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Digital Twin Earth Intelligence for Climate Changes DTEClimate, ctr. nr. 760008/30.12.2022

Specific RDI Project 2: “Active measures for Restoring Sweer-Water Lakes and Coastal Areas affected by Eutrophication addressing the Enhancement of Resilience to Climate Change and Biodiversity” (ACT4D-Eutrophication)

D2-4.2 - REPORT ON CO-CREATION PROCESS FOR ADAPTING TO CLIMATE CHANGE. CASE STUDY CO-DESIGN OF SOLUTIONS FOR REVERSAL OF EUTROPHICATION (D-EUTROPHICATION) IN THE SIUTGHIOL LAKE

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DOCUMENT CHANGE RECORD

Issue	Date	Chapter	Change
1.1			
1.2			
2.0*			

**Note. This version is an update of a prior deliverable. Specific contributions brought in the reported period have been highlighted in yellow.*

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1. Introduction

1.1 Scope

The report covers all the aspects related to the co-creation process for adapting to climate change - case study co-design of solutions for reversal of eutrophication (d-eutrophication) in the Siutghiol lake.

1.2 Document Overview

This document completely follows:

Chapter 1	outlines of the purpose of this document
Chapter 2	lists the applicable and reference documents.
Chapter 3	gives a general description of the processes for reducing eutrophication in lakes
Chapter 4	describes the solutions for reversal of eutrophication in the Siutghiol Lake

2. References

2.1 Applicable Documents

The following project documents contain provisions which, through reference in this text, become applicable to the extent specified in this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

[AD01] Financing agreement	CODE Issue: Date:
[AD02] Application Form	CODE Issue: Date:
[AD03] Project Management Plan	CODE Issue: Date:
[AD04] Technical note of use case scenarios and user requirements	CODE Issue: Date:
[AD05] Data cube report	CODE Issue: Date:
[AD06] Technical note on methods algorithms and tools	CODE Issue: Date:

2.2 Reference Documents

The following standards or documents are referenced in this document. Documents which are recognised best practices may be listed for the purpose of information.

[RD01] Space engineering – Software, ECSS-E-ST-40C	
[RD02]	

3. Processes for reducing eutrophication in lakes

The planet is getting warmer as an impact of exponentially increasing anthropogenic greenhouse gas emissions, especially CO_2. According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), the global average surface temperature has undergone a warming of 0.85°C (0.65 to 1.06) from 1880 to 2012, proving that global warming is occurring.

A warmer climate will affect the hydrological cycle and change atmospheric and meteorological properties such as precipitation patterns, atmospheric water vapor and evaporation, and consequently impact water quality by intensifying many forms of water pollution.

One form of water pollution is water eutrophication, which occurs when high concentrations of nutrients, such as nitrogen and phosphorus, are present in the water. In recent years, specific concerns about the impacts of climate change on water eutrophication, which causes global environmental challenges regarding the management of water resources, have been raised.

The Fifth Global Environment Outlook (GEO-5) reports that more than 40% of water bodies all around the world suffer from different levels of eutrophication. The reason for this phenomenon is an important issue of great concern is its potential consequences, threatening the reliable supply of drinking water.

In the initial phase of the project under the activities that have been carried out in WP 4, there were evaluated the accumulated experience in addressing the eutrophication processes of sweet water lakes. In the next chapter, there are synthesized the results of these analyses.

3.1 Thermal Stratification

Stratification in lakes is a natural phenomenon caused by solar heating resulting in the development of a thermocline. This becomes a barrier to heat, dissolved oxygen and dissolved nutrient transfer between the upper and lower water column.

