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01 to 03 February 2023

TECHNICAL PAPER ON NUTRIENT VALUATION METHODOLOGY WITH CASE STUDIES FOR JAMAICA AND BARBADOS

This meeting is being convened virtually. Delegates are kindly requested to access all meeting documents electronically for download as necessary.

Case Studies on Nutrient Management Valuation in Jamaica and Barbados: Introduction, Final Analysis and Recommendations

Part of an Economic Valuation Pilot Project financed by the Global Partnership on Nutrient Management (GPNM) established under the UNEP's Global Programme of Action for development of the Marine Environment from Land-Based Activities (GPA)

PRELIMINARY REPORT
(Part 1 of the Report on the Case Studies)

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1st February 2023

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Abbreviations

BAMC	Barbados Agricultural Management Co Ltd
BADMC	Barbados Agricultural Development and Marketing Corporation
BAS	Barbados Agricultural Society
BMP	Best Management Practice
BWA	Barbados Water Authority
CAFO	Concentrated Animal Feeding Operation
CARDI	Caribbean Research and Agricultural Development Institute
CARPHA	Caribbean Public Health Agency
CAWASA	Caribbean Water and Sewerage Association
CReW+	Caribbean Regional Fund for Water and Wastewater Management
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
ENA	European Nitrogen Assessment
EPA	United States Environmental Protection Agency
EPD	Environmental Protection Department, Barbados
EU	European Union
GAP	Global Good Agricultural Practice
GEF	Global Environment Facility
GEF-GNC	Global Environment Facility Global Nutrient Cycling Project
GPA	Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities
GPNM	Global Partnership on Nutrient Management
GDWQ	Guidelines for drinking-water quality
IAMPO	International Association of Plumbing & Mechanical Officials

IDB	Inter-American Development Bank
IFA	International Fertilizer Association
IICA	Inter-American Institute for Cooperation on Agriculture
INI	International Nitrogen Initiative
ISO	International Organization of Standards
IWWM	Integrated Water and Wastewater Management
JAS	Jamaica Agricultural Society
LBS Protocol	Protocol Concerning Pollution from Land-Based Sources and Activities to the Cartagena Convention
MAFS	Ministry of Agriculture and Food and Nutritional Security, Barbados
MAR	Meso American Reef Association
MEJGC	Ministry of Economic Growth and Job Creation Jamaica
MENB	Ministry of Environment and National Beautification, Green and Blue Economy, Government of Barbados
MHURECC	Ministry of Housing, Urban Renewal, Environment and Climate Change of Jamaica
MHW Jamaica	Ministry of Health and Wellness of Jamaica
MHW Barbados	Ministry of Health and Wellness of Jamaica
MoAF	Ministry of Agriculture and Fisheries of Jamaica
MSI	Marine Science Institute
NEPA	National Environmental and Planning Agency of Jamaica
NEWS	Global Nitrogen Export from WaterSheds
NGO	Non-Governmental Organization
NRCS	United States Natural Resources Conservation Service
NRM	Natural Resource Management
NUE	Nutrient Use Efficiency
OAS	Organisation of American States
OECD	Organization for Economic Development and Cooperation

ORMPPA	Ocho Rios Marine Park Protected Area
ORMP	Ocho Rios Marine Park
ORPA	Ocho Rios Protected Area
PIOJ	Planning Institute of Jamaica
PMAB	Pollution Monitoring Assessment Branch of Jamaica
RADA	Rural Agricultural Development Agency
RNPRSAP	Regional Nutrient Pollution and Reduction Strategy and Action Plan
RUSLE	Revised Universal Soil Loss Equation
SBRC	Sustainable Barbados Recycling Centre
SCOPE	Scientific Committee on Problems of the Environment
SDGs	UN Sustainable Development Goals
SOCAR	State of the Convention Area Report
STATIN	Statistical Institute of Jamaica
TSS	Total Suspended Solids
UK	United Kingdom
UNEP	United Nations Environment Programme
UP	University of the Philippines
US	United States of America
USD	United States Dollars
USDA	United States Department of Agriculture
UTECH	University of Technology Jamaica
WCR	Wider Caribbean Region
WHO	World Health Organization
WMP	Wastewater Management Plan
WMU	Watershed Management Unit
WRA	Water Resources Authority of Jamaica
WRI	World Resources Institute
WWTP	Wastewater Treatment Plant

1. Background

A. The Nutrient Challenge

The sustainability of the global environment as well as the human population of eight billion depends not only on the availability of nutrients but also on the smart nutrient management. Nutrients – such as nitrogen, phosphorus, potassium and various micronutrients - are essential for plant growth, food production and ultimately adequate nutrition for humans. Around the world, biochemical cycles have been changed due to the rapid growth of human activities. The world's Nitrogen and Phosphorus cycles are now out of balance, causing major environmental, health and economic problems that have received far too little attention (Sutton et al. 2013). The regional impacts of this have been varied, with excessive use of nutrients in many wealthy countries and some developing countries, and insufficient use less developed regions.

The emissions of nitrous oxide (N_2O), nitrogen oxides (NO_x) and ammonia (NH_3) to air, and loss of nitrogen (N) and phosphorus (P) compounds to water is a direct result these changes. The biggest sources of nutrient pollution are fertilizer and manure in agriculture and wastewater from sewage urban and rural areas. Excessive application of Nitrogen and the production of Nitrogen compounds for use in agriculture as well as high Nitrogen loads in wastewater discharges cause negative impacts to fresh, coastal, and marine waters, air, and soils. Excessive application of Phosphorus in agriculture and high P loads in wastewater discharges also causes water pollution and its use in fertilizer production depletes finite supplies. It is also important to understand that many of the environmental problems caused by N and P emissions to water and air have cross-boundary drivers and are inter-related such as eutrophication, climate change, particulate matter in air, and effects on human health, ecosystems, and biodiversity.

A new global effort is needed to address the 'The Nutrient Nexus' where reduced nutrient losses and improved nutrient use efficiency (NUE) across all sectors simultaneously provide the foundation for a Greener Economy to produce more food and energy while reducing environmental pollution (Sutton et al. 2013). This requires individual sectors to develop and promote smarter methods, technologies, and practices for efficient nutrient use, understand different sectors' needs and challenges, and identify opportunities in the nutrient value-chain for profitable and responsible nutrient management. Ultimately, all sectors must work collaboratively towards the goal of optimizing the planet's nutrient cycles for delivery of our food and energy needs, while reducing threats to social and economic well-being, including threats to climate, ecosystem services and human health.

B. Nutrient Use Efficiency for Economic, Health and Environmental Benefits

i. Introduction

It is now more widely understood that food, energy, and water security are inextricably linked, and implications for the more than 500 million small holder farmers in the developing world to get beyond subsistence and improve quality life require technical assistance and support. New integrated approaches to manage nutrients across various disciplines (i.e., agriculture, aquaculture, livestock and wastewater) are needed to ensure environmental, economic and social benefits for key stakeholders and coastal ecosystems (UNEP, 2011).

The United Nations Food and Agriculture Organization's (UNFAO) Nutrition Strategy aims to reduce malnutrition through efficient, inclusive, resilient and sustainable agrifood systems. This includes providing nutritious food, and enhanced livelihood opportunities in an environmentally sustainable way. Our current food systems contribute to, and are affected by, extreme weather events associated with climate change, land degradation and biodiversity loss. For a food system to be sustainable it must be profitable throughout, illustrate long term social and economic viability, provide broad-based benefits for society, and have a positive or neutral impact on the natural resource environment (FAO 2022).

The global agricultural sector is currently facing a major challenge in the form of chemical fertilizer shortages and high import prices. Farmers in countries that have been highly dependent on fertilizer imports from Ukraine, Belarus, and the Russian Federation have been particularly impacted. Nations have demonstrated different responses to mitigate the high price of fertilizers. Some fertilizer producing countries restricting export to guarantee local supply, some Governments implementing fertilizer subsidy programs for farmers, some countries reducing fertilizer imports due to high prices, and some countries increasing chemical fertilizer production and supporting local level initiatives for biofertilizer production.

For the global crop and livestock production to remain productive during this 'fertilizer crisis', immediate action is required to increase fertilizer use efficiency, prioritize fertilizer for agricultural purposes, monitor stocks as well as import volumes, and prices; and ensure this information through transparent platforms (FAO 2022). This situation has made the need for diversification of plant nutrient sources, beneficial nutrient reuse, and increasing the use of non-chemical fertilizers such as biofertilizers, even more urgent for meeting the agricultural sector's nutrient needs. Global food and fuel prices have also risen steadily in the past few years. Thus countries which import substantial amounts of fertilizer face significant affordability challenges not just from high prices of these two commodities but also because of rising shipping costs.

Achieving high levels of nutrient use efficiency in agriculture requires adoption of best management practices (BMPs) to maximize nutrient recovery rates in plants, nutrient absorption rates in livestock, and minimize nutrient losses from emissions, leaching, run-off and erosion. The nutrient recovery rate is the ratio of the amount of nutrient in the harvested crop to the amount of nutrient applied. Cropping BMPs include selecting the right fertilizer product and applying the right amount at the right time and place to match plant needs and reduce nutrient losses; applying biofertilizers; and adopting a cropping and soil management system to improve soil organic material, reduce pests, control soil moisture, to maximize plants' ability to efficiently uptake nutrients.

Efficient nutrient use in livestock raising is becoming increasingly important as consumption of meat and dairy products increases globally and animal production has become more intensive. Livestock raising BMPs include ensuring quality of raw materials in animal, optimal diet formulation, maintaining animal health for optimal nutrient absorption, and raising crops and livestock in close proximity. One effect of climate change is an increase of temperature and water stress. Proper crop and livestock nutrition will help build resilience in agriculture, a prerequisite for climate change adaptation (IFA, 2016).

Wastewater, when properly managed, besides delivering substantial environmental and public health benefits through lower pollutant loads and creates economic opportunities through reuse of reclaimed water and biosolids to produce general fertilisers, soil conditioners, biomass, water or energy. The average person excretes approximately 5.7 kg of nitrogen, 0.6 kg of phosphorus and 1.2 kg of potassium per year (Heinonen-Tanski 2004). Of human excreta, urine contains some 90% of the nitrogen, 50–65% of the phosphorus and 50–80% of the potassium. Wastewater sludge and urine, when suitable treatment steps and risk management approaches are applied, can be reused as a nutrient-rich source of fertilizer including substantial amounts of N, P, and K for cropping, pasture, agroforestry, and revegetation of cleared or disturbed land.

ii. Nutrients in Agriculture

Essential nutrients in the form of macro and micronutrients in sufficient quantities are required for growing healthy, productive and nutritious crops, and nutrient use efficiency (NUE) is a critically important concept for crop and livestock production systems. Seventeen elements have been shown to be essential for plants: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulphur (S), magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl), nickel (Ni). Furthermore, additional elements may be essential to a few plant species, e.g. sodium (Na) and cobalt (Co). Carbon, H and O are obtained from the atmosphere and water.

The essential mineral elements can be divided into three groups being primary macronutrients (N, P, and K) secondary macronutrients (C, Mg, and S) and micronutrients (Fe, Mn, Zn, Cu, B, Mo, Cl and Ni). These nutrients illustrate a wide variety of characteristics and processes in terms of how, where, and when they become available to and useable by plants. Microbes also play a very important role in soil health and plant growth including, and not limited to, boosting the bioavailability of nutrients in the soil.

Nutrient sources include atmospheric deposition, rock weathering, soil nutrients from previous applications, crop residues, biological N fixation, chemical fertilizers, compost, manure, biosolids, and added irrigation water. If a single essential plant nutrient is available in insufficient quantity, it affects plant growth and thus the yield (IFA, 2016). Plants absorb nutrients in various chemical combinations however they can only use nutrients after they have been converted to their inorganic (mineral) form.

a) Primary Macronutrients (N, P, and K)

Primary macronutrients boost plant enzyme function, improve biochemical processes and help in plant cell growth. Lack of primary nutrients can affect plant health, growth and eventually the crop production output.

Nitrogen:

Nitrogen is essential for plant growth, development, and reproduction. N contains chlorophyll, the compound by which plants use sunlight energy to produce sugars from water and carbon dioxide (photosynthesis). N is also a major component of amino acids, the building blocks of proteins. Nitrogen (N) is one of the most widely distributed elements in nature since it’s the most abundant gas in the atmosphere. Plants take up most of their N as ammonium (NH_4^+) or nitrate (NO_3^-) ion. Some direct absorption of urea can occur through the leaves, and small amounts of N are obtained from materials such as water-soluble amino acids. While N isn’t found in mineral forms like phosphorus (P) or potassium (K), it’s largely present in organic compounds.

Soil-based N undergoes many complex biological transformations that make it challenging to manage. Soil nitrogen exists in three general forms: organic N compounds, ammonium (NH_4^+) ions, and nitrate (NO_3^-) ions. Typically, 95 to 99% of potentially available N in soil is in organic forms as relatively stable organic matter or in living soil organisms and microbes such as bacteria. The majority of available N is in the inorganic forms NH_4^+ and NO_3^- (sometimes called mineral N). N in soil that might be used by plants comes from N-containing minerals which generally decompose slowly and from atmospheric deposition. Both of these processes contribute only slightly to N nutrition in soils.

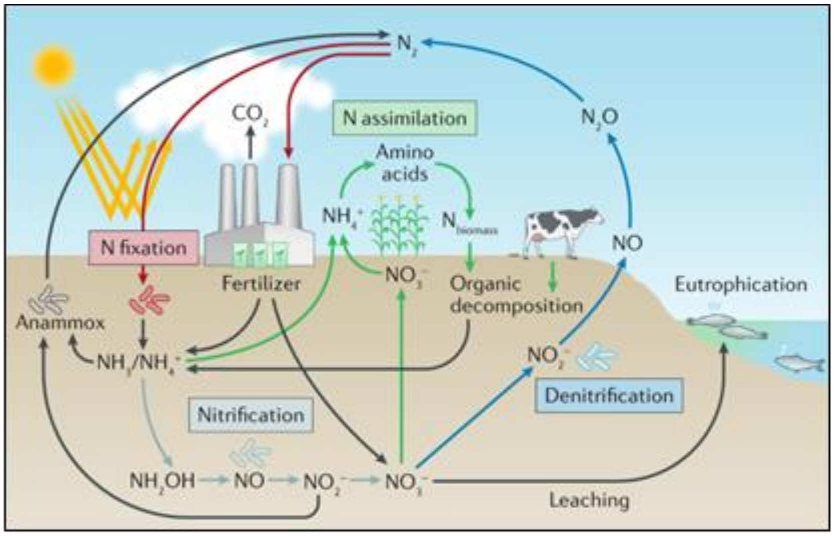
However, on soils containing large quantities of NH_4^+ (rich clays which are either naturally occurring or resulting from added fertilizer) the amount of mineral N can remain substantial over time. Atmospheric N exists in the very inert N_2 form and must be converted to become useful in the soil. The amount of N added to soil through atmospheric deposition is directly related to thunderstorm activity.

Leguminous plants can fix substantial amounts of atmospheric nitrogen and convert it to a usable form provided that the soil contains a bacterium called Rhizobium which carries out the nitrogen fixation process. Rhizobia infect (nodulate) the roots of the legume plant while receiving food energy from the plant. The bacteria fix N while releasing excess N for use by the host legume plant and into the soil for use by other plants. Well-nodulated legumes already have enough N from bacteria and are not likely to benefit from added N fertilizer.

Nitrogen in the form of nitrates is very mobile in soil. In addition to N uptake by plants, N is losses are commonly attributed to run-off, erosion and leaching. N is also lost to the atmosphere through conversion of nitrate to N gases.

Visual signs of Nitrogen deficiency can include yellowing and paleness of leaves and new growth, limited growth, early maturing and small sized fruit or flower, leaves that are smaller and darker in colour than normal.

The Nitrogen Cycle is vital for all life on earth. It is the biogeochemical cycle by which N is converted into multiple chemical forms as it circulates among atmospheric, terrestrial, and marine ecosystems. The conversion of N can occur through both biological and physical processes. Key processes include fixation, ammonification, nitrification, and denitrification.



Source: Nature (Journal)

Phosphorus:

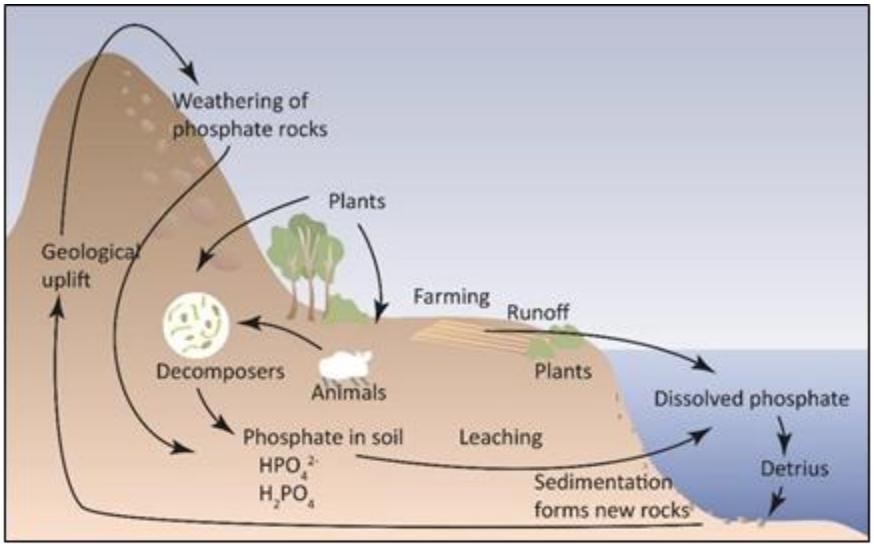
Phosphorus is essential for general plant health and vigor, and for root development, stalk and stem strength, flower formation and seed production. P is part of several key plant structure compounds and plays an important role capturing and converting the sun's energy into useful plant compounds. Plants take up P from the soil as primary and secondary orthophosphates ($H_2PO_4^-$ and HPO_4^{2-}).

Organic P is found in plant residues, manures and microbial tissues and the percent of P which is organic form is typically greater in high-organic-matter soils. Inorganic forms of soil P consist of apatite (the original source of all P), complexes of iron and aluminum phosphates, and P absorbed onto clay particles. Solubility of these P compounds and of organic P is extremely low. The amount of P in solution at any one time is very small.

Soluble P come from either fertilizer or natural weathering and reacts with clay, iron and aluminum compounds in the soil, and through process of P fixation is converted to less available forms. Because P fixation processes, P moves very little in soils (typically up to 10mm) and crops absorb a limited portion of fertilizer P during the first cropping season. Fixed P will remain in the root zone and be gradually available for future crops. Little soil P is lost by leaching, and soil erosion and crop removal are the main ways in which soil P is lost.

Visual signs of Phosphorus deficiency can include fruit of small size and poorly coloured, burnt leaf edges with a purple, blue or reddish colour underneath, and yellowing of veins of old leaves.

The phosphorus cycle is necessary for sustaining life. It is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere. Unlike many other biogeochemical cycles, the atmosphere does not play a significant role in the movement of phosphorus, because phosphorus and phosphorus-based compounds are usually solids at the typical ranges of temperature and pressure found on Earth.



Source: Atmospheric Chemistry and Physics (Journal)

Potassium:

Potassium is essential for root, stem and overall plant growth, and promotion of flowering and fruiting. K promotes water movement in plants and improves drought tolerance. Plants take up K in its ionic form

(K^+) and the majority of K uptake is at an earlier growth stage than they uptake N and P. Around 90 to 98% of K in soils is in insoluble primary minerals that are resistant to chemical breakdown. K is released very slowly and in small quantities from these minerals.

Slowly available K comprises up 10% of total K supply and may originate from dissolved primary minerals or from K fertilizers. This K attaches to clay minerals and is slowly available to plants. The amount of K available depends on the type and amount of clay in the soil.

Readily available forms of K comprise up to only 2% of total K in the soil. This K is dissolved in the soil solution and attaches to clay and organic matter. This K is "exchangeable" because it can be replaced by other positively charged ions (cations) such as H, Ca and Mg. The K in the soil solution may be taken up by the plant or lost by leaching, especially on sandy and coarse soils.

Visual signs of Potassium deficiency can include leaves that are smaller and darker in colour than normal, older leaves can be a blue/purple colour with yellow edges, and slow plant growth.

b) Secondary Macronutrients (Ca, Mg, and S)

Calcium:

Calcium plays an important role in improving nutrient absorption in plant roots, activates enzymes, and helps in disease resistance in plants. Without sufficient calcium, root development and activity is affected. In soil, when limestone is added to reduce acidity, calcium replaces hydrogen (H) ions from the surface of soil particles. Ca is also essential for microorganisms which turn crop residues into organic matter, release nutrients, and improve soil aggregation and water holding capacity. Ca helps enable nitrogen-fixing bacteria that form nodules on the roots of leguminous plants to capture atmospheric nitrogen gas and convert it into a form that plants can use. Ca is very mobile in soils and losses can occur through leaching and plant uptake and harvesting. Visual signs of Calcium deficiency can include new leaves and new shoots that grow badly and are underdeveloped, and fruit growth that is unusual.

Magnesium:

Magnesium is an important component of chlorophyll and is essential for different processes like photosynthesis, respiration and enzyme systems. Magnesium also acts as a phosphorus carrier in plants, and is necessary for cell division and protein formation. Phosphorus uptake could not occur without magnesium, and vice versa. Mg availability to plants is often related to soil pH, and when pH values are low, Mg availability to plants decreases. Mg losses from soil can occur through leaching and plant uptake and harvesting. Visual signs of Magnesium can include edges of leaves which turn yellow or have yellow spots but veins stay green, brown spots on leaves, and old leaves drop early off trees.

Sulphur:

Suphur helps in the synthesis of proteins and amino acids. It is also essential for processes like photosynthesis and nitrogen fixation. Plants uptake S from organic matter and minerals in the soil and the available amount is often insufficient for attaining desired yields. S in the soil is useable by plants when it is converted to the sulfate (SO_4^{2-}) form by soil bacteria. Sulfate is mobile in the soil and can lost through leaching or from the soil surface with water evaporation. Visual signs of Sulphur deficiency can include dull colour leaves and new shoots that develop poorly.

c) Micronutrients (Fe, Mn, Zn, Cu, B, Mo, Cl and Ni)

Though micronutrients are abundant in most soils, plants usually acquire them in relatively trace amounts. Tracer elements include B, Cu, Fe, Mn, Zn are required by plants in only minute amounts but play an essential role in plant growth and development. Plant metabolism, nutrient regulation, reproductive growth, chlorophyll synthesis, production of carbohydrates, fruit and seed development are functions performed by micronutrients. Loss of micronutrients in soil can occur through plant uptake by high yield crops, erosion, and leaching.

d) Microbes

Soil microbes play a major role in plant growth, performance, disease resistance, nutrient assimilation and much more. Microbes boost the biological availability of nutrients borne in soil, competing with pathogenic microbes and modifying plant signalling mechanisms. Macronutrients such as N, P, and S are bio-available in small quantities because they are bound in organic molecules. Certain microorganisms in soil can convert organic N, P and S into mineral forms. Inorganic or ionic forms such as nitrate, phosphate and sulfate are released into the soil which the plants can assimilate.

iii. Nutrient Use Efficiency (NUE) in Crop Production

Nutrient Use Efficiency in crop production including agroforestry can be greatly impacted by fertilizer management as well as by soil-and plant-water management. The International Fertilizer Association (IFA) states that the objective of nutrient management is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses from the field. The IFA defines NUE as the proportion of the nutrient applied from all sources that are taken up by the harvested crop (IFA et al 2016). In discussing nutrient management, it is also important to acknowledge that many of the environmental and public health costs of farming are not borne on site. Providing farmers and stakeholders with the knowledge and means for more efficient nutrient use as well as Illustrating its economic and environmental benefits are key steps for achieving NUE in agriculture.

