DEFEATING TOXIC ALGAE BLOOMS (CYANOHABS)

THE EUTROPHY SOLUTION

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Defeating Toxic Algae Blooms:

The Eutrophy Solution

Prior to getting started there are a few terms that need defining.

Eutrophic: (of a lake or other body of water) rich in nutrients and so promoting growth of aquatic vegetative biomass in the form of weeds, algae and Cyanobacteria through a variety of complex interacting mechanisms.
Biome: a large naturally occurring community of flora and fauna forming a major habitat.
Benthic: the zone at the bottom of a water body, including the sediment
Biomass: any living or dead matter
Biodiversity: the variety of life in the world or in a particular biome or ecosystem
Cyanobacteria: a class of organisms that produce toxin producing blooms commonly called "bluegreen algae", HABs (Hazardous Algae Blooms) or CyanoHABs
Nutrients: key inputs for the formation of biomass (the emphasis in this context usually being placed on nitrogen, phosphorus and to a lesser extent carbon
Potable Water: water that is of drinking quality
Stratification: layering of the water column due to water having different temperature and dissolved oxygen levels
Sediment: muck, sludge and silt that accumulates on the bottom of a water body
Wastewater treatment infrastructure: an aquatic biome in which nutrients and contaminants are removed from water to improve water quality.

"Eutrophic water bodies are just wastewater treatment infrastructure waiting to be commissioned"

Executive Summary

Eutrophication of bulk water resources in rivers, lakes, dams and reservoirs is at the epicenter of the Global Water Crisis because it is degrading vast quantities of freshwater resources at an accelerating rate at the same time that population growth and urbanization are accelerating the demand for clean safe water.

Eutrophication is conventionally defined as an excessive amount of nutrients in a water body and treatments are aimed at lowering nutrient levels in the water.

But exactly what kind of biomass nutrients in these water bodies are directed into forming is at the heart of eutrophication.

That is because a eutrophic aquatic biome is eventually dominated by biomass in the form of cyanobacteria because they dominate the uptake of nutrients, so toxic HABs are the end game of eutrophication.

They are able to dominate nutrient uptake due in no small way the the fact that conventional palliative treatments aimed at countering the symptoms of eutrophication have acted to stockpile nutrients where Cyanobacteria want them, and where only they can access them; in benthic sediments. So these misguided treatments are accelerating the process and making things worse.

In developing The Eutrophy Solution we took a different view of the problem. We reasoned that nutrients and nourishment are a good thing. The problem was that the nutrients were being misappropriated and monopolized for the production of the wrong kind of biomass in a eutrophic environment.

So the solution would lie, not in shuffling nutrients around the water body like deck chairs on the Titanic, but in creating an environment where nutrients could be dominantly taken up in the formation of biomass in a productive Food Chain.

By achieving this, eutrophic water bodies are directed to perform the function of wastewater treatment works as they remove contaminants and nutrients from the water and direct them into the formation of desirable biomass that ensures sustainable optimum water quality.

Billions are spent constructing additional new wastewater treatment infrastructure to remove contaminants and nutrients from water. Implementation of The Eutrophy Solution effectively commissions eutrophic water bodies as wastewater treatment infrastructure in a fraction of the time and at a fraction of the cost of conventional methods.

It is only by implementing effective solutions to reverse eutrophication that the scourge of toxic algae blooms can be defeated, and the quality of water resources can be maintained.

This in turn is the only pathway to Renewable Water which is the only way that the Global Water Crisis can be resolved and adequate water for drinking, bathing and water borne sanitation for everyone can be achieved.

Eutrophication is a distortion of the Nutrient Cycle that allows algae and cyanobacteria to dominate nutrients in an aquatic biome.

Public and professionals need to understand that conventional treatments are making things worse.

By creating conditions that promote nutrient uptake into a productive Food Chain, toxic cyanobacteria are starved, nutrients are removed, fish numbers, size and health are improved, optimum water quality is restored.

Eutrophic water bodies are all just wastewater treatment infrastructure waiting to be commissioned.

Toxic CyanoHABs

Every year CyanoHABs (Cyanobacteria Hazardous Algae Blooms or toxic bluegreen algae blooms) appear earlier, last longer, and are more widespread and more intense. This rapid, accelerating degradation of bulk water resources as they succumb to eutrophication is the single biggest threat to sustainable water and food security globally.

