Ammonia	oceanic waters *(Saltwater)*	1 - 2.5 µg/l
Ammonia	Kona coast - island of Hawaii: where salinity > 32.00 ppt	2.5 µg/l
Nitrate + Nitrite	estuaries	8 – 35 µg/l
Nitrate + Nitrite	open coastal waters: wet season *(Saltwater)*	5 – 25 µg/l
Nitrate + Nitrite	open coastal waters: dry season *(Saltwater)*	3.5 - 20 µg/l
Nitrate + Nitrite	oceanic waters *(Saltwater)*	1.5 - 3.5 µg/l
Phosphate	Kona coast - island of Hawaii: where salinity > 32.00 ppt	5 µg/l
Total dissolved nitrogen *[total nitrogen]*	Kona coast - island of Hawaii: where salinity > 32.00 ppt	100 µg/l
Total dissolved phosphorus *[total phosphorus]*	Kona coast - island of Hawaii: where salinity > 32.00 ppt	12.5 µg/l
Total nitrogen	open coastal waters: dry season *(Saltwater)*	110 - 250 µg/l

11 https://www.epa.gov/wqs-tech/state-specific-water-quality-standards-effective-under-clean-water-act-cwa#tb2

12 The lower number in a range represents the geometric mean that is not to be exceeded. The upper number represents a value that should not be exceeded more than 10% of the time.

Total nitrogen	open coastal waters: wet season *(Saltwater)*	150 - 250 µg/l
Total nitrogen	oceanic waters *(Saltwater)*	50 - 100 µg/l
Total phosphorus	open coastal waters: dry season *(Saltwater)*	16 - 45 µg/l
Total phosphorus	open coastal waters: wet season *(Saltwater)*	20 - 60 µg/l
Total phosphorus	oceanic waters *(Saltwater)*	10 - 25 µg/l

It is evident, from Table 3.2, that Hawaii:

- regulates several forms of both nitrogen and phosphorus
- differentiates between coastal and oceanic waters
- differentiates between wet and season when setting coastal WCQs

It is also noted, and this may be relevant to island states and those continental states with coastal coral reefs, that Hawaii has set a dry season (geometric mean) standard of 3.5 µg/l for nitrates + nitrites in open coastal waters, equivalent to 0.0035 mg/l as N^-. Although the difference between total dissolved and total is not clear, the data reflected in Table 3.1 appear to indicate values of around 100 µg/l (0.1 mg/l) and 16 µg/l (0.016 mg/l) as acceptable WQCs for total nitrogen and total phosphorus respectively in coastal waters in the dry season.

In Barbados, in 2004, the author of this report was requested to draft a Table of Prohibited Concentrations to facilitate the enforcement of the Marine Pollution Control Act (MPCA). The recommended ambient water quality standards for TN and TP were 0.1 mg/l and 0.015 mg/l respectively. The ambient water quality standard recommended for chlorophyll a was 0.5 µg/l. The recommended ambient water quality standards for Barbados were based on a review of the latest Australian and New Zealand Guidelines for Fresh and Marine Water Quality at that time (ANZECC, 2000).

The US EPA also recommends water quality criteria for nutrients based on criteria for 14 distinct eco-regions. However, these criteria appear to be aimed primarily at reducing excess nutrients in freshwater bodies.

As discussed in Section 1.1, in the context of nutrient pollution, for the purposes of the report, the SOCAR appears to have made the following decisions:

- The Wider Caribbean Sea should be designated into two areas – continental & island
- The parameters that should be monitored are dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP).
- The numeric water quality criteria to be used for DIN are < 0.1 mg/l (continental) & < 0.05 mg/l (island)
- The numeric water quality criteria to be used for DIP are < 0.01 mg/l (continental) & < 0.005 mg/l (island)

As discussed in Section 3.1, it can be argued that the island water quality criterion for nitrogen (as used in the SOCAR) may not be sufficient to protect the most sensitive designated use or purpose of the water body if that purpose is the protection of tropical coral reef ecosystems or other sensitive marine receptors. It is noted that the LBS Protocol does provide for two classes of water, with Class 1 waters being defined as those that "*are particularly sensitive to the impacts of domestic wastewater*". Waters containing mangroves, seagrass beds and coral reefs are specifically included in Class 1. This built-in flexibility could be maintained and even expanded in a revised Protocol to allow for the setting of different ambient and end-of-pipe (discharge) standards for nutrients depending on the ecology of the receiving waters.

3.7 Total Maximum Daily Loads

Robust ambient water quality criteria provide a foundation for logical setting of Total Maximum Daily Loads (TMDLs) – the maximum amount of a pollutant that can be received by a waterbody, without that water body exceeding the water quality criterion for that pollutant, including seasonal variations. For a point source in the US, the EPA assigns a waste load allocation (WLA), including WWTPs regulated under the NPDES. Non-point sources are assigned load allocations (LA), which include natural background sources.

The TMDL is calculated as the sum of all of the WLAs and Las and then a margin of safety (MOS) is added (NRC 2001). The equation is expressed below:

$$TMDL = \Sigma WLA + \Sigma LA + MOS$$

Under the CWA, States are required to develop TMDLs for impaired waters and submit these TMDLs to the EPA for approval. Preparation of a TMDL for a pollutant(s) usually consists of the following steps:

- Characterisation of the watershed and receiving water body
- Setting of ambient water quality standards to protect the most sensitive aquatic receptors and preserve/enhance the beneficial uses of the water body
- Selection of the pollutants of concern
- Determination of the assimilation/carrying capacity of the receiving water body
- Estimation of current and projected loads from all sources
- Determination of any needed reduction in loads and a margin of safety
- Allocation of allowable pollutant loads for individual pollutant sources

The EPA defines a TMDL as *"a written, quantitative plan and analysis for attaining and maintaining water quality standards in all seasons and for a specific water body and pollutant."*. It could be interpreted from this language, that the EPA could apply TMDLs to ocean waters but there may be a loss of jurisdiction outside of the 3-mile territorial boundary.

The larger the water body and the greater the ocean currents (the rate of exchange of water within the water body), the more load could be assimilated. So, how would the TMDL for the receiving water body be defined for discharges into coastal marine waters?

In Florida (a coastal state), the Department of Environmental Protection has divided the Upper East Coast Basin in to polygons, each with a distinctive water body identification number (WBID). The following briefly describes the approach taken with applying TMDL's to nutrient discharges into the Atlantic Ocean from along the Palm Coast (WBID 2363D) (Magley, 2013) (See Figure 3.1 below).