One approach for improving NUE in crop production is the ‘Five Element Strategy’ (source: ‘Our Nutrient World’ (2013) p61). This strategy elements are as follows:

1) Implement the 4R Nutrient Management Stewardship approach promoted by the fertilizer industry i.e. right source, rate, timing, and location using low-emission application and precision placement methods. Proper implementation of the 4R approach requires informed and full consideration of site-specific conditions, available nutrients in soils, and other available organic matter. The proportion of organic matter in the total amount of fertilizer applied should be as high as possible.

2) Select the Right Crop Cultivar. The crop should be planted with the right spacing and right time, and within the right crop rotation

3) Irrigate the crop whenever needed, using precision methods, such as drip irrigation, combined with soil water harvesting methods and soils conservation practices

4) Implement Integrated Weed, Pest, and Disease Management Measures. When properly implemented this will minimize yield losses while protecting the environment

5) Site Specific Mitigation Measures for Reducing Nutrient Losses. Erosion control measures, cover crops, tillage management, contour farming, best practices for fertilizer and manure applications, and buffer strips

The five-element strategy emphasizes close monitoring of critical growth factors in plant growth. This includes the premise that if one critical growth factor is in short supply that plant growth and development will be significant reduced. Crop yields are determined by:

1) Crop yield determining factors such as CO_2 concentration, temperature, genetic potential of the crop, and planting density

2) Crop yield limiting factors, being water and nutrient availability

3) Crop yield reducing factors such as pests and diseases, weed infestations

Furthermore, the strategy states that resource efficiency is highest when all other limiting factors are near their optimum. For example, NUE for Nitrogen is highest when total N supply meets the N demand of a crop that is not limited by deficiencies of other essential nutrients and water, and where yield is not reduced by weeds, pest and diseases (Mosier et. al, 2004). Plants often use many times the amount of N as P so adding similar amounts of these can lead to build up of P over time which can have negative environmental effects.

NUE must not be to the detriment of other key performance areas such as soil fertility and water productivity. For example, NUE can be increased by mining soil nutrients but it this is not a sustainable practice as this would reduce fertility over time. Similarly, higher use efficiency could be achieved by reducing fertilizer application, but this could also lower crop yield.

Soil nutrient balance provides information about environmental pressures and this balance can be monitored through periodic soil testing. A nutrient deficit (negative value) indicates declining soil fertility. A nutrient surplus (positive data) indicates a risk of polluting soil, water and air. Nutrient balance is defined as the difference between the nutrient inputs entering a farming system (mainly livestock manure and fertilisers) and the nutrient outputs leaving the system (the uptake of nutrients for crop and pasture production). (Source OECD).

It is important to recognize that agricultural nutrient cycles are open systems with unavoidable losses. These losses negatively impact productivity, profitability and environmental services. The goal of the agricultural sector is to reduce losses while steadily increasing crop yield. Efficient use of nutrients with adoption of nutrient BMP's increases benefits and reduces risks associated with various farming activities. Nutrient Use Efficiency (NUE) in agriculture can be analysed in multiple ways applying a range of criteria and measures using and using different calculations.

Table <insert#> Methods for Calculating Nutrient Use Efficiency (NUE)

Measure	Calculation
Nitrogen Use Efficiency	Nitrogen Use Efficiency = (annual harvested crop in Kg N ha-1 yr-1)/ annual Inputs [Synthetic N fertilizer + symbiotic N fixation, + manure application + atmospheric deposition] to cropland
Phosphorus Use Efficiency	Phosphorus Use Efficiency = Phosphorus Use Efficiency (PUE) of the agricultural system and of its subsystems = Total P harvested in economic outputs such as crops, meat, milk and eggs/ Total P inputs [P fertilizers for cropland, P from mined phosphate rock, atmospheric P deposition in cropland and pasture areas]
Partial Factor Productivity (PFP)	PFP = Y/F (kg grain/kg N)
Agronomic Efficiency (AE)	AE = $(Y-Y_0)/F$ (kg grain/kg N)
Partial Nutrient Balance (PNB)	PNB = R/F (kg N/kg N)
Recovery Efficiency (RE)	RE = $(U – U_0)/F$ (%)

Y= Yield F=Fertiliser R=Removal U=Uptake $_0$ = without fertilizer inputs

iv. Nutrient Use Efficiency in Livestock Production

As global consumption of livestock and dairy products continues to increase, the critical importance of efficient nutrient use is becoming clearer. Production of animal-based foods is typically more resource-intensive and has greater environmental impact than plant-based foods. Animal-based foods accounted for more than three-quarters of global agricultural land use and around two-thirds of agriculture's production-related greenhouse gas emissions in 2009, while only contributing 37 percent of total protein consumed by people in that year (WRI 2022 webpage).

Common approaches and best management practices for achieving NUE in livestock raising include:

1) Animal Breeding, Housing and Health – Selecting the best animal breeds, environment (indoor and outdoor), and veterinary services for achieving optimal animal growth and health
2) Dietary Management – Selecting the best feed type and rate based on animal type and size, and considering digestibility and nutrition content
3) Nutrient Management Planning – Establishing a plan comparable to the USDA Comprehensive Nutrient Management Planning framework for animal operations that includes:
    a) Production area organized into sub-areas for individual activities
    b) How water quality criteria and soil erosion prevention will be achieved
    c) Mitigation measures for any excessive air emissions
    d) Compliance with Federal, State, and local laws
    e) Satisfies the owner/operator's production objectives

Additional livestock raising BMPs include:

- Grazing Management – Minimizing the water quality impacts of grazing and browsing activities on pasture and range lands, including making sure animals are kept out of watercourses, and maintaining buffer strips
- Animal Feeding Operations (AFOs) Management - Minimizing impacts of animal feeding operations and waste discharges through runoff controls, waste storage, waste utilization, and nutrient management
- Limit Gas Emissions from Animal Housing – Minimize GHG emissions as well as impacts on local air quality

A greater proportion of livestock raising is now done in large scale and intensive operations (also known referred to as Animal Feeding Operations (AFOs). These operations are usually geographically concentrated with supporting supply, processing, distribution, and business services nearby, and are often far from cropping operations. Substantial amounts of manure accumulate at AFOs. Some of this manure is reused onsite or shipped to other facilities or farms for producing compost and other biofertilizers. However, much of the manure is disposed of resulting in loss of large amounts of valuable nutrients. In addition, managing large amounts of manure creates logistical challenges in terms of storing, loading, and shipping the manure as well as environmental challenges in terms of controlling gas emissions, odours, and waste discharges in the form of run-off and leaching. This geographic pattern which has developed for AFO's is in direct contrast with traditional farming where cropping and livestock operations were typically situated close together. This situation allowed for efficient recycling of nutrients and reduced nutrient losses. Livestock manure could be collected and distributed on cropping areas as an organic fertilizer and crop wastes could in turn be mixed with manure to produce compost or combined with other livestock feed.

v. Chemical Fertilizers

In the industrialized world and in many developing nations, chemical fertilizers, which are produced by the fertilizer industry are the main source of added nutrients to agriculture to achieve yields and crop standards. It is estimated that chemical fertilizers are responsible for < > percent of global crop yields.

Classes of fertilizers include:

'Straight' fertilizers: Fertilizers which supply only one primary macronutrient, namely N, P, or K. Examples include urea, sulphate, potassium chloride and potassium sulphate.

'Complex' fertilizers: Fertilizers which contain two or three primary macronutrients of which two primary macronutrients are in chemical combination. These fertilizers are usually produced in granular form. Examples include Diammonium phosphate, nitrophosphates and ammonium phosphate.

'Mixed' fertilisers: Fertilizers which are physical mixtures of straight fertilizers. They contain two or three primary macronutrients. Mixed fertilizer are made by thoroughly mixing the ingredients either mechanically or manually.

(TNAU, 2022)

Fertilizers can be classified on physical form, as either solid or liquid. Solid fertilizer forms include powder, crystals, prills, granules, supergranules, and briquettes. Liquid fertilizers are applied with irrigation water or applied directly.

Efficiency use by plants of chemical fertilizers is estimated at N 30-50%, P 15%, K 50-60%. Many farmers use multi-nutrient fertilizer products and spread this to their fields in a uniform approach as opposed to a by-nutrient and/or by-plant approach. The result can result in over fertilization. Over fertilization can cause too high of a salt concentration and high soil acidity hurting beneficial soil microorganisms and sudden plant growth with an insufficient root system to supply adequate water and nutrients to the plant. Also, it can reduced growth and leave plants weak and vulnerable to pests and diseases. Signs of over fertilization include stunted growth, burned or dried leaf margins, wilting, and collapse or death of plants. Environmental impacts of over fertilization can include excessive discharges of nutrients to waterways causing algae bloods and eutrophication and release of greenhouse gases. The use of N fertilizers and animal manures is the main anthropogenic source of N_2O emissions, which besides being a major greenhouse gas, is the most powerful ozone-depleting compound.

As described above in this report, the global agricultural sector is currently facing a major challenge in the form of chemical fertilizer shortages and high prices. There is an urgent need to increase the proportion of biofertilizer use in agriculture and further diversify the sources of plant nutrient.

vi. Biofertilizers/Organic Fertilizers, Diversification of Plant Nutrient Sources, and Soil Health

In the industrialized world, and for some developing nations, chemical fertilizers are the predominant source of soil and plant nutrient enrichment. However, chemical fertilizers should not be considered in isolation. For optimal fertilizer use sustainability and performance, these should be combined with use of organic nutrient sources and the selection of appropriate crop varieties; crop, water and soil management practices. Crops respond to nutrients from all sources but can only take up nutrients in their inorganic form. Organic nutrient sources must be mineralized (converted from an organic to an inorganic form) before being taken up by plants. The amount of nutrients provided by different sources varies greatly between and within agro-ecosystems.

Organic nutrient sources can be applied as fertilizer or soil conditioner. The functional difference between these two applications are fertilizers directly affect plant growth by improving the supply of nutrients in the soil; and soil conditioners improve the soil's physical condition, for example soil structure and water infiltration, thus indirectly affecting plant growth. A good agricultural soil consists of 25% water, 25% air, 45% mineral material and 5% organic matter (FAO 2014).

Biofertilizer inputs can include manure, biosolids from wastewater, left over organic materials from farm, agroforestry, and industrial processing, seaweed and other ocean vegetation. Biofertilizers created with a mixture of fungi, bacteria, and yeasts increase biological nitrogen fixation, electrical conductivity, available carbon, and cation exchange capacity, and can restore soil health, improve soil fertility, and reduce the need for agrochemicals. Application of organic material also helps provide soil structure and retain moisture. Because organic fertilizers release nutrients at a slower rate and in a less concentrated form than chemical fertilizers, a greater volume must be applied to meet desired crop yields. Periodic soil testing should be conducted to determine optimum types and amounts of organic materials to be added for maintaining soil health.

Before applying human and animal waste as fertilizer it is necessary to remove harmful bacteria and pathogens that could be present. The most practical method to achieve this is biological decomposition and stabilization of organic substrates, under conditions that allow for the development of thermophilic temperatures. This typically involves mixing the human waste with other organic wastes such as manure, food and crop waste to produce hot compost. The hot compost must be sufficiently aeration through actions such as turning or using a blower, and moisture content must be managed. Industry practitioners generally recommend that compost temperature should be maintained at over 45 degrees Celsius and moisture content over 50% for the biologic process to achieve proper decomposition. The final product should be stable, free of pathogens and plant seeds, so that it can be beneficially applied to land.

Livestock manure is a valuable nutrient source, and nutrient content of manure varies widely between sources such as type of livestock and farm management practices. It is widely recognized that poor quality feed for livestock results in manure with low nutrient contents. Typical N-P-K content in chicken, cow and sheep manure is 1.1-0.8-0.5, 0.6-0.2-0.5, and 0.7-0.3-0.9 (Qasim 2019). Manures should be analyzed for nutrient content prior to application as fertilizer. In recent years, new technologies have emerged to process manures into organic fertilizers that are easier to store, transport, handle and apply. Examples include manure processing plants that pelletize drier manures (e.g. poultry) for direct use as organic fertilizers or that enrich manures by addition of inorganic fertilizer nutrients (for example P-enriched compost) in order to create more balanced fertilizers. Manures may have pathogens and it is important that manures be sufficiently broken down before they are applied to crops. This is particularly important for chicken manures.

Biosolids (residual solids from urban wastewater treatment) can be recycled and provide significant quantities of plant nutrients. Nutrients in biosolids vary in quantity and forms, depending on the source, treatment, storage and handling processes. Their content in plant nutrients and in possible contaminants should be regularly analyzed.

Many agriculture sector practitioners promote an Integrated Soil Fertility Management (ISFM) approach with organic fertilizers as an essential component. The International Plant Nutrition Institute (IPNI) defines ISFM as ‘A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles.’ In the current ‘fertilizer crisis’ as described above, and high fertilizer costs facing farmers, ISFM is more relevant than ever, and there is an urgent need to rapidly increase the use of biofertilizers and methods for diversification of plant nutrient sources.

A similar approach to ISFM is FAO’s Sustainable Plant Nutrition concept which promotes the four areas of soil fertility, fertilizer use and management, nutrient reuse and recycling, and development of effective policies and regulations. This includes reducing reliance on chemical fertilizers through practices such as crop rotation with legumes which is estimated to fix between 72 and 350 kg of N/ha/yr and also helps combat global warming, and creating biofertilizers with a mixture of fungi, bacteria, and yeasts to improve soil fertility. The types of microbes present in biofertilizers produce different levels of effectiveness. Recent FAO research on common microbial strains used in biofertilizers production the following findings:

Microbial Strain	Nutrient Production/Kg/Yr/Ha	Crops Types Benefited	Yield Increase
Rhyzobium (symbiotic)	Fixes N 200-300 kg	Pulses and legumes	20-30%
Azotobacter	Supplies N 20-40 kg	Cereals, sugarcane, sunflower, cow pea, fruits	10-15%
Azospirillium	Supplies N 20-160 kg	Sugarcane, wheat, millet	Increases crop, production of plant hormones
Bacillus Spirillium	Stabilizes P 30-140 kg	Pulses, cereals, vegetables	Promotes growth substances

vii. Greenhouse Growing with Advanced Technologies and Methods

Greenhouse vegetable and fruit growing has been supported by a number of Caribbean Governments as a practical business opportunity for women and small communities while also providing nutrition and strengthening food security. A recent experiment conducted using a Controlled Environment Agriculture (CEA) greenhouse for vegetable growing by the UWI Department of Mechanical and Manufacturing Engineering showed plant growth rates of about two and a half times on the average in all growth parameters compared to standard greenhouses with roof butterfly vent (for natural ventilation).

Tomato, lettuce, pak choi were crops in a 10m x 30m CEA greenhouse with electric lighting, and using a fan and evaporative cooler on a coconut fibre cooling pad and natural ventilation to control temperature and humidity and provide air movement, and in a standard greenhouse. The same soil and nutrient regime was used for both greenhouses. In the CEA greenhouse, temperature was kept lower than the ambient temperature and relative humidity lower as well. The LED blue lights in the study were estimated to provide a light frequency of 400 – 500 nm.

UWI staff monitored the first 19 days of plant growth and recorded significantly higher average plant growth rates in the CEA greenhouse for plant height, stem diameter, and leaf area (Suraj 2018). Plant heights and diameter for tomatoes, lettuce and pok choi were 1.77, 2.67 and 3.88 and 1.12, 2.4 and 5.5 times those in the conventional greenhouse.

The study proposes that the lower temperatures in the CEA greenhouse lowers the rate of plant transpiration and prevents exhaustion while increasing plant stem water retention and promoting leaf growth. Blue light has the effect of increasing the opening of plant stomata (which regulates a plant's retention of water) and chlorophyll production, and improving the photosynthetic rate. Use of blue light over the majority of a 24-hour period prolongs active photosynthesis.

viii. Reducing Greenhouse Gases in Agriculture

Agricultural activities related to cropping and livestock activities produce substantial amounts of GHG's such as CO_2, CH_4, and N_2O. The agricultural sector is responsible for an estimated two-thirds and three-quarters of manmade methane and nitrous oxide. Sources of these emissions include chemical fertilizers, cultivated and drained soils, crop residues, livestock digestive processes, and manure. GHG emissions can be reduced through more efficient management of carbon and nitrogen flows.

Agricultural systems hold substantial carbon. Farming practices which promote CO_2 capture, removal from the atmosphere, and storage include better use of fertilizers and irrigation; reducing tillage and using perennial crops; decreasing bare fallow; returning crop residues to the soil; cover cropping; organic farming including increasing earthworms, microbes, and fungi, increasing soil depth; agroforestry; rotational grazing; selection of appropriate livestock feed additives; and more efficient use of machinery including using green energy as a power source.

The main areas of agricultural practices for reducing CH_4 emissions are better manure management such as covering stored manure, efficient manure spreading on fields, and selection of appropriate animal feed additives. Spreading of liquid manure in narrow bands, injection into soil, and immediate incorporation into soil can reduce N emissions 40-90%. CH_4 when used as a biogas drastically reduces methane emissions and is an important power source. Land accounts for a relatively small proportion of methane emissions however better land management practices can reduce these.

N_2O emissions in agriculture are mainly through application of nitrogenous fertilizers and cattle raising. Better nitrogen management through nutrient management planning reduces nitrous oxide emissions. Tropical soils are often P limited rather than N limited like many temperate climate soils. Addition of N rich fertilizers to tropical soils can produce many times the amount of nitrous oxide emissions compared to application to temperate soils.

C. Wastewater Management and Nutrient Reuse

i. Benefits of Wastewater Reuse

Sanitation is a key element of sustainable development and significantly influences people's health and wellbeing. Wastewater from humans and agriculture, when suitable treatment steps and risk management methods are applied, can be reused to provide substantial environmental benefits through lower pollutant loads, reducing the need for chemical fertilizers, and supplying water and nutrients to agriculture and vegetation, and economic benefits through reuse for producing fertilisers, soil conditioners, biomass, water supply, and energy. Wastewater reuse products include plant-available nutrients (mainly N, P, and K) vast potential for increasing production in cropping, pasture grasses agroforestry, and revegetation of cleared and/or disturbed land. The average person produces 4.5 kg of N, 0.5 kg of P and 1.2 kg of K every year (McConnville et al. 2020).

There is a broad range of valuable products from wastewater reuse as agricultural inputs including liquid fertilisers (stored urine, concentrated urine, sanitised blackwater, digestate, and nutrient solutions); solid fertilisers (dry urine and struvite soil conditioners); dried faeces (pit humus and dewatered sludge); compost (ash from sludge, biochar, and nutrient-enriched filter material); biomass and proteins (algae, macrophytes, black soldier fly larvae, and worms); water for irrigation and aquaculture; and energy supply in the form of biogas. Before applying human waste as fertilizer it is necessary to remove harmful bacteria and pathogens that could be present.

Wastewater reuse products have different characteristics and advantages involve a variety of technologies and methods for treatment, storage, and application. Before applying human waste as fertilizer it is necessary to remove harmful bacteria and pathogens that could be present. Wastewater reuse products made from domestic sources generally have low chemical concentrations however pharmaceutical residues and microplastics may be present. Reuse products which may include industrial sources, such as wastewater and de-watered sludge from centralized conventional treatment plants, may contain chemicals and heavy metals. Testing is necessary to prevent pathogens and heavy metals from entering the food chain. A number of wastewater reuse products are described in more detail in this report Annex < > in table format include technologies used, characteristics, application method, advantages, disadvantages and other important considerations.

ii. Sanitation Safety Planning

Wastewater management and reuse requires proper sanitation safety planning (SSP) along the entire sanitation chain, at each step from toilet, containment, conveyance, treatment, storage, and disposal and reuse (reference WHO). Health risks must be identified and prioritized in order to guide management and investment according to risk. Also, SSP identifies operational monitoring priorities and regulatory oversight mechanisms that target the highest risks and provides assurance to authorities and the public on the safety of sanitation related products and services. Proper SSP also establishes effective accountability mechanisms for public and private operators and service providers.

A clear and adequate National level legal framework including regulations, guidelines and standards is required for identifying requirements for proper sanitation management throughout the sanitation management chain. In developing national level guidelines for wastewater management, WHO and ISO guidelines and standards should be consulted with regards to producing, treating, storing, and applying wastewater reuse products. Sanitation safety planning and management can include a number of proven effective systems including and not necessarily limited to Hazard and Critical Control Points (HACCP) and which has is commonly employed around the world. Standards for wastewater reuse are helpful for industry and important for the public however they are voluntary until they are included in regulations.

Table < > Example National Legal Framework for Sanitation Management

Toilet Containment & Onsite Treatment	**Conveyance**	**Treatment**	**End Use/Disposal**
Planning and Building Regulations	Utility Regulation		Reuse Standards (all end types)
Technical Standards		Treatment Standards (Liquid Effluent & Sludge)	
Consumer Protection	Occupational Health & Safety Regulations		
National Guidelines	Licensing	Licensing	
Environmental Health Regulations (Public Health & Nuisance Abatement)			

Source: WHO Kate Mendicott presentation…

Countries, in establishing a legal framework and developing projects for wastewater, excreta and greywater reuse in agriculture, must identify groups who are potentially at risk. This includes and is not necessarily limited to farm workers (and their families, if they all participate in the activities or live at the site where the activities take place); local communities in close proximity to activities, and people who otherwise may have contact with fields, ponds, wastewater, excreta, greywater or products contaminated by them; and product consumers (WHO 2006). Wastewater reuse initiatives and projects also require proper monitoring of system design, operations and verification to ensure that specified targets are being met.

iii. Health Risks Associated with Reuse of Wastewater and Excreta

Risks associated with reuse of excreta (including source-separated urine and faeces) stem mostly from excreta-related pathogens. Urine does not usually contain high pathogen concentrations but when collected can illustrate some cross-contamination. Greywater generally has lower concentrations of pathogens than wastewater, but it may still contain some pathogens, which are introduced into the greywater from washing babies' diapers, laundry, personal hygiene or other sources.

The exposure route for humans and animals to bacteria, parasites, protozoa, viruses, toxins, and pesticides is contact and consumption. For heavy metals and chemicals such as hthalates and phenols, antibiotics, halogenated hydrocarbons (dioxins, furans, PCBs) the exposure route is consumption. In terms of vector-borne pathogens such as dengue and Japanese encephalitis virus, exposure is through contact. Skin irritation is the result of contact exposure.

Bacteria die off more rapidly on crops than some other pathogens but may still present a health risk and in some instances have led to disease outbreaks of cholera, typhoid and dysentery. The exposure route is contact and As these pathogens can survive in the environment sufficiently long to pose health risks, produce disinfection/washing and cooking are important health protection measures.

