Human health impacts associated with cyanoHABs: Summary of a literature review prepared for the International Joint Commission (IJC), Great Lakes regional office

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Wash. D.C.

Outline Topics

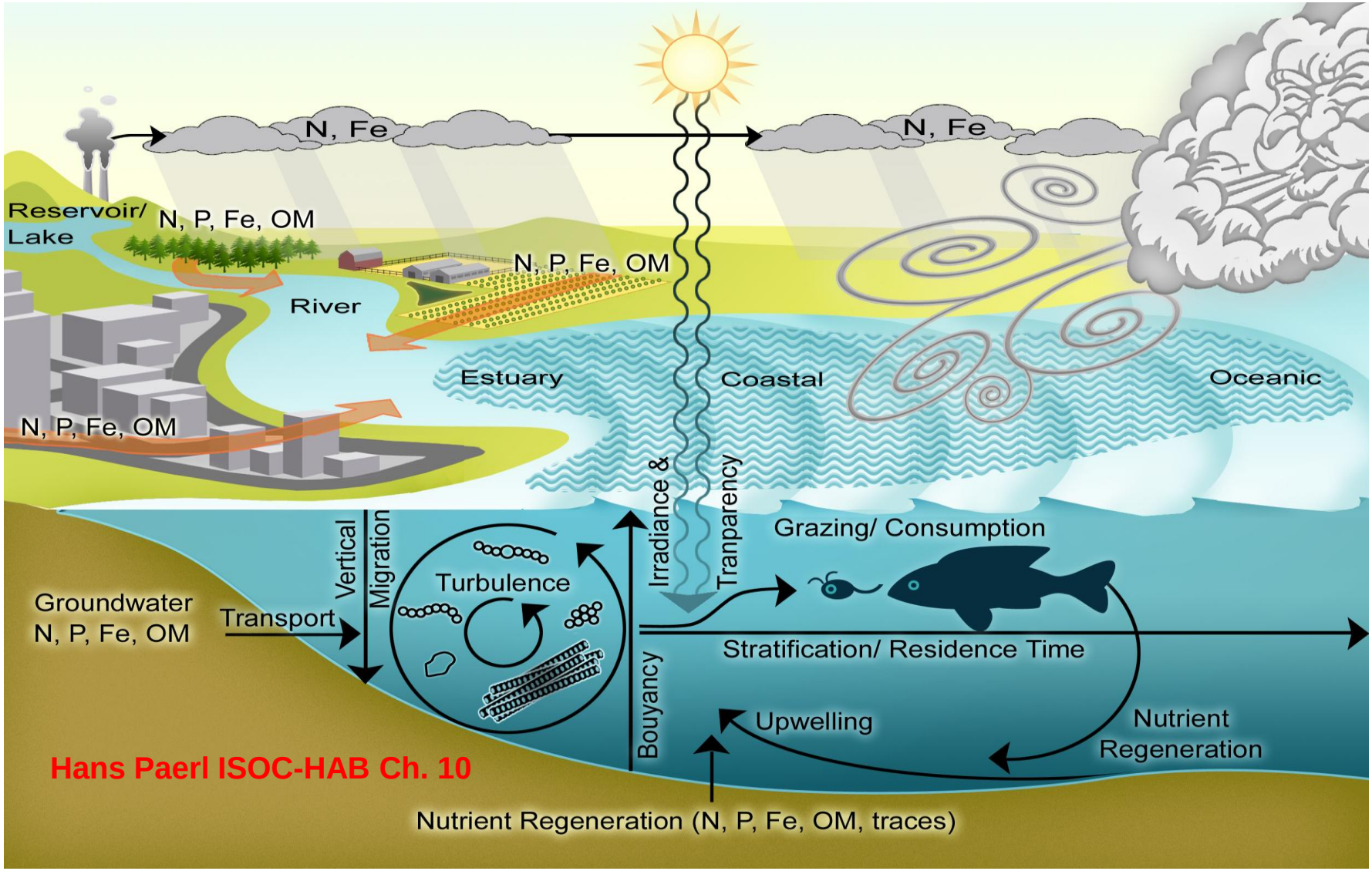
- Factors leading to exposure
- Distribution and types
- U.S. national plan
- Recent national surveys
- Great Lakes regional studies-Canada and the U.S.
- Summary health events