Using the Identification of Impaired Surface Waters Rule (IWR) (Rule 62-303, Florida Administrative Code (F.A.C.)), the Palm Coast estuary was deemed impaired for nutrients in 2010 having exceeded a criterion for chlorophyl-a (chl*a)*. The water quality standard, in the F.A.C., for nutrients is expressed as a narrative: *"In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna."(* Rule 62-302, F.A.C) and annual average chl*a* levels are used as numeric targets to indicate whether the narrative criterion has been exceeded.

Using historical water quality data, including seasonal variation, and linear regression models, it was determined that TN and TP loads would have to be reduced by 29% and 23% respectively, to reduce the average chl*a* concentration in coastal waters to less than the targeted 4.5 µg/l. There are 4 permitted WWTPs in the watershed. However, the analysis of all sources (point, non-point & background) indicated that the combined discharges from the WWTPs contribute only 2% and 6% of the TN and TP loads respectively contributed by non-point sources. The decision was taken to monitor the WWTP WLAs and to reduce non-point source loads through best management practices (BMP) (Magley, 2013).

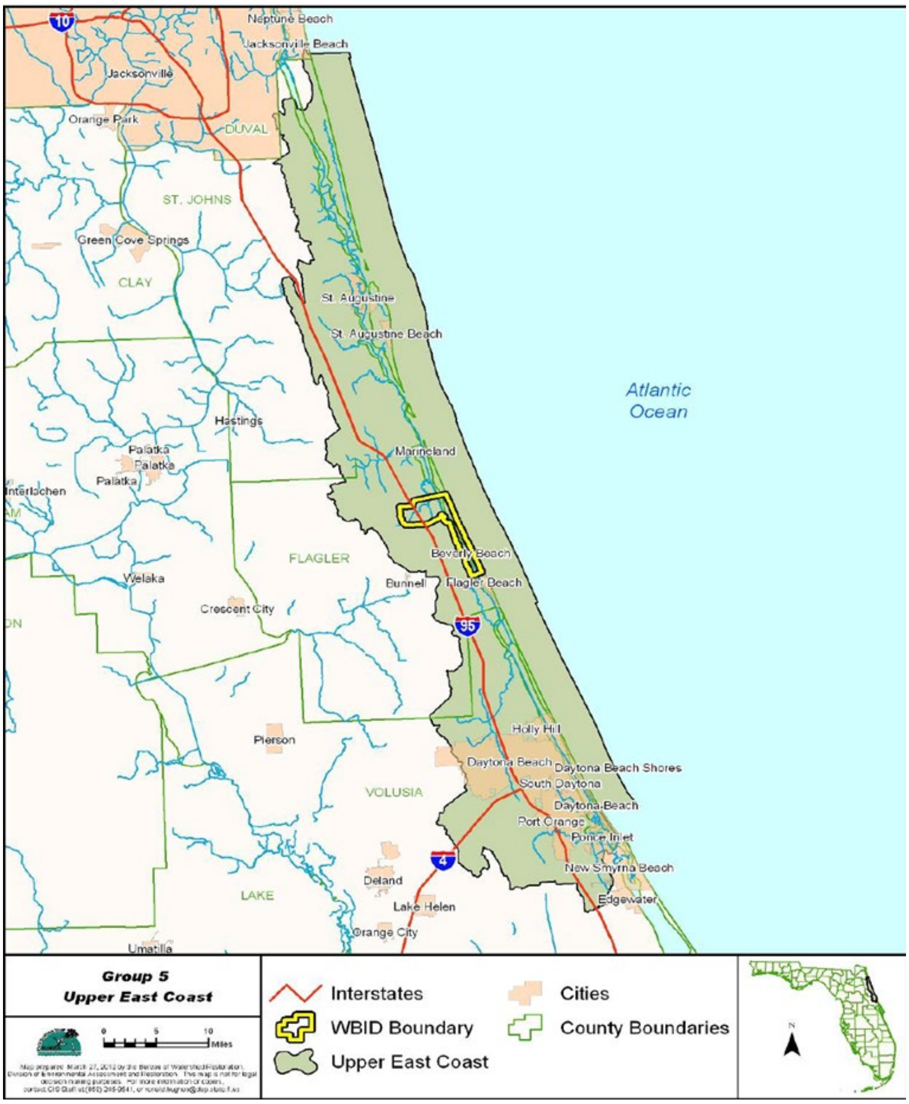

Figure 3.1: Location of the Palm Coast Watershed (WBID 2363D) in the Upper East Coast Basin (reproduced from Figure 1.1 – Magley, 2013)

The TMDL approach to nutrient discharges along the east coast of Florida is recommended as a best practice. It is noted that the use of TMDLs relies on extensive data gathering and continuous monitoring. Not only do all sources of loads have to be determined and then monitored, but a robust ability to monitor the impact of the varying loads of pollutant(s) on the receiving water body is also necessary.

It may not be practical, from a governance perspective, to attempt to apply the TMDL approach to the WCR with its numerous sovereign members. However, an amended Protocol could encourage individual member states to develop the capacity to apply the concept to regulating nutrient discharges from point sources into coastal waters under their jurisdiction. Capacity building will be required for some of the smaller member countries.

4 SELECTIVE REVIEW OF EXISTING WASTEWATER DISCHARGE NUTRIENT STANDARDS

The standards used by the US EPA and selected US states to control nutrient discharges has been discussed previously. Similarly, the approaches of the EU and the WHO have also been discussed, albeit briefly. Below is a summary of the standards utilised by some of the countries within the WCR.

4.1 CARICOM

Perhaps as a result of obligations under the Cartagena Convention, the Caribbean Environmental Health Institute (CEHI), now part of the Caribbean Public Health Agency (CARPHA), was mandated, by the CARICOM Heads of Government, to develop and recommend standards for wastewater discharges in the region. In January 1998, CEHI hosted a United Nations Meeting of Experts. As a result of that meeting, the following effluent guidelines were recommended (see Table 4.1 below):

Table 4.1: Proposed Effluent Guidelines for the Discharge of Municipal Wastewater into Coastal Waters of the Wider Caribbean Region

Parameter	Non-sensitive Waters	Sensitive Waters[1]
Faecal Coliforms	-	Shell fish areas: 43/100 ml
		All other areas: 200/100 ml
pH	6 - 10	6 - 10
Total Suspended Solids	100 mg/l	30 mg/l
BOD_5	150 mg/l	30 mg/l
COD	300 mg/l	150 mg/l
Total Inorganic Nitrogen	-	10 mg/l
Ammonia	-	5 mg/l
Total Phosphorous	-	1 mg/l
Chlorine Residual	-	0.1 mg/l
Fats, oils, greases	5 mg/l	2 mg/l
Floatables	Not visible	Not visible

[1] Most hotels, other commercial and industrial establishments, in the Caribbean, discharge wastewater into waters that would be deemed to be sensitive.

No further apparent action has been taken at the level of CARICOM over the last two decades.

