HARMFUL ALGAL BLOOMS (HABs) AND CYANOBACTERIA IN SURFACE WATER: KEY FACTS, RISK, AND MANAGEMENT

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What is the problem?

Our fresh and marine waters are increasingly threatened by human growth. We have long taken these resources for granted and wrongly assumed a limitless supply of clean water. We have (mis)use them for both consumption[1] and waste disposal[2] and are now facing the results of this activity. Millions of tons of fertilizers and other wastes are discharged into these waterbodies annually, watersheds are undergoing extensive urbanization and development[3], and waters themselves are dammed, regulated, redirected, dredged or drained. And many waterbodies are responding by showing symptoms of stress and chaos: thick green surface slicks or shoreline mats, taste and odour, dense beds of aquatic plants, animal, fish and invertebrate die-offs, invasive species. Many of these events themselves represent direct or indirect threats to the ecosystem and our current lifestyle and socioeconomic activity; some represent a more severe threat to the health and integrity of humans, animals and aquatic/terrestrial foodwebs. In particular, reports of toxic algal blooms and animal/fish poisonings have increased significantly. National and global concern with these outbreaks – ecological and socioeconomic implications and problems with their control and management – has grown considerably over the past few decades, yet management of toxic blooms continues to be a major issue, as these events and their associated risks, are often difficult to predict and identify.

In the past, the tendency has been to construct longer and deeper intakes to avoid capturing contaminated water, and to develop better and more expensive water treatment. However, we are now realizing that the physics and biology of lakes play a major role and can impinge on these intakes in many ways. And it is increasingly difficult and costly for water treatment plants to identify and monitor all the new chemicals and other threats that we as a society are releasing into source waters. For example in the Great Lakes we are seeing many more incidences where large mats of algae, detached by waves etc. alongshore, are carried to drinking water and industrial intakes and required shutting down the plants to allow the operators to backwash and remove this biological material.

Some of the problems that Europe and other areas of the world have experienced or are currently facing make our situation look mild – China for example[4]. Canadians have a choice to save our water resources from the same fate, if we act now. The longer we leave things the way they are and continue our use and misuse of this vital resource the higher the risk will be to our health and that of our lakes and rivers. There is a tremendous cost in lost

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[1] Drinking, washing, cooling, processing, irrigation (largest) etc. by homes, cities, industries, agriculture, horticulture, fisheries, aquaculture; shipping routes etc.

[2] Major sources of wastes from direct input or runoff/seepage include: sewage, storm sewers, landfills, manure and other agricultural applications, aquaculture and fish farms, mining, forestry and other industries

[3] Urbanization, paving and roadways, clearing, deforestation, wetland drainage, shoreline development, mining etc.

[4] *"July 17, 2007. An outbreak of blue algae in a Chinese reservoir has left nearly 25,000 people without water and 100,000 others with reduced supplies, state media said on Wednesday of the latest in a series of water pollution scares. REUTERS/Stringer (CHINA) "*

incomes to tourist and recreational industries, reduced property values, cattle and livestock poisoning, contamination of food and water, upgrading treatment plants (often not feasible in smaller communities) and health costs.

Research has increased our understanding of these events; however much remains to be understood as we identify more toxins and toxic species, and there is widespread concern and misunderstanding/ misinformation about these events. We need much more information and scientific studies, <u>but this has to also be coupled with concerted changes in our behaviour as citizens</u> – our use of cosmetic fertilizers, pesticides, pharmaceuticals, detergents and cleaners (many household cleaners still have a high phosphorus content), our pet waste and garbage, our water use, our reliance on private vehicles etc. etc.

Some of the more general and relevant facts (and fiction) are outlined below and some useful websites for more detailed information.

What are Harmful Algal Blooms (HABs)?