Parasites are a major risk in agriculture where untreated wastewater and excreta are used and sanitation standards are low. This includes helminths (large macroparasite worms that infect the gastrointestinal tract) which are soil transmitted, and (tremadoes such as schistosoma haematobium, a parasitic blood fluke and intestinal worm) which can be present in faecal matter in septic tanks and the latrine pits and whose eggs can survive for years in such environ. The chance of hookworm infections increases where farmers do not wear adequate shoes or boots. Health risks associated with the use of greywater in agriculture are considered to be lower than those for wastewater or faeces.

Protozoa (Giardia, Cyclospora, Cryptosporidium, Entamoeba spp.) and viruses can be present in wastewater-irrigated vegetables at harvest time, in markets and in water supplies and survive in long enough in the environment to pose health risks. Virus contamination of crops can potentially lead to disease outbreaks. In areas where vector-borne diseases are present, vector-borne pathogens can be exist in water resources. Skin irritation such as dermatitis (eczema) can result from contact to microbial and chemical hazards.

iv. Development of the Wastewater Value Chain

Wastewater reuse strategies, in order to be sustainable must illustrate strong economic, health, and environmental benefits for the public, Government, and businesses. These benefits must be greater than financial and time costs to implement and operate these systems in addition to the demonstrated health and environmental costs from not having these systems. An enabling environment is required for businesses to unlock revenue streams in the wastewater value chain so they can become economically sustainable and viable. Successful business models are needed to attract more entrepreneurs and investors to the sector.

In designing and managing systems for reusing wastewater for fertilizer and other products and uses, it is essential that operators and users - households, farmers, Government staff and businesses in the wastewater value chain - have the knowledge, skills, and necessary tools and resources to safely and efficiently carry out this process. This requires a supporting environment based on risk-based regulation, management, monitoring and investment, and which includes guidelines and standards that employ common language which is clear for all users.

Development of appropriate wastewater reuse standards if often driven by private and non-profit professional and grassroots association advocating for business opportunities in the wastewater value chain and for better environmental outcomes by reducing wastewater discharges and reusing nutrients. The International Association of Mechanical and Plumbing Officials (IAMPO), as part of its advocacy efforts in India is building relationships with Government and private fertilizer companies to establish standards for use of faecal sludge in compost for non-food agriculture. This would include application for urban agroforestry, plant and tree nurseries, and landscaping. IAMPO will provide technical support to fertilizer companies for compost manufacture with faecal sludge from wastewater treatment plants, sampling of the product, and applying it to soil and documenting how soil composition changes.

IAMPO will present these findings to Government including expected important economic and environmental benefits. Classification of the product - for example as faecal sludge compost, soil enhancer, or fertilizer – is also significant as it could have implications for product regulation and certification. The IAMPO estimates that STP faecal sludge typically comprises 3 to 5% of wastewater influent volume. If 10,000 litres treated are daily and a 5% ratio is used, 500kg of faecal sludge can be captured. Over 30 days this would amount to 15,000 kg of faecal sludge.

IAMPO's strategy for expanding use of faecal sludge in compost manufacture includes 'piggybacking' on fertilizer companies supply chains to farmers. The main responsibilities of STPs is achieving adequate wastewater treatment and in most cases they do not want the added responsibility for testing sludge and manufacturing compost. IAMPO proposes that fertilizer companies would pick up the sludge samples and test and certify them, haul the sludge to compost manufacture sites, and bag and sell the compost on the market per IAMPO's established standard IAPMO-01:2022. Sampling costs are substantial and IAMPO is exploring whether this cost can be reduced.

v. Wastewater Reuse Products

a) Urine

Human and livestock urine as a fertilizer source has significant advantages in that its contained nutrients, primarily nitrogen and phosphorus, can be made available relatively quickly in their mineralised forms which are directly accessible for plants. It is commonly applied as a liquid fertiliser to fields and as an additive to enrich compost. Urine may contain up to 80% of the N and 45% of the P in wastewater. Urine can be collected directly using urine diverting toilets and 'aged' in containers. This involves pathogen removal through a rise in pH and ammonium concentrations, high temperature, and time. This process is relatively simple, requires no energy, and in rural villages can be a very practical waste treatment and reuse method. A disadvantage of not collecting urine and feces separately is that together they create an anaerobic environment that increases odour causing bacteria and reduces the speed and effectiveness of the composting process. Urine, when collected separately, can be made into a number of valuable fertilizer products including urea in liquid and cube form, dry urine powder, and granulated fertilizer. Because urine is heavy and relatively costly to transport, it is more efficient to apply liquid urine to fields or compost at or near to collection sites.

b) Sanitized Blackwater

Sanitized blackwater can be a very practical and valuable source of N, P and other nutrients for application to agriculture and other lands to promote vegetation growth. It can be collected from conventional plants, small package plants, and septic and holding tanks, and treatment and application (usually done by spraying) can be carried out at the neighbourhood level or managed by municipal utilities. Solids content before treatment is generally 2% or less and adding lime increases solids content and reduces the pH. The added lime may create P and Mg sediments creating a settled sludge. If flushwater is limited and blackwater is collected in a closed system, it can be self-sanitising due to the urea from the urine. Any ammonia-forming addition will, because the treatment is performed in a closed system, increase N content of the blackwater and its value as fertiliser. Urea additions to blackwater of 0.5 to 2% by weight results in a N concentration increase of 2.5 to 10 kg N/m^3. Urea/ammonia-treated blackwater when applied should be incorporated into the soil so that N losses are minimized. Transporting blackwater can be expensive and time consuming thus reuse near to where it is collected is more practical.

c) Pit humus

Pit humus from latrines is an important source of N, P, K and organic material and is readily available in rural areas. Pit humus is low cost and relatively simple to produce and can be done manually at the household level. Pit humus can make agriculture possible in areas which otherwise would not support productive cropping or pasture. Added to soil, it increases nutrient content and improves soil structure and its ability to store air and water. The latrine should be vented, and two vents will provide better air flow, to promote composting. Adding soil and leaves may also produce oxygen. The overall texture and quality of pit humus depends on materials added to it. Pit hummus should be mixed into soil before crops are planted. It can also be used to start seedlings in greenhouses or mixed into an existing compost for further treatment. For generating pit humus, a one-year minimum storage time is recommended to eliminate pathogens and reduce viruses and parasitic protozoa. Pit humus should not be applied to crops less than one month before harvest, and this is especially important for crops that are consumed raw. Pit humus as a compost can transported in bulk as truck loads and can conveniently shipped in bags to sell in stores.

d) Dewatered Sludge

Dewatered sludge can be produced from wastewater from a range of collection systems such as household holding tanks, centralized treatment plants, and livestock manure slurry. Sludge quality and composition varies depending on input sources, but generally contains significant amounts of organic C, P and sometimes N and can increase water-holding capacity. Dewatered sludge from treatment facilities can be categorized as primary sludge where settleable solids are mechanically removed and a pre-thickening method may be used, and secondary sludge where it treated by bioreactors, processes using inorganic oxidizing agents, and/or other methods. For continuous production, dewatered sludge produced must regularly removed from the treatment tanks to ensure sufficient volume to properly treat incoming wastewater.

The removed sludge is treated by aerobic processes such as composting which is a practical method for small-scale plants, or anaerobic digestion which is more commonly used by larger-scale plants operations. Less mechanically intensive processes for producing sludge include waste stabilization ponds, aerated ponds, and unplanted and planted drying beds. Dewatered sludge can be transported offsite to recycling centres for mixing with compost, or to cropping, pastureland, or revegetation sites for directly spreading onto or mixing into soil or blending with other organic materials to create compost. Because of its typically high nutrient content and textural nature it can also be effective for slopes stabilization and preventing erosion. Untreated sludge should not be applied to agricultural land unless it is injected or incorporated into the soil.

Dried faecal sludge (DFS) can be composted alone, but high losses of nitrogen will occur due to the relatively low carbon to nitrogen ratio. Therefore, mixed DFS with another carbon-rich organic is more effective. Suitable materials include certain food and market wastes, straw or sawdust, and some cropping wastes. Faecal sludge that is used for compost manufacture should have a moisture content of less than 70%. However, FS collected from household septic tanks typically has a moisture content over 90% because it is diluted by flush water. Liquid FS must be dewatered and this can be done through mechanical or nonmechanical processes.

A common and economical method for large-scale FS dewatering is drying beds. Operators often layer these beds with sand and gravel to a depth of up to one meter. Porosity of the sand layer must be maintained ensure water can drain quickly from the wet sludge. A small portion of de-watering occurs as a result of evaporation. FS is typically hauled to drying beds in vacuum trucks and pumped out. Because FS exits the truck under high pressure, the sludge should be discharged into a concrete receiving chamber so as not to disturb the filter bed layers. The sludge should be filtered to remove debris before it is fed into the drying beds. Drains and grids must be kept clear and any foreign materials must be disposed of to a designated waste facility. Grass and weeds should also be removed. Sand is slowly lost from the drying bed from continuous FS application and removal and should be periodically replenished. FS drying time is typically one to three weeks depending on sludge type and climate. The FS should be removed from the drying bed when the surface shows cracks using a spade or other suitable equipment. If dried FS is to be stored, it should be bagged stored in a low-moisture and UV unexposed area.

e) Compost

Compost Beneficial Uses:

Composting of organic materials including human and animal wastes adds nutrients and organics and improves the soil ability to store air and water. It can make agriculture possible in areas which otherwise would not be productive for crops. Compost is usually low cost to produce and can be performed from the household and village level up to large scale operations run by municipalities, cropping and livestock operations, or waste reuse companies. It generally has few chemical inputs unless made with material with significant amounts of pesticides, significant amounts of chemical excreted from humans, or from industrial processing activities.

Compost can be mixed into the soil before crops are planted, used to start seedlings or greenhouse plants, or spread on pastureland. It should not be applied to crops less than one month before harvest, and this is especially important for crops that are consumed raw. Additional advantages to farm by-products in compost and soil conditioner can include less bulk to be transported of site, easier field distribution, reduced fire risk, reduction of unpleasant odours, weed suppression, less chance of root borer attacks on plants. Compost can also be used as an input for manufacturing soil conditioner for improving soil structure to increase aeration, water holding capacity, oxygen penetration and nutrient absorption in soil, and help and help maintain the pH level. Whereas finished compost consists of relatively fine organic particles, soil conditioner has on average larger particles, and typically includes inorganic materials such as rock dust, expanded clay, and sand.

Compost Manufacturing Process:

Compost production requires active monitoring and control of the composting process to remove harmful bacteria and pathogens that could be present and to break down plant seeds. The most practical method to achieve this is biological decomposition and stabilization of organic substrates in conditions that promote bacteria and fungi allow for the development of thermophilic temperatures. Temperature should reach and maintain 50°C for at least one week before use, and moisture content should be maintained at around 50 to 60%. Too little moisture inhibits bacteria activity and too much moisture results in slow decomposition as well as odour production in anaerobic pockets. Thermophilic compost has to be actively managed mostly by turning the material to extend the temperature over all parts of the compost heap and for sufficient aeration. After this phase, the temperature of the compost drops and is not restored by turning or mixing. Decomposition is taken over by mesophilic microbes (the maturation phase). Chemical reactions continue, making the remaining organic matter more stable and suitable for use by plants. Maturation may require a year or more before the compost can be used.

A blend of feedstock is more likely to provide optimum conditions for composting than a single feedstock. Added organic waste should not have contaminants (such as high levels of heavy metals) and should contain appropriate carbon amounts for an optimal C:N ratio after feedstock mixing. Microorganisms that digest compost need to consume approximately 30 parts of carbon for every part of nitrogen. Thus feedstock should be blended to create a C:N ratio of about 25-30:1. If there is too much N (for example over 60%) which can result from too much added faecal sludge or manure, microorganisms cannot use it all and the excess N can be lost as noxious ammonia gas. If the C:N ratio is too high, which can result from too much added wood or paper wastes, decomposition slows down.

Compost operations should contain a ‘thermophilic stage’ area and the ‘maturation stage’ area. After an initial approximately four week-period of heating, mass and volume are reduced by about 40% and 50% respectively due to carbon losses. Compost heaps of the same age may heaped together into an intermediate stage area for four to five additional weeks. Next, the co-compost is placed into the maturation area for the remaining time.

To ensure compost quality and that is safe for use, systematic monitoring must be carried out. Parameters testing can include macronutrients (e.g., N, P and K), pathogens (per WHO guidelines), heavy metals, heavy metals to ensure permitted levels are not exceeded, germination tests - to ensure no active weed seeds remain, pH and electrical conductivity (salinity).

Matured compost should be dried prior to sieving. To facilitate drying, it should be spread thinly and turned intermittently. A sieving grid of 6-8mm is commonly used. For producing pelletized compost, sieve size is typically up to 5mm and is based on the specifications of the pelletizer machine. Resulting coarse material from sieving can be re-added to the co-composting process from the beginning or be ground. Matured and adequately dried compost (moisture content of < 40%) compost should be stored and protected from contamination by unsafe wastes or fresh compost. It should be bagged in a way that protects it from moisture but ensures some air flow. Woven polypropylene bags suitable.

Commercial-scale composting provides an opportunity to recycle large volumes of nutrients present in wastewater and in agricultural by-products for beneficial reuse. The compost can be transported in large volumes by truck from treatment sites and bagged for sale in stores. Large-scale composting requires substantial land areas for the reason that compost is relatively bulky compared to other fertilizers and agricultural inputs. Commercial-scale compost production sites can have significant environmental, and neighbourhood impacts thus adequate operator training is needed.

Dried Faecal Sludge (DFS) as Nutrient Rich Input in Composting:

DFS is a valuable source of nutrients in the manufacture of compost which, when properly managed, produces a quality and safe product for application. Feacal sludge, once adequately dried, should be transported to composting sites and mixed into material immediately. Moist DFS should be mixed with other compost materials within two days to avoid creating anaerobic pockets and odours. Attaining an optimum C:N ratio of about 25-30:1 for blended compost can be achieved by relatively high C content materials such as garden or market waste with high N content materials such as DFS at a ratio of 3:1 (by weight). Compost made with FS typically illustrate ranges of composition of elements as follows: organic matter 35 to 55%, total carbon 15 to 30%, total nitrogen 1 to 3%, total phosphorus (as % P2 O5 equivalent) 1 to 4.5%, total potassium 0.5 to 2%, total sulfur 0.5 to 2.5%. Research has shown that N levels in compost made with DFS to be significantly higher than in compost made only with plant material.

In contrast to chemical fertilizers, a finished non-enriched compost can be considered as a weak slow-release fertilizer, having an NPK composition of about 1-1-1 (N-P2O5-K2) plus a certain amount macronutrients and micronutrients. Industrial fertilizers have higher N-P-K but lacks other important nutrients.

FS-based compost can be used for cropping as an organic soil ameliorant or conditioner, or to add value to a particular growing medium like coconut coir. Yields can increase by 20-50% compared to using only inorganic fertilizer. Composts have most benefit on very light sandy soils and also on heavy clayey soils through improving soils structure. In sandy soils, compost binds sand particles and creates smaller pores which holding water better, improves nutrient storage capacity, and provides nutrients. In clayey soils, compost loosens soil by creating wider pores for better aeration and less compaction, which helps pants roots and soil organisms. Improved soil structure increases water infiltration and leads to more stable aggregates, reducing the risk of waterborne and wind-borne erosion. Compost is often applied in combination with other soil amendments (biochar, rice husk, manure, etc.) to further improve fertility. Application of compost is by broadcasting or placement.

Common application rates of FS-based composts range between 5 and 25 metric tonnes (MT) per hectare (ha). The optimum quantity depends on the soil and crop type and growth stage. Application should consider crop requirements, the degree to which the soil can meet crop needs over the growing period, and the nutrient-release characteristics of any applied soil input. Enriched compost can be applied at lower rates if it satisfies all of the cultivated plant’s nutrient needs. Compost can be enriched by directly adding and mixing in chemical fertilizers in a dry, paste, or liquid form, or adding beneficial microbes.

Adding urea to compost can substantially boost N content while also increasing pH and lowers the coliform count.

f) Irrigation Water

Irrigation water can be produced from many different wastewater sources, and its characteristics vary depending on treatment processes. Treated effluent from a conventional centralised wastewater treatment plant contains N, P and K and can be source of fertilizer and irrigation water. To increase the nutrient value or irrigation water, urine or other fertilisers can be added to create "fertigation".

Irrigation system installation and operation costs can range from low to high depending on design. Appropriate irrigation technologies for treated wastewater are drip irrigation either above or below ground, and surface water irrigation that routes water overland in furrows or channels. More complex systems may require expert design and installation. Drip irrigation can be prone to clogging and this is largely dependent on the content of the irrigation water. Care should be taken to ensure sufficient head pressure to reduce potential for clogging. Long-term use of poorly or improperly treated water may cause accumulation of persistent pathogens, imbalanced nutrient levels, buildup of salts, and increased concentrations of metals, metalloids, and contaminants. Flood, spray and sprinkler irrigation should be avoided to minimise evaporation and contact with pathogens. Raw sewage or untreated blackwater should not be used as irrigation water, and effluent from secondary treatment should be used with caution.

An additional benefit of irrigation water is it can reduce reliance on groundwater. When properly treated and applied, irrigation water can improve the availability of drinking water by infiltrating into the ground and replenishing groundwater supplies. Water recovered from wastewater can have other agricultural uses as well such as aquaculture, washing down livestock operations, cleaning food processing facilities, and heating and cooling of buildings.

g) Biogas

Biogas, a valuable source of renewable energy, can be produced from human and animal waste, plant material, green waste, and food waste employing a variety of technologies. It can be produced in different scales including the household level, on small to large farms and food processing plants, and from wastewater treatment plants. Biogas technology can be relatively simple, low cost, and operated with a basic level of training by households and small farms. Larger-scale biogas production operation in industrial scale agriculture and wastewater treatment plants is more mechanized process using equipment to recover organic matter, solids, and nutrients such as nitrogen and phosphorus from sewage sludge and requires more advanced operator training. Biogas can be used to meet on-farm energy needs including electricity generation for lighting barns or houses; heat for warming barns, greenhouses, and boilers for cleaning animal lens; energy for cooling milk; and fuel for running on-site vehicles.

Biogas is a mixture of gases, primarily consisting of methane (CH_4), carbon dioxide (CO_2) and hydrogen (H_2S) produced by anaerobic digestion with anaerobic organisms or methanogen inside an anaerobic digester, biodigester or a bioreactor. To release biogas stored energy, operations combust CH_4, H, and CO gases or oxidize them with oxygen. Biogas from household-level is most suitable for cooking or lighting. Biogas produced in large anaerobic digesters can be compressed using a process which removes CO_2, H_2S, and certain other elements to create biomethane. Biomethane is a near pure source of methane, for use in combustion engines, fuel cells, or gas turbines to generate electricity. Biogas average methane content is 55 to 75% which implies an energy content of 6 to 6.5 kWh/m$_3$. This corresponds with energy in other fuels as: 1kg firewood:200L biogas, 1kg dried cow dung:100L biogas; and 1kg charcoal:500L biogas.

Residence time for biogas production in common systems is about 14 to 40 days. For large mechanized systems residence times can longer. For example, in the upflow anaerobic sludge blanket digestion (UASB) system solid residence times can be up to 90 days. However, USAB systems in addition to managing large amounts of waste, separate water from sludge and water residence time can be as short as 1 hour to 1 day. This allows water to be released and reused for other purposes while maintaining available space in the UASB system for receiving more effluent.

Biogas use can help to reduce emissions of greenhouse gases such as CO_2, CH_4 and N_2O by more than 90% over the entire life cycle compared with fossil fuel use. Plant growth absorbs CO_2 from the atmosphere and biogas production removes nearly all $CO_{2.}$ However, CO_2, CH_4 and N_2O gases can leak out from stored biogas. The main safety concerns in biogas production are related to hydrogen sulphide gas which is created and is a toxic gas and can explode. Digesters should be made of corrosion-resistant material, equipment should be designed not to let biogas in or out, gas travel distanced should be minimised to reduce losses from leakages, and drip valves should be installed for the drainage of condensed water.

vi. Wastewater Management Systems for Nutrient Reuse

a) Pit Latrines Waste Reuse

Pit latrines contain wet faecal sludge, involve limited maintenance, and the common practice is to cover these pits once they fill up. However, sludge removal creates an option for reuse of nutrients and organic matter in agriculture and other uses and reduces impacts to groundwater. Removal methods commonly range from using buckets, pumping directly to nearby spot to dry and mix with other materials, or pumping to a haulage truck to dispose to spread on pasture, a designated outdoor sludge drying bed, or a wastewater treatment facility. Pit latrines are associated with significantly greater environmental risk, particularly in areas with porous geology and close to groundwater supply sources. The pit must be accessible for the service providers and their equipment level will be easier to assess. Some homes use dual pit-latrine system. When one pit is almost full, it is covered, and the second pit is used. Once the second pit is filling up, the content of the first pit is removed. Due to the extended resting time (at least one or two years after several years of filling), the material within the older pit is partially sanitized and humus like.

b) Composting Toilets Waste Reuse

In rural villages, composting toilets can be a very suitable way to treat human waste. A compost toilet with a reliable 'or vault' container base (for preventing to pollution to groundwater) and which allows sufficient aeration is relatively affordable and simple to install. Often, in compost toilets the N to C ratio is above optimum. Bulking materials such as straw, leaves, ash, paper waste, and agricultural wastes can be added to improve pile aeration and increase the C to N ratio. For composting toilets which have at least a small supply of flushing water, a vermifilter toilet can be used where earthworms are used to promote decomposition. Solids accumulate on the surface of the filter bed while liquid drains through the filter medium and is discharged from the reactor. The solids (feces and toilet paper) are aerobically digested by aerobic bacteria and earthworms into castings (humus), thereby significantly reducing the volume of organic material. The end product from a compost should be dry and odourless. When properly managed, economic benefits of the compost toilet are additional nutrients for application to agriculture, pasture, and tree growing, and health and environmental benefits substantial because pollution is minimal.

c) Septic Tanks Wastewater and Sludge Reuse

Septic tanks are often a practical option for wastewater disposal in areas not served by sewage systems and where their adequate outdoor space to place the septic tank system. When adequately designed, sited, installed, and maintained they can be a provide a basic level of treatment and be and affordable and reliable and wastewater management system to serve one or more households while also allowing biosolids to be removed following relatively simple and cost-effective steps. Settling and anaerobic bacterial digestion processes reduce solids and organics equivalent to primary treatment. Typically, effluent flows to a septic drain field. If the system is not appropriately sited and designed and properly maintained groundwater pollution may occur. Sludge accumulates in the tank and the amount increases with holding time. It is recommended that de-sludging occur every 2-6 years and/or when sludge volume 60% of the septic tank working capacity (US EPA).

To improve treatment efficiency using septic tanks, tanks can be connected to a simple onsite sewage facility or to drain to wetland where nutrients, organic matter, suspended solids and pathogens are removed. Such wetlands can be used to grow plans for commercial sale or for use as animal feed. Mechanical aerators can be added to tanks to add oxygen and change the bacteria to aerobic bacteria and increase the rate of solids decomposition. To serve multiple households, larger septic tanks can be installed with multiple vertical baffles providing more surface area for microbes to grow. As the baffles deteriorate from the sulfuric acid in the tanks, they can be lifted out and new baffles can be slid in. Concrete baffles can be produced local with cement and basic materials. Sludge can be removed either manually or mechanically such as using a vacuum truck for example, and mixed and with other materials to produce compost for use in biofertilizer and soil conditioner. For removing sludge from the tank, the scum mat must be manually broken to facilitate pumping. If the liquid level is higher than the outlet pipe, to prevent grease and scum from flowing into the outlet drain, the tank liquid level must be lowered. A thin level of sludge should be left in the bottom of the tank to facilitate microbial growth.