CyanoHABs: Factors in Their Formation

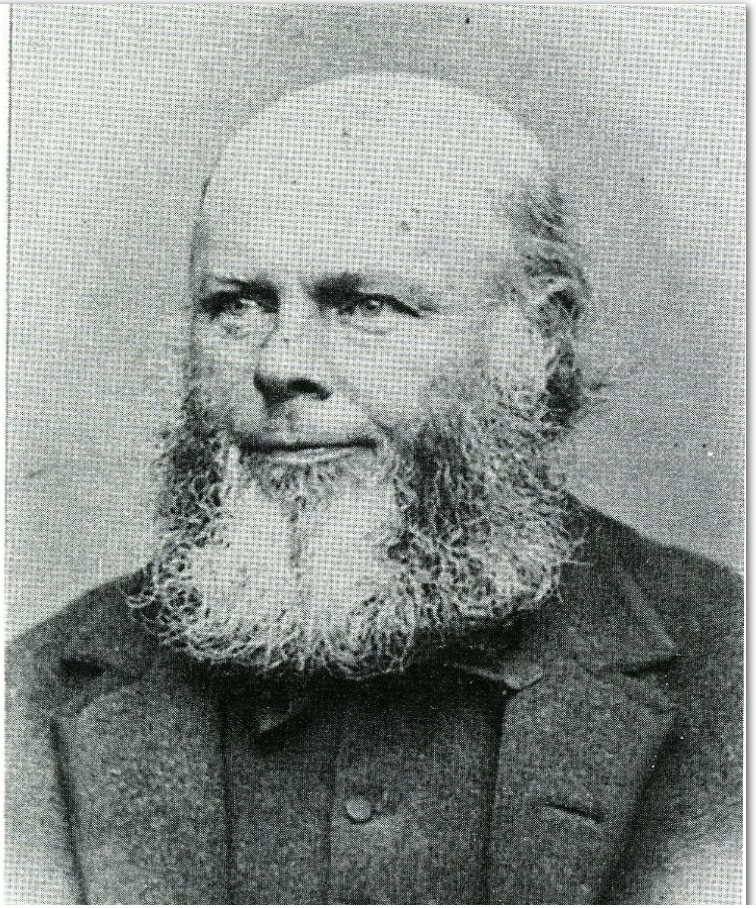
- Urban, agricultural and industrial expansion
- Increased nutrient input-nitrogen and phosphorus
- Water use and hydrologic changes-diminished water flow and less mixing
- Climate (temp increase) plays an interactive role
- Blooms become more common, more intense and of longer duration

CyanoHAB Causes

Nutrients, Hydrodynamics, Climate



Toxic Cyanobacteria-1878-"Poisonous Australian Lake"