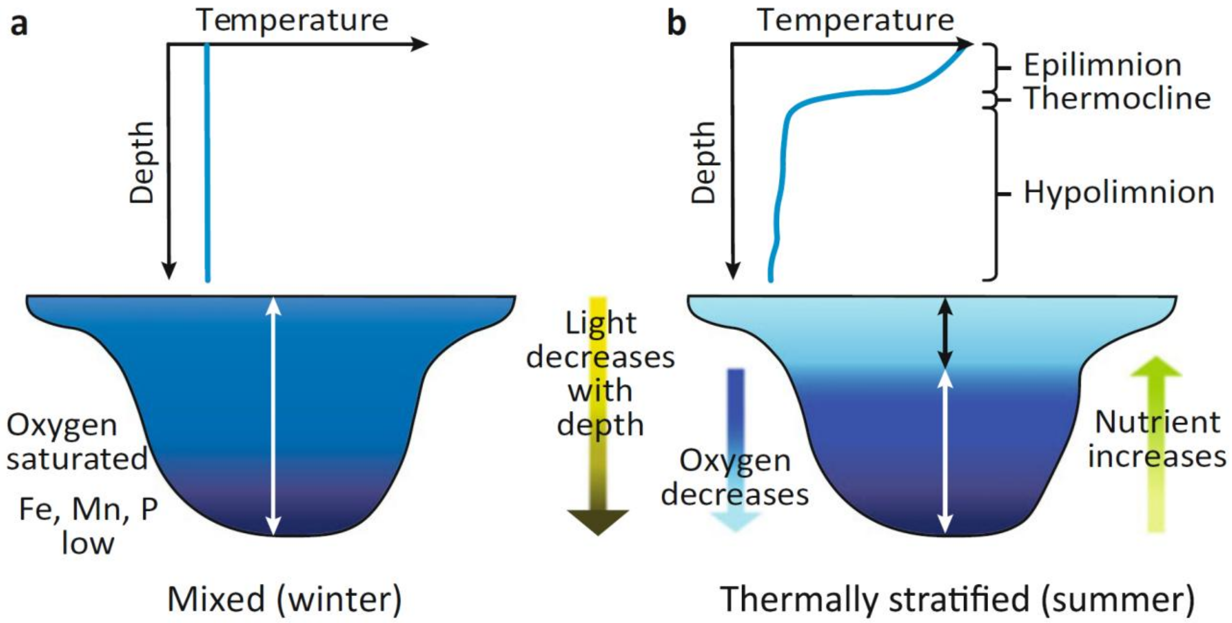

Figure 1 - Schematic diagram of a lake showing the concept of (a) fully mixed and (b) thermally stratified lake

Nutrient runoff from land and phytoplankton growth in lakes can cause bottom waters to become oxygen depleted and potentially unsuitable as a habitat for aquatic biota. Conversely, reduced depth of mixing above the thermocline provides a high light field that enhances algal and cyanobacteria growth and, in nutrient rich conditions, the lake becomes degraded, the natural lake eutrophication process.

Stratification in a lake water body is caused by density differences between water in the upper and lower water column (Figure 1 - a). Thermal stratification is the process whereby such differences are due to temperature (rather than salinity) effects and results in the separation of the lake water column into three layers definable by the temperature-induced density differences: the epilimnion at the top is the warmest, the metalimnion in the middle is cooler than the epilimnion and the hypolimnion at the bottom is the coldest. The thermocline within the metalimnion is the zone is where the largest temperature change occurs with change in depth (Figure 1 - b). As the temperature gradient across the thermocline increases, it becomes a barrier to the rapid mixing of heat and oxygen down to the hypolimnion and transporting nutrients released from the sediment up to the epilimnion. Eventually, the thermocline reduces these flux rates to the rate of diffusion.

3.2 Lake Mixing

3.2.1 Natural Processes

Natural mixing of lakes occurs regularly in shallow lakes by strong winds. However, wind energy may generally not be strong enough to cause full depth mixing of deeper lakes and reservoirs during summer stratification (Lossow et al. 1998). This is because energy transfer from a surface wind wave down into a lake is through orbital rotation currents produced by the wave. The orbital velocities generally decrease with increasing depth and, in lakes of small to medium depth, and may only extend to a depth equivalent to ca. nine times the amplitude of the surface wave (Kumagai 1988). This effect is an important driver of thermal stratification in summer when wind speeds tend to be lower than at other times of year. In autumn, the cooling surface water will reduce the temperature gradient across the thermocline making it easier for wind-induced currents to mix the lake to the bottom (Gibbs et al. 2016). This event is called ‘turn-over’.

The potential for wind mixing may be assessed by using the Osgood index (US Department of Agriculture 1999) or the Wedderburn number (Wedderburn 1912). The Osgood Index is defined as the mean depth (z) of a waterbody in meters divided by the square root of the surface area (A) inkm^2, or $z/A^{0.5}$. It reflects the degree to which a lake or reservoir will mix because of forces of wind. Low numbers indicate a shallow, large lake that is readily mixed by wind, although during a period of calm days, it may become temporarily stratified.