In many ways, this is a self-inflicted catastrophe; firstly because it is the consequence of urbanization, population growth and the highly engineered water resource management strategies and infrastructure that we have implemented over the past few hundred years and secondly, because to date our misguided attempts to address the symptoms of eutrophication have actually made things worse.

We have been the engineers of our own demise. It is man-made inputs from wastewater treatment plants and agricultural activities that load water resources with the contaminants/nutrients that are driving "eutrophication", which is the process by which this systemic degradation of water resources takes place.

Eutrophication is a progressive systemic biological process that degrades the whole water body until a transformational tipping point is reached and the eutrophic water body becomes dominated by rampant algae and toxic cyanobacteria blooms. Cyanobacteria are the cause of toxic Hazardous Algae Blooms or HABs, and once they release their toxins there is no way to purify the water to make it safe for drinking, swimming or recreation.

When safe drinking water cannot be supplied, the news is full of "the water shortage" as our taps dry up because there is no safe toxin-free water to send to them. But there is no shortage of water. There is plenty of water, it is just too contaminated with algae and toxic cyanobacteria for it to be purified for consumption.

CyanoHABs are like AIDS was 40 years ago

Toxic CyanoHABs are like AIDS was 40 years ago, an "under the radar" global scourge that will affect everyone; rich and poor, young and old, urban and rural. Like AIDS, eutrophication can progress unrecognized and without major overt symptoms for years in a lake dam or reservoir, and by the time symptoms present it is too late; the capacity to combat the threat and recover full health has been lost. Sadly, as with AIDS, all the victims can do is accept their fate.

When water resources are rendered unusable it is not just a few unfortunate individuals who suffer or are deprived. It is whole communities, towns and cities. And millions of people suddenly afflicted by a lack of drinking water, no washing or bathing, no sanitation, rampant contagious diseases like cholera and dysentery don't quietly accept their fate.

Social and political turmoil is stirred up as protests and tempers flare, and where borders are involved many are predicting that disputes over water resources will lead to wars. Right now, there are too many scientists, bureaucrats, officials and politicians ignoring the fact that the fuse on this time bomb has been lit.

Eutrophication

The word "eutrophy" is derived from the Greek "eutrophos" which means "well nourished". The term was coined around 1930 to describe water bodies experiencing prolific algae blooms that were associated with high levels of the nutrients Nitrogen (N) and Phosphorus (P) in the water.

Over the next 30 years eutrophication became a more prevalent and high-profile issue as more and more lakes, dams and reservoirs became plagued with algae blooms. In the 1970's veterinarians, particularly in Australia and South Africa, started reporting numerous incidents of dead sheep that farmers were finding at watering holes where bright green algae blooms were present.

It was Professor Wayne Carmichael, then a graduate student at the University of Alberta, who determined that it was Cyanobacteria that formed these "Hazardous Algae Blooms" or CyanoHABs and produced the toxins responsible for the fatalities.

One may well ask why "well nourished" should be a bad thing. The answer lies in the process of "eutrophication" by which nutrients are misappropriated and monopolized into the production of algae and cyanobacteria, rather than a productive "Food Chain" which produces fish.

Eutrophication is thus a distortion of the Nutrient Cycle that allows algae and cyanobacteria to dominate nutrients in an aquatic biome. This is to the detriment of the productive Food Chain needed to maintain the water quality necessary to ensure sustainable food production

Eutrophication is a distortion of the Nutrient Cycle that allows algae and cyanobacteria to dominate nutrients in an aquatic biome.

and the modern lifestyle (bathing, water borne sanitation and drinking water on tap) required by a global urbanized population that has ballooned since the Industrial Revolution.

Eutrophication is a systemic transformation of the aquatic biome, that superficially manifests in a variety of symptoms. These are usually labeled "causes" and "effects" of eutrophication but this characterization fails to consider the systemic nature of the problem or the Systems Theory paradigm that governs it.