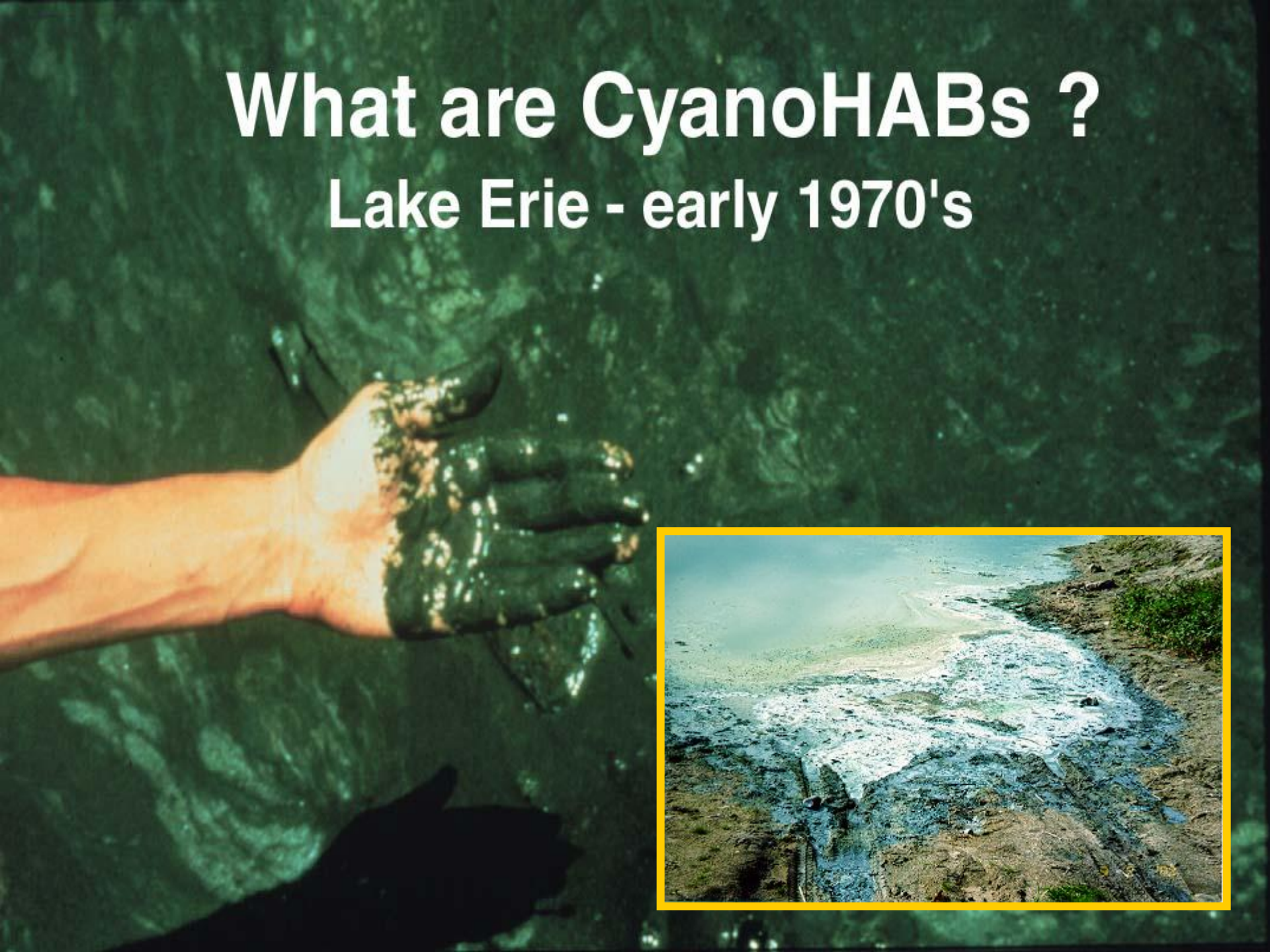
- Nature. May 2, 1878 (sheep poisonings).

George Francis.

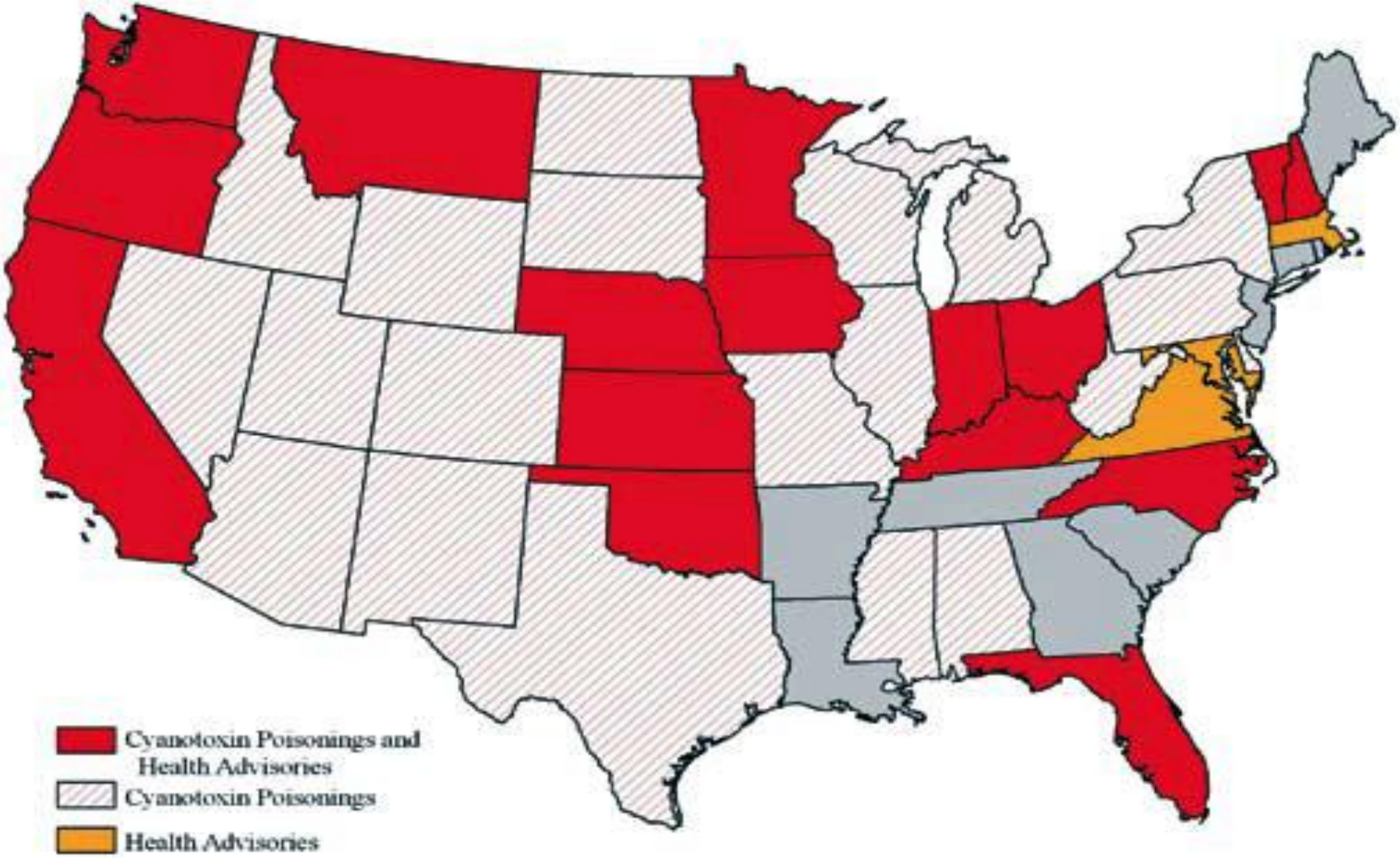
- **Similar early documented mass algae poisonings in the U.S. in 1883, 1887, and 1925.**
- Rose, E. T. (1953). "Toxic algae in Iowa lakes." Proc. Iowa Acad. Sci. **60: 738-745.**
- Rose, E. T. (1954). "Blue-green algae control at Storm Lake." Proc. Iowa Acad. Sci. **61:**604-614.