The Wedderburn number W gives an indication of how likely the lake is to mix and can be interpreted by:

- $W \geq (L/4)h_e$ - Strong thermal stratification, little mixing, small internal seiche amplitudes.
- $\frac{1}{2} < W < (L/4)h_e$ - Wind-induced mixing stronger that thermal stratification, more surface mixing than instability at the thermocline, large internal seiche amplitudes.
- $h^e/L < W < \frac{1}{2}$ - High degree of mixing between the epilimnion and the hypolimnion, much upwelling at the thermocline (unstable) surface at the upwind end of the basin.
- $W \leq h_e/L$ - complete overturn (mixing).

Where he is the epilimnion thickness at rest condition and L is the length of the lake basin. Partial mixing of a thermally stratified lake will transfer nutrients from the hypolimnion into the epilimnion where they can support phytoplankton growth and, in some cases, even result in autumnal blooms.

Full depth mixing in autumn disperses nutrients from the hypolimnion throughout the lake. These nutrients support phytoplankton growth and typically result in a spring growth that may reach bloom proportions. If the lake is deep and the hypolimnion has become anoxic or anaerobic, full depth mixing at turn-over may result in a drop in DO concentration throughout the lake water column, reflecting the volumetric mixing ratio of the hypolimnion/epilimnion and the conservation of mass of the DO concentration in each layer. This effect may last for a short period until the lake becomes fully re-oxygenated again but may have adverse effects on aquatic biota that were living in the epilimnion.

3.2.2 Artificial Processes

The process of artificially mixing a lake is called destratification. The main reasons for artificially mixing a lake or reservoir are to raise the DO concentration in the bottom water and to improve water quality by preventing the release of Fe, Mn and SRP from the sediment. Therefore, the term aeration is used together with artificial mixing as the two processes act in concert.

Artificial destratification is the mechanical manipulation of water circulation within a reservoir with the aim of weakening or eliminating the density stratification of the water column. Density stratification is a nearly ubiquitous feature of reservoirs globally and most commonly is the result of thermal stratification caused by seasonal warming of the upper regions of the water column in response to solar heating. It is quite common in temperate and tropical climates for thermal stratification to commence in early spring as both day length and air temperatures increase and to persist through late autumn.

Left undisturbed, density stratification can suppress vertical transport of heat, dissolved nutrients and dissolved oxygen to rates approaching as little as 1–10 times molecular diffusion levels. Vertical transport can be 10–100 times faster in actively mixing zones of the water column such as the surface layer, where wind mixing and cooling by evaporation and conduction supply mixing energy (turbulent kinetic energy, or TKE) and along the bottom boundaries where velocity shear (a change in velocity with distance from the boundary) introduces TKE.

The suppression of vertical transport arising from density stratification facilitates oxygen depletion of deeper waters as well as the release of nutrients and reduced forms of iron and manganese from anaerobic sediments. The severity of these water quality problems are reservoir-specific and reflect differences in local climate, inflows and outflows and pollutant loading. In addition, density stratification is frequently accompanied by relatively shallow (< 6 m deep) surface mixing layers (SMLs) (just 0.1 °C can be a sufficient temperature change to suppress transport downwards through the bottom of the SML) which provide support for the development of harmful algal blooms of buoyant algae by increasing the amount of light experienced by the algae within the SML. As a general rule, if the SML depth is less than three times the euphotic depth (the depth to which 1% of the light incident at the water surface penetrates), the light environment will be conducive to blue-green algal bloom formation.

Artificial destratification typically uses bubble plumes or mechanical mixers to induce vertical currents in a reservoir. A bubble plume introduced at the bottom of the water column will rise to the surface and lift the surrounding water with it. As the plume rises, it entrains water laterally from the reservoir so that by the time the plume reaches the water surface it contains a mixture of water drawn from nearly the full height of the water column. At the surface, the plume will have a temperature intermediate to that observed at the top and bottom of the water column. The plume spreads radially along the surface for only a few meters before it plunges back down through the water column until it reaches its level of neutral buoyancy, i.e. the level at which the temperature of the reservoir away from the bubble plume matches the temperature of the descending water. At the level of neutral buoyancy, an intrusion forms and the plume spreads horizontally until it reaches the boundaries of the reservoir. In its simplest form, this sets up two counter-rotating circulation gyres with flow moving away from the plumes at the level of the intrusion and moving towards the plume at the top and bottom of the water column.