For the purposes of this report a brief review of the standards applied to nutrients discharged by states within the WCR is summarised below in Table 4.2.

4.1.1 Selected Latin American and Caribbean Countries within the WCR

Table 4.2: Nutrient Wastewater Discharge Standards of some member states within the WCR

Parameter (mg/l)	Col	CR	Cuba	DR	Gua	Hon	Nic	Pan	T&T	Bar	Jam
N-NO3	0.1							6			30
N-NO2	0.02										
N-NH3	0.3					20		3	10		
Total N	1	50	10		25		30			5	
P-PO4		25		3				5			10
Total P	0.4		5		15	5	10		5	5	
Total Kjeldahl Nitrogen (TKN)						30					
N-(NH4+NO3)				18							
N -NH4				10							
Total Organic N								10			

Notes and References for Table 4.2 above are provided at Appendix 1. As is evident from Table 4.2 above, there is significant variation in both the parameters monitored and the numeric standards applied to regulate the discharge of nutrients within the member states of the WCR. It is noted that, from the states reviewed in Table 4.2, the range of wastewater discharge standards (omitting the apparently very stringent Colombian standards) for TP was 5 - 15 mg/l and for TN was 5 -50 mg/l.

Table 4.3 below, reproduced from Chapter IV of the RNPRSAP, gives some indication of the parameters currently measured by those who responded to a survey conducted within the WCR.

Table 4.3: Summary of the parameters and matrices that are monitored for nutrient pollution by 12 respondent English and French-speaking countries/territories (Values are percentages. NR: no response) (reproduced from Table 4.3, Ch. IV, RNPRSAP)

Parameter	Domestic wastewater			Industrial Wastewater			Surface Water			Groundwater			Coastal/Marine		
	Yes	No	NR	Yes	No	NR	Yes	No	NR	Yes	No	NR	Yes	No	NR
Total nitrogen	33	33	33	42	17	17	42	25	33	58	25	17	67	17	17
Total Phosphorus	42	25	33	42	17	17	42	25	33	58	25	17	58	25	17
Silica	8	58	0[1]	0	78	0[2]	17	42	0[3]	17	58	0[4]	17	50	0[5]
Chlorophyll-a	8	58	0[1]	Not Applicable			33	25	0[3]	0	8	0[4]	33	42	0[5]
Faecal coliform	58	25	17	50	17	8	42	25	33	58	17	25	67	17	17
Enterococci	25	50	25	25	42	8	33	33	33	33	42	25	58	25	17
E. coli	33	42	25	25	42	8	42	25	33	42	33	25	58	33	8

[1]For domestic wastewater, the remaining 33% of respondents were unsure about silica and chlorophyll-a monitoring.
[2]For industrial wastewater, 22% of respondents were unsure about silica monitoring.
[3]For surface water, the remaining 42% of respondents were unsure whether silica and chlorophyll-a were monitored in their country/territory.
[4]For groundwater, 25% of respondents were unsure about silica monitoring, and 92% for chlorophyll-a monitoring.
[5]For coastal/marine waters, 33% of respondents were unsure about silica monitoring, and 25% about chlorophyll-a monitoring.

It would appear to be a good practice, in the context of a nutrients monitoring programme for wastewater treatment plants, recognising the constraints of the sampling, analytical and data management capacities of some of the smaller countries within the WCR, to, at a minimum:

- Measure and control discharges of NH4+- toxicity to fish
- Measure and control discharges of TN and TP and/or DIN and DIP – eutrophication, sensitivity of corals
- Monitor chlorophyll-a in the receiving water body - indicator of nutrient pollution
- Monitor silica concentrations – Redfield ratio

5 A CASE STUDY ON THE DEVELOPMENT OF A WATER REUSE AND NUTRIENTS MANAGEMENT PLAN – BARBADOS

The following is a brief review of the enabling factors and the initial approaches being used by one of the insular states within the WCR to reduce the discharge of wastewater, in particular nutrient loads to the Caribbean Sea, augment its freshwater resources and increase food security. The case study identifies the approaches used and experiences gained to date by a government in the region as it seeks to comply with the current standards set in Annex III of the LBS Protocol and develop and implement a national water reclamation and nutrients management plan. The lessons learned by Barbados as it assesses the environmental risks/benefits; builds out its regulatory framework, identifies potential end uses and evaluates the appropriate treatment technologies, using an iterative process, may be useful in determining the required amendments to the Protocol,

Never waste a crisis. Acceding to the LBS Protocol in 2019, a global pandemic in 2020/21, a resultant economic crisis and increasing impacts of climate change have forced the government of Barbados to move decisively towards a national water reclamation plan. Nutrient discharges from densely populated coastal areas and from agricultural lands are one of the key drivers of coral reef degradation along the west and south coasts of the island (DeGeorges et. al., 2010).

5.1 Barbados' Key Economic and Water-related Statistics

- Resident population of ~ 287,000, with ~ 1 million visitors per year.
- Land area = 430 km^2, Exclusive Economic Zone = 186,898 km^2
- Gained independence from the UK in 1966 – rapid shift from agrarian to service-based economy
- Ranked 16th highest population density in the world
- GDP in 2019 - ~ US$ 5 billion. In 2020 – US$ 4 billion.
- > 99.5% of population served with piped drinking water (155,000 m^3/day) (source: fresh and brackish groundwater)
- Agriculture is estimated to abstract a further 36,000 m^3/day
- Total renewable freshwater resources = 281 m^3/year/capita
- Rainfall expected to decline by 15 – 30% by 2100.

In hydrogeological terms, the island is an accretionary prism formed as two tectonic plates collide. A cross section of the island (See Figure 5.1 below) reveals that most of the island has a karstic limestone cap sitting on relatively low permeability oceanics, which dip towards the coast. As a result, any pollutant that is persistent in groundwater (e.g. nitrates) will eventually seep through the limestone and flow towards and discharge into coastal waters; and Barbados' most valuable physical economic asset is its coral reef ecosystems, which are highly sensitive to nutrient pollution.