What are CyanoHABs ?

Lake Erie - early 1970's



U.S. states with anecdotal reports of acute cyanotoxin poisonings of animals and/or humans and states that have issued recreational health advisories. Anecdotal reports of acute cyanotoxin poisonings were compiled from literature sources (Yoo et al. 1995; Chorus and Bartram 1999; Huisman et al. 2005) and newspaper articles.



Summary: Types and Health Significance Ranking of Cyanotoxins

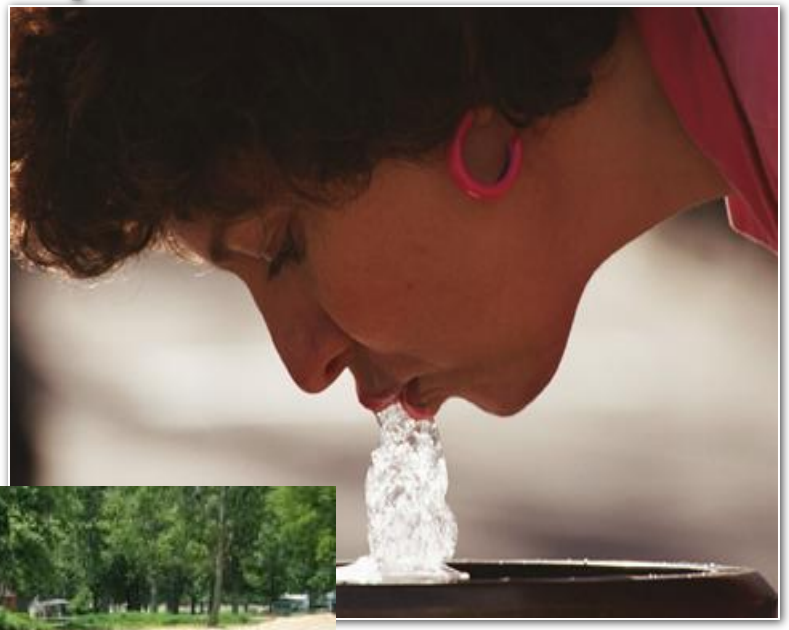
Microcystins (most common of cyanotoxins; widespread poisonings).
Anatoxins (common; with animal poisonings).
Cylindrospermopsins (widespread in U.S.; poisonings from Australia).
Lyngbyatoxins (possible presence in continental U.S.; poisonings in South and Central Pacific).
Nodularins (unknown in NA; some animal deaths internationally).
Saxitoxins (sporadic; with some animal deaths).
BMAA (world wide; but health significance largely unknown).
LPS (world wide; unknown).