- Cyanobacterial blooms are often referred to by the more general term, HABs, although cyanobacteria are *not* algae (below). Blooms occur <u>primarily in response to elevated nutrient levels</u>.
- *HABs are not new* - there are historical records of these outbreaks since biblical times.
- Blooms can occur naturally in fertile areas such as the prairies, but since the early 1900s with human population growth and environmental degradation, have become a major issue.
- They have been targeted for remediation in Canada and worldwide since the mid 1900s. <u>Their potential toxicity was only formally recognized more recently</u>, although cattle deaths suspected to be linked to these events were recorded as early as 1878[5].
- <u>The term 'HABs' usually implies 'toxic blooms'. *However this depends on the operational definition of 'harmful'*</u> – blooms may be non-toxic, but can cause socio-economic harm (drinking water odour, fouling (nets, water intakes), clogging (filters), anoxia, recreational/tourist industries (beach closures, impaired water quality, aesthetics).

Where do they occur?

- Despite restoration efforts for many inland waters - including the vast waters of the Great Lakes - there is a perceived[6] general increase in the number and severity of blooms and noxious compound (toxins, taste-odour etc.) outbreaks in Canada and worldwide. Moreover, we really do not have a good estimate of these outbreaks, because:
    - The vast majority of waterbodies are not monitored
    - Many blooms are not identified or formally recorded.

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[5] Francis, G. 1878. Poisonous Australian Lake. *Nature,* 18:11
[6] Because toxins have only recently been recognized as a potential threat and thus there are few historical data, this increase is based more on anecdotal evidence and not been formally quantified; reports may also be biased to the increase in public awareness of these outbreaks

- Visible blooms are not the only potential source of toxins
- Sediment core interpretation can be contradictory and cannot be relied on as the only piece of evidence to diagnose the history and status of a lake. Each system needs to be assessed carefully for all potential sources of nutrients.

- Toxic and non-toxic Cyanobacterial blooms occur across Canada, in lakes, reservoirs, ponds, rivers, dugouts, sloughs and estuaries[7], notably where there is extensive urban/agricultural basin development or wastewater influx to surface waters.

What are the organisms?

- Most marine HABs-causing organisms are eukaryotic algae while cyanobacteria are the major species of concern in inland waters.
- **Cyanobacteria are often called 'blue-green algae', although this term is incorrect** because: i) *They are bacteria, not algae*, although both groups are photosynthetic (i.e. transform CO_2 to sugars using energy from the sun) and include a species which range in size from microscopic cells to macroscopic plant-like growths ii) *They range considerably in colour* (black, yellow-green, pea green, blue-green, red)
- Cyanobacteria evolved over 1.5 billion years ago, and have had a lot of time to adapt to all kinds of environments, including 'extreme' conditions (high/low temperatures, pH and light, UV, pollution etc.).
- **Many are extremely beneficial and essential components of aquatic and terrestrial foodwebs.** ***However, it is the uncontrolled growth of the more noxious cyanobacteria that threatens our water resources. Many of these:***
- **Can store P,** an essential growth requirement (below), and thereby 'stock up' when it is readily available (e.g. in spring pulses from watershed runoff).When the supplies are limited later in the season, they are thus able to outcompete other more benign algae.
- Are favoured by warm temperatures and manufacture effective sunscreens, thus are able to tolerate high UV
- **Can control their buoyancy** and move up and down in the water column, utilizing the sunlight at the surface and the nutrients in deeper water. This is one of the reasons why scums sometimes 'appear' at the surface overnight.
- **Can escape predation**. Some species form large clusters or filaments and because of their size they cannot be ingested by filter feeders. These and other cyanobacteria also use 'chemical warfare' - taste bad or are toxic and avoided by predators. As a result, predators preferentially ingest smaller and/or more benign competing algal cells, which leaves an 'open playing field' for the growth of noxious species.

