Managing cyanobacterial blooms in recreational waters: decision support tools for public health responses

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Abstract: Freshwater blooms of cyanobacteria present a challenge to those tasked with managing beaches during bathing season, both to ensure the protection of public health, and to avoid lengthy beach closures. The combined effects of climate change and environmental pollution could cause blooms to become more frequent, intense, and persistent in the future in some locations, necessitating regularly review and update of response protocols. Decision support tools are used to help manage bloom events and inform responses. These can advise on the triggers for inspection, testing, posting of advisories, closing of beaches, and when to rescind advisories and reopen beaches. The aim of this paper was to present an overview of approaches and decision support tools used to inform public health responses to cyanobacterial blooms.

During bathing season in Canada, most bloom monitoring is reactive, with a limited coverage of proactive monitoring, except at priority beaches. Responses to blooms vary widely, but many are informed by decision protocols or flow charts using visual inspection and single-level indicators, or alert level frameworks using multiple indicators and alert levels. The only health-based indicators used in any system are cyanotoxins, but capacity for frequent testing is often limited. Approaches to rescinding advisories also vary in the types of indicators and length of time used to determine when it is safe to resume recreational activities. This can vary from days to weeks, with some jurisdictions taking more precautionary approaches. Responsible authorities must balance public health protection with available resources for testing and monitoring with public acceptance of extended beach closures. With the prospect of more frequent and pervasive blooms in the future, there will be a need to allocate scare resources efficiently, which may require regular review and update of response protocols. Adapting approaches may require using a range of more accessible indicators alongside local knowledge, site history, and new tools to inform site-specific responses.

Key words: cyanobacteria, harmful algal bloom, decision support, beach monitoring alert level frameworks

Introduction

Cyanobacteria, also referred to as blue-green algae, are a group of photosynthetic bacteria that can propagate in lakes, ponds, and rivers, forming dense blooms. These blooms are often referred to as harmful algal blooms (HABs) due to the cyanotoxins produced by some species, presenting a health hazard to humans and animals. While reported incidence of severe health effects due to recreational exposures to cyanobacteria is low, some individuals are at greater risk, especially children exposed during primary contact activities (e.g. swimming) (O'Keeffe, 2024). Incidents of mild to moderate and generic symptoms such as gastrointestinal symptoms, headache, fever, or irritation, may be more common, but often go unreported or are mistaken for other illnesses.

The presence of a HAB in recreational freshwaters can lead to public health advisories and beach closures during bathing season. These events can impair access to recreational sites and affect local businesses and tourism sector operators (Smith et al., 2019). Beach operators and agencies tasked with protecting public health during a HAB can face challenges in balancing the need to minimize public health risks while avoiding unnecessarily lengthy beach closures. These can include the lack of available resources, monitoring capacity, and access to timely testing for cyanotoxins. Blooms can also be dynamic – growing, collapsing, or shifting location throughout the day or based on local weather and water conditions. These factors can cause uncertainty in determining when to issue an advisory and close a beach, and when it is safe to rescind advisories.

Water temperature and nutrient loading are the key drivers of cyanobacterial growth, and changes to the climate, land use, and surface water pollution can affect the occurrence, intensity, and persistence of blooms (Chapra et al., 2017; Igwaran et al., 2024). In a changing climate, multiple stressors could act synergistically or

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Table 1: Examples of how climate-related events could affect drivers of blooms (Birk et al., 2020; Bui et al., 2018; Larsen et al., 2020; Merel et al., 2013).

Climate issue	Factors that favour growth	Factors that limit growth
Warming	• More days with temperatures suited to growth. • Decreased duration of ice coverage; changed timing of lake turnover.	• Extreme high temperatures may be suboptimal for growth and cause die off for some species.
Extreme rainfall and flooding	• Increased external nutrient loading from diffuse runoff. • Early season events could trigger earlier bloom events, and possibly extend bloom season.	• Disruption of thermal stratification due to increased mixing. • Increased oxygenation of water, reducing internal nutrient loading. • Leaching of humic acids increases colour, reducing light penetration. • Mid-summer events could mitigate growth due to increased flushing.
Drought	• Extended periods of hot, dry, calm weather enhance stratification favouring bloom events.	• Extended drought can reduce external nutrient loading and food available for sustained growth.
Wildfire	• Increased nutrient loading due to deposition of ash and movement of organic material into waterbodies, facilitated by post-wildfire runoff.	• Runoff following a fire could increase turbidity and reduce light available for photosynthesis, affecting growth of cyanobacteria.

occasionally antagonistically on growth, and affect species composition or toxin production (Table 1) (Birk et al., 2020; Richardson, 2018; Richardson et al., 2018; Vione & Rosario-Ortiz, 2021). These factors could contribute to more frequent, intense, and persistent blooms in the future especially in shallow and more eutrophic lakes, and make bloom events less predictable (Favot et al., 2023; Hayes et al., 2020; Paterson et al., 2017; United States Environmental Protection Agency, 2022; Winter et al., 2011).