These "causes and effects" include stratification and deoxygenation of the water column, accumulation of anaerobic, nutrient-rich organic sediments, high levels of nitrogen and phosphorus in the water column, and a proliferation biomass formation in the form of invasive aquatic weeds, algae and cyanobacteria culminating in toxic cyanobacteria blooms or "CyanoHABs".

But the key to understanding eutrophication lies in the name; "well nourished". The problem is that <u>it is the algae and cyanobacteria that become well nourished</u> by dominating the uptake of the available nutrients, not the biodiverse organisms that make up a productive Food Chain and are synonymous with the sustainable Water Cycle and Nutrient Cycle that we need to ensure Renewable Water on a global scale.

If it wasn't for toxic Cyanobacteria, eutrophication would not be much more than an unsightly cosmetic issue. But the inevitable endpoint of the eutrophic process is toxic CyanoHABs that result from Cyanobacteria dominating nutrient uptake in eutrophic conditions. These toxic blooms are known by a variety of terms; toxic bluegreen algae, BGA, toxic HABs (Hazardous Algae Blooms), CyanoHABs.

They render the water body unusable for recreational activities such as swimming, water skiing, fishing, kayaking, cause mass fish-kills and they can make it impossible to purify the water to produce safe drinking water, resulting in lethal toxins in a town or city's drinking water and "do not drink the water" alerts on radio, TV, and newspapers describing the situation as a "water shortage".

Playing "Whack-a-Mole" with the symptoms

Billions of dollars have been spent on treating symptoms of eutrophication that have misguidedly been thought of as causes.

These symptoms include high nutrient levels in the water and sediment that fuel an excessive proliferation of invasive aquatic weeds, algae and toxic cyanobacteria (usually in that order).

Because of this, treatments have focused on attempting to reduce nutrient levels in the water and have included

- Using chemicals such as alum to precipitate phosphorus into the sediment
- Using aeration to raise dissolved oxygen levels to precipitate phosphorus into the sediment
- Applying herbicides to kills aquatic weeds that die off and sink into the sediment
- Applying algaecides to kill algae that die off and sink into the sediment

There is a big industry that makes a lot of money selling these treatments, and it's been a great business model for them because they can come back every year to repeat their treatments and make the situation worse next year.

Their sales pitch is compelling and seemingly logical:

"The phosphorus levels in the water are too high? We'll precipitate the phosphorus down into the sediments with alum."

"The phosphorus levels in the water are too high? We'll precipitate the phosphorus down into the sediments with an aeration system."

"You have too many invasive weeds? We'll kill them with an herbicide."

"You have massive algae blooms?" We'll kill them with algaecide."

These explanations of how to treat the symptoms of eutrophication sound simple and logical. But the situation keeps getting worse and these treatments are a big part of the cause of this.

History will view the decades that we have spent applying these various chemicals as a self-inflicted catastrophe because it has only served to make the situation more and more favorable for CyanoHABs by accumulating nutrients in the sediments where the cyanobacteria can preferentially feast upon them. This is evidenced by the fact that these toxic CyanoHAB blooms are occurring earlier in the summer, lasting longer, are more intense and more widespread every year.

Public and professionals need to understand that conventional treatments are making things worse.

Until both the public and water industry professionals get a better understanding of how Cyanobacteria exploit eutrophic conditions, and how conventional "treatments" make eutrophication worse and thus are driving the worsening of CyanoHABs every year, we will be doomed to a worsening Global Water Crisis.

Understanding Eutrophication

Rather than defining eutrophication as "*too many nutrients in the water body*" we chose to define it as "*too many nutrients being taken up to produce the wrong kind of biomass: toxic cyanobacteria*".

This naturally leads one to investigate what it is about a eutrophic water body that so strongly favors the appropriation of nutrients by cyanobacteria. How do they inevitably come to dominate nutrient uptake?

It is important to understand that eutrophication is a systemic process – it affects the whole water body or aquatic biome. You cannot have eutrophication in one area of a lake only. Equally, you cannot only treat or remediate one area of a lake.

Because eutrophication is systemic, it operates according to the laws of Systems Theory which means that eutrophication is a multi-faceted reorganization of a whole biome with many factors at play.

This produces a plethora of symptoms that might show some correlation that is too easily confused as causation. There is feedback and interaction between the causative factors and the symptoms making it more complex than simple cause and effect.