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[7] . They have been reported in coastal an inland BC, the Prairies (Alberta, Saskatoon), central Canada (notably Lake Winnipeg, Lake of the Woods), Ontario (Great Lakes, Lake Simcoe, Canadian Shield, 'cottage country'), Quebec (e.g. Lake Champlain, St Lawrence River, Laurentians, Eastern Townships), the Maritimes and even in far northern waterbodies

- Many species can fix atmospheric nitrogen (N_2) **but need P to fuel this activity**.*If all else favours cyanobacterial growth, then they will develop the community that can fix* N_2 *, when needed*
- Until recently, in freshwaters, cyanobacteria were the only known sources of toxins[10] to affect humans. With increased nutrient supply, cyanobacteria typically become dominant[1] and are hence most frequently problematic. Non-toxic compounds produced by some of these blooms[2] can have threaten the integrity and aesthetics of surface waters used for drinking, recreation, crop irrigation and husbandry

What are the toxins?

Cyanotoxins are colourless and tasteless. They are produced by some species of cyanobacteria and are stored in the cells, released when cells rupture. These toxins include hepatotoxins, neurotoxins and dermotoxins. **There is no way of knowing by visual or microscopic inspection whether cells are producing toxins or other compounds and which compounds these may be**. There is growing evidence that these toxins have severe impacts on foodwebs.

- The major route of human exposure to these toxins is via ingestion e.g. drinking water or during recreation in contaminated water; absorption through skin not a major risk as the toxin does not readily cross skin. Other minor forms of exposure may include consumption of certain health food or inhalation e.g. via showers
- To date, the focus has been on **microcystins**, the most stable toxins. Over 90 different varieties of these potent **hepatotoxins** (liver toxins) have been identified together with other related toxins (nodularins, cylindrospermopsin), several of which can be produced by a bloom at one time.
    1. Microcystins, as the name suggests, were named after the cyanobacteria genus *Microcystis* from which they were first identified. However many other species also produce these and other hepatotoxins
    2. These toxins cause a range of symptoms (gastroenteritis, vomiting, fever, flu-like symptoms, ear/eye/throat/mouth irritation, rashes, abdominal pain, blurred vision, kidney and liver damage; at lethal levels, they produce massive liver haemorrhaging and heart failure. Long-term chronic exposure has been linked with increased incidence of liver cancer.
    3. Microcystins are accumulated and/or bound in tissues of bivalves such as mussels. They are also accumulated (but not concentrated) in fish tissue - another potential pathway for human exposure.
- There is little published data on the risk and occurrence of other cyanobacterial toxins in Canadian waters:

[10] However, recently surface waters in the Southern USA have been invaded by toxic blooms of the brackish golden alga *Prymnesium parvum*

1. **Neurotoxins** (‘alkaloids’ e.g. saxitoxins[11], anatoxins). Sufficient exposure to fatal doses[12] of this second group can cause death of humans and animals within minutes by causing paralysis of the respiratory muscles. They are rapidly degraded once released and thus difficult to detect and monitor and their role in any suspected toxicity events is hard to demonstrate.

2. **Dermatoxic Lipopolysachharides (LPS)** all cyanobacteria contain lipopolysachharides in their cell walls and the concentrations increase with the density of these cells in the water. Exposure to sufficient amounts of these compounds may cause gastroenteritis, skin and eye irritations and hayfever. Aerosol contact (e.g. fine spray) may cause asthma, eczema, and blistering in nose and mouth membranes.

What is the risk of toxins and other noxious chemicals occurring in a waterbody?

- The risk is determined by i) the capacity for each cell to produce them; ii) the growth and spatial/temporal patterns of these cells; iii) the triggers and environmental factors that control production; iv) the stability of the chemicals once released into the environment.

- **The risk cannot be assessed by visual or sensory inspection**; there is no consistent relationship between odour and toxin production.

- **Individual species produce compounds which differ in potency, toxicity and/or stability.** Blooms and other growths may be composed of one or several species which differ in their production

- **Many toxins and odour compounds are only recently recognized and/or chemically identified**. Not all bloom-forming species produce them, ii) **producers are not restricted to plankton[13] but include benthic/shoreline[14] mats and deep-living populations**;

- **Cell production varies** among species, and with environment.

- Production is not always directly related to growth. We are still trying to understand why even in an unispecific[15] bloom only ~50% of the cells may have the gene for toxin production turned on.