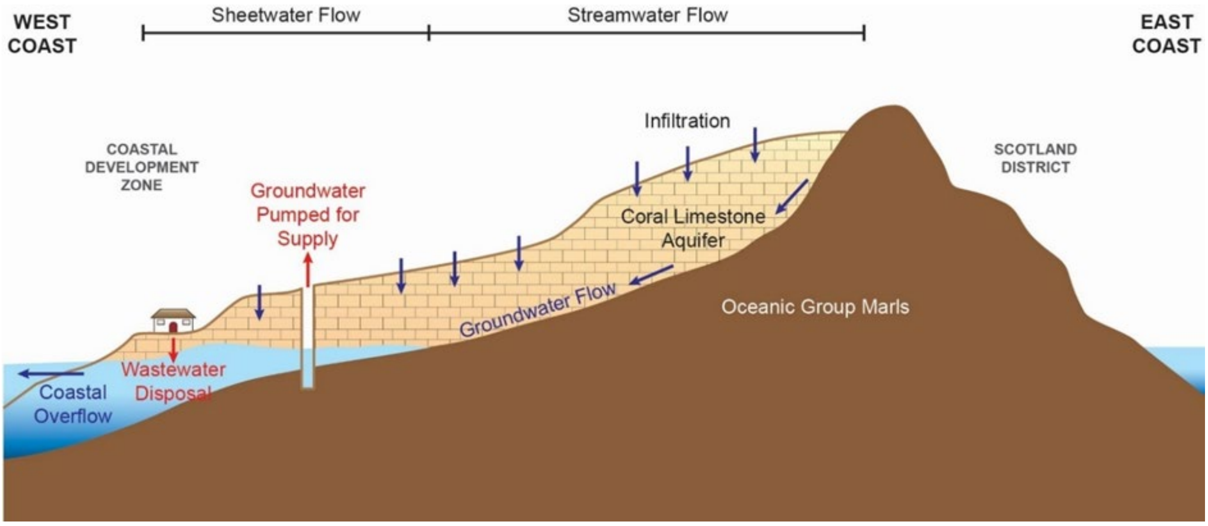

Figure 5.1: West to East Cross Section of Barbados

5.2 The Enabling Factors

According to the World Bank, *"Barbados is a high-income service economy."* (World Bank, 2021). In 2017, Barbados was one of the most indebted nations in the world with a debt to GDP ratio of 157%. In 2018, the incoming administration approached the IMF and completed a public debt restructuring program in December 2019.

In March 2020, Covid-19 struck. Almost literally overnight, the tourists left. The economy, overly reliant on tourism, plunged, with a 17.3% loss in gross domestic product in 2020 as compared to 2019. The outlook for 2021 remains heavily dependent upon having a healthy (economically and physically) tourism season this coming winter in the northern hemisphere.

Supply chains were disrupted and concerns over food security heightened, prompting a renewed focus on promoting local agriculture. But Barbados is a water scarce country, currently unable to meet potable and irrigation water demand in a 1 in 15 year drought and is expected to receive 20 – 30% less rainfall by 2100, depending on what climate models are used (Climate Studies Group Mona (Eds.), 2020).

In 2014 the FAO estimated the total renewable water resources for Barbados at 80 million m^3/year under average rainfall conditions. This is equivalent to 281 m3/year per inhabitant, which is significantly less than the threshold of 1000 m3/year /person that defines water scarcity. In 2019, Barbados experienced its driest year on record since 1947; just 736.5 mm (29") of rainfall was recorded at the airport in that year, whereas in an average year approximately 1270 mm (50") of rainfall would be expected (Nation News, 2020).

Some of the groundwork for a move towards water reclamation had been done before the pandemic struck. In 2019, Barbados acceded to the LBS Protocol. The immediate legal consequence being that the two existing municipal WWTPs:

I. one serving the capital – Bridgetown, a contact stabilisation activated sludge process provided secondary treatment but without disinfection, discharging to a 300 meter long marine outfall; commissioned in 1982 and with a capacity of 7,000 m3/day;

II. and the other serving the touristic south coast (9,000 m3/day); an advanced preliminary treatment plant with fine screens discharging to a 1000 meter long marine outfall;

were both not in compliance for discharges into Class 1 waters. Both plants would have to be upgraded. Therefore, the cost to upgrade the plants to the level of treatment required to discharge into Class 1 waters under the LBS Protocol (See Table 2.1) was considered the baseline for the economic analysis of the feasibility of water reclamation, making the economics of water reclamation more attractive.

Importantly, the Cabinet (the highest decision making body of the government), during one of the driest years on record, had recently approved a national water reuse policy (EPD 2019). This represented a paradigm shift. Wastewater was now to be considered a resource. The vison statement and objective of Barbados' water reuse policy are reproduced in the textboxes below.

Vision: Water is a national resource which shall be used to improve the quality of life for citizens, maintain the natural biodiversity of the land, and promote domestic, agricultural and industrial activities in support of sustainable development and a green economy.

Perhaps most importantly, sources of affordable finance – grant funding from the Green Climate Fund and a loan from the Exim Bank, have been identified to capitalize the needed WWTP upgrades and the construction of a reclaimed water distribution network.

Objective: To promote the safe use of reclaimed, storm and non-potable water in urban, agricultural and the industrial sectors such that human health and environmental quality is not compromised

5.3 A Proposed Water Reclamation Plan for Barbados

On May 20th 2019, the author of this report made a presentation entitled *"Reclaimed Water as a Component of an Integrated Water Resources Plan for Barbados"* at the National Consultation on Water Resources attended by most members of the Cabinet. A possible wastewater reuse scenario, as depicted below in Figure 5.2, was presented.

It envisaged upgrading both the Bridgetown and south coast WWTPs to a level that could provide water fit for the purposes proposed for reuse and constructing the "spine" of what would eventually become a national water reclamation network capable of recharging aquifers in the south and west of the island and of irrigating agricultural lands in the southern, central and northern areas of the island.