To understand these systemic changes let's break them down into Physical changes and Biological changes.

Physical Changes

The two main physical that changes occur as eutrophication takes hold are stratification and deoxygenation.

Stratification of the water column manifests in two ways, by temperature and dissolved oxygen levels.

The basic laws of physics tell us that

- Warmer water is less dense than cold water. So warm water rises to the top and denser cold water sinks to the bottom
- Oxygenated water is less dense than deoxygenated water. So oxygenated water rises to the top and denser deoxygenated water sinks to the bottom.

When stratification or layering takes place in a eutrophic water body, at the bottom you have dense, heavy, colder deoxygenated water. Because this water is denser and heavier it is effectively locked in at the bottom of the water column by gravity.

Deoxygenation of the water has major consequences because it creates what are called anaerobic conditions in the benthic zones at the bottom of the water body.

Living organisms can be broken down into two types – aerobic ones that need oxygen and anaerobic ones that don't. Anaerobic conditions obviously favor anaerobes. Fish need oxygen in the water to breath, so this is bad news for fish.

Weeds, algae and cyanobacteria are anaerobes and don't need oxygen, so this is good news for them.

The third significant physical change that takes place is an accumulation of organic sediment in this anaerobic benthic zone at the bottom of the water column. This organic sediment is rich in nutrients, so any organisms that can exploit these conditions and access these nutrients will be "well nourished" in eutrophic conditions.

Biological Changes

Again, the first point to note is that eutrophic conditions, especially lower in the water column, are less favorable to oxygen breathers or animal life and more favorable to plant life such as aquatic weeds, algae and cyanobacteria.

Floating aquatic weeds and algae can take up nutrients, most importantly nitrogen and phosphorus that are in the water column.

For rooted aquatic weeds, a nutrient rich sediment provides a perfect rooting bed for them to flourish.

So, weeds and algae are usually the early beneficiaries of eutrophication as they can take up available nutrients and deny them to zooplankton, insects and fish that form a productive Food Chain.

But over time, it is the potentially toxic Cyanobacteria or bluegreen algae than can best exploit eutrophication to their advantage.

Nutrients such as nitrogen and phosphorus are taken up by aquatic weeds & algae during the summer months as they bloom and flourish. In winter they die off, sink to the bottom and decay. This decomposition makes the nutrients available again in the sediment. In addition to this you get other organic inputs, such as leaves from trees that add to the nutritious sediment.

So, recycling of nutrients occurs as positive feedback loops that drive worsening algae. Then, over time, Cyanobacteria blooms take over as eutrophication itself is worsened by similar positive feedback loops.

Biologically, what we see are conditions that favor nutrient appropriation in favor of life-forms that we *do not* want in our water. Algae, then toxic cyanobacteria, become "well nourished" in a eutrophic water body.

But what is it that ultimately enables cyanobacteria to get the upper hand and become dominant?

Understanding Cyanobacteria

To understand what Cyanobacteria are and where they came from, we need to go back to when the very first life-forms emerged on earth.

Because there had never been any living thing on earth there was no food as such, so the very first life-forms on earth had to be autotrophic – meaning that they had to be able to create their own nutrition or food from scratch from the chemicals available in "primordial soup".

Conditions were harsh, so the raw materials that they had to work with were substances that are toxic to us such as hydrogen sulfide, ammonia and methane. The first organisms to evolve on earth were bacteria called extremophiles. Such organisms still proliferate where such extreme conditions still exist – at the bottom of the ocean where sulfurous material leaks through from the earth's crust and in eutrophic water bodies.

To do the chemical processing for biomass formation on a diet of hydrogen sulfide, ammonia and methane takes a lot of chemical energy and is inefficient. So, organisms evolved that could harness the energy in sunlight to fuel their biomass formation through photosynthesis. These organisms are what we call Cyanobacteria or bluegreen algae.

Calling them "algae" is a bit confusing. They are perhaps better thought of in evolutionary terms as a half-way step between autotrophic bacteria and algae, possessing characteristics of both;

- They can utilize ammonia and methane as nutrient sources like autotrophic extremophiles
- They can utilize the sun's energy to photosynthesize

Cyanobacteria are extremely resilient, agile and adaptable, so with autotrophic bacteria as their only competitors, and the sun's energy driving their photosynthesis, they produced biomass prodigiously and became by far the most dominant life-form on earth for hundreds of millions if not billions of years.