- **We may get toxins and other problems (e.g. taste and odour) without seeing any blooms**. For example, dense mats of cyanobacteria growing on the sediment surface may pose a risk. Toxins (tasteless and colourless) may persist in the water for up to several weeks after a bloom has died. The rate of degradation depends on the conditions. Some compounds are also degraded by light (esp. UV).

- **Some toxins and taste-odour compounds are highly stable,** are not removed by boiling or conventional treatment (e.g. chlorination), persist and bioaccumulate in

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[11] produced by dinoflagellates in marine systems and cause Paralytic Shellfish Poisoning).
[12] Toxicity varies significantly among the different toxins; see references for more information
[13] Free-floating
[14] living on the bottom sediment, or attached to rocks, plants and other surfaces
[15] consisting of one species

waters leaving beach and recreational areas, small water users and fisheries industries at risk.

- **Water movements may transport the released compounds** away from bottom mats, or move toxin-containing cells over distances
- **The potential for toxicity increases with**
- **Eutrophication, notably phosphorus (P). Blooms require P**. Natural reserves of P are in the shortest supply in our watersheds, and this nutrient is the primary factor that limits the growth of plants and algae in inland surface waters – and given sufficient supplies, promotes excessive growth of nuisance cyanobacteria
    1. **Nitrogen is secondary** (many cyanobacteria are N-fixers, others are promoted by high N-loading) Most lakes are naturally deficient in bioavailable P. The most bioavailable form is phosphate (PO_4) (e.g. from sewage, septic systems, fertilizers etc.). Other forms of organic dissolved P (e.g. wastes and some natural sources) are used more slowly. P that is associated with particles, cells or mineral (e.g. complexed to aluminium and iron) is poorly available.
    2. **Temperature and extreme conditions**: climate warming is likely to promote these outbreaks which are favoured by warm temperatures, intense runoff events, high irradiance and long growing seasons
    3. **Exotic species** introduction by i) direct introduction of new toxic cyanobacteria and ii) changes in food webs, water clarity and nutrient recycling (e.g. dreissenids)
    4. Overall, ***with substantially lower biomass, we will have substantially lower risk of toxins*** anoxia, foodweb effects etc. ***So we need to apply nutrient management that is designed to control biomass.***
- There have been no reported human fatalities in Canada toxins, but deaths have occurred in other countries. Numerous incidences of livestock and wildlife poisonings and fish kills have been reported; there is a suspected link to avian botulism outbreaks

What short-term treatment options are there for these chemicals and algal/cyanobacteria outbreaks?

- **Chlorination** at levels generally employed by water supply facilities has **little effect on toxins and some odour compounds**; however these compounds can be removed by carbon filtration or ozonation, thus most major water supplies represent only a minor risk for humans if these treatments are employed. Of more concern are minor water treatment or distribution facilities or individual exposure (e.g. via recreational contact with concentrated material) where preventative measures may not have been employed or small carbon filtration units are not frequently recharged. As noted above, some of the toxins cannot be removed by boiling.
- **The use of algicides such as copper sulphate** breaks open the cells and releases the compounds into the water, thereby increasing the problem of effective removal[16]

[16] It is far more difficult to remove dissolved material than particles including cells

- **Attempts to control blooms using techniques such as aeration and bubbling, sediment treatment and P-**precipitation are at best short term measures that do not fix the underlying causes, and in many cases these can have variable and/or unexpected outcomes such as shifts to other undesirable toxin producers.

What are the current guidelines and management policies in Canada and elsewhere?

- The Health Canada (HC) guideline for treated drinking water microcystin-LR content in Canada is 1.5 µg/L (WHO is 1.0, Australia 1.3, U.S.A. 1.0 µg/L). This does not consider chronic effects of long-term repeated exposure to non-acute levels of the carcinogenic (tumour promoting) toxins (notably microcystins). Currently HC is revising the guidelines and is proposing a recreational level of 20ug/L total microcystins.
- Ontario has adopted this level as the maximum acceptable concentration (MAC) and advocates visual monitoring of drinking and recreational water bodies with a history of blooms during the high risk season, and follow-up according to a protocol similar to that developed in Europe, Australia, and the World Health Organization[17] .