Achievement of aeration to the bottom of a lake requires full depth mixing of the water column to raise the DO concentration at the sediment–water interface above 5 mg L^{-1}. Artificial mixing is achieved by establishing a circulation current that draws surface oxygenated water down to the bottom of the lake to replace bottom water raised to the surface by the mixing device. DO in the downward-circulation current will raise the DO concentration in the bottom water. This level of mixing may also allow nitrification of any released NH_4-N to NO_3-N at the sediment–water interface, thereby reducing NH_4-N and DIN concentrations in the lake.

Artificial mixing to increase lake bottom water DO concentrations has the added advantage of increasing the aerobic habitat for fish and benthic biota. It may, in some cases, also have a potentially negative effect in raising the bottom water temperature thereby reducing cold water refuges for fish such as trout, forcing them to move into the colder inflow streams.

A further common reason for mixing a lake or reservoir is to disperse or prevent algal (and particularly cyanobacterial) blooms developing (Visser et al. 2015) by making use of the critical depth factor. Consequently, in a eutrophic lake or reservoir, full depth mixing may result in a change in the phyto plankton species composition from buoyant cyanobacteria, which can form surface blooms and scums in calm conditions, to diatoms and chlorophytes, which require turbulence to keep them suspended in the water column.

3.3 Artificial oxygenation of anoxic layers of water

Hopkins et al. (1991), Oliveira and Minkowycz (1998), and Boyd and Hanson (2010) pointed out that once the dissolved oxygen (DO) concentration is less than 5 mg/l, fish and aquatic fauna will have a poor appetite, slow down growth, become ill, and even die off from hypoxia. Thus, it needs to supply oxygen continually to aquaculture water body for maintaining the DO dynamical equilibrium.

Since the late 1980s, many kinds of aeration facilities have been developed to improve the level of DO. They are impeller, waterwheel, jet, and fine-bubble-diffusing (FBD) aeration aerator. As a common device for increasing DO level, with advantaged energy-saving, environmental protection, easy installation, adaptability, and other good characteristics, the FBD aeration systems have been used increasingly in sewage treatment aeration reaction ponds, aquaculture ponds, contaminated reservoirs, and other water bodies that have a naturally unacceptable DO level. A FBD system usually consists of air compressor, diffuser, and air supply pipes from the air compressor to the diffuser. The diffuser is located at the bottom of the water body to maintain a consistent oxygen level. Multiple air bubbles of different diameters are generated from the diffuser, and then the oxygen is transferred through the air bubble interface and the turbulent water surface, consciously increasing DO in water.

Four general shapes of fine-bubble diffusers, namely plates, tubes, domes, and discs, are available on the market. Among them, discs, rolled up by a certain length of aeration tube, are popular in aquaculture ponds across the world, especially in China. There are four main indexes that can be used to measure the performance of aeration system: oxygen volume mass transfer coefficient (KLa), standard oxygen transfer rate (R), standard aeration efficiency (SAE), and standard oxygen transfer efficiency (E) (ASCE 2007). Among the most used important indicators are K_La and E. K_La is generally determined using the American Society of Civil Engineers (ASCE) standard method, while E can be calculated using the formula proposed by with K_La as one independent variable (ASCE 2007). So, establishing a predictive model of these two indicators will have a significant impact on the operation and management of the ponds.

Predictive model of aerobic effect is a classic subject, and there have been many studies in the past few decades. Deswal (2011) used a Gaussian regression method to predict the K_La in a multi-directional bubble aerator. Al-Ahmady (2011) established a predictive model of K_La for air diffuser aeration and aeration, which provided theoretical basis for the analysis and design of activated sludge pool. In order to evaluate the K_La in practical application and reduce the actual operation work, Pittoors et al. (2014) studied the predictive models of K_La in activated sludge aeration tank and tap water aeration tank, respectively. Schierholz et al. (2006), in order to predict the K_La below 32 m in deep reservoirs, studied the oxygen transfer rate of the diffuser and established the predictive models for oxygen mass transfer coefficients of bubblewater and water-surface air respectively. However, these studies mainly focus on the prediction of mass transfer coefficient of oxygen mass and lack the prediction of other evaluation indexes.