But there was a catch; although photosynthesis doesn't need oxygen as in input, it produces oxygen as an output.

So over hundreds of millions of years, Cyanobacteria emitted huge amounts of oxygen into the atmosphere, fundamentally changing it. First the oxygen reacted with methane to produce carbon dioxide.

Cyanobacteria were the first organisms to bring about their own demise by emitting gas into the atmosphere.

Algae evolved that could use carbon dioxide as a nutrient, and as this was becoming more and more abundant it gave them a competitive advantage over cyanobacteria. Cyanobacteria also developed the ability to use carbon dioxide as a nutrient. This put them on a par with the algae but did not give them any competitive advantage over algae.

With both cyanobacteria and algae photosynthesizing to proliferate prodigiously, the atmosphere became plentiful in oxygen itself or aerobic. This created an environment that favored aerobic organisms and they – the animal kingdom - began to proliferate to the detriment of cyanobacteria.

So, cyanobacteria were the first organisms to bring about their own demise by emitting gas into the atmosphere.

But Cyanobacteria haven't gone extinct. They are still around, and making a comeback, so let's understand the conditions that are driving this.

Conditions Driving CyanoHABs

Billions of years ago cyanobacteria thrived in "primordial soup" – which is an aquatic environment in which there is little to no oxygen and nutrients are available in the form of substances such as hydrogen sulfide, ammonia, and methane.

Where do they find these conditions nowadays?

We are creating them at the bottom of eutrophic water bodies.

Recent research indicates that 20% of the methane emitted into the atmosphere does not come from hydrocarbon combustion but from the bottom of eutrophic water bodies.

So finally let's understand how Cyanobacteria are able to exploit eutrophic conditions and appropriate nutrients to outcompete other life forms and bloom so prodigiously.

There are four key facts about a eutrophic water body that we need to understand:

1. Cyanobacteria need to be at the bottom to take advantage of all the nutrients that are available in "primordial soup" conditions where they can assimilate them, but competitors can't
2. Cyanobacteria need to be at the surface in order to hog the sunlight to photosynthesize and proliferate
3. A eutrophic water body is stratified into layers
4. Cyanobacteria have tiny gas vesicles in their cells that they can inflate and deflate.

In a stratified water column where the density of the water varies with each layer, if you can control your buoyancy by inflating and deflating a gas vesicle, you can

- descend to the bottom at night, load up on nutrients in the form of methane and ammonia that competitors such as aquatic weeds and algae cannot process as nutrients and then
- float back up to the top during the day to hog the sunlight and convert all those nutrients into new biomass as you rapidly proliferate and bloom thus outcompeting your competitors for both nutrients and the sun's energy.

So, by causing eutrophication we are actively creating conditions that promote the proliferation of potentially toxic Cyanobacteria that degrade our water resources.

Equally by inflicting the favored treatments to reduce nutrient levels in the water;

- Using chemicals such as alum to precipitate phosphorus into the sediment
- Using aeration to raise dissolved oxygen levels to precipitate phosphorus into the sediment
- Applying herbicides to kills aquatic weeds that die off and sink into the sediment
- Applying algaecides to kill algae that die off and sink into the sediment

we have stockpiled these nutrient where the cyanobacteria want them; in the anaerobic sediments. Because the benthic zones are anaerobic, they are also stockpiled *how* the cyanobacterial want them: in a chemical form such as ammonia and methane that only cyanobacteria can utilize as nutrients.

Billions of dollars spent in efforts to make things better are actually making things worse.

The Eutrophy Solution

In developing The Eutrophy Solution, rather than defining eutrophication as "*too many nutrients in the water body*" we chose to define it as "*too many nutrients being directed into the formation of the wrong kind of biomass: toxic cyanobacteria*".

We followed the Scientific Method and established a logical model or hypothesis whereby we articulated the root causes of eutrophication as described above. We also articulated a new definition of eutrophication as described above and laid out what sustainable changes needed to be facilitated in a eutrophic water body to re-establish conditions where nutrient uptake is dominated by the full biodiversity of organisms that make up a productive Food Chain.