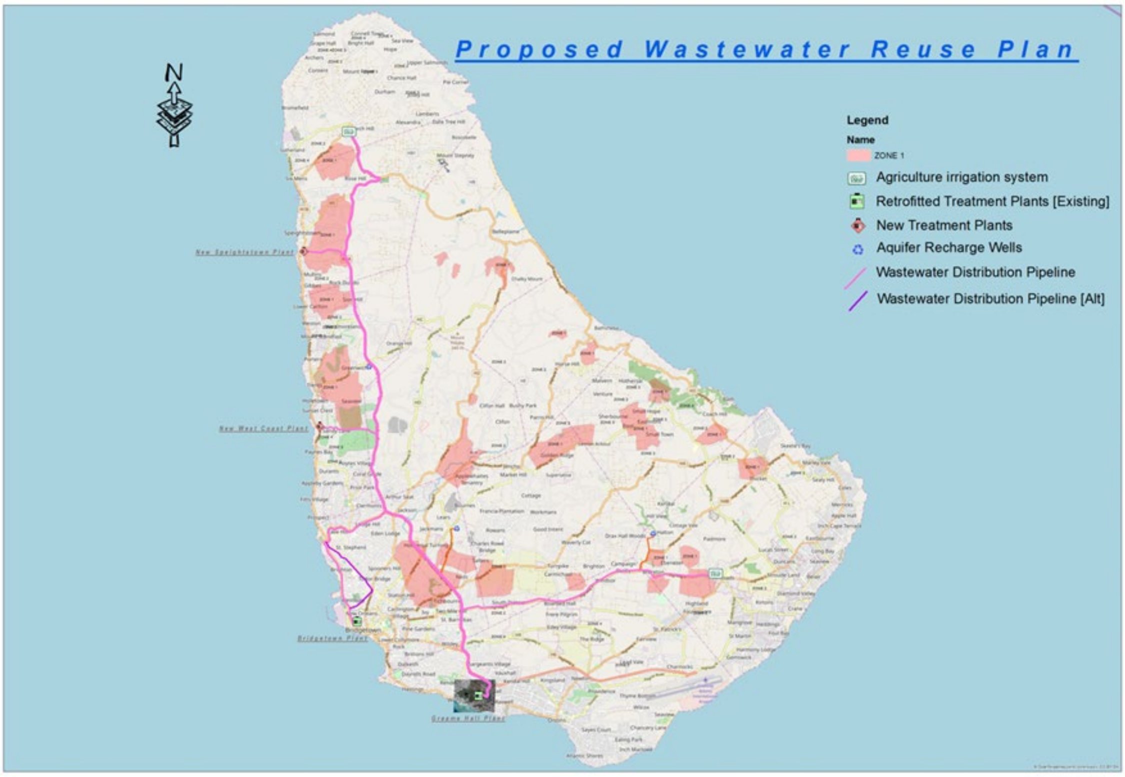

Figure 5.2: Proposed Wastewater Reuse Plan for Barbados

5.4 South Coast Water Reclamation Pre-Feasibility Study

Within the space of three months (September – November 2020), a working group comprised of technical officers from the ministries with responsibility for water resources, agriculture, public health, development planning and control, environment and economic affairs, assisted by consultants (AECOM Canada Ltd.) conducted a pre-feasibility analysis to reclaim water from the upgraded south coast WWTP. The evaluation included a "triple-bottom line" analysis (social, environmental, economic) of several reuse scenarios/options to choose the preferred option. The standards that could be applied for each reuse option were reviewed, including those set by states in the USA (e.g., Nevada, Florida, California) and the WHO. The reuse options considered included the following:

- Recharge of a groundwater aquifer with the intention of withdrawing the same water at a public supply well with only chlorination as the treatment applied. This option was referred to as potable aquifer recharge.
- Recharge of a groundwater aquifer with the intention of withdrawing the same water for irrigation or as feedwater for a reverse osmosis plant; and unrestricted agricultural

reuse (including food crops consumed raw). This option was referred to as non-potable reclamation.

The standards proposed by the regulators (Ministries of Water Resources, Health, Environment and Agriculture), for these two categories of water reuse in Barbados, are reproduced below in Tables 5.1 and 5.2.

Table 5.1: Potable Aquifer Recharge Water Quality Standards Proposed for Barbados (AECOM 2020)

Parameter	**Reclaimed Water Quality**
Total Organic Carbon	Less than 3 mg/L
Turbidity	Less than 2 Nephelometric Turbidity Units
Total Nitrogen (as N)	Less than 5 mgN/l
Total Phosphorus (as P)	As needed, depending on site-specific factors
pH	Between 6.5 and 8.5
Faecal Coliforms	< 1 CFU/ 100 ml
Total Coliforms	< 1 CFU/ 100 ml
Chlorine Residual	Below 0.1 mg/L prior to recharge or discharge to marine environment
Drinking Water Standards	Meet primary and secondary drinking water standards
Total Dissolved Solids	Less than 450 mg/L

Table 5.2: Non-potable Reclamation Water Quality Standards Proposed for Barbados (AECOM 2020)

Parameter	**Reclaimed Water Quality**
Biochemical Oxygen Demand (5-day)	Less than 30 mg/L

Total Suspended Solids	Less than 30 mg/L
Total Nitrogen (as N)	Less than 5 mgN/l
Total Phosphorus (as P)	As needed, depending on site-specific factors
Total Dissolved Solids	Less than 450 mg/L
pH	Between 6.5 and 8.4
Faecal Coliforms & Total Coliforms	<1 CFU/100ml
Chlorine residual	Below 0.1 mg/L prior to recharge or discharge to marine environment

It is notable, from Tables 5.1 and 5.2, that the indicators chosen to control nutrient discharges were Total Nitrogen and Total Phosphorus and the threshold value chosen for nitrogen was 5 mg/l, whilst flexibility was provided for phosphorus.

After comparing several reuse scenarios, this "college" of regulators and engineers made the following "homegrown" decisions to make the water reclamation system (for both municipal sewerage facilities) appropriate to local cultural norms and technical capacity:

- Although technically possible, it was too expensive and probably culturally difficult to attempt direct potable reuse.
- The island did not have the current capacity to regulate the types of crops that could be irrigated or the method of irrigation. Therefore, any reclaimed water to be used for irrigation must meet water quality standards for unrestricted agricultural reuse, even on crops eaten raw.
- Reclaimed water would be also used to recharge groundwater aquifers during the wet season (June to November) when irrigation demand was low.
- Groundwater recharge would be done through injection wells rather than infiltration basins due to the high clay content in local soils.
- Recharge would be into the saturated rather than the vadose zone to allow for backwashing of the injection wells.

- To allow for aquifer recharge and to provide the farmers with a “clean slate”, nitrate levels in the reclaimed water would be reduced as much as possible, using the best available biological nutrient removal (BNR) technology. It was deemed beyond the current technical capacity of local WWTP operators to attempt chemical removal/recovery of phosphorous from the wastewater. It was decided to aim for a TN of < 5 mg/l and a TP of < 5 mg/l.
- Total Dissolved Solids in the reclaimed water should meet a standard of < 450 mg/l for unrestricted agricultural reuse.

Other factors that influenced the choice of the indicator parameters and threshold values were current technical capacity to detect the parameters (see Table 5.3) and the availability of suitable treatment technologies (See Tables 5.4 – 5.7).

Table 5.3: Limits of Detection for Nutrient Parameters in Marine Samples in Barbados (provided by the Government Analytical Services, Government of Barbados, March 2021)

Parameter	**Limit of Detection (mg/l)**
Total Nitrogen	0.1
Nitrates (by Cadmium reduction)	1.0
TKN	2.0
Nitrites	0.01
Ammonia	0.05
Total Phosphorous	0.05
Orthophosphates	0.01

Biological Nutrient Removal (nitrification and denitrification) has become conventional technology. In 2005, the US EPA prepared a fact sheet on BNR processes and costs (US EPA, 2005). Tables 5.4 – 5.7 below are reproduced from the 2005 US EPA fact sheet.