Thus, based on sufficient laboratory experiments in different conditions (submerged depths of diffuser, air flow rates, aeration tube lengths), empirical models for KLa and E can be developed with independent non-dimensional variables of water bathymetry, hydrodynamics, and dimensions of FBD aeration system. Such models will be helpful for understanding effects of FBD aeration system on DO levels in pond water under various conditions.

3.4 Artificial Destratification

The thermal or density stratification that results from differential heating of surface waters can often lead to the deterioration of water quality. As water at the surface is heated, it becomes less dense (more buoyant) and floats on the cooler denser water below. A diurnally stratified lake or reservoir is typically characterized by a surface layer that stratifies during daytime and mixes nocturnally with convection as heat is lost to the atmosphere. A seasonally stratified lake or reservoir typically has a metalimnion that marks the zone of sharp temperature change between the epilimnion (surface water) and the hypolimnion (cooler bottom water) and persists over some months.

The bloom-forming cyanobacteria tend to dominate phytoplankton communities when lakes or reservoirs are stratified as they contain gas vesicles which provide buoyancy and overcome losses from sedimentation. Under these conditions of relative water column stability, algae that have a density greater than water, such as diatoms, will tend to settle out. Buoyant cyanobacteria, however, will float up and concentrate their biomass in the illuminated, near-surface mixed layer. The degree of mixing, therefore, plays a key role in determining phytoplankton competition and succession (Visser et al. 2015).

Density stratification within a lake or reservoir indicates there is no or restricted vertical mixing, limiting gas exchange with the atmosphere. Microbial activity in the sediments, termed the sediment oxygen demand, can utilize the available oxygen, significantly reducing the dissolved oxygen concentrations.

This can lead to hypoxic or anoxic conditions in the diurnally stratified lower water layer or seasonal hypolimnion, with redox conditions that promote the flux of nutrients and metals from the bottom sediments. Reduced manganese will be released from sediments when dissolved oxygen concentrations in the overlying water are less than 4 mg L^{-1}. Iron and phosphorus are released from the sediments at still lower oxygen concentrations. Iron and manganese are problematic as they can persist in reduced form during water treatment and cause 'dirty water' issues as they oxidize upon exiting the consumer's tap. Nutrients released from the sediment are a concern as they can increase algal growth, with the cyanobacteria being of particular concern as they produce toxins and compounds that cause taste and odor issues for potable water.

Artificial destratification is a commonly used technique to disrupt or prevent the initiation or persistence of stratification, making the water column of a lake or reservoir more vulnerable to overturn from wind or convection, and increasing gas transfer to the hypolimnion. There are two distinct types of devices used for artificial destratification: bubble-plume aerators and surface mounted mechanical mixers. Bubble-plume aerators disrupt the stratification (Figure 2) and transport gas and heat deeper in the water column. There are many examples of successful bubble-plume aerators. In Chaffey Dam (Australia), the years when the bubble-plume aerator was operated had considerably lower phosphorus concentrations in the hypolimnion than in years when the aerator was not operated (Sherman et al. 2000).

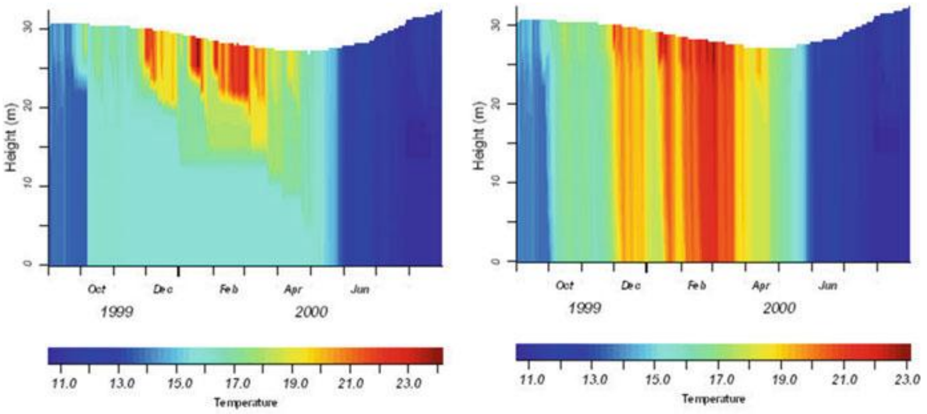

Figure 2 - Model simulation of Myponga Reservoir over 12 months using the one-dimensional hydrodynamic model DYRESM. (left temperature profile under natural conditions, right - temperature profile using artificial destratification)