By creating conditions that promote nutrient uptake into a productive Food Chain, toxic cyanobacteria are starved, nutrients are removed, fish numbers, size and health are improved, optimum water quality is restored.

In essence, there are three changes that need to be effected:

1. Physical Changes that will negate the competitive advantages that Cyanobacteria have in eutrophic conditions.

2. The conversion of organic contaminants into nutrients that are available to be taken up in the formation of desirable biomass such as zooplankton and fish.

3. The promotion of the active uptake of those nutrients by organisms that create the foundations of a productive Food Chain, so that such a Food Chain can be re-established and sustained.

Most importantly we had to ensure that the solution is a holistic one that operates in a systemic, synergistic manner that exploits feedback effects to our advantage. We reach this goal by establishing feedback loops that strengthen and entrench the conditions that we want to prevail to ensure sustainability of the solution.

We have developed the technology to achieve all these changes in a consistent, scalable manner for water bodies of all size, shape, depth and condition.

Specifically, we have developed unique Biotechnology Solutions to achieve

1. Physical Changes
   - Destratification of the water column to negate the advantage that Cyanobacteria have by being able to navigate up and down a stratified water column
   - Reoxygenation of the benthic zone at the bottom of the water column in favor of aerobic not anaerobic life-forms

2. Conversion of Organic Contaminants into Nutrients for assimilation into a productive Food Chain
   - Reduction in N and P levels in the water column and in the sediment
   - Reduction and elimination of the muck and sediment itself

3. Processing of nutrients by assimilation into a productive Food Chain as evidenced by
   - Reduction in the proliferation of aquatic weeds, algae, Cyanobacteria and pathogenic anaerobes such as e. coli
   - Improved fish life
   - Improved biodiversity

Eutrophic water bodies are all wastewater treatment infrastructure waiting to be commissioned.

Conclusion

Eutrophication is a potentially terminal threat to every water body on earth. Degradation of water resources to the point where they cannot be used to provide for our potable water, bathing, sanitation and public health needs can rapidly escalate into politically explosive crises and wars.

Conventional so called “best management practices” of bulk water resources validate the truth of the old adage that “*if you keep doing what you are doing, you will keep getting what you have been getting*”. But in this case, by continuing with these practices you will also keep accelerating what you are accelerating, which is the eutrophic process and the inevitable crises that will follow.

Eutrophication is a nutrient processing problem, which means the solution lies in the domain of biochemistry and Biotechnology, not concrete and steel engineering. So the development of the Eutrophy Solution is founded in research, insight and innovation. That has all been completed, tested and proven over the last decade and the Eutrophy Solution is delivering relief from toxic CyanoHABs and water degradation all over the world.

Now all that is required is insight, comprehension and decisiveness among those who prowl the corridors of power over water resource management.

The conventional term for infrastructure that removes nutrients and contaminants from water is “wastewater treatment works”. Wastewater treatment works are infrastructure assets.

Every eutrophic water body can become a highly efficient infrastructure asset, actively removing nutrients and contaminants from our water resources – in other words **every eutrophic pond, lake, dam and reservoir is wastewater treatment infrastructure just waiting to be commissioned**.

Who is SIS.bio?

SIS.bio is the developer and provider of the only proven Integrated Water Resource Management (IWRM) Solution Platform for Renewable Water.

SIS.bio is a turnkey Solution Provider. Through our relationships with global experts, academics, innovators and consultants we offer:

1. Consulting and advisory services on the development and implementation of Integrated Water Resource Strategy for Renewable Water based upon managing water quality throughout the Water Cycle to ensure maximum reusability of water resources

2. Bio-Engineering and Solution Design for
    - refurbishment and rehabilitation of existing WWT infrastructure
    - reversal of eutrophication of dams, lakes, reservoirs etc
    - maintenance of water quality in dams, lakes, reservoirs etc
    - maintenance of water quality in intensive commercial aquaculture operations

3. Technical support, skills transfer and capacitation of local partners globally

4. Real-time performance monitoring of infrastructure operations and water quality to support proactive operations, maintenance and management practices.

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