Treatment efficiency is moderate in basic septic system designs however increases with holding time as does ammonia concentration. Studies have shown for basic septic tanks receiving raw wastewater and with holding times of three days the following removal rates can be achieved: COD 65.3%, BOD 68.4%, TSS 65.3%, phosphorus 29.3%, and total Kjeldahl nitrogen (organic nitrogen and ammonia) 26.8%. Double-baffle septic tanks with three-day holdings times have shown removal rates of COD 74%, BOD 76.5%, TSS 76%, phosphorus 33.1%, and total Kjeldahl nitrogen 31.2%, and faecal coliform bacteria 95% (Source Haroun 2013). Sludge accumulation has been shown to be 10-15% faster in double-baffle tanks. Over a three-day period, volatile organic matter content of sludge in conventional and double-baffle tanks can decrease from 68.2% to 53.5%. Aerobic septic tanks, where air is forced into the tank, have significantly higher treatment efficiency rates. The sludge settles faster, and sludge removal is required more frequently.

d) Treatment Plants Wastewater and Sludge Reuse

Wastewater treatment plants can be designed, and modified to a certain degree, with technologies to reuse wastewater and sewage sludge for multiple purposes including agriculture. Sewage sludge treatment technologies are installed downstream of wastewater treatment. Sources of water for potential reuse can include municipal wastewater, industry process and cooling water, stormwater, agriculture runoff and return flows, and produced water from natural resource extraction activities. Wastewater from these sources is treated to meet "fit-for-purpose specifications" for a particular next use while bringing wastewater to the quality level needed for ensuring public health, environmental protection, or specific user needs. Faecal Sludge Treatment Plants (FSTP) and Sewage Treatment Plants (STP) will produce qualities of sludge. STP typically accepts a variety of influent sources thus there is more risk of other types of contaminants.

Reclaimed water for crop irrigation and compost made from extracted biosolids must meet quality standards to prevent harm to plants and soils, maintain food safety, and protect the health of farm workers. For compost manufacture, extracted biosolids from wastewater can be mixed with manure from different types of animals, landscaping debris (grass clippings, leaves, chipped tree limbs, prunings, etc.); industrial Food Waste (fruit pumace, vegetable waste, fish by-products); pre- and post-consumer food waste (from grocery stores, restaurants, etc.); shredded paper, cardboard and some tableware; and farm livestock mortalities. Mechanical systems while requiring less land area, often require a higher energy input, more frequent maintenance, and more skilled personnel than nature based solutions such as wetlands and reed ponds.

An oxidation ditch is a mechanized secondary treatment system which is highly efficient in BOD reduction and nutrient removal thus providing effective sludge treatment. Whereas most wastewater treatment plants use an oxidation basin, the ditch is a circular channel. Horizontal rotating biological contactors (RBCs) drive wastewater around the ditch and provide more efficient aeration then in packaged plants. High DO results in a greater variety and number of microorganisms. After BOD has been removed, wastewater flows out of the ditch, sludge is removed in the clarifier and is pumped to an aerobic digester where it is thickened with the help of aerator pumps. Treatment time in an oxidation ditch is approximately two days which is significantly longer than the 4-hour period in packaged plants.

Oxidation ditches are often suitable for small to medium size communities as designs can be relatively simple and low cost to operate where power prices are moderate. Oxidation ditch treatment greatly reduces the amount of sludge produced compared to packed plants and results in a highly concentrated sludge. Concentrated sludge provides an economical option for reuse as it is easier to remove, transport, and dry prior to applying it or mixing with compost.

e) Natural Based Solutions for Wastewater Treatment and Reuse

Nature-based solutions (NBS) for wastewater treatment are being increasingly used around the world, and when properly designed and managed, can provide a sustainable, low-cost, and environmentally friendly treatment option. NBS involves a range of approaches and methods and these fall into two main categories being water-based and substrate systems. Water-based solutions include ponds in-stream restoration, surface flow wetlands, and ponics technologies. Substrate-based systems include soil infiltration systems, building-based systems, zero-discharge systems, subsurface flow wetlands, and sludge treatment reed beds (Cross 2021). For each individual situation where a NBS is to be employed, the chosen option and its particular design must take into account the anticipated rate at which wastewater is to be received, the environment to receive the treated wastewater, and the intended level of treatment.

Natural and Constructed Wetlands:

The commonly used NBS option for wastewater treatment is natural and constructed wetlands. This approach uses natural processes involving aquatic plants, soils, and their associated microbial assemblages. Contaminants are recycled, transferred, or removed through sediment trapping, nutrient removal and chemical detoxification. Wastewater received by the wetland can be primary, secondary, or tertiary treated wastewater; raw domestic water that may or may not have been pre-screened and/or diluted by stormwater, greywater, and river-diluted wastewater. Wetlands are less expensive to build than other treatment options, have low operation and maintenance expenses and required labour, and can tolerate fluctuations in flow. Also, wetlands facilitate water reuse and recycling, improve water quality, provide habitat for many wetland organisms, can visually enhance the landscape. Wetland design is to take account the anticipated amount of water and contaminant load to be received by the wetland, the environment to receive treated water from the wetland, and the intended level of treatment.

Wetlands however have certain disadvantages in that most types of wetlands require larger land areas than do conventional wastewater treatment systems. The relative cost and benefits of obtaining land for establishing a wetland should be compared to the costs and benefits of other wastewater treatment options. Wetlands require a minimum amount of water to achieve treatment efficiencies, and these may vary seasonally and with environmental conditions. Also, while average treatment performance may be acceptable, wetland treatment cannot be expected to meet stringent discharge standards at all times. Biological components are affected by toxic chemicals and surges of pollutants may temporarily reduce their treatment effectiveness.

Types of constructed wetlands include surface flow wetlands, subsurface flow wetlands, and hybrid systems that incorporate surface and subsurface flow wetlands. Wetland systems can be combined with conventional treatment and/or other treatment technologies. Selecting an appropriate wetland design for receiving domestic wastewater, agricultural wastewater, industrial effluent, mine drainage, and stormwater runoff varies depending on the effluent composition, whether the wetland vegetation is intended to be reused and for what purposes, the downstream environment, and monitoring and maintenance requirements and availability of qualified persons to perform these duties.

Horizontal flow treatment wetlands (HFTW) are constructed with gravel beds and plantings and generally require more area than more advanced wetland treatment designs. Wastewater enters and saturates the wetland creating an anoxic environment and producing subsurface flow. Wastewater particles become caught in the planted vegetation and are acted upon by bacteria already present in the system. Plants roots secreet oxygen into environment supporting chemical and biological processes which further degrade the wastewater particles in the water and filter material and transform them into food and CO_2 for the plants. Plants which are killed by pollution sink to the bottom and provide additional material for growth new waste-eating bacteria. HFTWs are often combined with other treatment methods such as vertical flow treatment wetlands (VFTWs) to improve nitrogen removal, but also with free water surface treatment wetlands (FWS-TWs) and ponds, depending on the treatment goal. Treatment efficiency in horizontal treatment wetlands generally ranges as follows: COD 60–80%, BOD5 ~65%, TN 30–50%, NH_4-N 20–40%, TP (long term) 10–50%, and TSS >75.

In vertical flow treatment wetlands (VFTW) primary treated wastewater is intermittently loaded on the surface of the filter and percolates vertically downward. After each loading, air re-enters the pores of the filter produce aerobic digestion of the wastewater. Effective primary treatment is required to remove particulate matter to prevent filter clogging. Also, a loading tank is required to collect the primary treated wastewater between loadings. VFTWs are used when aerobic treatment of the wastewater is required (e.g. nitrification). An advantage of VFTWs is less area is required than other NSBs, clogging risk is lower than in in horizontal flow (HF), there is no specific hazard with mosquito breeding. One requirement of VFTWs which could be viewed as a disadvantage is a loading tank is required to collect primary treated wastewater between loadings, and the feeding system needs either mechanical (siphons) or electromechanical (pumps) components. WFTW treatment efficiency ranges are as follows: COD 70–90%, BOD5 ~83%, TN 20–40%, NH4-N 80–90%, TP 10–35%, TSS 80–90%, and bacteria Faecal coliforms ≤ 2–4 $\log_{10}$ (source Katherine Cross).

French VFTW's involve two vertical stages with different filter media. For temperate climates, the process involves alternating of the first three and two second stage beds. When properly managed, French VFTW's produce a high-quality end product. Treatment efficiency is greater than for standard VFTW's with indicators ranges of COD >90%, BOD5 ~93%, TN 20–60%, NH_4-N 60–90%, TP 10–22%, and TSS >90. For relatively simple designs, no energy is required if there is sufficient slope and maintenance requirements are low. More complex designs and layouts often require pumping stations. French VFTW can be an effective for communities of up 2,000 people.

In tropical climates, French VFTW's can be potentially more effective for the reason that warm temperatures typically enhance both nitrification and denitrification and increase mineralization of the deposit layer. Less maintenance and/or removal of the organic deposit layer is required. Also, stones can be used for construction of entry and trickling filters instead of sand which is an advantage in small islands nations where sand may not always be available. One version of French VFTWs which has illustrated effectiveness in tropical climates is saturated/saturated vertical-flow treatment wetlands (US/S VFTW).

Wetlands receiving wastewater can also be source of agricultural production for growing crops like rice and sugar cane shoots and aquatic animals for consumption such as fish, crabs, prawns and ducks. Higher economic benefits are achieved through integration of crops and animals in modified flooded fields such as rice with one of the above animal species. The paddy fields or cane shoot fields provide shade, shelter, and organic matters for the animals, which in turn oxygenate the soil and water, consume pests and favor nutrient recycling. Animals, especially fish and ducks, can be part an integrated pest management (IPM) system to make the agricultural activities more sustainable and environmentally friendly by reducing reliance on chemical fertilizer and pesticides which would normally be used to achieve crop yields.

Soil Infiltration:

Soil infiltration, either slow-rate or fast-rate is another relatively common approach to treat primary or secondary wastewater. Soil infiltration is conducted through controlled application to a vegetated land surface, providing treatment as well as irrigation to agricultural fields, pastures or forest lands. Wastewater infiltrates into the ground and as it travels through the soil matrix, goes through a process of physical straining and filtering, chemical precipitation, ion exchange and adsorption and biological oxidation, assimilation, and reduction. Advantages of this approach is its low energy use and water percolating downward can potentially be recovered though installed underground drains and can contribute to groundwater recharge. As wastewater percolates through the highly porous soil matrix, it goes through a process of physical straining and filtering, chemical precipitation, ion exchange and adsorption and biological oxidation, assimilation, and reduction.

Slow-rate (SR) infiltration is the process whereby the water percolates slowly. Upon reaching groundwater, the quality of the water is such that either minimal or further treatment is required for the water to be reused. Rapid-rate infiltration involves a highly porous soil matrix. After the percolating water has reached groundwater, reusing the water typically requires additional treatment, and is more likely to be used for crop irrigation or industrial uses than as drinking water.

Soil infiltration as a wastewater treatment method can cause contamination of groundwater, and accumulation of high dissolved salts concentrations resulting in soil structure dispersion. To use soil infiltration has a wastewater treatment method, users must be familiar with underlying soils characteristics and geology, permeability and depth to aquifers, and how percolating wastewater will interact with the receiving environment and vice versa. Seasonal weather variations and precipitation patterns should also be taken into account. Regular monitoring of effluent entering the ground and below ground water quality is required. The few layers of soils should be regular replaced and any build- up of organic matter removed. Treatment efficiency of slow-rate infiltration is typically as follows: COD 94-99%, BOD5 90–99% (<2 mg/L), TN 50–90% (<3 mg/L, depending on loading rate, C:N ratio, and crop uptake and removal), NH4-N ~80%, TP 80–99% (<0.1 mg/L), and TSS 90–99% (<1 mg/L). Slow-rate soil infiltration is often compatible with pond treatment systems including pond-in-pond systems and as a final infiltration unit for treatment wetlands.

Rapid-rate (RR) soil infiltration involves similar treatment processes as slow-rate soil infiltration however less filtering and treatment of the wastewater occurs. Accordingly, this method is more suitable when used in conjunction with one or more other treatments. In considering rapid-rate rate soil infiltration as a treatment option, soil depth, permeability and depth to groundwater should be carefully examined. Generally, RR soil infiltration systems do not achieve N levels required for discharge to drinking water aquifers. Similar potential disadvantages are associated with this treatment method as for slow-rate soil infiltration. Treatment efficiency for RR soil infiltration is typically COD ~78%, BOD5 95–99%, TN 25–90%, NH4-N ~77%, TP 0–99%, TSS 95–99%.

Ponds:

Waste stabilization ponds (WSP) such as surface area ponds, facultative ponds, maturation ponds, and anaerobic ponds for treating wastewater are relatively low cost to construct and maintain, are robust against load fluctuations, require a limited amount of time for maintenance, and can provide effective treatment when properly managed. Sometimes, two or three of the above types of ponds are used together to treat wastewater in sequence by locating them on a gentle slope. WSPs do require regular monitoring and maintenance for water quality, vegetation growth, and pests, erosion prevention, pond liners, control structures, monitoring seepage, and desludging every several years. In cases where mechanical equipment such as aerators are used, the equipment is often delicate, and close attention should be given to its proper care. Maintaining a healthy algal population is very important as the algae generate the oxygen for to break down biosolids.

After wastewater is sufficiently treated in the pond, it can be reused for crop irrigation and industrial purposes. The required frequency of sludge removal depends on the pond type and design, the rate at which wastewater is received and its pollutant load, and how the pond is operated and maintained. Removed sludge is a valuable source of nutrients. Determining how the sludge will be reused should consider its source of the wastewater and the sludge reuse purpose and the receiving environment.

vii.International and other National Guidelines and Standards for Wastewater Reuse

a) WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater:

WHO has produced Guidelines for the safe use of wastewater, excreta and greywater in order to provide an integrated preventive management framework for maximizing the public health and environmental benefits of wastewater, excreta and greywater use in agriculture and aquaculture. The Guidelines approach is intended to support the establishment of national standards and regulations that can be readily implemented and enforced and are protective of public health.

The WHO Guidelines were developed base on the Stockholm Framework integrated approach that combines risk assessment and risk management to control water-related diseases. The WHO Guidelines are built around a health component and an implementation component and use a risk analysis approach. The Health component: i) Establishes a risk level associated with each identified health hazard; ii) Defines a level of health protection that is expressed as a health-based target for each risk; and iii) Identifies health protection measures that, used collectively, can achieve the specified health-based target. The Implementation component: i) Establishes monitoring and system assessment procedures; ii) Defines institutional and oversight responsibilities; iii) Requires system documentation; and iv) Requires confirmation by independent surveillance. (Source: WHO).

The 2006 Guidelines comprise four volumes and provide information on the assessment and management of risks associated with microbial hazards: Volume 1 - Policy and Regulatory Aspects; Volume 2 - Wastewater Use in Agriculture; Volume 3 – Wastewater and Excreta Use in Agriculture; and Volume 4 – Excreta and Grey Water Use in Agriculture.

<u>Volume 1 - Policy and Regulatory Aspects</u>:

Volume 1 of the WHO Guidelines explains requirements to promote the safe use of excreta and greywater in agriculture, including minimum procedures and specific health-based targets, and how those requirements are intended to be used. It presents policy issues and regulatory measures distilled from the technical detail found in volumes 2, 3 and 4 as well as essential information for development of policies, procedures and regulatory frameworks, at national and local government levels.

<u>Volume 2 - Wastewater Use in Agriculture</u>:

Volume 2 of the WHO Guidelines explains requirements to promote safe use concepts and practices, including health-based targets and minimum procedures. It also covers a substantive revision of approaches to ensuring the microbial safety of wastewater used in agriculture. It distinguishes three vulnerable groups: agricultural workers, members of communities where wastewater-fed agriculture is practiced and consumers. It introduces health impact assessment of new wastewater projects.

<u>Volume 3 - Wastewater and Excreta Use in Agriculture</u>:

Volume 3 of the WHO Guidelines supersedes the previous two volumes and provides information on assessment of microbial hazards and toxic chemicals and the management of the associated risks when using wastewater and excreta in aquaculture. It explains requirements to promote safe use practices, including minimum procedures and specific health-based targets. The guideline describes the DALY (disability-adjusted-life-year) approach for setting health-based targets and defining a level of protection sufficient for each identified hazard. DALY's are a measure of the health of a population or burden of disease specific to a specific disease or risk factor. DALY’s attempt to measure the time lost because of disability of death from a disease.

Volume 4 - Excreta and Grey Water Use in Agriculture:

Volume 4 of the WHO Guidelines provides guidance on the assessment and management of risks associated with microbial hazards. It explains requirements to promote the safe use of excreta and greywater in agriculture, including minimum procedures and specific health-based targets, and how those requirements are intended to be used. This volume also describes the approaches used in deriving the guidelines, including health-based targets, and includes a substantive revision of approaches to ensuring microbial safety.

Table < > WHO Recommendations for Storage Treatment of Dry Excreta and Faecal Sludge Before use at Household and Municipal Levels (Source 2006 Guidelines)

Treatment	Criteria	Comment
Storage; ambient temperature of 2-20°C	1.5–2 years	This will eliminate bacterial pathogens; regrowth of E. coli and temperature of Salmonella may need to be considered if rewetted; will reduce viruses and parasite protozoa below risk levels.
Storage; ambient temperature of 20-35°C	>1 year	Substantial to total inactivation of viruses, bacteria and protozoa; inactivation of schistosoma eggs (<1 month) inactivation of nematode (roundworm) eggs, e.g., hookworm (Ancylostoma necator) and whipworm (Trichuris), while a +/- complete inactivation of Ascaris eggs will occur within one year
Alkaline treatment	pH >9 over 6 months	If temperature >35°C and moisture <25°C; lower pH and/or wetter material will prolong the time for absolute elimination

b) ISO Standards for Sludge Recovery, Recycling, Treatment, and Disposal, and Application:

The Organization for International Standards (ISO) describes good practices for the incineration and other organic matter treatment by thermal processes of sludges in ISO/TR 20736:2021(en) Sludge recovery, recycling, treatment and disposal — Guidance on thermal treatment of sludge. Thermal conditioning is excluded. The document applies to sludges specifically derived from storm water handling; night soil; urban wastewater collecting systems; urban wastewater treatment plants; and treating industrial wastewater similar to urban wastewater. It includes all sludge that may have similar environmental and/or health impacts but excludes hazardous sludge from industry and dredged sludge.

Currently under development is ISO/DIS (Draft International Standard) 19388 Sludge recovery treatment and disposal – Requirements and recommendations for the operation of anaerobic digestion facilities. The purpose of ISO/DIS 19388 is a standard which when adhered to will produce sufficient energy recovery based on sufficient biogas production in proportion to volatile solids ratio and to control by-products qualities.

ISO 19698 Sludge recovery, recycling, treatment, and disposal – Beneficial use of biosolids – Land application. This document provides guidance on the conditions of beneficial use of biosolids produced from industrial and municipal sludge and municipal biosolids derived products (e.g. composts, growing media) in the production of food and feed crops, energy crops, forestry crops and for the remediation of disturbed sites. It applies to biosolids for land application and includes biosolids from wastewater treatment (municipal, industrial and private onsite systems). ISO 19698 does not apply to hazardous sludge that originates from wastewater which, due to its nature, physical, chemical or infectious properties, is potentially hazardous to human health and/or the environment during use, handling, storage or transportation and which requires special disposal techniques to eliminate or reduce the hazard.

c) United States Environmental Protection Agency's (USEPA's) Standards for the Use or Disposal of Sewage Sludge

The USEPA's Standards for the Use or Disposal of Sewage Sludge (Title 40 of the Code of Federal Regulations [CFR], Part 503) also considers domestic septage and sets separate (simplified) requirements for its application on nonpublic contact sites. These include agricultural land, forests or reclamation areas (USEPA 1993a). Domestic septage is defined in this context as a liquid or solid material removed from a septic tank, cesspool, portable toilet or similar system that receives only domestic (and not industrial) sewage. Part 503 uses the term biosolids instead of sewage sludge to describe primarily organic solid products produced by wastewater treatment processes that can be beneficially recycled, including material derived from biosolids, like co-composts or other sludge–waste mixtures.

USEPA's Standards include:

- Pollutant ceiling concentrations in biosolids (see Appendix G Table < >)
- Recommended methods for septage stabilization including temperatures and treatment time periods to reduce pathogens to safe levels for land application (see Appendix G Table < >)
- Selected related criteria as specified by USEPA regarding the minimum duration between the application of Class B biosolids and harvesting of certain crops, animal grazing and public exposure/access to reduce health hazards to levels equivalent to those achievable with the unregulated application of Class A biosolids (see Appendix G Table < >)
- Requirements on application methods for the use of untreated septage

d) CGIAR Resource Recovery and Reuse (RRR) Subprogram of the Research Program on Water, Land and Ecosystems (WLE)

Resource Recovery and Reuse (RRR) is a subprogram of the CGIAR (Consultative Group on International Agricultural Research) Research Program on Water, Land and Ecosystems (WLE) for applied research on the safe recovery of water, nutrients and energy from domestic and agro-industrial waste streams. This subprogram aims to develop RRR business models, assess and mitigate risks from RRR for public health and the environment, support public and private entities with innovative approaches for the safe reuse of wastewater and organic waste, and improve rural-urban linkages and resource allocations while minimizing the negative urban footprint on the peri-urban environment. This subprogram works closely WHO, FAO, UNEP, United Nations University (UNU) other partners around the world.

The RRR Series 14 Regulations for Faecal Sludge Management from On-site Sanitation Facilities (2020) led by the Integrated Water Management Institute (IWMI) includes regulations and guidelines for faecal sludge capture and containment, emptying and transportation, treatment and disposal, and use. The regulations and guidelines incorporate research, strategies, regulations, and guidelines developed by IWMI, WHO, USEPA, EU and other nations.

RRR Series 15 Training Manual for Faecal Sludge-Based Compost Production and Application (2020), also led by IWMI, includes regulations, guidelines and BMPs for safety measures and compliance, drying of faecal sludge, co-composting of DFS, product quality enhancement, and use of faecal sludge-based co-compost in Farming.

viii. Reducing Greenhouse Gas Emissions in Wastewater Management

Wastewater treatment, onsite sanitation (OSS), and sewage collection produce GHG emissions of carbon dioxide, methane, and nitrous oxide (Global Water Alliance 2022). This includes an estimated 525 million tonnes of CO_2 per year globally with wastewater and sludge contributing 257 million tonnes and onsite sanitation systems 267 million tonnes. N_2O has 300 times the effect of CO_2 as a greenhouse gas. The approximate portion of greenhouse gas emitted in the form of CO_2, CH_4, and N_2O from wastewater and sludge treatment plants is 43%, 25%, and 32% respectively, and from OSS it is 0.5%, 94%, and 5.5%. CO_2, CH_4, and N_2O.