Cyanotoxins—Mode of Action

- Neurotoxins
- Hepatotoxins
- Dermatoxins

Cyanobacterial Toxins: Potential Sources of Exposure

- **Surface drinking water**
- **Recreational waters**
- **Food web**
- **Dietary supplements**
- **Hemodialysis**



Cyanotoxins—Target Organisms

Location	Organisms
Water Environment	◆ Wild Birds & Fish ◆ Wild Invertebrates ◆ Aquacultured Fish and Invertebrates
Water Users	◆ Domestic & Wild Animals ◆ Humans ◆ Agriculture (Plants)

U.S. National Plan for CyanoHABs

- EPA- International Symposium on Cyanobacteria Harmful Algae Blooms, September 6-10, 2005.
- Hudnell, H.K. (ed.). 2008. Proceedings of the Interagency, International Symposium on Cyanobacterial Harmful Algal Blooms. RTP North Carolina, Sept. 2005. Advances in Experimental Medicine & Biology. Springer Science. Vol. 619, 948 pp.
- http://www.epa.gov/cyano_habs_symposium/monograph.html
- FHAB legislation website: http://www.freshwaterhablegislation.com/
- The Freshwater Harmful Algal Bloom Research & Control Act of 2010 (FHAB Act) was passed by the House of Representatives on March 10, 2010. The FHAB Act was folded into the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA; HR3650) reauthorization bill. Senate passage is pending.
- Hudnell, H.K. (2010) The state of U.S. freshwater harmful algal blooms assessments, policy and legislation, Toxicon, 55, 1024-1034.

The Discipline of CyanoHABs

- **1980. First International Conference On Toxic Cyanobacteria. Proceedings entitled: "The Water Environment Algal Toxins and Health". Plenum Press, 1981 (ed. by WW Carmichael). Wright State Univ.**
- **1993. Bath, UK, 1995. Bornholm, DK.**
- **1998. 4th ICTC. Beaufort, NC, USA.**
- **2001. 5th ICTC. Noosa, Queensland, AUS.**
- **2004. 6th ICTC. Bergen, Norway.**
- **2007. 7th ICTC. RDJ, Brazil.**
- **2010. 8th ICTC. Istanbul, Turkey**
- **2013. 9th ICTC. South Africa**

Summary from:
Human Health Effects from Harmful Algal Waterblooms a Synthesis
March 29, 2013

This report was prepared for the International Joint Commission (IJC), Great Lakes Regional Office. It is being done as part of the 2012-2015 Cycle of the Great Lakes Sciences Advisory Board (SAB) work group for Lake Erie Ecosystem Priority (LEEP) "Taking Action on Lake Erie". This work group defined 4 priorities: 1. External & Internal TP/DRP Loads, 2. Climate Change, TP/DRP inputs/outputs, Harmful/Nuisance Algal Blooms (HNABS), 3. Effectiveness of (US/Can) Agric. & Urban BMPs in TP/DRP Load Reduction, 4. Current & Revised TP Targets: Modelled outcomes.

This report addresses the objective to assess the human health impacts associated with harmful algae waterblooms (HABs) especially those associated with waterblooms of cyanobacteria or blue-green algae.

CyanoHAB Occurrence

- North American cyanoHAB history: Carmichael and Stukenberg (2006).
- Graham et al. (2009): at least 22 states in the United States (44 percent) have information available on the Internet about cyanobacteria, cyanotoxins, and potential health risks to humans and animals. At least five states have routine statewide (Iowa, Nebraska, and New Hampshire) or watershed-based (Maryland and Vermont) monitoring programs for cyanotoxins in freshwaters at the state level, and four others (California, Florida, Massachusetts, and Oregon) have developed guidance documents to support monitoring at the local level. Several coastal states (e.g., Florida, Maryland, and Massachusetts) have incorporated the largely freshwater cyanotoxins into existing programs monitoring recreational hazards associated with marine algal toxins.