Table 5.4: Mechanisms Involved in the Removal of Total Nitrogen (US EPA 2005)

Form of Nitrogen	Common Removal Mechanism	Technology Limit (mg/L)
Ammonia-N	Nitrification	<0.5
Nitrate-N	Denitrification	1 – 2
Particulate organic-N	Solids separation	<1.0
Soluble organic-N	None	0.5 – 1.5

Table 5.5: Mechanisms Involved in the Removal of Total Phosphorous (US EPA 2005)

Form of Phosphorus	Common Removal Mechanism	Technology Limit (mg/L)
Soluble phosphorus	Microbial uptake Chemical precipitation	0.1
Particulate phosphorus	Solids removal	<0.05

The EPA also rated different wastewater treatment technologies for their ability to remove nitrogen and phosphorous (see Table 4.6 below).

Table 5.6: Comparison of Common BNR Configurations (US EPA 2005)

Process	Nitrogen Removal	Phosphorous Removal
Modified Ludzack-Ettinger (MLE)	Good	None
A^2/O (MLE preceded by an initial anaerobic stage)	Good	Good
Step Feed	Moderate	None
Bardenpho (4 stage)	Excellent	None
Modified Bardenpho (5 stage)	Excellent	Good
Sequencing Batch Reactor (SBR)	Moderate	Inconsistent
Modified University of Cape Town (UCT)	Good	Excellent
Oxidation Ditch	Excellent	Good

Table 5.7 summaries the limits of the technologies for large and small (< 100,000 US gallons/day) (< 379 m3/day) WWTPs as determined by the US EPA.

Table 5.7: Limits of Technology for Large and Small WWTPs (US EPA 2005)

Size of WWTP	Limit of Technology for TN Removal (mg/l)	Limit of Technology for TP Removal (mg/l)
Large	3	0.1
Small	6 - 12	Not cost effective

Taking all these factors into account, the preferred water reuse options were chosen along with the preferred treatment technologies. The process flow diagram of the preferred option for the proposed upgrade of the south coast WWTP is shown below in Figure 5.3.

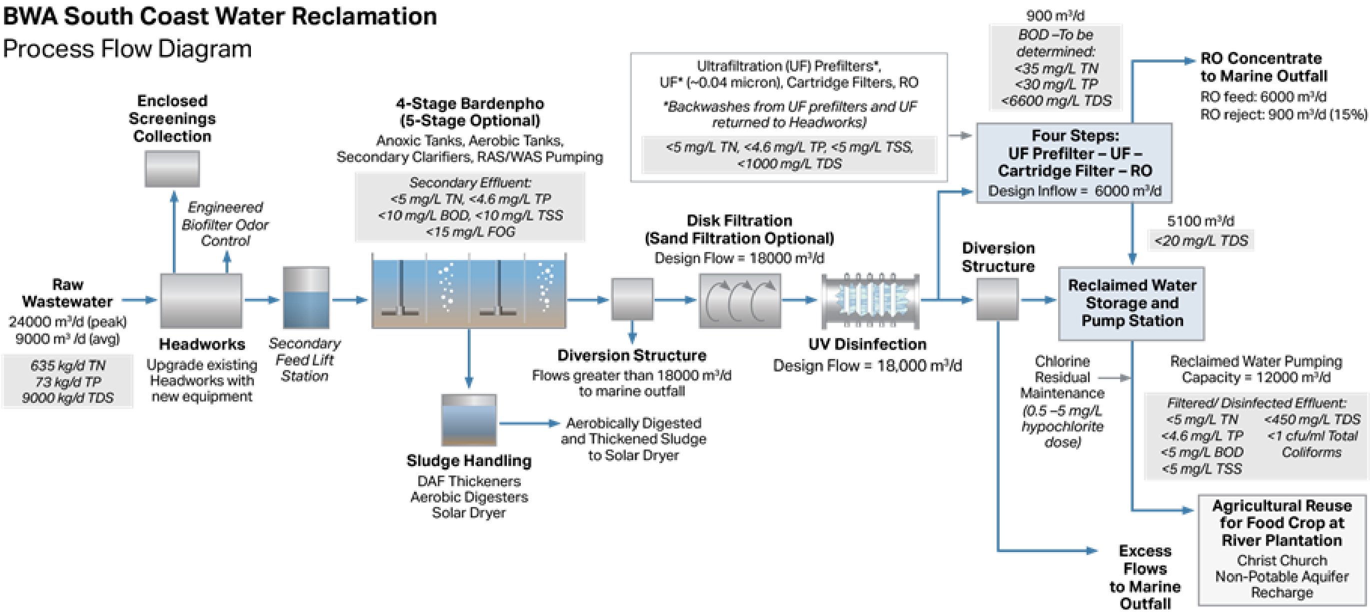

Figure 5.3: Process Flow Diagram for Proposed Upgrade of South Coast WWTP (AECOM 2020)

5.4.1 Concentrations Vs. Loads

It should be noted from Figure 5.3, that to control TDS levels, a reverse osmosis process will be used to remove dissolved solids from two thirds of the process stream and then the RO permeate will be blended back with the rest of the product water. The RO concentrate will be sent to a marine outfall, because an economically feasible means of nutrient recovery from the concentrate has not been identified.

When the nutrient loads into the sea from the baseline (advanced preliminary treatment) are compared with the expected loads after project implementation, the following becomes evident.

Current Baseline daily nutrient loading to outfall:

- Total nitrogen = 9,000 m3/day X 70 mg/l = 635 kg/day
- Total phosphorus = 9,000 m3/day X 8 mg/l = 73 kg/day

Preferred option expected daily nutrient loading to outfall:

- Total nitrogen = 900 m3/day X 35 mg/l = 31.5 kg/day (a 94.6% reduction in daily load)
- Total phosphorus = 900 m3/day X 30 mg/l = 27 kg/day (a 63.6 % reduction in daily load)

However, it is likely that if only numeric concentrations were used to set either national or LBS Protocol effluent discharge standards for nutrients, the RO concentrate discharge would probably fail, even though the project would achieve the environmental objective of significantly reducing nutrient loads into nearshore waters.

5.4.2 Expected National Economic Impact

It is anticipated that the capital costs to upgrade the two WWTPs is likely to be around US$ 170 million. Approximately 40 km of reclaimed water distribution network will be constructed (colored purple) to convey approximately 14,000 m^3/day of reclaimed water capable of irrigating approximately 364 hectares of agricultural lands and recharging groundwater aquifers.

The anticipated benefits include:

- ~ US$ 30 M increase in annual revenues from agriculture,
- savings in foreign exchange,
- augmented freshwater resources, and
- increased food security.

6 CONCLUSIONS AND RECOMMENDATIONS

There is considerable evidence that globally the nitrogen cycle has been significantly altered and the demand for phosphates is increasing. Several areas of the wider Caribbean Sea, particularly nearshore coastal waters adjacent to mouths of major river basins have been deemed to have poor water quality with respect to nutrient content.