The main source of CO_2 emissions in wastewater management is burning of fossil fuels for powering wastewater treatment equipment. Reduced energy use and associated CO_2 emissions in wastewater treatment can be achieved through better operational practices and employing efficient treatment technologies. Green energy sources for powering wastewater treatment include solar power, wind turbines, and biogas produced from faecal sludge and other organic matter. Solar panels and biodigesters, when properly constructed and fastened, have been proven to be resilient to high winds from storm events. Solar drying of faecal sludge requires no energy input beyond spreading and turning.

Substantial amounts of CH_4 are lost to the air through open sewers and untreated discharge. Methane emissions from wastewater occurs in underground sewers occurs when it flows under pressure without air and when pressure changes take place for example when it passes under manholes and through inlets to wwtp's. CH_4 emissions also occur in the primary settling stage in treatment plants. In handling and managing sludge methane is main GHG produced. When properly managed and using anaerobic digestion, substantial amounts of methane can be captured and used to power wastewater treatment equipment while lowering the carbon footprint of wastewater treatment.

N_2O emissions in wastewater treatment are mostly a consequence of nutrient removal at the primary and subsequent treatment stages. Removing carbon increases energy for digestion but means more N_2O at the denitrification stage. High nutrient loads and poor aeration reduces ability of bacteria to function properly. Nitrous oxide emissions increase in spring as temperatures rise. Emissions of N_2O emissions can also occur from sludge management but these amounts are small compared to methane.

In on-site sanitation systems such as septic tanks and pit latrines, methane builds up in unemptied containers. Infrequent emptying causes GHG emissions to increase. These emissions are reduced in OSS when sludge is sent to treatment plants. Treatments plants also produce GHG emissions however these can be reduced through proper operation and employing suitable technologies.

D. Nutrient Management Valuation and Assessment Tools

There are a number internationally recognized tools for nutrient management valuation and assessment developed by a range of public institutions and independent research agencies.

European Nitrogen Assessment (ENA):

The ENA, an outcome of the ESF Nitrogen in Europe (or N*in*E) programme, addresses current N issues, the cascade effects and the interactions and feedbacks. The ENA was developed in order to provide insight for governments and other stakeholders on how the benefits of fixed nitrogen to society compare against the various negative effects of excess nitrogen in the environment. ENA is the first Europe-scale assessment of reactive nitrogen in the environment and highlights the multidisciplinary nature of the N cycle processes. The ENA uses individual farm case studies to explain impacts of different N use practices at the national and global scale. It identifies and assess five key societal threats, provides a framework for a multi-sector approach to manage the nitrogen cycle in Europe, includes the first cost-benefit analysis for different reactive nitrogen forms and scenarios.

United States Environmental Protection Agency (EPA) Spreadsheet Tool for Estimating Pollutant Loads (STEPL)

STEPL provides a Visual Basic (VB) interface, and which is intended to be user-friendly, to create a customized spreadsheet-based model in Microsoft (MS) Excel. It computes watershed surface runoff; nutrient loads including N, P, and 5-day biological oxygen demand (BOD5); and sediment delivery based on various land uses and management practices. STEPL can be used to evaluate loading and load reductions at a variety of scales such as large watersheds, down to an individual agricultural fields based on size and characteristics of each area (such as total acreage and acreage of each land-use) the user selects and enters into the spreadsheet. For each watershed, the annual nutrient loading is calculated based on the runoff volume and the pollutant concentrations in the runoff water, as influenced by factors such as the land use distribution and management practices. The annual sediment load (sheet and rill erosion only) is calculated based on the Universal Soil Loss Equation (USLE) and the sediment delivery ratio. The sediment and pollutant load reductions that result from the implementation of BMPs are computed using the known BMP efficiencies.

International Nitrogen Initiative N-Print Nitrogen Footprinting Tool

The project is an internationally supported project, composed of a team of researchers from the United States and the Netherlands. The overarching purpose of the project is to educate the general public about the causes and effects of nitrogen pollution and how we can each have an impact on nitrogen pollution through our everyday choices. The N-print website provides resources to learn about issues pertaining to nitrogen pollution. The website contains an N-Calculator which can calculate a person's personal N footprint, and an N-Institution tool, which has been designed to help universities and other institutions calculate and reduce their nitrogen footprints.

The Global Nutrient Management Partnership (GPNM) Calculator

The GPNM was established under the aegis of the UNEP's Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) as his described in more detail in section <enter #> in the report. The GPNM calculator is used to input data on agriculture and sewage, and total loadings of nitrogen and phosphorus in kilograms in both watersheds/catchments to estimate the current status of total nitrogen and phosphorus loads. Basic watershed input categories include population, total area, % land, % urban land, % agricultural land, % of population that is sewered and connected to a WWTP, and total N & P fertilizer application kg/year. Additional data input categories include agriculture and sewage and subcategories of data for each.

Nutrient loading implications of alternative future scenarios based on changes in management decisions can also be evaluated using the calculator by selecting measures such as implementing agricultural best management practices or increasing sewage treatment. This option allows the user to specify the level of implementation for up to eight agricultural best management practices (BMPs). The calculator is best suited for the agricultural sector as it does not include measures from the wastewater or other point sources.

2. Introduction

A. United Nations Environment Program Framework for Addressing Nutrient Pollution in the Wider Caribbean Region

The United Nations Environment Program (UNEP) identifies the nutrient challenge as representing two main processes: 1) excess nutrient loading to the environment and associated degradation of fresh and coastal waters, air, soil, and ecosystems; and 2) nutrient deficit, mainly in the context of agricultural systems that remove more nutrient than is being displaced, resulting in decline of soil and productivity and eventual land degradation.

i. The Cartagena Convention and Protocol Concerning Pollution from Land Based Sources and Activities (LBS Protocol)

The United Nations Environment Program (UNEP) Cartagena Convention Secretariat, within the framework of its Protocol Concerning Pollution from Land Based Sources and Activities (LBS Protocol) which was entered into force in 2010, is working to address the issue of pollution in the Wider Caribbean. The LBS Protocol includes regional effluent limitations (Annex III) for domestic wastewater (sewage) and requires the development of plans (Annex IV) to address agricultural non-point sources of pollution. In 2019, the Secretariat developed the region's first State of the Convention Area (SOCAR) report which showed that several sites in coastal waters throughout the Caribbean and Gulf of Mexico Large Marine Ecosystems had poor status with respect to selected water quality indicators, including N and P. SOCAR classifies the waters of the WCR as good, fair, or poor based on the threshold ranges of DIN and DIP as indicators. UNEP is currently reviewing LBS Standards in order to incorporate wastewater reuse and capacity building needs for developing the policy and regulatory environment in the Caribbean region.

ii. Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA)

The GPA, adopted in 1995, was created as a unique intergovernmental mechanism to counter the issue of land-based pollution. Parties set as their common goal sustained and effective action to deal with all land-based impacts upon the marine environment, specifically those resulting from sewage, persistent organic pollutants, radioactive substances, heavy metals, oils (hydrocarbons), nutrients, sediment mobilization, litter, and physical alteration and destruction of habitat. Since 2012, marine litter, nutrient management, and wastewater have been highlighted as priority source categories to be addressed.

iii. Global Partnership on Nutrient Management (GPNM)

The UNEP Cartagena Convention Secretariat participates in the Global Partnership on Nutrient Management (GPNM) was established in 2010 under the aegis of the UNEP's Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA). The GPNM assists in the development of a coherent global policy and advocacy response to help address the nutrient challenge at local levels, as well as facilitate the exchange of information, good practices, and expertise to assist delivery of knowledge-based remedial action to countries. Also, the GPNM provides a space where countries and other stakeholders can forge more co-operative work across the variety of international and regional fora and agencies dealing with nutrients, including the importance of assessment work and uptake and application of nutrient management project outcomes. When fully operational, the GPNM Caribbean Platform along with the LBS Protocol will become the major regional platform for harmonized nutrient management in the WCR.

iv. Regional Nutrient Pollution Strategy and Action Plan (RNPRSAP)

In 2021, the Secretariat finalized a Regional Nutrient Pollution Strategy and Action Plan (RNPRSAP) which provides a framework for increasing collaboration and action to reduce the impacts of excess nutrient pollution on priority coastal and marine ecosystems in the region. The RNPRSAP, in addition to identifying the many challenges and barriers for effective management of nutrient pollution, highlights potential Nutrient Use Efficiency (NUE) opportunities through making better use of nutrients, including the reduction of losses and waste, for reducing pollution threats while improving food and energy production.

v. Nutrient Use Efficiency (NUE) Links with UN Sustainable Development Goals

Human food production is directly and indirectly related to many of the United Nations 17 Sustainable Development Goals for 2030 including and not limited to Goal 2 - Zero Hunger, Goal 6 - Clean Water and Sanitation, Goal 8 - Decent Work and Economic Growth, Goal 13 - Climate Action, and Goal 14: Life Below Water. UN SDGs also include the goal to halve nitrogen waste globally from all sources of nitrogen pollution by 2030 (Colombo Declaration on Sustainable Nitrogen Management).

UNEP's Regional Nutrient Pollution Reduction Strategy and Action Plan for the Wider Caribbean Regional lists the following Targets and Resolutions on nutrient pollution as follows:

- SDG Target 14.1 (By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution)
- Target 6 of the Convention on Biological Diversity Post-2020 Global Biodiversity Framework (By 2030, reduce pollution from all sources, including reducing excess nutrients, to levels that are not harmful to biodiversity and ecosystem functions and human health)
- United Nations Environment Assembly (UNEA) Resolutions (2019): Resolution on Sustainable Nitrogen Management, calling for the mobilization of a coherent, multi-sector, multi-impact approach to nitrogen management

- The Colombo Declaration on Sustainable Nitrogen Management (under the UN Global Campaign on Sustainable Nitrogen Management), which sets an ambitious target to halve global nitrogen waste by 2030. This is expected to lead to immediate benefits in combatting climate change, air pollution, and biodiversity loss, US$100 billion in savings and innovations in sectors like farming, energy, and transport

vi. GEF-CReW+ Project for Jamaica and Barbados

The Caribbean Regional Fund for Wastewater Management (CReW+) is a partnership project funded by the Global Environment Facility (GEF) that is being co-implemented by the United Nations Environment Programme (UNEP) and the Inter-American Development Bank (IDB) in 18 countries of the Wider Caribbean Region (WCR). Responsible executing agencies are GIZ, Cartagena Convention Secretariat.

The CReW+ project is implementing small scale solutions for the improved management of water and wastewater that can be upscaled and replicated. The project plans to significantly reduce the negative impact of untreated wastewater on the environment and people of the WCR. Support is provided to participating countries to implement practical solutions to the problems of improper wastewater management and poor sanitation at the local community levels including by using Nature Based Solutions (NBS). Another purpose of GEF CReW+ projects for participating nations is to support activities to that will support the future development National Nutrient Reduction Action Plans.

For the Jamaica CReW+ project, the objective is to strengthen the regulatory capacities of the country in the water and wastewater sector, as well as to counteract the lack of investment in order to promote an adequate wastewater management. The project supports Components 1, 2, and 3 of the CReW+ project for the Caribbean through the following activities: Component 1 (executed by CAR/RCU and GIZ) - Development of a National Wastewater Policy green paper and Strategy; Component 2 (executed by GIZ) - Promotion of an investment-friendly environment in favour of the water, wastewater and sanitation sector in Jamaica; and Component 3 (executed by CAR/RCU) - Implementation of rural and community level Integrated and Innovative Water and Wastewater low-tech solutions.

Barbados CReW+ project activities aim to improve understanding of and access to financing mechanisms, leading to increased uptake of wastewater treatment systems by developers and communities. In addition, the water and wastewater sector will be strengthened through the demonstration of scalable and innovative IWWM low-technology solutions. The Barbados project supports Components 2 and 3 of the CReW+ project for the Caribbean through the following activities: Component 2 - Evaluation of the enabling environment needed for a Wastewater Revolving Fund and Development of a Co-financing/revolving fund mechanism to support uptake of wastewater treatment and reuse programmes. Component 3 - Demonstration of scalable Integrated and Innovative Water and Wastewater low technology solutions for example, constructed wetland with water reuse for agro-horticultural purposes.

vii. UNEP Collaboration with FAO

UNEP and FAO Caribbean Offices collaborate on themes such as sustainable food systems, ecosystem services and biodiversity in agriculture, forestry and fisheries, data and statistics, and international legal instruments, legislation and regulatory matters. The FAO Nutrition Strategy, part of the Organization’s strategic framework, aims to reduce malnutrition through efficient, inclusive, resilient and sustainable agrifood systems. UNEP and FAO together are actively supporting new joined-up initiatives to bring attention for the need for a systems-based approach that addresses the range and complexities in food production in a holistic and sustainable manner.

In 2022, FAO organized a seminar on the use of biofertilizers in Brazil, Chile, Peru, and the Caribbean to to disseminate techniques and methods that can help countries cope with fertilizer shortages and high prices resulting from the war in Ukraine. Representatives from these countries shared their experiences using biofertilizers (organic fertilizers) and compost. The event also discussed techniques such as crop rotation, leguminous plants, and other options for diversification of plant nutrient sources to replace or complement chemical fertilizers. FAO also highlighted the need to prioritize the fertilizer use for agricultural purposes and improving the efficiency of their use; keeping international trade of these inputs open; monitoring stocks, import volumes, and prices; and sharing this information through transparent platforms.

B. Project Purpose and Scope

Within the framework of an Economic Valuation Pilot Project financed by GPNM, the Secretariat has contracted a Consultant, Mr. Andrew Harnden, to develop two case studies on Nutrient Management Valuation in Jamaica and Barbados which are both Contracting Parties to the Cartagena Convention's LBS Protocol. As stated in the Terms of Reference for this assignment, the analysis will support the Secretariat's efforts to develop new regional quantitative discharge standards for nitrogen, and possibly also for phosphorus. The project is intended to promote and instigate an improved understanding of nutrient management and prevent nutrient over-enrichment through demonstrating best practices and supporting policy options that will stimulate and incentivize cost effective action and contribute to broader environmental sustainability benefits not only for Jamaica and Barbados but for other Caribbean nations as well. The project will also support another UNEP Caribbean priority initiative which is to develop National Nutrient Reduction Action Plans. The Final Report for Jamaica and Barbados Case Studies on Nutrient Management Valuation will be presented to the Cartagena Convention Scientific and Technical Advisory Committee (STAC) on <insert date>.

i. Case Studies Two Main Activities

The case studies will involve two main activities:

a. Investigating options for the improvement of nutrient use efficiency (NUE) (e.g. application of 4R Nutrient Stewardship Concepts – Right rate, right source, right placement, and right timing), demonstrating social and economic benefits for health, environment, and the supply of food and energy; and

b. Quantifying the multiple costs and benefits of meeting the nutrient management targets for food security, marine, freshwater and terrestrial ecosystems, mitigation of greenhouse gases and other climate threats, and improvement of human health as proposed in the Our Nutrient World (2013) report.

ii. Participating Government Agencies

Government agencies directly participating in the two case studies include:

Jamaica:

- Ministry of Economic Growth and Job Creation (MEGJC)
    - National Environmental and Planning Agency (NEPA) including the Planning, Projects, Monitoring, Research and Evaluation Division, and the Environmental Management and Conservation Division. NEPA is the focal agency for the Jamaica Case Study.
    - Policy Planning and Evaluation Division
- Ministry of Agriculture and Fisheries (MoAF) Rural Agricultural Development Authority (RADA)

Barbados:

- Ministry of Environment and National Beautification, Green and Blue Economy (MENB) including the Environmental Protection Department (EPD) and the Coastal Zone Management Unit. EPD is the focal agency for the Barbados case study.
- Ministry of Agriculture and Food and Nutritional Security (MAFS) including the Planning and Communications Unit and the Pesticide Control Unit

Other Government agencies serving as data sources for the two case studies include:

Jamaica:

- Water Resources Authority (WRA)
- Ministry of Health and Wellness (MHW)
- National Water Commission (NWC)
- Statistical Institute of Jamaica (STATIN)

Barbados:

- Barbados Water Authority (BWA)
- Ministry of Health and Wellness (MHW)
- Barbados Statistical Service (BSS)

iii. Options to be Considered for Nutrient Use Efficiency

Options for nutrient use efficiency (NUE) will be considered with particular focus on the following:

1. Existing in-country wastewater treatment technology;
2. Fertilizer manufacturing and usage by the major agricultural subsectors;
3. Phosphate additives in detergents – recognizing ongoing work at the national and regional levels to establish standards; and
4. Benchmarking the state of the local environments (soils and marine) for the pilot countries

Review of options will include substantial focus on high environmental risk activities, cost-benefit-assessment, and how practical outreach and education activities to assist operators and stakeholders to better understand and manage risk and realize benefits.

iv. Selected Case Study Locations: Rio Bueno/White River Watershed, Jamaica and Belle Groundwater Catchment, Barbados

The two locations selected for the case studies are the Rio Bueno/White River Watershed in St. Ann Parish Jamaica and the Belle Groundwater Catchment of Barbados which straddles the Parishes of St. George and St. Michael. The selection of these two locations was jointly agreed upon by NEPA Jamaica, MENB Barbados, and The Consultant Mr. Harnden. Both of these watersheds/catchments have substantial populations; illustrate a diversity of agricultural producers, unplanned settlements, wastewater management practices, stakeholders and natural values; are major tourist destinations; and emit substantial amounts of nitrogen and phosphorus. Therefore, the two watersheds/locations provide opportunities for improving NUE across a range of sectors and quantifying the multiple costs and benefits. In this report, the Belle Groundwater Catchment is a various instances referred to as the Belle Catchment for ease of writing purposes.

v. Sectors and Stakeholders to be Targeted by the Case Studies

The work outputs will principally target the following sectors and stakeholders listed in the table below:

Sector	Jamaica Stakeholders	Barbados Stakeholders
Mid- to senior-level policy makers within relevant Government ministries	• National Environmental and Planning Agency (NEPA) • Ministry of Agriculture and Fisheries (MoAF) • Ministry of Economic Growth and Job Creation (MEGJC) • Water Resources Authority (WRA) • National Water Commission • Ministry of Health and Wellness (MHW) • National Water Commission (NWC)	• Ministry of Environment and Natural Beautification (MENB) • Ministry of Agriculture and Food and Nutritional Security (MAFS) • Planning and Development Department • Barbados Water Authority (BWA) • Ministry of Health and Wellness (MHW)
Agricultural producers' cooperatives and associations and environmental organizations (including organizations promoting women's and youth economic development)	• Inter-American Institute for Cooperation on Agriculture (IICA) Youth Farm Program Jamaica • National Youth in Agriculture Committee of Jamaica • Jamaica Agricultural Society (JAS) • Environmental Foundation of Jamaica (EFJ) • Jamaica 4H Club	• Inter-American Institute for Cooperation on Agriculture (IICA) Youth Farm Program Barbados • Barbados Agricultural Development and Marketing Corporation (BADMC) • Barbados Agricultural Management Co Ltd (BAMC) • Barbados Agricultural Society (BAS) • Organic Growers and Consumers Association (OGCA) of Barbados

Universities with programs in environmental science and/or agriculture	• University of the West Indies (UWI) Jamaica Campus • Jamaica College of Agriculture, Science and Education • Jamaica University of Technology (UTECH) • Moneague College Environmental and Agricultural Studies	• University of the West Indies (UWI) Barbados Campus • Barbados Community College
Sector	**Wider Caribbean Region Stakeholders:**	**Global Level Stakeholders**
Development support agencies in the policy arena in the Wider Caribbean Region and at the Global level	Caribbean Research and Agricultural Development Institute (CARDI), Caribbean Water and Sewerage Association (CAWASA), Organization of Eastern Caribbean States (OECS), Caribbean Farmers Network (CaFAN), Meso American Reef Association (MAR)	The Global Partnership on Nutrient Management (GPNM), UNEP, UNFAO, Sustainable Sanitation Alliance (SuSanA), International Nitrogen Initiative (INI), World Health Organization (WHO), Global Environment Fund (GEF), Inter-American Development Bank (IDB), World Resources Institute (WRI), OAS (Organization of American States), United States Agency for International Development (USAID), European Union (EU)

vi. Development of the Case Study Approach with Jamaica and Barbados Participating Government Agencies

The Consultant and Jamaica and Barbados Government project participants held meetings <insert #> meetings during the period of 3rd June to <insert date> October 2022 to confirm project scope including selection of study locations and project stakeholders, undertake case studies design, review collected data and calculations, confirm to be used to assess nutrient use efficiency review options for nutrient management valuation. select stakeholders for post-case study small grants pilot projects, and review and finalize the case studies report.

Meeting participants included UNEP Caribbean Program staff, Jamaican Government Departments NEPA and MoAF, Barbadian Government Departments MENB and MAFS, and several research agencies who shared methodologies and findings from previous studies including University of the Philippines Marine Science Institute (MSI), United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Caribbean Office, and GPNM staff. The list of project meetings including participating agencies and individual staff names and titles as well as a brief description of the main subjects discussed is included in the Annex to this report in section number <enter #>.

The Consultant and participating Government agencies agreed that the case study approach for nutrient use efficiency and nutrient management valuation would include the following:

- Focus on agricultural (crop and livestock) systems and domestic wastewater management systems that illustrate actual or potential medium to high environmental risk. Consider potential nutrient recovery and recycling within the study locations.
- Review of methodologies and lessons learned from similar studies in the Wider Caribbean Region and other parts of the world.
- Develop the case studies in in a logical way and conduct research and analysis that will be practical for local policy planners so they can readily use it to demonstrate multiple benefits of better and more efficient nutrient use.
- Identifying potential local business and livelihoods opportunities including for women and youth consistent with the options identified for the application of NUE, soil quality improvement, and crop production.
- Summarize the Jamaica and Barbados state of the environment and provide an overview of the agricultural and wastewater sectors including challenges, trends, opportunities; current Government goals and initiatives; the main legislative framework for these sectors including for nutrient management; and Ministerial responsibilities.
- Agricultural data review of cropping practices, chemical and biofertilizer use, soil management, conservation practices, nutrient absorption rates, yield rates, livestock raising practices, animal feed sources and rates, animal growth rates, and livestock environmental management practices in small to large operations.
- Wastewater data review of small to large settlement wastewater systems. However, more attention would be given to informal and lower income communities where there is limited treatment, and the predominant wastewater disposal method is pit latrines and/or septic tanks.
- Select study target locations as the Rio Bueno/White River Watershed and Belle Catchment. Provide an overview of the environment, and agricultural and wastewater sectors in these locations. Analysis of NUE would involve focus on selected individual cropping and livestock operations and small settlements wastewater systems.
- The sites sample size for the cases studies would be: Rio Bueno/White River 4 cropping and 2 livestock operations, and 2 small settlements; and Belle catchment 4 cropping and 2 livestock operations, and 3 small settlements.
- The consultant, with input from participating Government staff, would prepared a survey for distribution to selected Jamaican and Barbados farmers to collect information on fertilizer use; cropping, soil management, and conservation practices; and farmer business challenges and goals, and farmer ideas for future support from Government and other regional and international development agencies.
- A portion of the individual agricultural operations used in the study, for example those willing to have and participate in staff on-site visits and assessments, would be eligible for funding as part of a post-case study pilot/demonstration project. The Consultant shared UNEP’s suggestion that funding would come from: (a) UN Small Grants Programme if there is money left over from other

projects; and/or (b) Savings from reducing the budget for the proposed end-of-project workshop/exchange involving field visits.