Artificial de-stratifiers are often deployed to control cyanobacteria. The theory is that phytoplankton will be mixed deeper in the water column and so become light limited. Furthermore, in a fully mixed water column, the advantage of cyanobacteria buoyancy is nullified. It is evident that stratification still occurs outside of the immediate influence of the bubble plume. Visser et al. (1996) demonstrated that Microcystis aeruginosa colonies remained positively buoyant close to a bubble plume in Lake Nieuwe Meer (The Netherlands) as the mean light that colonies experienced was low due to deep mixing and photosynthate (sugar) accumulation insufficient to overcome the buoyancy provided by gas vesicles. In contrast, Microcystis colonies in the more stratified regions further away from the aerator cells were not fully mixed, floated up and experienced higher mean light near the surface. Artificial mixing to control cyanobacteria is not always successful and should be carefully designed, taking into account key characteristics of the lake—like average and maximum depth—and characteristics of the dominant cyanobacteria - like size and flotation velocity (Visser et al. 2015).

The fact that intense temperature stratification can occur in the surface layers and support cyanobacterial populations, even when bubble-plume aerators are used, prompted trials using surface mounted mechanical mixers. These consist of large impellers that draw water through a draft tube in either an upward or downward flow configuration. Lewis et al. (2010) measured flow in a downward impeller configuration and showed that a small temperature difference between the surface water and the water at the depth of exit meant that the warmer buoyant water returned rapidly to the surface and mixing with the adjacent water was minimal. While the energy use of these systems is considerably less than bubble-plume aerators, the mixing is inefficient and the surface mounted mixers need considerably more maintenance. Small solar-powered mixers, for example, are ineffective at mixing lakes and have an extremely small zone of influence (Upadhay et al. 2013).

Artificial destratification not only mixes dissolved gas that diffuses into the sediment, but also transfers heat. The warmer temperatures may stimulate microbial activity, which will increase oxygen demand and may also increase the bottom-sediment contaminant fluxes if oxygen is in short supply.

Hypolimnetic oxygenation is a possible alternative to artificial destratification as a method to limit metal and nutrient fluxes from sediment. A major benefit is that oxygen is delivered to the bottom waters and diffuses to the bottom sediment, but the lake is not destratified and so a cooler hypolimnion is maintained. Hypolimnetic oxygenation is becoming more widely used and may present a sound alterative to artificial destratification as the climate warms and vertical density stratification increases. It has less potential, however, to specifically remove the physical conditions that promote buoyant colonial cyanobacteria.

3.5 Nitrogen and Phosphorus removal

Nitrogen (N) and phosphorus (P) are the key nutrients causing eutrophication in waterways. Therefore, they are compulsorily removed from wastewater sources in most developed countries. In conventional biological nutrient removal (BNR) systems, N removal is accomplished by a two-stage treatment, aerobic nitrification and anoxic denitrification (Metcalf and Eddy, 1991), whereas P removal is achieved through enhanced biological phosphorus removal (EBPR) under alternating anaerobic–aerobic conditions using polyphosphate-accumulating organisms (PAOs) (Comeau et al.,1986; Wentzel et al., 1988). Both N and P removal processes require COD, which is often the limiting substrate in the incoming wastewater. Making best use of the available COD for N and P removal is one of the objectives of current research and development efforts in BNR design and operation.