Website links:

CYANOBACTERIA:
http://www.cyanonet.org/faq.html
http://www-cyanosite.bio.purdue.edu/cyanotox/cyanotox.html
http://www-cyanosite.bio.purdue.edu/cyanotox/toxins.html
http://www-cyanosite.bio.purdue.edu/reslink.html
http://www.who.int/water_sanitation_health/bathing/bathing3/en/index.html
http://www.who.int/water_sanitation_health/dwq/chemicals/cyanobactoxins.pdf
http://www.health.qld.gov.au/phs/Documents/ehu/11870.pdf
http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/cyanobacteria-cyanobacteries_e.html
http://canarydatabase.org/browse/exposure/2030
http://www.bigelow.org/hab/fre.html

'BLOOM RESPONSE PROGRAMS'
http://www.murraybluegreenalgae.com/algal_alerts.php
www.oregon.gov/DHS/ph/envtox/docs/bga**guidance**sampling.pdf
http://naturalresources.nsw.gov.au/water/algal_problems.shtml

PHOSPHORUS and EUTROPHICATION
http://www.unep.or.jp/Ietc/Pamolare/about_pamolare.asp
http://www.chm.bris.ac.uk/motm/antx/antx.htm
http://ioc.unesco.org/hab/activit.htm
http://72.14.209.104/search?q=cache:RUqT3LBZG0AJ:water.usgs.gov/nawqa/nutrients/pubs/wri99-4007/wri99-4007.pdf+scope+phospho+dishwasher+detergent+switzerland&hl=en&ct=clnk&cd=1&gl=ca
http://www.unep.org/publications/
http://www.ceep-phosphates.org/

[17]Ontario Ministry of the Environment 2003. Technical Support Document for Ontario Drinking-water Quality Standards, Objectives and Guidelines, PIBS 4449e01.
http://www.ene.gov.on.ca/envision/gp/4449e01.pdf

WASTE MANAGEMENT
http://www.unep.or.jp/Ietc/Publications/Freshwater/FMS10/index.asp
http://www.unep.or.jp/Ietc/Publications/Freshwater/FMS1/index.asp
http://www.unep.or.jp/Ietc/Publications/TechPublications/TechPub-15/main_index.asp
http://www.unep.or.jp/Ietc/Publications/TechPublications/TechPub-15/main_index.asp

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Table 1. Current Regulatory and advisory limits for cyanobacterial toxins in drinking and recreational waters (from Chorus, 2005).

Country	Drinking water	Recreation
Australia	6,500 cell ml^{-1}	20,000 cells ml^{-1}
Microcystins:	1.3 µg L^{-1}	10-20.0 µg L^{-1}
Cylindrospermopsin:	1.0 µg L^{-1}	*Australia also has a livestock consumption value*
PSTs (Saxitoxin):	3.0 µg L^{-1}	
Anatoxin-a	12.0 µg L^{-1}	
Brazil (MAV)	10,000 cells ml^{-1}	
Microcystins:	1.0 µg L^{-1}	
Cylindrospermopsin:	15.0 µg L^{-1}	
PSTs (Saxitoxin):	3.0 µg L^{-1}	
Canada		
Microcystins:	1.5 µg L^{-1}	
New Zealand (MAV)		
Microcystins:	1.0 µg L^{-1}	
Cylindrospermopsin:	1.0 µg L^{-1}	
PSTs (Saxitoxin):	3.0 µg L^{-1}	
Anatoxin-a	6.0 µg L^{-1}	
Anatoxin-a(S)	1.0 µg L^{-1}	
WHO		20-100,000 cells ml^{-1}
Microcystins:	1.0 µg L^{-1} Czech Republic, France, Japan, Norway, Poland, Spain	20.0 µg L^{-1} Australia, France, Germany, Netherlands