- A proposed end-of-project workshop/exchange would be organized for Barbados & Jamaica staff involving field visits. The Consultant shared UNEP's proposal that this be carried out in partnership with the Meso American Reef Association (MAR). MAR's program activities are relevant to the Jamaica and Barbados case studies and the having more participants would reduce the costs per person for the workshop.

vii. Data Collection Activities Conducted for the Case Studies

Pursuant to establishing the main approach to case studies with project participants, the Consultant conducted data collection activities including review of publications, reports, data sets, websites and other relevant information sources, as well as meetings and discussions with staff from and not limited to the following agencies and organizations:

- Jamaica Government Ministries of the National Environmental and Planning Agency (NEPA), Ministry of Agriculture and Fisheries (MoAF) and the Rural Agricultural Development Authority (RADA), Ministry of Economic Growth and Job Creation (MEGJC), Water Resources Authority (WRA), Ministry of Health and Wellness (MHW), and Statistical Institute of Jamaica (STATIN).

- Barbados Government Ministries of the Ministry of Environment and Natural Beautification (MENB) and the Environmental Protection Department (EPD), Ministry of Agriculture and Food and Nutritional Security (MAFS), Planning and Development Department, Barbados Water Authority (BWA), Ministry of Health and Wellness (MHW), Barbados Statistical Service (BSS) Office.

- International development and research agencies and partnerships UNEP, The Global Partnership on Nutrient Management (GPNM), Global Environment Fund (GEF), International Nitrogen Initiative (INI), International Fertilizer Association (IFA), World Health Organization (WHO), Inter-American Development Bank (IDB), World Resources Institute (WRI), OAS (Organization of American States), United States Agency for International Development (USAID), European Union (EU), International Atomic Energy Association (IAEA)

- Jamaican, Barbados and Caribbean region research agencies and agricultural support organizations University of the West Indies (UWI) Life Sciences Department, Mona Campus Jamaica and Department of Agriculture in Trinidad and Tobago; Jamaica Agricultural Society (JAS), Jamaica Environmental Trust (JET), Barbados Agricultural Development and Marketing Corporation (BADMC), Barbados Agricultural Society (BAS), Organic Growers and Consumers Association (OGCA) of Barbados; Caribbean Research and Agricultural Development Institute (CARDI), Caribbean Water and Sewerage Association (CAWASA), Organization of Eastern Caribbean States (OECS), Caribbean Farmers Network (CaFAN), and Meso American Reef Association (MAR)

- US Environmental Protection Agency (EPA), US Department of Agriculture (USDA) and the National Resources Conservation Services (NRCS) and Caribbean Area State Office

C. Nutrient Use and Impacts in the Wider Caribbean Region (WCR)

i. Environmental Impacts of Nutrients in the WCR:

Human activities in the Wider Caribbean Region have resulted in steadily increasing discharges of nutrients such as Nitrogen and Phosphorus to land, air, and terrestrial, coastal, and marine waters with significant impacts to the environment and human health. Across the region, excessive discharges of nutrients affect soil health, cause greenhouse gases, have negative impacts on biodiversity, and cause eutrophication which also reduces the productivity and overall health of aquatic ecosystems. Obvious signs of eutrophication include algal blooms, hypoxia (low oxygen levels in the water), and dead zones (source: UNEP RNPRSAP 2021).

The nitrogen and phosphorus loads in the WCR have several major sources. These sources and their relative N contributions are groundwater (agriculture) 40.1%, surface water (agriculture) 19.8%, groundwater (natural) 14.6%, vegetation in floodplains 13.7%, sewage 9.3%, surface run-off (natural) 1.2%, atmospheric deposition 1.1%, and aquaculture 0.2%. The P sources and contributions as a percentage are surface run-off (agriculture) 55.7%, weathering 19.7%, sewage 10.9%, vegetation in floodplain 10.3%, surface run-off (natural) 3.2%, and aquaculture 0.2% (UNEP RNRSAP 2021).

The main sources of excessive nutrient discharges in the region are the agriculture sector followed by cities and rural settlements wastewater. Excessive discharges of nutrients from agriculture in the WCR are caused by lack of consistent application of good farming practices in fertilizer usage; cropping, livestock, soil, and water management; and conservation practices. In the region's wastewater sector, excessive discharges are the result inadequate wastewater treatment infrastructure and operation, a lack of application of good practices such as and not limited to reuse of wastewater and biosolids (which are rich in N, P and other nutrients that could be applied agriculture and land for other productive uses), and inappropriate siting of settlements and commercial facilities.

However, nutrient discharges to the environment in the WCR can be attributed to other often human activities as well such as deforestation, clearing of other vegetation, and disturbance of soils for development, forestry, mining and quarrying, and roads. Climate change is impacting the Caribbean and its Small Island Developing States (SIDS) in many ways. Mountains and hilly terrain cover much of the landscape on many of the islands. As a result, deforestation and vegetation clearing leaves the landscape even more susceptible to the devastating forces of storms and effects of drought such as erosion, accelerated loss of agricultural soils, and high nutrient concentrations in waterways. Most Caribbean islands nations are prone to the effects of natural hazards and the coastal zone is particularly susceptible to the effects of these events as a high percentage of the population since a large percentage of the islands' socio-economic assets are located in coastal areas.

ii. Predominant Geology and Soils of the WCR:

The geology of many Caribbean nations, with the exception of several island nations of the Lesser Antilles, is predominantly limestone and highly porous. This means rainfall enters the ground almost immediately and smaller portion enters surface waters. In WCR island nations with this geology, groundwater accounts for most of the water supply. The limestone has the effect absorbing and neutralizing some contaminants. However, in some areas significant amounts of contaminants from agricultural run-off, erosion, and leaching as well as wastewater discharges from human-based activities which are not piped to treatment facilities enter the ground and can affect the quality of this below ground water supply. Also, groundwater re-emerges at lower elevation streams and rivers and flows into lower-level stream elevations and into the sea. Contaminants in groundwater which are not absorbed or neutralized by minerals in the geology are transferred to these lower elevation aquatic environments. In areas of steeper slopes ground infiltration is slower, and contaminated water can run more quickly towards stream and rivers. On several island nations of the Lesser Antilles, the geology is predominantly volcanic. Much of this water runs off as surface water and smaller proportion enters the ground than in island nations where the geology is comprised mainly of limestone.

The vast majority of soils in the Wider Caribbean Region have low fertility and poor soil structure and are vulnerable to degradation from human activities and extreme weather events. The main soil groups are Acrisols, Ferralsols, and Plinthosols (FAO, Main Report Regional Assessment of Soil Changes in Latin America and the Caribbean (2015)). Most soils are geologic and residual in nature, have a thin top hummus layer, and high acidity. In tropical climates such as the Caribbean region high temperatures limit the growth of microbes and buildup of organic matter, high rainfall causes nutrients to be leached downward. These soil environments generally illustrate low productivity and most of the biomass exists in the surface layer and in the above ground vegetation. Texturally, the soils are characteristically stratified which creates challenges for water management. As most of the nutrients in these soils are contained in the organic matter of the topsoil, its degradation and/or removal severely reduces soil fertility. Also, many Caribbean soils are rich in iron oxides which bind to phosphorus in the soil making it unavailable to plants.

An effect of climate change in the Caribbean is longer dry seasons and shorter wet seasons. Also, there has also been increase in the intensity of storm events. Higher air and sea surface temperatures, according to meteorologists, promotes the development of weather systems with accumulate excessive stored energy which form into hurricanes. Less regular rainfall, an increase in intense storm events, and warming temperatures reduce groundwater recharge. Less frequent rains mean less water seeping into the ground, and during intense storms the ground is unable to absorb all the rainfall and much of it runs off to the sea. An effect of warmer temperatures is that rainwater evaporates faster leaving less water to seep into the ground. Water scarcity is becoming more common across the WCR, and stress vulnerabilities have increased for farmers and communities.

iii. Agricultural Activities and Practices in the WCR:

Agriculture in the majority of Caribbean islands nations for the past few centuries and until recent decades was dominated by sugarcane. In recent decades, with Government direction and allocation of public resources, support from international development agencies, educational institutions, and private sector initiative, agriculture in many countries has diversified to the extent that vegetable and fruit growing and livestock raising make up large a proportion of agricultural output. It is widely acknowledged in the agricultural and environmental sectors in the region that farm-level productivity and management of ecosystem services are highly dependent on the practices used by farmers to maintain soil quality, water use efficiency, and crop management risk strategies.

There has been advancement in farming methods, inputs, technologies, and management practices including more efficient use of nutrients in the region. Larger and wealthier farmers and agribusiness companies in the region have been more able to take advantage of modern advances in the sector. Poorer farmers though they are often experienced in growing certain crops and managing soil, are less able to afford many of the new inputs and technologies and usually have less access to information on new farming techniques. Regardless of progress in the agricultural sectors in the Caribbean, inefficiencies in nutrient use and inadequate nutrient management are common in the areas of fertilizer application, cropping and soil management, livestock feeding and range management, reuse of cropping wastes and manure, and conservation practices. Most farmers have not established a nutrient management plan or nutrient reuse plan for their operations.

Caribbean soils are generally of poor quality as cropping soils and their high vulnerability to degradation requires that they be amended organically in order to be used productively and be sustainably in agriculture. Chemical fertilizers, while providing essential nutrients in inorganic form which can be taken up quickly by plants, often have limited effect in enhancing soil structure and increasing important microbes. Also, chemical fertilizers often increase soil pH, and Caribbean soils are vulnerable to this.

In the WCR, the use of biofertilizers and soil conditioners made from compost material is becoming more popular and has shown to positive impacts. Agriculture sector practitioners in the region state for organic amendments to be successful, they must be applied regularly and using select material inputs, and this can have the added benefit of increasing indigenous microbes in the soils. Experts also point to the damaging effects of monocropping which disturbs at the common rate of four times per year causing carbon loss to the atmosphere and increases nutrient losses from run-off. A widely promoted practice in the WCR is integration of high fertilizer using crops with nitrogen fixers to reduce the need for applied fertilizers.

Despite the fact that the average estimated application of fertilizer N per hectare of arable land in the Caribbean region (32 kg N per ha per year) is far below the world estimated average of (60 kg N ha per year) the region's farmers rely predominantly on chemical fertilizers for achieving desired crops yields (Martinelli et al. 2006). Only a small amount of chemical fertilizer used in the Caribbean is manufactured in the region. The vast majority of chemical fertilizer used is imported by local companies which then blend and sell the fertilizer directly to farmers or to smaller retail outlets. Application rates for nitrogen fertilizer and phosphate fertilizer application rates measured as kg/ha of cropland for Caribbean islands nations have fluctuated over the past several decades. The 1980s and the period from around 2009 to 2015 saw higher application rates, and in recent years rates have trended downward. The overall trend from 1961 to 2018 for N and PO fertilizer application rates for Caribbean islands nations is mostly flat. In contrast, for WCR's continental countries as a group, N and PO fertilizer application rates have steadily increased. This trend also applies to all WCR countries combined (UNEP RNRSAP 2021).

The current high global price of chemical fertilizers has created challenges for Caribbean countries to increase crop and animal productivity through chemical fertilizer application. Thus there is an urgent need for implementation of management practices that can increase nutrient use efficiency. This applies particularly to N which in terms of fertilizer volume is the most imported and applied nutrient. Based on FAO statistics, in 2009 the proportions N, P, K imported into the Caribbean were 47%, 22% and 31% respectively. Often the main fertilizer sources available to farmers are NPK blends in 25 kg bags (RADA 2012). Making available to farmers more direct N, P and K sources such as urea (46 % N), triple superphosphate (45% P) and potassium chloride (muriate of potash, 62% K) would likely substantially reduce total fertilizer use. Most small and medium holder Caribbean farmers apply fertilizers using a by-plant approach. Incorporating a by-nutrient application approach in farmer practices would further improve nutrient use efficiency and reduce overall fertilizer costs because farmers can select which nutrient to apply and blended fertilizers are usually more expensive on a per nutrient basis.

Most farmers also apply compost or soil conditioner to their crops which they either manufacture themselves, purchase from local vendors, or obtain from public recycling centres. Common inputs in commercial compost include sugar cane milling byproducts such as molasses, filter press mud, and bagasse; sugar cane trash, landfill waste, other crop residues, biochar, animal manures, compost produced from organic waste, green manure/cover crops, soil conditioners/microorganisms and other byproducts such as vinasse from the rum industry. Small holder farmers rely primary on organic materials left over from their own farming activities or in their own community from other farms, crop and animal processing facilities, and agroforestry operations.

Caribbean farmers typically spread mulch on their fields and this also reduces soil temperature. Lower soil temperature improves conditions for microbial growth and reduces volatilization of high N content chemical fertilizers and manures such as chicken manure. Cover cropping or rotational cropping is also widely practiced in the region on all slopes and soils using common crops such as sweet potatoes, pumpkins, legumes and melons. Cover cropping effectively creates a living mulch or green manure for protection against soil erosion, wind damage and heavy rains. It is also useful in the early stages of reforestation projects when seedlings are still young, and less suitable when trees are large. Less expensive crops to plant and maintain are yams and sweet potatoes.

iv. Women in Caribbean Agriculture

In the Caribbean agricultural sector, the position of women compared is to men is characterized as fewer women formally employed, a higher number of women informal workers, lower average wages, fewer women in leadership roles and as businesses owners, and greater vulnerability to hardship. In a study completed by UN women in 2017 in Jamaica, 144,528 men were formally employed in agriculture compared to 49,644 women, and in Barbados 2,903 men and 1,128 women were formally employed. Women as a group are more vulnerable to hardship, and this is particularly the case for those in informal work roles as these positions do not come with employee benefits and rights that full-time workers are more likely to have. The study also pointed to key barriers for women such as: 1) Limited access to resources (e.g., land, labor, and capital) to invest in business opportunities that may be derived from the implementation of SAPs; 2) Limited access to education and technical knowledge for diversification and/or expansion in the viable value chains; and 3) Limited access to available credit to purchase necessary inputs which have become more expensive over time.

Caribbean regional organizations, Governments, and international agencies such as and not limited to UN Women have launched a range of programs in the agricultural sector that engage local women and men small holder farmers and aspiring entrepreneurs in designing new development projects for their communities. This includes trainings to build knowledge and skills in more advanced farming methods with better equipment, seeds, fertilizer use, and animal feed; cropping and livestock management; greenhouse growing; composting and soil health; climate resilient practices and sustainable farming; value-adding activities; access to finance, land, digital technology such as GPS and online marketing platforms, and more lucrative markets; financial management; and negotiation skills for achieving better terms with input suppliers, service providers, and wholesalers. Initiatives also focus on strengthening women's leadership roles, addressing power dynamics, and influencing policy in public health, education, and in business associations to make sure women's needs and goals are addressed.

v. Wastewater Management in the WCR:

The coverage of conventional sewerage connected to wastewater treatment plants in the Wider Caribbean Region ranges from 0 to 30 % (Reuter et al. 2019). Sanitation is predominantly provided by septic tanks and other onsite solutions though sewerage coverage service has increased in many Caribbean island nations in recent years. Most towns and cities are located in coastal areas and have wastewater treatment plants. The level of plant performance varies and depends on the plant capacity, age, design, maintenance, staffing levels, operational procedures, monitoring equipment, and operator training. Discharge of improperly treated wastewater effluent is a main contributor to coastal zone degradation. Rural areas are underserved in terms of wastewater treatment. Lower population densities in rural areas make the cost of piped wastewater infrastructure more expensive, and rural household are generally poorer and would have difficulty affording these more expensive services. Wetlands, both natural and constructed, increasing being used in the WCR as a natural capital solution providing an additional wastewater treatment step. Using wetlands for this purpose has shown to be successful. Proper wetlands maintenance includes regular removal of non-native plant species such as and not limited to cattails.

In small and unplanned settlements in the Caribbean, domestic wastewater disposal directly to sinkholes or pit latrine is common. There is some use of septic tank systems. The effectiveness of septic tanks and leach fields varies with the system design, age, condition and siting. Many settlements on the outskirts of cities and in rural areas are unplanned, and there is not sufficient space for septic systems. Wastewater from rural settlements that is directly disposed of into the ground or inadequately treated, depending on the number of households, local terrain, geology, and proximity to ground and surface water can cause contamination of aquifers, streams and rivers.

Climate change affects Caribbean islands wastewater infrastructure through sea level rise, increasing salinity, unpredictable patterns of rainfall and drought, and increasing frequency and severity of tropical storms and other natural disasters. Storm surges and high winds can damage to coastal wastewater treatment plants and outfall pipes. Excessive storm water runoff can cause erosion to inland and coastal wastewater piping, box culverts, lift stations, foundations of treatment plants, and to septic and holding tanks, while also causing tanks and treatment plants to overflow.

Across, WCR, compared to drinking water, wastewater treatment receives substantially lower levels of investment and governments do not have sustainable funding mechanisms for needed capital investments in wastewater. The wastewater value chain in the Caribbean is generally not well developed or supported in terms of practical and affordable technologies, methods and services being promoted and made available. Currently, public and private wastewater infrastructure and services in Caribbean nations do not generate enough revenue for public utilities to be financially self-sufficient or for most private operators to make consistent profits. Overall, a small fraction of wastewater is reused in the form of reclaimed water and biosolids for agriculture and other activities. A number wastewater reuse projects have been implemented in the Caribbean region. This includes several successful wastewater reuse projects on urban landscaping and golf courses supported by CReW+.

The LBS Protocol sets effluent limitations for domestic wastewater discharges into the WCR.

Table < > 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	150 mg/l	30 mg/l
pH	5-10 pH	5-10 pH
Fats, Oil and Grease	50 mg/l	15 mg/l
Floatables	Not visible	
Faecal Coliform (Parties may meet effluent limitations either from faecal coliform or for E. Coli (freshwater) and enterococci (saline water)).	N/A	Faecal Coliform: 200 mpn/100 ml; or a. ecoli: 126 organisms/100 ml b. enterococci:35 organisms/100 ml
*Does not include algae from treatment ponds		

vi. Action for Sustainable Nutrient Management in the WCR:

Many Caribbean island nations have established ambitious goals for sustainable development and protection of the environment. Progress has been made in terms of governance, management and development and implementation of a legal framework at the National and local levels to guide and promote efficient, effective, and environmentally responsible nutrient management strategies and programs for agricultural and wastewater sectors.

26 nations are signatories of the UN Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (Cartagena Convention). The Cartagena Convention includes the Land-based Sources of Marine Pollution Protocol (LBS Protocol) to which 14 nations are signatories. The Cartagena Convention through the LBS Protocol commits signatory countries to take appropriate measures to prevent, reduce, and control pollution of the WCR from land-based sources and activities, through the use of the best practical means available, and in accordance with each country's capabilities.

A number of Caribbean nations are signatories to the United Nations Framework Convention on Climate Change (UNFCCC) and to the 2030 Agenda for Sustainable Development which includes the UN Sustainable Development Goals (SDGs) <insert Table # reference>. The UNFCCC sets legally binding obligations for developed countries to reduce their greenhouse gas emissions. Of UN SDGs, at least ten are directly or indirectly related to the agricultural and wastewater sectors and nutrient management. Government departments and other environment sector agencies and community-based organizations have made concerted efforts using a range of public outreach and stakeholder engagement and demonstration activities.

Current high global prices for fertilizer, fuel and food have had major impacts on the economies of Caribbean island nations created additional challenges for agricultural sector. The main crops in the region are heavily dependent on chemical fertilizers, and these recent global developments follow on the heels of a rise in food insecurity amongst Caribbean island nations in 2020 and 2021 due to the social and economic disruptions caused by the COVD-19 pandemic. Recognizing their nations' vulnerabilities, and in order to reduce dependence on foreign fertilizer and food products, many Caribbean Governments, UNEP, FAO and regional agencies are partnering in new initiatives to increase nutrient use efficiency in agriculture, diversify plant nutrient sources and increase biofertilizers use, and build a broader and more resilient agricultural base.

However, there remains a lack of clear separation between institutions in terms of jurisdictional and operational responsibilities for service provision, revenue generation, monitoring, regulation, enforcement, and public outreach and education. Also, there is currently, no formal mechanism or process for the relevant institutions for coordination and ensuring communication, enhancing collaboration, and resolving disagreements.

3. Key Findings from the Jamaica & Barbados Case Studies

4. Case Studies Analysis

A. Using the GPNM Calculator to Estimate Total N and P Discharge Load for Jamaica & Barbados Watersheds/Catchments

The GPNM calculator will be used to input data on agriculture and sewage, and total loadings of nitrogen and phosphorus in kilograms in both watersheds/catchments model to estimate the current status of total nitrogen and phosphorus loads.

Basic watershed input categories include population, total area, % land, % urban land, % agricultural land, % of population that is sewered and connected to a WWTP, and total N & P fertilizer application kg/year.

Additional data input categories can include, and not necessarily be limited to, N&P as measured in:

- Agriculture: fertilizer application kg/km^2/yr, manure application kg/km^2/yr, removed from agri land via harvest and grazing kg/km^2/yr, biological fixation by agri kg/km^2/yr, deposition on agri lands
- Sewage: fraction of total sewage export as DIN/DIP, fraction of total sewage export as DON/DOP, amount of sewage N/P entering surface waters kg/km^2/yr, amount of sewage N/P entering surface waters (DON/DOP) kg/km^2/yr kg, fraction of anthr. non-point sources of N/P entering as DIN/DIP, fraction of anthr. non-point sources of N/P entering as DON/DOP, fraction of non-anthr. non-point sources of N entering as DIN, river DIN/DIP retention, river DON/DOP retention, and percentage of total suspended solids (TSS) occurring as PN/PP.

Nutrient loading implications of alternative future scenarios based on changes in management decisions can also be evaluated by selecting measures such as implementing agricultural best management practices or increasing sewage treatment. This option allows the user to specify the level of implementation for up to eight agricultural best management practices (BMPs). It is best suited for the agricultural sector as it does not include measures from the wastewater or other point sources. The eight BMP options are: 1) Nutrient Management, 2) Riparian Forest Buffers, 3) Riparian Grass Buffers, 4) Conservation Tillage, 5) Conservation Cover Crops, 6) Wetland Restoration, 7) Grazing/Pasture Management, and 8) Animal Waste Management Systems.

The GPNM box Calculator uses the Global Nitrogen Export from WaterSheds (NEWS) model to estimate the current status of total nitrogen and P loads (i.e., dissolved inorganic, dissolved organic, and particulate) in more than 5,000 major river basins around the world. Input data displayed represent default values from the Global NEWS model's 2000 baseline). Any BMP implementation selected by the user will represent the percentage of implementation above and beyond the year 2000. Implementation is only applied to the arable land in the basin (as determined by the Global NEWS model). Users can use the sliders to adjust the percentage.

B. Target values and reference lines for NUE

The target values we chose for NUE will depend on the type of agricultural system and environmental conditions. We will illustrate this in a line graph with upper and minimum limit target value representing desired good management. The target values in this example was considered mainly for crop production system that represent the main agricultural practice in the studied watershed. In other regions where livestock or crop-livestock production system is priority, target and reference values must be adjusted.