More studies have been showing that nitrification and denitrification can occur concurrently in one reactor under aerobic conditions with low dissolved oxygen (DO), through the so-called simultaneous nitrification and denitrification (SND) process (Bertanza, 1997; Helmer and Kunst, 1998; Keller et al., 1997; von Münch et al., 1996). In addition, it has been reported that N removal can be achieved by partial oxidation of ammonium to nitrite, which is then directly reduced to N gas (Surmacz-Gorska et al., 1997; Yoo et al., 1999). This process, termed SND via nitrite, saves 40% of the COD requirement compared with conventional denitrification via nitrate. It has also been reported to achieve higher denitrification rates and a lower biomass yield during aerobic growth (Turk and Mavinic, 1986,1989).

Furthermore, it has been found that denitrification can be accomplished by the so-called denitrifying PAOs (DPAOs) in anaerobic–anoxic EBPR systems, allowing simultaneous nitrate/nitrite reduction and P uptake using the same COD (Kerrn-Jespersen et al., 1994; Kuba et al., 1993). In addition, compared with PAOs, DPAOs are 40% less efficient in generating energy, and thus have a 20% to 30% lower cell yield (Kuba et al., 1994; Murnleitner et al., 1997). Therefore, the use of DPAOs in BNR systems is highly beneficial in terms of lower COD demand, reduced aeration cost, and less sludge production.

Ideally, if SND via nitrite could be accomplished with the DPAOs, even more COD could be saved, because the soluble COD in the domestic wastewater is typically limit-just anaerobic and aerobic conditions.

4. Solutions for reversal of eutrophication in the Siutghiol Lake

Eutrophication reversal in Siutghiol Lake requires a multi-pronged approach, addressing both external nutrient loading and internal nutrient cycling. Solutions for reversal of eutrophication are grouped into five components:

I. **Reduce external nutrient loading:**

- Upgrading wastewater treatment, which requires implementation of advanced treatment (upgrading existing wastewater treatment plants to incorporate advanced technologies like biological nutrient removal (BNR) or chemical precipitation to effectively remove nitrogen and phosphorus), regular maintenance of the facilities (ensuring proper operation and maintenance of wastewater treatment facilities to minimize nutrient discharges).
- Controlling agricultural runoff implies using best management practices, focused on promoting the adoption of sustainable agricultural practices, such as cover crops (planting cover crops during off-seasons to prevent soil erosion and absorb excess nutrients) and buffer strips (establishing vegetated buffers along waterways to intercept and filter runoff), as well as using precision fertilization approaches (i.e. applying fertilizers at the right time and in the right amount to minimize nutrient losses) and appropriate manure management (storage and application of manure to reduce nutrient leaching).
- Managing urban runoff applies the following measures and actions: implementation of stormwater management practices, e.g. rain gardens (creating vegetated depressions to capture and filter stormwater), bioswales (constructing shallow channels lined with vegetation to slow down and filter runoff), permeable pavements (using permeable materials that allow water to infiltrate into the ground) and green roofs (installing vegetation on rooftops to absorb rainwater and reduce runoff).
- Reducing atmospheric deposition from industrial and vehicular sources that contribute to atmospheric deposition of nitrogen and phosphorus.

II. **Address internal nutrient cycling for increasing efficiency of the measures for long-term eutrophication control:**

- Sediment dredging to be used to remove nutrient-rich sediments from the lake bottom that will reduce the pool of nutrients available for release into the water column. Thus, dredging should target areas with high nutrient concentrations, while thorough environmental assessments are crucial to minimize ecological disruption.
- Hypolimnetic aeration to be used to introduce oxygen to deeper layers of the lake that will prevent the release of phosphorus from sediments. Thus, oxygen promotes oxidation of iron and manganese, which bind phosphorus in the sediment, reducing its availability for release. It can be achieved using diffusers, airlift systems, or other aeration technologies.
- Biological control implies using organisms that will consume excess nutrients or bind them in their tissues. Such organisms can be filter-feeding organisms such as mussels and zooplankton, which will consume algae and suspended particles containing nutrients or submerged and emergent aquatic plants, which will absorb nutrients from the water column and compete with algae.
- Manipulating the food web is used to adjust the fish community to favor species that control algae populations and reduce herbivorous fish that can promote algal growth.

III. **Restore ecological balance, which involves a multifaceted approach aimed at re-establishing a healthy and diverse ecosystem:**

- Reintroducing native aquatic plants to release oxygen through photosynthesis, improving water quality; to absorb excess nutrients from the water, reducing the risk of algal blooms; to provide shelter and food sources for various aquatic organisms, as well as to stabilize shorelines and prevent sediment runoff.