Although the major source of nutrients is from the excessive use and inappropriate application of fertilisers, the impact of point sources like the discharges from WWTPs should be regulated. The LBS Protocol uses a qualitative narrative (see text box below) to seek to control nutrient content in WWTP discharges.

> Each Contracting Party shall take into account the impact that total nitrogen and phosphorus and their compounds may have on the degradation of the Convention area and, to the extent practicable, take appropriate measures to control or reduce the amount of total nitrogen and phosphorus that is discharged into, or may adversely affect, the Convention area.

The following practices are recommended:

- The narrative water quality criterion for nutrients in the LBS Protocol should be supplemented with both numeric discharge standards and ambient water quality standards for nitrogen and phosphorous. The suggested "good" ambient values for DIN and DIP in the SOCAR should be constantly reviewed based on the latest available science.

- If adopted, the numerical standards should:
    - be set for the different forms of nitrogen and phosphorus currently monitored by countries within the WCR;
    - allow for flexibility and consideration of local conditions (extra strength agreements, allowance for mixing zones);
    - consider the limits of detection (see Table 5.3). Note the current detection limits for TN and TP in Barbados, which currently does not have the capacity to conduct analyses for DIN and DIP;

- o be probably based on monthly averages, with an indicated minimum frequency of sampling;
- o be based on expected performance, which is affected by the availability and appropriateness of technology

It may also be appropriate and prudent to use a TMDL approach to nutrient management if sufficient data are available. It is recognized that a TMDL approach may not be able to account for synergistic impacts of different pollutants and may be site specific.

It is considered beyond the scope of this report to recommend actual numeric values for limits on nitrogen and phosphorous (in their various forms) in wastewater discharges. It is recommended that the LBS Science and Technology Advisory Committee (LBS STAC) develop a work programme, in consultation with the contracting Parties, to develop and constantly monitor numeric standards both for nutrient concentrations and loads based on a thorough understanding of the impacts on sub-regional marine ecosystems.

However, based on the data presented in Table 5.7 (although from 2005), it would appear reasonable to set an effluent discharge standard for TN for larger WWTP at somewhere between 5 – 10 mg/l if Annex III of the LBS Protocol were to be amended. However, for TP, waste water treatment technologies appear to be still immature, complicated and expensive. For those communities without municipal sewerage systems, more emphasis should be placed on, and more research should be conducted to improve the nutrient removal efficiency of on-site or small communal wastewater treatment systems.

Wastewater reuse, in particular, irrigation of crops which would allow for nutrient recycling should be encouraged but under a strict public and environmental health regulatory regime.

Finally, it recommended that parameters like chlorophyll a and silica should also be added to Annex III of the LBS Protocol to provide better indication of the polluting potential of nutrient discharges into the WCR.

7 REFERENCES

AECOM. 2020. "South Coast Water Reclamation Pre-Feasibility Study". *Prepared for the Barbados Water Authority, Government of Barbados (November)*.

ANZECC. 2000. "Australian and New Zealand Guidelines for Fresh and Marine Water Quality."*Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand 1(4)*. Retrieved on April 4, 2021.

Baird and Associates. 2017. "Appendix D: Adaptation Measures to Counter the Effects of Climate Change with a Focus on Water Resource Management and Flood Resilience." *Stormwater Quality in Barbados* 4. Produced for the Government of Barbados.

Baker, D.M. et. al. 2010. "Caribbean octocorals record changing carbon and nitrogen sources from 1862 to 2005." *Global Change Biology (2010)*. doi: 10.1111/j.1365-2486.2010.02167.x

Climate Studies Group Mona (Eds.). 2020. "The State of the Caribbean Climate*". Produced for the Caribbean Development Bank.*

Coast, P., Magley, W., & Ph, D. 2013. *Nutrient TMDL for(July)*. https://floridadep.gov/sites/default/files/palmcoast-nutr-tmdl.pdf.

DEFRA. 2012. Waste water treatment in the United Kingdom. *Implementation of the European Union Urban Waste Water Treatment Directive – 91/271/EEC.* Retrieved on March 28, 2021. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69592/pb13811-waste-water-2012.pdf.

Degeorges, A., Goreau, T. J., & Reilly, B. 2010. Land-Sourced Pollution with an Emphasis on Domestic Sewage*: Lessons from the Caribbean and Implications for Coastal Development on Indian Ocean and Pacific Coral Reefs*. 2919–2949. https://doi.org/10.3390/su2092919

Department of Conservation and Recreation. 2014. *Commonwealth of Virginia Virginia Nutrient Management Standards and Criteria. 23219 (July)*. https://www.dcr.virginia.gov/document/standardsandcriteria.pdf.

Drescher, A., Glaser, R., & Richert, C. 2011. *"Demand for key nutrients (NPK) in the year 2050.*" Department of geography, University of Frieburg. (*November)*. https://esdac.jrc.ec.europa.eu/projects/NPK/Documents/Freiburg_Demand_for_key_nutrients_in_2050_Drescher.pdf.

EPD. 2019. "National Water Reuse Policy." *Environmental Protection Department, Ministry of Environment and National Beautification, Government of Barbados*.

FAO. 2012. "Balanced feeding for improving livestock productivity – Increase in milk production and nutrient use efficiency and decrease in methane emission." *FAO Animal Production and Health Paper (173)*. Rome, Italy.

Fischhendler, I. 2007. Escaping the " polluter pays " trap : *Financing wastewater treatment on the Tijuana – San Diego border*. *3*. https://doi.org/10.1016/j.ecolecon.2006.12.012.

Gysin, A., Lycke, D., & Wirtel, S. 2018. "Phosphorus: Polluter and Resource of the Future – Removal and Recovery from Wastewater." *Chapter 19: The Pearl*. 359–365. doi: 10.2166/9781780408361_359. https://doi.org/10.2166/9781780408361.

Hastings, M. G., Jarvis, J. C., & Steig, E. J. 2009. *Anthropogenic Impacts on Nitrogen Isotopes of Ice-Core Nitrate*. *324(June)*. Doi: 10.1126/science.1170510.

Houk, P., *et al.* 2020. Nutrient thresholds to protect water quality and coral reefs. *Marine Pollution Bulletin*, *159*(January), 111451. https://doi.org/10.1016/j.marpolbul.2020.111451.

IFDC. 2010. "World Phosphate Rock and Reserves". International Fertiliser Development Center, USA. https://pdf.usaid.gov/pdf_docs/Pnadw835.PDF.

IISD. 2019. "MEA Bulletin - Guest Article No. 82 - Thursday, 10 December 2009*." Global Partnership on Nutrient Management Taking Shape (82)*. Retrieved May 22, 2021. https://enb.iisd.org/email/mea-l/guestarticle82.html.