C. Methodological approach to evaluate costs and benefits of meeting the nutrient management targets

For analysis in this section, consider tools such as Social Cost-benefit assessment (CBA)

- For comparing alternative options for assessing economic impacts from different nutrients management strategies and practices and to provide guidance to support policy making.
- Economic value of a negative environmental impact can be linked to nutrients (nitrogen) by dividing the associated economic loss by the value of the nutrient emissions (implicitly assuming no effect threshold), following methodology described in the European Nitrogen Assessment
- In using international models such as from Europe, these need to adapted to the local environment Unit costs to be translated to JAM and BB using the correlation between unit damage cost and GDP European countries and the concept of purchasing power parity (PPP) based on data provided by the Word Bank (https://data.worldbank.org/). The economic value of direct benefits in agriculture was based on yield response of agricultural goods to nitrogen inputs and current world market prices for major crops and commodities.

D. Quantify Economic, Social and Health Costs (Currently and Under Future Scenarios with Better Management Practices)

This section will incorporate calculation from the above sections to assess and quantify the multiple costs and benefits of meeting the nutrient management targets for food security, marine, freshwater and terrestrial ecosystems, mitigation of greenhouse gases and other climate threats, and improvement of human health as proposed in the Our Nutrient World (2013) report.

Calculation methods will include formulas from the publication 'Our Nutrient World 2013' such as:

- Nutrient pollution loss = per capita nutrient use X population X (1-full chain NUE); and
- Full-chain nutrient use efficiency. Full-chain NUE_N = (N in food and durable products)/(Industrial N production + Biological N fixation + Combustion source NO_X formation)

This assessment will consider LBS Protocol regional effluent limitations for domestic wastewater (sewage), LBS Protocol water quality standards for Class 1 and Class 2 Waters, Barbados Government list of prohibited concentrations including domestic use end of pipe concentrations, Jamaica fresh and marine water quality standards, and Jamaica sewerage effluent standards.

Cost-effectiveness analysis will be conducted that estimates the potential of available control measures to reduce discharged nitrogen and P loads and the annualized cost per kilogram of annual reduction for each of the measures.

Also, the case studies will indicate when nutrient over-enrichment problem areas are likely to occur; and to estimate the magnitude of expected effects of further nutrient loading on coastal systems under a range of scenarios.

5. Recommendations:

Information for each selected cropping and livestock operation will be entered into a matrix developed by the consultant with types of agricultural management practices including and not limited to those below. For each operation, scores will be awarded for: a) the extent to which each management practice is employed; and b) overall level of conformance with best practices. The latter score could also consider consistency in application of best practices in the operation. BMPs would include, and not necessarily be limited to those listed below, which have been referenced from 'Our Nutrient World' (2013) p61-72,

Wastewater Reuse:

Policy formulation and adjustment: the step-by-step process The development and maintenance of a national policy framework for the safe use of wastewater, excreta and greywater are part of a step-by-step, iterative process that should address the formulation and mainstreaming of new policies and the adjustment and harmonization of existing ones. At the heart of this process lies a productive policy dialogue among all interested parties. The steps of this process include: • establishment of a mechanism for ongoing policy dialogue; • defining objectives; • situation analysis, policy appraisal and needs assessment; • political endorsement, dialogue engagement and product legitimazation; • research

Need dialogue btw those for and against faecal sludge reuse. Advocacy groups can showcase how products can be made safe.

6. References

Ali, Qasim et al., Bahaudinn Zakariya University (2019) Agronomic Crops

Atis, Maxine et al., The Nature Conservancy (2021) Nature Based Solutions for Wastewater Management Barriers and Opportunities in the Caribbean

Australia, State of Queensland Department of Environment and Heritage Protection, Environmental Policy and Planning Division (2016) Reef Water Quality, Farming In Reef Catchment, The method for calculating the optimum amount of nitrogen and phosphorus to be applied to sugarcane properties regulated under the Environmental Protection Act 1994

Australia, State of Queensland (2018) Reef 2050 Water Quality Improvement Plan 2017–2022

Baird, W.F. & Associates Coastal Engineers Ltd (2015) Ecosystem Based Adaptation Pilot Project 9.9 - Phase 1 Report. Prepared for Barbados Coastal Zone Management Unit

Baird, W.F. & Associates Coastal Engineers Ltd (2017) Adaptation Measures to Counter the Effects of Climate Change with a Focus on Water Resources Management and Flood Resilience – Stormwater Quality in Barbados. Prepared for Barbados Ministry of Environment and Drainage Project Management Coordination Unit

Barbados Ministry of Agriculture and Fisheries (2021) Table of Poultry Sales (Baby Chicks) 2000-2021 & Crops 2000-2007

Barbados Ministry of Agriculture and Fisheries (2022) Fertilizer rates by crop type

Barbados Ministry of Agriculture and Fisheries (2022) Table of Fertilizer Imports for the Period 2000 to June 2022

Barbados Ministry of Agriculture and Fisheries (2022) Table of Revised Annual Production, various crops 2008-June 2022

Barbados Ministry of Energy and the Environment, Environmental Protection Department, Marine Pollution Control Section (2007) Inventory of Selected Land Based Sources of Pollution and Estimation of Land Based Pollutant Loads in the Marine Environment Part 1

Barbados Ministry of Energy and the Environment, Environmental Protection Department, Marine Pollution Control Section (2009) Inventory of Selected Land Based Sources of Pollution and Estimation of Land Based Pollutant Loads in the Marine Environment Part 2

Barbados Ministry of Environment, Natural Resources and Beautification, Environmental Protection Department (2018) National Water Reuse Policy

Barbados Ministry of Environment, Natural Resources and Beautification, Environmental Protection Department (2022) Annual Report 2011-2022

Barbados Ministry of Energy and Water Resources, Green Paper on the 2020 Water Protection and Land Use Zoning Policy

Barbados Ministry of Health, Environmental Engineering Division (1989) Groundwater Pollution Risk Assessment for Belle Public Water Supply Catchment

Barbados Ministry of Health, Environmental Engineering Division (1991) Groundwater Pollution Risk Assessment for Hampton Public Water Supply Catchment

Barbados Ministry of Physical Development and Environment, Environmental Engineering Division (2002) A Review of Chemical Imports in Barbados.

Barbados Statistical Office (2022). Various compiled data on Office website including Population and Housing Census, data tables, graphs, maps and infographics https://stats.gov.bb/statistics/

Berger, Madeline et. Al. (2022) Sources and discharge of nitrogen pollution from agriculture and wastewater in the Mesoamerican Reef region. Journal of Ocean and Coastal Management

Big, Alberto and Protz, Maria for FAO Jamaica (2014) Climate Smart Land Husbandry in Jamaica: A Manual for Extension.

Bouwman, A.F. et al. Department of Earth Sciences–Geochemistry, Faculty of Geosciences, Utrecht University (2015) Approaches for Modeling Nutrient Dynamics, Transfer, and Impacts along the Aquatic Continuum from Land to Ocean

Brink, C., and H. van Grinsven (2011) Costs and benefits of nitrogen in the environment, p. 513-540. In M. A. Sutton et al. [eds.], European Nitrogen Assessment. Cambridge University Press

Bruulsema, T.W., P.E. Fixen and G.D. Sulewski et al. International Plant Nutrition Institute (IPNI) (2012) 4R Plant Nutrition Manual: A Manual for Improving the Management of Plant Nutrition, metric version

Cashman, Adrian, AKWATIK Ltd Barbados (2002) Diagnostic Analysis of the Governance Framework. Report: A Sustainable Financing Mechanism for Integrated Wastewater Management in Barbados

Chandler, Francis (2016) Chapter 10 Managing Sugar Cane Nutrition in Sugar Cane Farming in Barbados - A Reference Handbook on Sugar Cane Growing and Field Management

Cross, Katherine (2021) Nature-Based Solutions for Wastewater Treatment: A Series of Factsheets and Case Studies

CWWA (2019) Regional Strategic Action Plan for the Water Sector in the Caribbean to Develop Resilience to the Impacts of Climate Change

FAO (2022) Biofertilizers and other Available Technologies to Address the Fertilizer Crisis in Latin America and the Caribbean, Seminar

FAO (2020) Study on the State of Agriculture in the Caribbean

FAO, IFAD, UNICEF, WFP and WHO (2022) The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable

FAO and Intergovernmental Technical Panel on Soils (ITPS) (2015) Status of the World’s Soil Resources (SWSR), Chapter 12 Regional assessment of soil changes in Latin America and the Caribbean

Foster, A.J., Macnack, Natasha; and Oconnor-Dennie, Tanika (2013) Improving Nitrogen Use Efficiency in Caribbean Agriculture, in Journal of Tropical Agriculture

Global Partnership on Nutrient Management (GPNM) (2013) Our Nutrient World Report. In collaboration with the International Nitrogen Initiative (INI)

GPNM (2018) Global Nutrient Management Toolbox Users Manual http://www.nutrientchallenge.org/gpnm-toolbox

Global Water Alliance (2022) Mapping Water's Carbon Footprint (Presentation)

Haroun, Basem Mikhaeil and Nasr, Fayza A (2013) Treatment of domestic wastewater using conventional and baffled septic tanks. Environmental Technology (Journal)

Heileman, Sherry; McManus, Liana Talaue; Corbin, Christopher Corbin; Christian, Linroy; Banjoo, Darryl; Adrian, Steven; and Mayorga, Emilio; (2019) State of the Cartagena Convention Area. An Assessment of Marine Pollution from Land-Based Sources and Activities in the Wider Caribbean Region

Heinonen-Tanski, Helvi (2003) Human excreta for plant production. Review Paper

International Association of Plumbing and Mechanical Officials (IAPMO) (2022) Guide Standard: Treated Faecal Sludge Compost for Non-food Applications IAPMO – I TFSC – 01: 2022

International Atomic Energy Association (IAEA) (2013) Application of Isotope Techniques for Assessing Nutrient Dynamics in River Basins

International Fertilizer Association (IFA), World Farmers Organization (WFO) and Global Alliance for Climate Smart Agriculture (GACSA) (2016) Nutrient Management Handbook

Jamaica Environmental Trust (JET) (2017) Review of the Legal and Policy Framework for Air Quality in the Island of Jamaica

Jamaica Ministry of Agriculture and Fisheries (MoAF), Rural Physical Planning Division. Presented by Joan Brown Morrison Global Soil Partnership: Towards Prevention, Conservation and Restoration of Degraded Soils in Central America and the Caribbean (2013) Status, Priorities, and Needs for Sustainable Soil Management in Jamaica

Jamaica MoAF (2022). Agricultural data tables of Crop Area Reaped, Crop Production, Farmgate Prices, and Value. https://www.moa.gov.jm/content/agricultural-data

Jamaica Ministry of Environment, Job Creation, and Growth (MEJCG), National Environmental Planning Agency (NEPA) (2016) Final Draft Ocho Rios Marine Park Protected Area Management Plan 2015-2020

Jamaica MEJCG, NEPA (2022) Table of Phosphates and Nitrates Values in the White River Sub - Watershed Management Unit 2021-2022

Jamaica MEJCG, NEPA, Ecosystems Management Branch Conservation and Protection Sub-Division (2017) St. Ann Development Order Environmental Thematic Report Second Draft

Jayathilake, Nilanthi et al (2020) Guidelines and Regulations for Faecal Sludge Management from On-site Sanitation Facilities. Resource Recovery & Reuse Series 14. CGIAR Research Program on Water, Land and Ecosystems (WLE). Led by Integrated Water Management Institute (IWMI)

Martinelli, L.A., R.W. Howarth, E. Cuevas, S. Filoso, A. T. Austin, L. Donoso, V. Huszar, D. Keeney, L. L. Lara, C. Llerena, G. McIssac, E. Medina, J. Ortiz Zayas, D. Scavia, D. W. Schindler, D. Soto and A. Townsend (2006). Sources of reactive nitrogen affecting ecosystems in Latin America and the Caribbean: current trends and future perspectives. Biochemistry

Martinex, Gustavo et al. (2009) Caribbean Phosphorus Index Validation and Management Practices Evaluation on Fields under Manure Applications. Conference paper for ASABE

Mcconville, Jennifer et al. (2020) Guide to Sanitation Resource-Recovery Products & Technologies: a supplement to the Compendium of Sanitation Systems and Technologies

Nikiema, Josiane et al (2020). Training Manual for Faecal Sludge-Based Compost Production and Resource Recovery & Reuse Series 14. CGIAR Research Program on Water, Land and Ecosystems (WLE). Led by Integrated Water Management Institute (IWMI)

Norton, Rob; Davidson, Eric; and Roberts, Terry; Global Partnership on Nutrient Management (2015) Position Paper: Nitrogen Use Efficiency and Nutrient Performance Indicators

Organization of International Standards (ISO) (2021) ISO/TR 20736:2021 Sludge recovery, recycling, treatment and disposal — Guidance on thermal treatment of sludge

Otoo, Miriam and Drechsel, Pay (2018) Resource recovery from waste: business models for energy, nutrient and water reuse in low- and middle-income countries

Pacheco, Felipe Siqueira; Ometto, Jean; Gomes, Luciene; Miranda, Marcela; Tôsto, Karina; Simoni Maria Loverde; and Pessi, Diego (2018) Case Study on Nutrient Management Valuation in Rondonópolis Municipality in the Upper Pantanal Region of South America

Pacheco, Felipe Siqueira; Ometto, Jean; Gomes, Luciene; Miranda, Marcela; Tôsto, Karina; Simoni Maria Loverde; and Pessi, Diego (2018) Policy Brief from Case Study on Nutrient Management Valuation in Rondonópolis Municipality in the Upper Pantanal Region of South America

Partnerships in Environmental Management for the Seas of East Asia (2018) Global Foundations for Reducing Nutrient Enrichment and Oxygen Depletion from Land Based Pollution, in Support of Global Nutrient Cycle. Component D: Development of Nutrient Reduction Strategies through Application of Quantitative Source-Impact Modeling and Best Practices in the Manila Bay Watershed

Pro NGO! (2019) Enhancing CSOs' Contribution to Governance and Development Processes in Barbados and the Eastern Caribbean. Manual On Feasible Farming Technologies in the Context of Climate- Smart Agriculture

Qiu, Zhiguang et al., School of Agriculture and Food Sciences, University of Queensland, Australia (2022) Biofertilizers can enhance nitrogen use efficiency of sugarcane. Journal of Microbiology

Reetz, H.F. Jr. International Fertilizer Industry Association (2016) Fertilizers and their Efficient Use

Reuter, Stefan et al. (2019) Compendium of Sanitation Systems and Technologies for the Wider Caribbean Region. A Guide for Implementing the RSAP in the Sanitation Sector

Roberts, Terry L., International Plant Institute (2014) GPNM Task Team on Nutrient Performance Indicators and Nutrient Use Efficiency Workshop

Robinson Dwight, Project Coordinator, The University of the West Indies (Mona) (2020) Technical Assistance for a Rapid Ecological Assessment of the Wag Water, Rio Bueno and Rio Nuevo/White River Watershed Management Units in Jamaica JM-H2O-SER-01

Sealy, Hugh. Centre for Resource Management and Environmental Studies (CERMES). The University of the West Indies, Faculty of Science and Technology, Cavehill Campus, Barbados (2021) Information Paper on Nutrients Management Guidelines/Standards for Wastewater Discharges into the Wider Caribbean Region. In UNEP Technical Paper on Proposed Criteria for Nutrients Discharges for Domestic Wastewater Effluent UNEP(DEPI)/CAR WG.41/INF.23/Rev. 1 09 June 2021

Silva, Homero (2013) Baseline Assessment Study on Wastewater Management Jamaica. Prepared for CReW

Snaith, W.A. (1973) Forestry Development by a Bauxite Mining Company. In The Commonwealth Forestry Review (Journal)

Sotto, Lara Patricia A; Beusen, Arthur H. W.; Villanoy, Cesar L.; Bouwman, Lex F.; and Jacinto; Gil S. The Marine Science Institute, University of the Philippines and Faculty of Geosciences, Department of Earth Sciences – Geochemistry, Utrecht University (2015) Nutrient Load Estimates for Manila Bay, Philippines using Population Data. In Journal of Ocean Science (2015) 50(2):467-474

Suraj, Maria et al. Faculty of Engineering, UWI (2018) A Controlled Environment Agriculture Greenhouse for the Caribbean Region. In West Indian Journal of Engineering

Sustainable Sanitation Alliance (SuSanA). Website various information and documents.

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

Tamil Nadu Agricultural University (TNAU) (2022) Agritech Portal

Trotz, Maya. Wianella. Isaacs & Christy Prouty, University of South Florida. Water Sector Resilience Nexus (WSRN) Barbados. Prepared for Caribbean Community Climate Change Centre (2018) Environmental and Social Assessment

UNEP (2011) Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of Global Nutrient Cycle. Project document

UNEP (2020) Integrating Water, Land and Ecosystems Management in Caribbean Small Island Developing States (GEF-IWEco Project). June 2020 Newsletter

UNEP (2021) Regional Nutrient Pollution Reduction Strategy & Action Plan for the Wider Caribbean Region (RNPRSAP)

UN Women (2019) Status of Women and Men Report: A Gender Analysis of Labour Force Data and Policy Frameworks in Six CARICOM Member States

United States Department of Agriculture (USDA), Agricultural Research Service (2022) Website for RUSLE1.06 and RUSLE2 (Revised Universal Soil Loss Equation) https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/docs/revised-universal-soil-loss-equation-rusle-welcome-to-rusle-1-and-rusle-2/

United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) Caribbean Office (2020) Conservation Practice Standard Nutrient Management Code 590 (ac)

United States Environmental Protection Agency (EPA) (2022) User's Guide Pollutant Load Estimation Tool (PLET) Version 1.0

University of the West Indies (2004) List of Prohibited Concentrations. Produced for Barbados Ministry of Housing, Lands, and the Environment, Environmental Engineering Division, Coastal Zone Management Unit

World Resources Institute (2017) Preliminary Pollution Reduction Opportunity Analyses for the Manila Bay Watershed, Pampanga Province, and Cavite Province. Component D: Doc: D2.2-2 GEF Global Nutrient Cycle Project

World Health Organization (WHO) Guidelines for Drinking-Water Quality (GDWQ)

World Health Organization (WHO) (2013) Guidelines for Safe Use of Greywater and Excreta

WHO (2018) Sanitation Safety Planning - Second edition. Manual for step-by-step risk management for safely managed sanitation systems

Yusuf, Bibi Frazan, University of the West Indies (2009) Identification of Sources of Nitrate Concentrations in Barbados Public Water Supply. Research Paper

ANNEX

A. Draft business opportunity report

B. PowerPoint presentation that covers the background study, rationale, methodology, and findings

C. Draft policy brief for policymakers which includes country-specific actions, next steps, and budget.

D. Draft summary brief for other stakeholders, such as the private sector.

E. Case Study Completed Calculations

F. Table <insert#> Wastewater Reuse Products in Agriculture: Characteristics, Application, Advantages, Disadvantages and Other Considerations

This table lists a number of reuse products sourced from human and agricultural wastewater which are commonly used in agriculture for improving yields, and which can reduce the need for chemical fertilizers and other inputs.

Reuse Product & Technology	Characteristics	Application	Advantages	Disadvantages	Other Considerations
Urine Urine-Diverting Dry Toilet, urinal, urine-diverting flush toilet, urine storage tank/container)	○ Contains soluble N, P, K and S, and some micronutrients. N is urine is in a form readily available to plants. +/- 90% of N, 60% of P and 75% of K excreted by humans is in the form of urine ○ Annual volume from a person is sufficient to fertilise +/- 300–400 m^2 of cropland (rate of 1.5L of urine to 1 m^2 of cropland). Equals 40–110 kg N/ ha ○ Optimal application rate depends on the N demand and tolerance of the crop, N concentration of the urine, and rate of ammonia loss during application	○ Store urine for a minimum period for 'curing' and pathogen reduction before applying. WHO guidelines are 1 month at 4°C for use with fodder crops and 6 months at 20°C for use with crops for human consumption ○ Apply into or close to ground to reduce possibility of direct contact with the edible parts of plants ○ Households can use urine on their own land or, it can be collected at one location for distribution/ transport to farmland	○ Reduces dependence on chemical fertilisers ○ Low risk of pathogen transmission ○ Ideal for rural and peri-urban areas where agricultural lands are close to the point of urine collection ○ Water can be removed to produce concentrated urine (as low as 3 to 7% of urine volume) for easier transportation	○ Urine is heavy and difficult to transport, and application is labour intensive ○ Large volumes of urine can be logistically challenging to manage ○ Odour may be offensive ○ Social acceptance may be low in some area	○ Volatilisation of ammonia from stored urine may pose health risk if fumes are inhaled ○ Additional safety measures should be taken if stored urine is used on a large scale ○ Strong odours should be mitigated ○ Concentrated urine requires specialised equipment for application to fields

Reuse Product & Technology	Characteristics	Application	Advantages	Disadvantages	Other Considerations
Sanitized Blackwater Ammonia Sanitisation/Urea Treatment, Lime Sanitisation	○ Solids content before treatment is generally 2% or less. Adding lime increases solids content and reduces the pH ○ Ca in the lime may result in P and Mg sediments creating a settled sludge ○ If flushwater is limited and blackwater is collected in a closed system, it can be self-sanitising due to the urea from the urine ○ Any ammonia-forming addition will, because the treatment is performed in a closed system, increase N content of the blackwater and its value as fertiliser ○ Urea additions to blackwater of 0.5 to 2% by weight results in a N concentration increase of 2.5 to 10 kg N/ m3	○ Urea/ammonia-treated blackwater should be incorporated into the soil upon fertilisation so that N losses are minimized ○ Benefits of using limed blackwater on agricultural land depend on soil acidity	○ Production technology is easy to use and implement with readily available materials ○ The alkaline nature of limed blackwater offers a remedy to acidic soils ○ The stabilisation process prevents the formation of greenhouse gases	○ Is relatively dilute as a fertiliser ○ High volumes relative to nutrient value means hauling long distances is less cost-effective ○ May not be fully accepted by farming communities	○ Risk of potential ammonia gas build up in top of a treatment container containing lime- or ammonia treated material ○ If limed black water still has high pH, safety precautions should be taken

Reuse Product & Technology	Characteristics	Application	Advantages	Disadvantages	Other Considerations
Pit hummus Double Ventilated Improved Pit Latrine, Fossa Alterna	○ Can be used to improve soil quality by addition of nutrients and organics and improve soil ability to store air and water ○ Texture and quality of pit humus depends on materials added to it. Adding leaves and soil may produce oxygen to promote composting	○ Should be mixed into soil before crops are planted, used to start seedlings in greenhouses, or mixed into an existing compost for further treatment ○ For generating pit humus, a one-year minimum storage time is recommended to eliminate pathogens and reduce viruses and parasitic protozoa. WHO guidelines should be consulted	○ Low cost to produce, technology is relatively simple, and can be made at household level ○ Can make agriculture possible in areas which otherwise would not be productive supported crops ○ Can improve soil structure and water-holding capacity and reduce chemical fertiliser needs ○ Generally has few chemical inputs (but may contain pharmaceutical residues) ○ As compost it can be conveniently stored and transported in bags	○ Matured pit humus will be dewatered and consolidated, making it quite difficult to remove mechanically ○ Maturation time can be long (up to one year) before is safe to use ○ Social acceptance may be low in some areas	○ If risk of pathogen transmission is suspected, particularly from double pit systems, longer composting times should be used ○ Should not be applied to crops less than one month before harvest (especially important for crops that are consumed raw)