- Using biomanipulation to adjust the fish community to restore a balanced food web. For restoring fish communities planktivorous fish are preferred (they feed on zooplankton, which in turn consumes algae, helping to control algal blooms). At the same time, populations of herbivorous fish should be reduced, which can overgraze aquatic plants, disrupting the ecosystem.
- Protecting and restoring riparian zones to control and improve nutrient filtration; planting vegetation for erosion control of the shorelines, preventing sediment runoff; actions for habitat enhancement. Reforestation and buffer strips (using trees and shrubs) are extremely useful for riparian zone protection.
- Addressing invasive species helps in restoring native biodiversity.

IV. Designing an effective monitoring and adaptive management system for eutrophication prevention in Siutghiol Lake requires a multi-faceted approach with the following main pillars:

- Determination of clear goals and quantifiable objectives by specifying the SMART goals (specific, measurable, achievable, relevant, and time-bound), i.e. by defining timing, levels, and thresholds for reducing nutrient concentrations, for maintaining dissolved oxygen levels, restoring of aquatic plant diversity, and preventing harmful algal blooms, including measures and procedures for emergency actions.
- Designing a comprehensive monitoring program, which identifies key parameters that reflect the lake's ecological health, such as water quality indicators with critical thresholds for nutrient concentrations (nitrogen, phosphorus), dissolved oxygen, chlorophyll-a, and turbidity; biological parameters, including threshold values for phytoplankton and zooplankton abundance and diversity, fish populations, benthic macroinvertebrates; physical parameters, such as water temperature and flow rates. The program must include methodologies and procedures for parameter sampling, such as establishing monitoring sites, determining sampling frequency, implementing quality assurance/quality control (QA/QC) measures to ensure data accuracy and reliability.
- Designing an appropriate data analysis and interpretation procedure, which should include robust statistical methods for data analysis and assessment of the effectiveness of management actions; produce relevant visuals, such as maps, graphs etc.; integrate data from multiple sources (monitoring programs, historical records etc.).
- Designing an adaptive management framework in such a way that the decision-making process is informed and flexible. It should include a set of management solutions able to recommend actions based on scientific understanding and stakeholder input and test the effectiveness of different management actions on a smaller scale. The feedback based on monitoring results and new scientific information, adapt management actions as needed should improve the adaptability of the existing system
- Engaging stakeholders (local communities, landowners and specific business owners) in the monitoring and management system on an active basis; sharing monitoring findings with the public and stakeholders as well as fostering relationships among stakeholders to ensure effective implementation of management actions.
- Opening the monitoring and management system to technological advancements by using remote sensing technology (satellite and UFV) to monitor water quality and vegetation cover over the entire water surface of the lake; engage volunteers in data collection and monitoring activities as well as developing early warning systems to prevent potential problems.

V. **Public awareness and engagement are crucial for successful eutrophication reversal in the long-term perspective.** The management system should include measures and actions focused on educating the public, involving stakeholders not just in monitoring but in education as well, as well as stress and promote responsible behaviors

- For education of the public there is a need for developing informative materials, organizing workshops and presentations, with participation of residents, students, local business actors; local media and social media campaigns should be intensively used to disseminate relevant information, including attraction of local influencers in media campaigns.
- Involving stakeholders into the decision making process includes organization of community meeting to discuss the eutrophication problem, gather input from residents, and develop a shared vision for lake restoration; formation of the lake stewardship group needed to advocate for lake protection, organize community events, and implement restoration projects; engage local businesses in supporting lake restoration efforts, such as sponsoring events, implementing sustainable practices, and promoting environmental awareness among their customers.
- Measures to promote responsible behavior should encourage water conservation practices in households and business processes and proper disposal of household waste, including fertilizers, pesticides, and other chemicals that can contribute to nutrient pollution. Adoption of sustainable practices, such as using eco-friendly fertilizers and composting organic materials should be implemented in households and business processes.
- Recognition of the efforts should represent an important part of the management system. Such actions as recognizing and rewarding individuals and organizations that contribute to lake restoration efforts or sharing success stories and positive outcomes of restoration efforts are crucial to inspire and motivate the community to keep the efforts of reversal eutrophication of Siutghiol Lake.

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