U.S. Surveys

- 2006 by the USGS: Midwestern US Cyanotoxin Reconnaissance of Cyanobacterial Blooms (2006 USGS MCR). USGS 2006 survey, (carried out in August) all lakes (n=23) had detectable microcystins when ELISA (enzyme linked immunosorbent assay) and LC/MS/MS combined, 30% had detectable anatoxin-a, and 9% had detectable nodularin-R (Loftin et al. 2008): http://ks.water.usgs.gov/studies/qw/cyanobacteria/
- 2007 EPA National Lake Assessment (U.S. Lakes Microcystin Dataset, 2007): http://water.epa.gov/type/lakes/NLA_data.cfm. This survey looked at microcystin occurrence in 1150 water bodies. Looking at only microcystins by ELISA, 9 (0.7 %) lakes exceeded WHO recreational guidelines (20 ppb) and 143 (12 %) lakes exceeded WHO drinking water guidelines (1.0 ppb) for microcystins.
- 2012 EPA NLA results not available

Canada surveys

- The first published report for Canada was by O'Donoghue and Wilton in (1951). In recent years, cyanoHABs have been reported to be a concern for most Canadian provinces, though they remain particularly prominent in the prairie provinces (Alberta, Saskatchewan, Manitoba) and in the province of Quebec. In 2010, Health Canada analyzed samples from recreational waters, drinking water sources, and treated drinking water based upon unpublished data in four Canadian provinces. Total microcystins were detected in many of the blooms tested, with concentrations in most samples ranging from 0-1.5 µg/L in 71% of 138 samples. A small proportion of samples (4%) had concentrations of total microcystin between 1.5 and 5 µg/L, while 25% of samples had concentrations greater than 5 µg/L and as high as 2000 µg/L. Microcystin was not detected in treated water (Giddings et al. 2012). In a published review of cyanobacterial toxins in Canada by Kotak and Zurawell (2007) they also concluded that the occurrence is widespread. Most provinces now have programs that will respond to cyanoHAB events.

Great Lakes CyanoHABs

- Widespread blooms (planktonic and attached, e.g., *Cladophora*) were a recognized impairment in offshore and nearshore areas in the Great Lakes in the 1960s and 1970s. Waterblooms dominated by the filamentous, non-cyanotoxin producing cyanobacterium *Aphanizomenon flos-aquae* were also present (Jeff Ruetter, Ohio Sea Grant, personal communication 2013). Concerns at that time were based around impaired aesthetics; taste and odor (T&O); foodweb decline; fouling of beaches, water intakes and fishing nets; and economic impacts. These were addressed largely by targeting total phosphorus (TP) to reduce chlorophyll a levels, which was mitigated through reductions in point-source nutrient loadings. In the mid to late 1990's there was a resurgence in algal blooms in parts of the Great Lakes, dominated by cyanobacteria capable of producing toxins or harmful metabolites, such as microcystins, compounds that were unidentified in the 1970s (Watson and Boyer 2009). The first presentation and publication of this reemergence was by Carmichael (2001) and Brittain et al. (2001). These cyanoHABs were dominated by the unicellular colonial microcystin-producing species *Microcystis aeruginosa*.

Great Lakes CyanoHAB Surveys

- Phytoplankton surveys, since 2001, have shown the increasing trend for toxigenic cyanobacteria in the Great Lakes and surrounding areas (Barbiero and Tuchman 2001, Boyer 2007, Winter et al. 2011). One of the earliest survey studies that showed the increased presence of microcystins was done by Murphy et al. (2003) for Lake Erie. Water samples were collected in the summer of 2001 for microcystin analysis, nutrients and algal enumeration from Hamilton Harbour (Lake Ontario), Wendt Beach (Lake Erie) and Presque Isle (Lake Erie). Microcystin concentrations varied largely. Most levels were below recommended guideline values but some, heavy scum found in wind-concentrated areas, were capable of acute poisoning if ingested. For example Hamilton Harbor where the waterbloom was >90% *Microcystis*, primarily *M. botrys, M. viridis* and some *M. wesenbergii*. At this location, microcystin-RR was the main microcystin, with microcystin-YR and -LR also present. The two samples of August 17 and September 7, taken during the peak of the cyanobacterial bloom, contained 60 and 400 µg/L, respectively of microcystin. A few dying birds were seen in the Hamilton scum. The concentrations of microcystins at the Lake Erie sites were less than 1 µg/L, yet dead birds were common.