Reuse Product & Technology	**Characteristics**	**Application**	**Advantages**	**Disadvantages**	**Other Considerations**
Dewatered Sludge Sludge from collection/storage and treatments units that has been dewatered such as: Septic tank, anaerobic baffled reactor, anaerobic filter, biogas reactor, settler, imhoff tank, anaerobic baffled reactor, anaerobic filter, waste stabilization ponds, aerated pond, trickling filter, upflow anaerobic sludge blanket reactor, activated sludge, sedimentation/thickening ponds, unplanted drying beds, planted drying beds, biogas reactor	○ Quality and composition varies depending on the source of the sludge, but generally contains significant amounts of organic C, P and sometimes N and can increase water-holding capacity ○ Dewatered sludge which includes industrial sources is more likely to contain contaminants such as heavy metals ○ Domestic sources may also contain pharmaceutical residues and microplastics	○ Can be applied with mechanical equipment or manually ○ If significant amounts of faecal pathogens are present then pathogen removal should be done prior to application ○ WHO guidelines should be consulted	○ Low cost to produce and can be made/treated at neighbourhood and/or city scale ○ Practical for revegetating and boosting growth of existing plants over large areas and reducing erosion	○ Odours may be offensive, depending on prior treatment ○ May require special spreading equipment ○ Social acceptance may be low in some areas ○ Distribution and transportation can have substantial costs	○ Risk of transmission of pathogens and potential presence of various contaminants means proper treatment and handling measure should followed

Reuse Product & Technology	Characteristics	Application	Advantages	Disadvantages	Other Considerations
Compost Vermicomposting and vermifiltration, black soldier fly composting (co-composting, composting chamber)	○ Adds nutrients and organics and improves the soil ability to store air and water ○ Generally has few chemical inputs unless made with material with significant amounts of pesticides or significant amounts of chemical excreted from humans	○ Mixed into the soil before crops are planted, used to start seedlings or greenhouse plants ○ Should not be applied to crops less than one month before harvest, and this is especially important for crops that are consumed raw ○ Production requires active monitoring and control of the composting process and temperature should reach and maintain 50°C for at least one week before use ○ WHO Guidelines should be consulted	○ Generally low cost to produce and can be made at household, neighbourhood and/or city scale ○ Can make agriculture possible in areas which otherwise would not be productive for crops ○ Can be bagged and sold or simply transported in trucks from treatment sites	○ Maturation may require a year or more before use ○ Is relatively bulky compared to other agricultural inputs and production of large volumes requires more land area	○ Measures should be taken in handling and transport ○ Industrial-scale compost production sites can have significant environmental, and neighbourhood impacts thus adequate operator training is needed

Reuse Product & Technology	Characteristics	Application	Advantages	Disadvantages	Other Considerations
Irrigation Water All technologies that produce an effluent as an output	○ Irrigation water characteristics vary depending on the preceding treatment processes ○ Treated effluent from a conventional centralised wastewater treatment plant contains N, P and K and can be source of fertilizer and irrigation water ○ Raw sewage or untreated blackwater should not be used ○ Effluent from secondary treatment should be used with caution	○ Appropriate irrigation technologies for treated wastewater are: 1) drip irrigation above or below ground, and 2) surface water irrigation that routes water overland in channels or furrows ○ Flood, spray and sprinkler irrigation should be avoided to minimise evaporation and contact with pathogens ○ Long-term use of poorly or improperly treated water may cause accumulation of persistent pathogens, imbalanced nutrient levels, buildup of salts, and increased concentrations of metals, metalloids, and contaminants	○ Reduces depletion of groundwater and improves the availability of drinking water ○ Low risk of pathogen transmission if water is properly treated ○ Low capital and operating costs depending on design	○ May require expert design and installation ○ Drip irrigation sensitive to clogging ○ Risk of soil contamination/degradation ○ Risk of nearby shallow/groundwater body contamination ○ Social acceptance may be low in some areas	○ To increase the nutrient value or irrigation water, urine or other fertilisers can be added to create "fertigation" ○ In drip irrigation systems, care should be taken to ensure sufficient head pressure to reduce potential for clogging

Reuse Product & Technology	**Characteristics**	**Application**	**Advantages**	**Disadvantages**	**Other Considerations**
Biogas Biogas reactor, upflow anaerobic sludge blanket rector UASB, biogas reactor	○ Biogas mixture is produced by anaerobic digestion process and is primarily composed of CH_4 and CO_2, with lesser amounts of H_2S, NO_3, and other gases ○ Can be generated from wastewater sludge or fresh excreta. CH_4 potential from faecal sludge is generally low. Other types of organic waste may be co-digested to increase biogas generation ○ Composition depends on the substrate that is being digested, microbial species present in the digester and process control and efficiency ○ Biogas average methane content is 55 to 75%, which implies an energy content of 6 to 6.5 kWh/m_3 ○ Energy in other fuels corresponds as follows: 1 kg firewood : 200 L biogas; 1 kg dried cow dung : 100 L biogas; and 1 kg charcoal : 500 L biogas	○ Distance which the gas travels should be minimised to reduce losses from leakages ○ Drip valves should be installed for the drainage of condensed water ○ When produced in household-level biogas reactors, biogas is most suitable for cooking or lighting ○ Biogas produced in large anaerobic digesters can be used for electricity generation or biofuel for vehicles ○ Typical consumption rates for biogas are: household burners: 200 to 450 L/h; industrial burners: 1,000 to 3,000 L/h; a 100 L refrigerator: 30 to 75 L/h depending on outside temperature; gas lamp, equivalent to a 60 W bulb: 120 to 150 L/h; generation of 1 kW of electricity with biogas/ diesel mixture: 700 L/h and biogas as vehicle fuel: approximately 960 L/km depending on the vehicle	○ Low-cost energy source from renewable resources ○ Can substitute fuel wood and other sources for cooking ○ For small home-systems, comparably few operation skills and maintenance required	○ Biogas can only be stored for several days (low energy density) and needs to be used daily ○ Biogas lamps have lower efficiency than kerosene lamps ○ Leaked and unburned methane can cause large greenhouse gas emissions ○ Compared to other gases, biogas needs less air for combustion, so conventional gas appliances need to be modified for biogas combustion (e.g., larger gas jets and burner holes)	○ There are risks from the various gases in biogas including explosion, asphyxiation, hydrogen sulphide poisoning, and GHG emissions ○ To prevent blocking and corrosion, accumulated water must be periodically emptied ○ Operators and should be trained on PPE and how to monitor for gas leaks, and ensure that system maintenance and repair is done by qualified technicians

G. United States Environmental Protection Agency’s (USEPA’s) Standards for the Use or Disposal of Sewage Sludge

Table < > Pollutant Ceiling Concentrations in Biosolids

Pollutant	**Ceiling Concentration (mg kg-1 dry weight)**
Arsenic	75
Cadmium	85
Copper	4,300
Lead	840
Mercury	57
Molydenum	75
Nickel	420
Zinc	7,500

Table < > Recommended Methods for Septage Stabilization and Pathogen Reduction

Recommended Method	**Treatment Process**
Aerobic digestion	40 days at 20° C or 60 days at 15° C
Anaerobic digestion	15 days at 35 to 55° C or 60 days at 20° C
Air drying	At least three months (with two of the months having average daily temperatures above freezing)
Composting or co-composting	Temperatures greater than 40° C for five days the temperature of all the material being composted must be greater than 55–65° C for at least four hours during the five days)
Lime stabilization	To bring the pH higher than 12 for 30 minutes, or bring the pH higher than 9 during more than six months if the temperature is above 35° C and/or moisture is below 25%

Table < > Minimum Duration Between Application and Harvest/Grazing/Access

Class B Biosolids	**Between Application and Harvest/ Grazing/ Access**		
Criteria	**Surface**	**Incorporation**	**Injection**
Food crops in which the harvested parts may touch the the soil/biosolid mixture (beans, melons, squash, etc.)	14 months	14 months	14 months
Food crops in which the harvested parts grow in the soil (potatoes, carrots, etc.)	20/38 months	38 months	38 months
Food, feed and fiber crops (field maize, hay, sweet corn, etc.)	30 days	30 days	30 days
Grazing animals	30 days	30 days	30 days
Public access restrictions - High potential for public exposure -Low potential for public exposure	 1 year 30 days	 1 year 30 days	 1 year 30 days

H. Project Meetings

A number of project meetings were held during the project inception and design period from 3rd June to <xx> August 2022 attended by the Consultant Mr. Harnden and project participants.

i. 3rd June 2022 Initial Project Meeting with UNEP Staff and the Consultant

Attendees: Mr. Chris Corbin, Program Manager, Marine Pollution; Ms. Jhenelle Barrett, Programme Management Assistant, Marine Pollution; and the Consultant Mr. Harnden

UNEP staff explained and discussed with Mr Harnden the following:

1) Project and purpose including project background in the global, Caribbean-wide, Jamaican and Barbadian context and the strategic and cross-cutting purpose of the case studies. The project should relate to Regional Nutrient Pollution Reduction Strategy Action Plan (RNPRSAP). Development of nutrient management valuation formulas should consider valuation approaches described in the 'Our Nutrient World' Report as well as in studies on Manila Bay including under the GNC Project. Studies on supporting women's and youth development through better nutrient management should also be reviewed in developing the case studies.

2) Project outputs must be readily adaptable by policy planners to quantify the economic benefits that will help influence policy design in supporting agricultural development and improved wastewater management and new business opportunities for operators and service providers, while maintaining the quality of ecosystem services. Both Jamaica and Barbados have expressed monitoring programs on nutrient use efficiency. A UNEP main priority is for countries to develop Nutrient Reduction Action Plans for food security, a more efficient nutrient cycle, and for addressing nutrient deficiency.

3) The approach will also outline with clarity the limitations in applicability thereby identifying future research needs. The work will consider how it will serve countries in addressing relevant Sustainable Development Goal targets with a particular focus on Small Island Development States (SIDS). UNEP staff provided Mr. Harnden background and subject information sources and contact information for project Government focal staff as well as participating staff from other Departments.

ii. 15th June 2022 Barbados Case Study Kick-off Meeting with UNEP Staff, Barbados Government Staff, and the Consultant

Attendees: Mr. Chris Corbin, UNEP Program Manager, Marine Pollution; Ms. Jhenelle Barrett, UNEP Programme Management Assistant, Mrs. Natalie Davidson, UNEP Environmental Officer; Marine Pollution; the Consultant Mr. Harnden; Barbados MENB staff Mr. Anthony Headley, Director EPD and Jamaica NEPA staff Mrs. Natalie Davidson, Wastewater Coordinator.

The meeting was facilitated by UNEP staff whereby the Consultant and Barbados MENB EPD attending staff were introduced.

The project focal staff person was confirmed as Mr. Headley Director MENB EPD. Names of additional project participating staff were provided including Ms. Gennia Oxley and Michael James, both of the MAFS, the latter of whom was identified as the MAFS point of contact for the project. The Hon. Adrian Forde, M.P. for Christ Church West was identified as the Minister responsible for Policy matters associated with the Cartagena Convention. The Barbados Planning and Development Department was also identified as an important project data source.

It was proposed by Mr. Headley and the Consultant that central considerations of the Barbados case study should include:

- A benchmarking exercise on the state of the environment prior to the case study proceeding.
- The impact of agriculture and wastewater on groundwater and nearshore natural systems. Barbados residential, commercial and agricultural water use is sourced almost entirely from groundwater and the nearshore environment provides important natural habitat and ecosystem services.
- Strategies for improving fertiliser efficiency, as this is a current priority of Government. Also, increasing fertiliser efficiency is an important step in improving food security and soil quality.
- Options for increasing the production and proportion of locally produced organic fertilizers (from animal manure) used in agriculture compared to chemical fertilizers to reduce dependency on imported fertilizers, lower the amount spent by farmers on fertilizers, improve agricultural soils health, and create business opportunities in local organic fertilizer production and sale of fertilizer from local animal manure or sewage.
- Options for nutrient extraction from wastewater for application in agriculture including and not necessarily limited to agroforestry, pastureland, and crops grown for human consumption and animal feed. Barbados adopted the National Water Reuse Policy in 2019 and is proposing to upgrade two wastewater treatment plants for reuse of reclaimed water in agriculture.
- The potential for improved nutrient use efficiency and better soil management to increase agricultural productivity and reduced the need for chemical applications in agriculture and chemical discharges to the marine environment
- Identifying the main activities contributing to water pollution (to waterways, groundwater, and the coastal areas) and review of best practice solutions including cost-benefit analysis for improving water quality discharges.
- In selecting the location for the case study, the interior of the Island should be the main focus. Due to the porous nature of Barbados geology, rainfall enters the ground quickly and becomes groundwater. Groundwater is affected by wastewater and agriculture. Barbados has mapped its groundwater and these maps should be reviewed
- Identify private and non-profit stakeholder organizations with local expertise for pilot project potential partnerships and and/or subcontracting to conduct ground-level activities
- Potential future local funding mechanisms and/or external funding sources for supporting programs for improving nutrient use efficiency

Mr. Headley described important relevant Barbados reports and data sources for the project which would be sent to Mr. Harnden.

iii. 28th June 2022 Jamaica Case Study Kick-off Meeting with UNEP Staff, NEPA Jamaica Staff, and the Consultant

<u>Attendees</u>: Mr. Chris Corbin, Program Manager, Marine Pollution; Ms. Jhenelle Barrett, Programme Management Assistant, Marine Pollution; the Consultant Mr. Harnden; and NEPA Staff Mr. Anthony McKenzie Director of Environmental Management and Conservation, Mr. Richard Nelson Senior

Manager Environmental Subdivision, and Mrs. Lisa Kirkland Senior Manager Pollution Monitoring and Assessment

The meeting was facilitated by UNEP staff whereby the Consultant and Jamaica NEPA attending staff were introduced.

The project focal staff person was confirmed as Mr. Mckenzie Director NEPA Environmental Management and Conservation. Names of additional project participating staff were provided including Peter Knight NEPA CEO and Gillian Guthrie Acting Chief Technical Director Planning and Environment Division MEGJC. MoAF and WRA were also identified as important project data sources.

In discussing the project it was agreed by NEPA Staff and the Consultant that the Ocho Rios watershed would serve as the location of the case study.

It was proposed by NEPA Staff and the Consultant that central considerations of the Jamaica case study should include:

- A benchmarking exercise on the state of the environment prior to the case study proceeding.
- Strategies for increasing the proportion of locally produced organic fertilizers used in agriculture compared to chemical fertilizers to reduce dependency on imported fertilizers, lower the amount spent by farmers on fertilizers, improve agricultural soils health, and create business opportunities in local organic fertilizer production
- Options for nutrient extraction from wastewater for application to agriculture for example in agroforestry, pastureland, or crops grown specifically for animal feed. Potential for direct application of wastewater and/or sludge to crops for human consumption is not currently a priority in Jamaica because of public perception including health concerns surrounding this process. Review examples of local pilot projects using school rainwater and wastewater sludge for agroforestry. Identifying private and non-profit stakeholder organizations with local expertise for pilot project potential partnerships and and/or subcontracting to conduct ground-level activities
- Engage relevant stakeholders for in identifying locations for new demonstration plots.
- Review licensing conditions for wastewater treatment plants and explore 'best bang for the buck' possible regulatory changes for improving water quality discharges
- The potential for improved nutrient use efficiency and better soil management to increase agricultural productivity and reduced the need for chemical applications in agriculture and chemical discharges to the marine environment
- Identifying the main activities contributing to water pollution (to waterways, groundwater, and the coastal areas) and review of best practice solutions including cost-benefit analysis for improving water quality discharges. Data review should include datasets from NEPA Pollution Monitoring and Assessment Branch
- Explore methods for efficient application of nutrients in greenhouse farming and economic potential
- Review of relevant studies and Environmental Impact Assessment (EIAs) done in Ocho Rios watershed

- Identification of successful regional and international examples of behavioural change in agriculture because there is limited information on this in Jamaica
- Review of data on phosphate use in detergents from the Bureau of Standards and other relevant agencies
- Consider potential for reusing partially treated water for cooling

NEPA staff described a number of important relevant Jamaica reports and data sources for the project which would be sent to Mr. Harnden.

iv. 14th July 2022 Meeting to Confirm Barbados Case Study Location and Data Sources with MENB Staff and the Consultant

Attendees: Mr. Anthony Headley, Director EPD MENB, Carlon Worrell Senior Environmental Protection Officer EPD, and the Consultant Mr. Harnden

MENB staff and Mr. Harnden agreed the Belle catchment, which provides the majority of the Island's water supply, would serve as the case study location for this project. MENB provided an overview of the Belle catchment including its geography, geology, history, economic uses, and its importance as the island's largest water supply source including its high water quality.

Relevant data sources for the Barbados case study were identified including and not limited to: Belle and Hampton Catchment maps and descriptions, crop and livestock production statistics, fertilizer imports statistics, the Planning and Development Department online database of development applications, the Town Planning Department Physical Development Plans, and the Draft Coastal Zone Management Plan. It was agreed that a MS Teams project site would be created for document sharing.

v. 26th July 2022 Meeting with UNEP Staff Dr. Christopher Cox Program Management Officer and the Consultant

Dr. Christopher Cox UNEP and the Consultant Mr. Harnden met in order to identify other completed nutrient valuation studies from different countries which would be relevant to developing the Jamaica and Barbados case studies as well as assessing nutrient use efficiency and formulating calculations for nutrient valuation. Dr Cox provided a brief summary of completed relevant studies under the GEF Global Nutrient Cycle (GNC) Project including the Philippines 'Preliminary Pollution Reduction Opportunity Analyses for the Manila Bay Watershed, Pampanga Province, and Cavite Province'. Also, Dr. Cox discussed the GPNM toolbox and options for using the GPNM calculator for assessing nutrification potential for various practices by calculating the delivery of dissolved N, P and silica.

vi. 9th August 2022 Meeting with University of the Philippines (UP) Marine Science Institute (MSI)

Attendees: Dr Gil Jacinto and Ms. Lara Sotto Graduate Student UP MSI and Mr. Harnden

Dr Gil Jacinto and Ms. Lara Sotto provided Mr. Harnden an overview of their work in developing nutrient management valuation modeling at the for the Philippines at the basin scale using local data, as well as for use by agencies around the world in developing additional nutrient management models. Dr Jacinto and Ms. Sotto forwarded to Mr. Harnden a variety of documents produced over the course of their projects including and not limited to modeling approaches, calculating load estimates, and presentations.

vii. 10th August 2022 Meeting with MoAF RADA Staff

Attendees: Acting CEO Mr. Winston Simpson, Mr. Vaughn Brady, Mr. Lockley Waites, and Mr. Earl Watkins of RADA, and the Consultant Mr. Harnden

The meeting was preceded by communications between CEO Mrs. Marina Young and Mr. Harnden. Mrs. Young provided Mr. Harnden links to relevant data sets available through the Agricultural Marketing Information Division (AMID) website and RADA was provided with a shape file map of the Ocho Rios watershed from WRA.

In the meeting, Mr. Harnden provided a summary of the project including background, purpose, scope, and initial proposed methodology. Staff explained the role of RADA as a Government department and current efforts in nutrient management and emphasized the case studies project should relate to and support current and future RADA projects. Staff and Mr. Harnden discussed relevant national and international data sources, nutrient valuation models, and the potential suitability of employing isotopic testing in tributaries to the main river in the watershed in order to identify sub-catchments with high pollutant loads. Also, staff and Mr. Harnden discussed exploring options for removing sludge from wastewater and applying it as fertilizer in agroforestry, grazing, and land rehabilitation. Prior to application of sludge for certain purposes, sludge will need to meet certain criteria based on official regulations and require official approval.

iii. 12th August 2022 Meeting with Mr. Edrick Marrero, USDA NRCS State Agronomist for the Caribbean Area, Discipline lead for the Nutrient Management Conservation Practice

Mr. Edrick Marrero and Mr. Harnden met to discuss USDA NRCS role and activities for Puerto Rico and the US Virgin Islands including:

- Extension services such as individual farm resources inventory visits for soil sampling, assessing slopes, rainfall and drainage; and reviewing yield and fertilizer application and whether or not a nutrient management is in place
- Comprehensive Nutrient Management Planning (CNMP) including introduction of new slow-release fertilizers
- Review of NRCS tools such as Revised Universal Soil Loss Equation (RUSLE) tool
- Watershed planning
- Climate change impacts and drought mitigation strategies such as increasing water infiltration and retention, conservation cover planting to increase soil structure using perennial crops such as peanuts which are also used for livestock feed

Mr. Marrero indicated he would email Mr. Harnden various tools NRCS Caribbean uses

ix. 24th & 31st August and 7th & 14th September 2022 Barbados Case Study Meetings to Confirm data collection

Attendees: The Consultant Mr. Harnden; Mr. Anthony Headley, Director EPD MENB, Mr. Carlon Worrell, Senior Environmental Protection Officer EPD; and Mr. Michael James Senior Agricultural Officer MAFS

The Consultant and the above EPD and MAFS staff met to confirm data needed for study, data sources available, data benchmarks and data trends, selection of individual sites for the study, maps production, data presentation in the reports, and how data collection and analysis could support future EPD and MAFS activities.

x. 30th August & 15th September 2022 Jamaica Case Study Meetings to Confirm Data Collection with NEPA and RADA Jamaica Staff, and the Consultant

Attendees: The Consultant Mr. Harnden; NEPA Staff Mr. Anthony McKenzie Director and Mrs. Donna Clarke Administrative Officer Environmental Management and Conservation, and Mrs. Lisa Kirkland Mrs. Lisa Kirkland Senior Manager and Mr. Andre Reid GIS Specialist Pollution Monitoring and Assessment; and RADA Mrs. Marina Young CEO and Mr. Sheldon Scoty St. Anne Parish Agricultural Manager

The Consultant and NEPA and RADA representatives briefly summarized what was discussed in previous project meetings and emails and agreed the purpose of today's meeting would be to confirm the study main location, identify potential individual agricultural operations and small settlements to include in study, and to confirm remaining data collection tasks.

Attendees agreed on the following:

- The Rio Bueno and White River watershed near Ocho Rios would be the selected watershed for the study
- The number of individual study sites would include four cropping and two livestock operations, and two small settlements. NEPA and RADA staff discussed a number of individual sites with the Consultant. Sites associated with medium- to high-risk activities such as not necessarily limited to chicken and swine raising. Cropping operations represent predominant types of vegetable-raising in the watershed
- Data collection sources should include National and Local Government; research agencies; universities; professional associations; and private sector farmers, input suppliers, service providers. Where hard data is not available, the local knowledge and experience of NEPA and MoAF technical staff and extension officers and other qualified local sector experts should be used towards producing data estimates. Data collection should include:
    - Fertilizer application rates (chemical, manure and other organics), feed rates, N and P concentrations in the Rio Bueno and White River and tributaries including from existing sampling sites (there are two in the White River); rainfall, slopes, and predominant soils categories and characteristics;
    - Other data categories and maps production as discussed in previous emails and meetings

      And if available,
    - Crop and livestock nutrient absorption rates, irrigation soil it was agreed by NEPA Staff and the Consultant that the Ocho Rios watershed would serve as the location of the case study.

xi. (date TBA) Meeting with Dr. Ramesh Ramachandran GPNM Chair (India) and Dr. Mark Sutton Co-chair (UK)

Note: Dr. Sutton indicated he is on leave due to significant health matters but intends to be available in within the next few weeks for discussion

Add additional meetings to this list