IUCN. 2007. "Guidelines For Applying The Precautionary Principle To Biodiversity Conservation And Natural Resource Management". *As approved by the IUCN Council 67. (May)*, 1–11. ***https://www.iucn.org/sites/dev/files/import/downloads/ln250507_ppguidelines.pdf.***

Jasinski, SM. 2017. Mineral Commodity Summaries (PDF). *U.S. Geological Survey*.

Marubini, F. and P. Davies., 1996. "Nitrate increases zooxanthellae population density and reduces skeletogenesis in corals." *Marine Biology* 127**:**319–328. Accessed September 22. https://doi.org/10.1007/BF00942117.

Mihelcic, J. R., Fry, L. M., & Shaw, R. 2011. Chemosphere Global potential of phosphorus recovery from human urine and feces. *Chemosphere*, *84*(6), 832–839. https://doi.org/10.1016/j.chemosphere.2011.02.046.

Nation News. 2020. "Driest Year Since 1947." Retrieved April 4, 2021. https://www.nationnews.com/2020/01/31/driest-year-since-1947/.

National Research Council. 2001. "Assessing the TMDL Approach to Water Quality Management: Washington, DC". The National Academies Press, 109. https://doi.org/10.17226/1014.

Neill, M. 2005. *A method to determine which nutrient is limiting for plant growth in estuarine waters — at any salinity*, *50*. 945–955. https://doi.org/10.1016/j.marpolbul.2005.04.002.

Norsok, 2019. "Effects of Struvite Application on soil and Plants: A short-term field study." Norsok Report 4 (10): Norewegian Centre for Organic Agriculture. https://orgprints.org/id/eprint/36472/1/NORSØKRAPPORT10struvittFINALSept52019trykk.pdf.

OECD. n.d. "Urban Water Quality Management – *Policies to implement wastewater reuse in Israel*." Retrieved on March 28, 2021. http://www.oecd.org/environment/resources/Israel-case-study-urban-water-quality-management-diffuse-pollution.pdf.

Rockström, J., et. al. 2009. "Planetary boundaries: Exploring the safe operating space for humanity." Ecol. Soc. 14 (*2*):32. **http://www.ecologyandsociety.org/vol14/iss2/art32/.**

Schullehner, J., *et al.* 2018. "Nitrate in drinking water and colorectal cancer risk: *A nationwide population-based cohort study*." *Int J Cancer*, 143(1):73-79. doi: 10.1002/ijc.31306.

Steffen, W., *et al.* 2015. Planetary boundaries : *Guiding changing planet. 1259855*. https://doi.org/10.1126/science.1259855.

Sutton M.A., *et al.* 2013. "Our Nutrient World: The challenge to produce more food and energy with less pollution*." Global Overview of Nutrient Management. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.*

Szmant, A. 2016. Nutrient Enrichment on Coral Reefs *: Is It a Major Cause of Coral Reef Decline ? Estuaries, 25*(4), 743–766. http://www.jstor.org/stable/1353030.

UNCED. 1992. "Annex 1 of Report of the United Nations Conference on Environment and Development". *Rio de Janeiro* (*June*): *3-14.* Rio Declaration on Environment and Development.

UNEP CEP. 2019. State of the Cartagena Convention Area Report: *An Assessment of Marine Pollution from Land-based Sources and Activities in the Wider Caribbean Region.*

UN Environment. 2016. "Regional Seas Strategic Directions (2017-2020)." *UN Environment Regional Seas Programme, Regional Seas Reports and Studies (201).*

US EPA. 2005. "Biological Nutrient Removal Processes and Costs." Retrieved on April 4, 2021. https://www.epa.gov/sites/production/files/documents/criteria_nutrient_bioremoval.pdf.

US EPA. 2015. *Preventing Eutrophication : Scientific Support for Dual Nutrient Criteria. (February)*, 1–6. https://www.epa.gov/sites/production/files/documents/nandpfactsheet.pdf.

US EPA.2017. Water Quality Standards Handbook. Chapter 3: Water Quality Criteria.

WHO. 1992. "A Guide to the Development of On-site Sanitation." *Part 1-The need for on-site sanitation (246)*.

WHO. 2006a. "Guidelines for the safe use of wastewater, excreta and greywater." *Policy and regulatory aspects (1)*. ISBN 92 4 154682 4 (v. 1).

WHO. 2006b. "Guidelines for the safe use of wastewater, excreta and greywater." *Wastewater Use in Agriculture (2)*. ISBN 92 4 154683 2 (v. 2).

WHO. 2017. "Guidelines for drinking-water quality: fourth edition incorporating the first addendum." Geneva: World Health Organization. Licence: CC BY-NC-SA 3.0 IGO

World Bank. 2019. "From Waste to Resource: Shifting paradigms for smarter wastewater interventions in Latin America and the Caribbean." *Background Paper VI: Market Potential and Business Models for Resource Recovery Products*. World Bank, Washington, DC.

World Bank. 2021. "Public Document." *Key conditions and challenges*. 92–93. Retrieved April4, 2021. https://pubdocs.worldbank.org/en/438851586546174000/mpo-brb.pdf.

8 APPENDIX

Table 8.1: References for Standards quoted in Table 4.2

Country	References	Comments
Columbia (Col)	Ministry of Environment and Sustainable Development. 2015. Resolution no. 0631	Domestic wastewater discharges to marine waters
Costa Rica (CR)	Decree no. 31545-S-MINAE. 2003. Regulation for approval and operation of wastewater treatment systems	Wastewater flows in sanitary sewers or a receiving body
Cuba	National Standardisation Office. Mandatory Cuban standard 27:2012 Disposal of wastewater to terrestrial waters and sewerage:	Class A coastal waters
Dominican Republic (DR)	Ministry of Environment and Natural Resources. 2012. Environmental standard on control of discharges to surface waters, sanitary sewers	Discharge to surface waters for pop 10,001-100,000
Guatemala (Gua)	Government Agreement 236-2006 Regulation of discharge and reuse of wastewater and sludge disposal	To receiving water bodies
Honduras (Hon)	Agreement no. 058 Secretary of Public Health 9 April 1996	To receiving water bodies
Nicaragua (Nic)	Decree no. 21-2017 Regulation establishing the provisions for the disposal of sewage	From domestic sewage treatment systems
Panama (Pan)	Technical regulation DGNTI-COPANIT 35-2019 Environment and protection of health, security, water quality,	Surface and groundwater

	discharge of liquid effluents.	
Trinidad and Tobago (T&T)	Water Pollution Rules, 2019	
Barbados (Bar)	Proposed Standards under the Marine Pollution Control Act	Class 1 waters. Proposed. Extra Strength Agreement allowed
Jamaica (Jam)	Wastewater and Sludge Regulations 2013	For existing plants. Obligatory Nutrients Management Plan