- In a Lake Ontario study Makarewicz et al. (2009) surveyed inshore areas for microcystins. Within the embayments, ponds, rivers, creeks, shore side, and nearshore and offshore sites of Lake Ontario, microcystin-LR concentrations were low in May, increased through the summer, and reached a peak in September before decreasing in October. Considerable variability in microcystin-LR concentrations existed between and within habitat types within the Lake Ontario ecosystem.. Remedial action plans for cyanoHABs were proposed by Watson et al. (2003) for Hamilton Harbor. One report of anatoxin-a neurotoxicosis was reported among dogs at a small lake in Ontario (Hoff et al. 2007).

Cyanotoxin Levels in Lake Erie from 5 Surveys-Boyer (2007)

Cruise	Date	# Samples	Toxin	% Samples contain Toxin	Max Level µg/L	Comments
Brittain	Sep-96	44	MC	10	3.4	Western Basin only
MELEE–VII	Jul-02	119	MC	7	0.7	whole lake; highest at Sandusky, Long Pt., Rondeau Bays
			ATX	14	0.04	
			PSTs	0		
MELEE–VIII	Jul-03	59	MC	41	0.65	whole lake; highest in West Basin & Sandusky Bay
			ATX	5	0.11	
Lake Guardian & OSU	Aug-03	48	MC	60	21	West Basin only, highest number Maumee River
			ATX	4	0.2	
MELEE–IX	Jul-04	40	MC	38	>1	Highest number Maumee River Sandusky Bay
			ATX	33	0.6	
			CYL	0		
Limnos	Aug-04	13	MC	85	2.4	Western Basin only
			ATX	31	0.07	
			CYL	15	0.18	

MC=Microcystin; ATX=anatoxin-a; PSTs=saxitoxin + neosaxitoxin; CYL=cylindrospermopsin

The current status of HABs in the Great Lakes
Watson and Boyer (2011):

Lake Superior – Status: Good

- There is very little quantitative current information on HABs in Lake Superior. Severe HAB outbreaks have not been documented in Lake Superior, although cyanobacteria, including *Microcystis*, are detected in samples taken during routine monitoring.
- **Lake Michigan – Status: Fair**
- Lake Michigan has a fairly extensive nearshore zone which accounts for a small fraction of the total volume. Yet the nearshore area has a key influence on the lake ecosystem. Cyanobacteria blooms are reported in some coastal regions in eutrophic embayments such as Green Bay and Muskegon Bay.
- **Lake Huron – Status: Fair**
- Lake Huron is one of the more oligotrophic of the Great Lakes, yet excessive phytoplankton and potentially toxic HABs occur in some nearshore areas, notably Saginaw Bay and Northern Georgian Bay.
- **Lake Erie – Status: Fair to Poor**
- Water levels in Lake Erie typically fluctuate about 36 cm/yr, but in some years up to 50 cm (e.g., 2002). There has been a steep decline in levels from a 1997 peak to below average during recent years, with significant fluctuations due to climate and storm events. This, together with the corresponding dynamics in the physical and chemical regime, has been accompanied by some disturbing trends in biota and system integrity. Not only does Lake Erie have the most extensive nearshore area, but toxic HABs are a particular concern and the focus of several recent studies.
- **Lake Ontario – Status: Fair**
- Lake Ontario has an extensive watershed development and urban input. Blooms of cyanobacteria and related impairments (cyanotoxins, T&O compounds) have been identified recently in some nearshore areas.

Great Lakes Human and Animal cyanoHAB Poisonings

- To locate case reports of cyanobacterial illness and death among animals and humans, the author reviewed websites and made contact with persons at the Federal, State and Provincial level for all areas adjoining the Great Lakes. Results of this search found that only Lake Erie has probable or suspect cases of human and animal poisoning from cyanoHABs. Case definitions provided by the Ohio Department of Health are as follows:
- **Case definitions:**
- **Suspect:** Exposure to water or to seafood with a confirmed algal bloom AND onset of associated signs and symptoms within a reasonable time after exposure AND without identification of another cause of illness.
- **Probable:** Meets criteria for S*uspect Case* AND there is laboratory documentation of a HAB toxin(s) in the water**.**
- **Confirmed:** Meets criteria for a *Probable Case* combined with professional judgment based on medical review.

Lake Erie Human cyanoHAB Cases

- For Ohio there were 2 probable and 7 suspect cases of human illness on Lake Erie in 2010. In 2011 and 2012 there were no probable or suspect cases of human illness (Table 3). In 2010 no animal illnesses or death were reported for Lake Erie (Table 4). This is the extent of reports from Ohio provided for this report. No other provinces or states provided any case reports that were documented per prescribed case definitions as confirmed, probable or suspect.

