Planktonic:

In-water Intervention and Prevention Strategy
Emerging Supporting Field Data

Benthic:

In-water Intervention and Prevention Strategy
No Supporting Field Data

There are a number of distinct patented methods for the formation of nanobubbles and impregnating them with air, oxygen, or ozone. These bubbles can then in turn be dispersed into receiving waters to mitigate or remediate contaminating organisms, chemical contaminants, and cyanotoxins. True nanobubbles are <100 nm in diameter and disperse throughout the water column much like a dissolved gas. They may persist for weeks to months in the water column. Treating water with nanobubbles is significantly different from any standard bubbling or aeration technique. Whereas larger bubbles are visible or rise to the surface, nanobubbles are too small to rise in the column in any significant fashion. Larger bubbles exiting the water column will not provide the required mitigating/remediation oxidation of cyanobacteria, contaminants, and cyanotoxins that nanobubbles provide. Larger, visible bubbles will aerate and destratify water bodies, a good option for HCB control, but will not kill the cyanobacteria (for more detail on aeration, see the artificial circulation and mechanical mixers and hypolimnetic oxygenation and aeration strategies).

Dispersed nanobubbles eventually collapse, releasing ozone into the water column. As ozone degrades it also produces hydroxyl free radicals and peroxides, strong oxidizing agents that act as effective bactericides (Tsuge et al. 2009). Nanobubbles impregnated with ozone are more effective at controlling cyanobacteria and destroying cyanotoxins/chemicals than nanobubbles filled with oxygen or air. However, all suggest potential efficacy for cyanobacteria control. Several unpublished white papers and reports indicate large reductions in planktonic chlorophyll concentrations resulting from ozone-impregnated nanobubble introduction (NBS 2018b); however, there are few examples of peer-reviewed replicated data. There are studies underway exploring the use of nanobubbling technologies (Anders et al. 2020, NCCOS 2020, 2021).

Nanobubble technology has added advantages as it is reconfigurable, scalable, and offers complete control of ozone or other gas incorporation. Actual operations often adjust bubbling time to suit the water body size and appropriate goal for the system, for example, reoxygenation, removing surface scums, or reducing water column chlorophyll. This control allows mitigation/remediation to occur while protecting nontarget species. Results from several recent field projects (NBS 2018a, b) have provided some indication that bottom mud organic matter is also oxidized using nanobubbles, potentially shifting muds from anaerobic to aerobic conditions. This process may also reduce the release of nitrogen and phosphorus into the water column, reducing the nutrient supplies that support overlying algal and cyanobacterial growth. Dissolved oxygen concentrations increase in the water column and the few data collected and reported indicate substantial short-term reductions in planktonic chlorophyll.

PLANKTONIC AND BENTHIC
EFFECTIVENESS • Water body types: Pond, lake/reservoir, bay/estuary, river • Any surface area or depth; small to large systems have been improved • Trophic state: Eutrophic, most effective in organic-rich systems • Any mixing regime • Any water body use • Best in systems with moderate to long residence times • Can prevent expected or reduce ongoing blooms with increase in hydroxyl and free oxygen radicals • Long bubble life ensures reoxygenation over a long period, including bottom sediments
NATURE OF HCB • All HCB types • Intervention and prevention strategy

ADVANTAGES • No waste products • Rapid and several-month persistence of nanobubbles ensures aerobic conditions for long periods • Reduces nutrient flux from nanobubble-produced aerobic bottom sediments • Aerobic sediments induce recolonization by bottom animals • Scalable • In contrast to microbubbles, which release their gas content quickly, nanobubbles reportedly remain for weeks to months, thereby providing long-term impact
LIMITATIONS • Bottom sediments and water column are oxygenated but effectiveness with large water body size and duration of improved conditions unknown • Need electricity, water access for deploying nanobubble hoses • Destruction of cyanotoxins unknown but may occur • At low nanobubble levels, cyanobacteria may be susceptible and algae more resistant • Oxidation will temporarily increase available nutrient supplies through release of nitrogen and phosphorus from oxidized organic matter, potentially supporting additional algal growth • Permits may be required

The current technology can be conducted using nanobubble generators, which are mobile and scalable from small boxes to truck-bed dimensions. They can also be fixed or incorporated into floating platforms. Nanobubbles impregnated with ozone produce the most rapid results (see ozonation), followed by oxygen, then by air generators. Because gases are generated on site, the only requirement for operations is access to electricity/power. Larger generating systems use substantial power, while smaller ponds or lakes could be treated with greener energy sources.

COST ANALYSIS

Within-growing-season costs are estimated below and will depend on size of the water body, organic matter present, and labor.

Relative cost per growing season: Nanobubbling

ITEM	RELATIVE COST PER GROWING SEASON
Material	$$
Personal Protective equipment	$
Equipment	$$$
Machinery	$
Tools	$
Labor	$$
O&M Costs	$$
Monitoring	$
OVERALL	**$$**

REGULATORY AND POLICY CONSIDERATIONS

Permits may be required for nanobubble dispersal and type of gas (air, oxygen, ozone) used. There may be additional safety concerns when using concentrated ozone. Short-term aesthetic issues during treatment disappear following treatment. Outreach to residents regarding placement of mobile or permanent bubble generator should be undertaken.

CASE STUDY EXAMPLES

Asia and United States: The current nanobubble technology (i.e., bubbles <100 nm) has been applied in 5–10 projects throughout these regions, but unfortunately even though improvements in water quality were achieved (e.g., increased water clarity, declines in planktonic chlorophyll, a shift in bottom sediment systems from anaerobic to aerobic conditions, return of aerobic bottom fauna), the absence of sample replication in these projects prevents inclusion of the strategy as a confirmed field mitigation strategy at this time.

To resolve effectiveness of the technology on bloom-forming algae and cyanobacteria, laboratory nanobubble exposure experiments are underway with freshwater HCB species as well as marine HAB taxa. Monitoring protocols for field projects should include multiple replicates for all field parameters likely to change from nanobubble treatment.

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