- In addition—Grand Lake St Marys and Buckeye Lake, Ohio, had 1 each "probable" human poisonings in 2010

Dog Deaths and Bird Illness-Ohio-2010

- *Between July 23 and August 11, Ohio received four reports of dog illnesses associated with Grand Lake St. Marys. The dogs were reported from Mercer County. Three of the four dogs died between July 22 and July 28. Symptoms included: seizures, diarrhea, vomiting and jaundice. Samples from only one dog were collected, but the histopathology was inconclusive due to autolysis (decomposition of the specimen). Stomach contents were negative. Liver and kidney are being held until they conduct their next validation run (date unknown). Until additional testing is conducted, this case is classified as Probable.
- On August 3 and August 11, two ill blue herons (Auglaize (1) and Mercer (1)) were reported and referred to the Ohio Department of Natural Resources (ODNR). No conclusion was reached as to what caused the illness of these blue herons.
- On August 20, Athens County Health Department reported two puppies who died on August 10 and 11 with a 1-2 day onset of lethargy, fever, excessive drooling, vomiting and diarrhea. Dogs displayed clinical signs 1-2 days after exposure to Burr Oak Lake. Both dogs met probable case definition.
- On August 26, an owner reported that her 6 yr old boxer was acutely depressed, anorectic and appeared in pain for 3 days after wading and gulping water from the lake at West Branch State Park/Berlin Lake. Dog had repeated exposure August 5-13. Owner also reported illness. However, a cyanobacteria bloom was not confirmed for this body of water during the dates in question, and therefore the canine and the human illness reports were both classified as "not a case."

Epidemiological Studies-Great Lakes Region

- Three epidemiological studies have been done on cyanobacteria in recreational waters (Stewart et al. 2006, Backer et al. 2008, Backer et al. 2010) in the United States. The 2008 study involved a small lake in Michigan and is pertinent to the Great Lakes area. This study did document low levels of microcystins in the water and in aerosol samples. Respiratory viruses were not detected but low levels of *E. coli* were. Yearly duration of exposure is shorter in those countries (i.e. U.S. and Canada) where the waterbloom growth season is shorter (3-6 months) compared to those with milder climates such as Australia and South Africa (6-12 months). The other two studies also detected microcystins but no toxicity was documented.
- In Canada one retrospective epidemiological study was done on four lakes in Quebec (Impacts de l'exposition humaine aux cyanobactéries, Février 2012). While not directly relevant to the Great Lakes, it does have relevance for the Great Lakes area. Summary points of that study are:
- There was a positive relationship between contact with bodies of water and GI symptoms relative to the numbers of cyanobacteria.
- Symptoms positively correlated with cell numbers include sore muscles, skin irritation, earaches, nausea, diarrhea, stomachache and vomiting.
- The authors were inclined to conclude cyanobacteria LPS was correlated with the symptoms.

Summary

- Cyanobacteria are a normal part of all ecosystems. However due to their long evolutionary period they can respond to anthropogenic modifications of aquatic environments, including nutrient over-enrichment (eutrophication), water diversions, withdrawals, and salinization.
- For the Great Lakes, nutrient enrichment is particularly important, with the waterbloom problems of the 1960's and 1970's being due to primarily point-source pollution. Today nutrient loading is coming chiefly from agriculture (2/3) and 1/3 from urban and recreational sources. The current phosphorus increases are a major reason for waterblooms of the cyanotoxin-producing cyanobacterium *Microcystis*.
- Each of the Great Lakes has documented cyanoHAB events but only Lake Erie has its indicator classification for HABs defined as fair to poor.
- To date, cyanotoxins detected in the Great Lakes are the liver toxins microcystins and cylindrospermospin, and the neurotoxins anatoxin-a and saxitoxins (Paralytic Shellfish Toxins). Only in Lake Erie have all of these cyanotoxins been detected with microcystins being detected at moderate health risk levels. In Lake Ontario only microcystins have been detected.
- Exposures to cyanotoxins have led to acute animal and human toxicity and acute lethal poisonings in animals and wildlife in many states and provinces of the Great Lakes area. Only for Lake Erie have a few cases of human illness and animal (dog) deaths been documented.
- In the Great Lakes, cyanoHABs have caused economic losses to the fishing and recreation industries while increasing costs for the treatment of potable water supplies.

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