Currently most responses to bloom events are reactive, but in a changing climate, more proactive approaches may be necessary to reduce public exposures (Stroming et al., 2020). More flexibility may also be required in responses depending on local conditions, recreational uses, and available resources. This paper provides an overview of current approaches to monitoring and decision support tools used in managing cyanobacterial blooms, including approaches to rescinding advisories and reopening beaches.

Approaches to monitoring for cyanobacteria in Canadian recreational waters

Routine monitoring for cyanobacteria during bathing season in Canada occurs in a relatively small number of lakes, typically based on historical bloom occurrence and recreational usage patterns. Active monitoring is limited in the territories and some Atlantic provinces due to a low occurrence of blooms in recreational waters (Health Canada, 2016). Other provinces apply a mixture of proactive surveillance and reactive monitoring throughout bathing season, which typically occurs from May/June to August/September.

Prioritization of efforts

Allocating scarce resources means prioritizing waterbodies for monitoring based on site characteristics and recreational usage (Chorus & Testai, 2021; Health Canada, 2022; United States Environmental Protection Agency, 2019a; World Health Organization, 2021). Sites with a history of blooms, high nutrient concentrations, advanced trophic status, stratification, low flushing rates, or a history of animal or human poisonings are more likely to experience blooms again. These sites could be a high priority for monitoring if heavily used for recreation, especially primary contact activities such as swimming, diving, water slides, or water skiing, or where frequent contact by lakeside homeowners, campers, or more at-risk groups such as children is likely. Prioritized sites for monitoring should include public access points during peak recreation times, but knowledge of site history and user behaviour may also inform monitoring activities or responses. For managed beaches with high levels of recreational use, visual inspection for blooms may be done alongside monitoring for other parameters, such as faecal indicator organisms. Testing for other cyanobacterial indicators or toxins may be less frequent (e.g. weekly/biweekly during bathing season, to biannually) (Alberta Health, 2022; Government of Alberta, 2023; Government of BC, 2024; Government of Manitoba, 2024; Government of Saskatchewan, 2024; Halifax Regional Municipality, 2024). Unmanaged sites may only be inspected or tested following a report of a bloom (Zurawell & Graydon, 2023).

Priority sites should be reviewed periodical due to changing environmental conditions or usage characteristics. Seasonal conditions or preceding extreme weather events could signal a need for increased vigilance and post-event monitoring. There may also be rationale for reducing monitoring at waterbodies that experience frequent and intense blooms each year. At such sites, season-long beach closures or advisories may already be in place, and frequent monitoring may not change public health recommendations (Chorus & Testai, 2021; Codd et al., 2020). Scarce resources may be more appropriately deployed elsewhere.

Indicators of blooms

Indicators used in HAB monitoring include those that signal conditions that favour blooms, the presence, density, or species of cyanobacteria, or cyanotoxin concentrations:

- **Visual indicators**: Presence of scum, water colour, consistency, presence of dead animals, water clarity or Secchi depth assessment, jar or stick tests.
- **Chemical indicators**: Nitrogen (N) or phosphorus (P) concentrations and ratios (N:P), cyanotoxins via field kit tests (e.g. Abraxis), or laboratory analysis.
- **Pigments**: Chlorophyll-a (chl-a, specific to phytoplankton) or phycocyanin (specific to cyanobacteria), detected by field instruments, drones, or satellite.
- **Biological indicators**: Microscopy to identify species, cell count, biovolume, molecular methods to detect toxin-producing genes, methods to identify toxic species.

The advantages and disadvantages of indicators have been reviewed elsewhere in the literature (Almuhtaram et al., 2021; Davis et al., 2019); however, most agencies use a combination of indicators that balance costs, accuracy, and speed of obtaining results to inform risk assessment. The only human health-based indicators are cyanotoxin concentrations determined by laboratory testing; however, testing can be costly and time-consuming, limiting the use in rapid responses. Toxin concentrations can also vary throughout the day or at different depths in the water column, and usually only one cyanotoxin type, microcystins (MCs) are measured, so the method and timing of sample collection could affect results and decision making (Cameron et al., 2024; Christensen & Khan, 2020). Visual indicators are thus the most frequently used to inform decisions on bloom management, followed by toxin concentrations and cyanobacterial cell count.

Decision support tools for HAB responses

Decision protocols and alert level frameworks are decision support tools that can be used to guide the assessment of hazards and deployment of measures to reduce public health risks from HABs. These tools are typically informed by guidelines produced by agencies such as the World Health Organization (WHO), Health Canada (HC), and the US Environmental Protection Agency (US EPA) (Health Canada, 2022; United States Environmental Protection Agency, 2019a; World Health Organization, 2021). A decision protocol can appear as a flow chart or decision tree to guide the appropriate sequence of assessment, monitoring, and response to an event. Some decision protocols use a single level guideline value for indicators, while others incorporate alert level frameworks that use multiple indicator levels, triggering different responses. Alert level frameworks are also used as standalone tools.

Decision protocols using single-level guideline values

Most decision protocols are triggered by a visual identification of a cyanobacterial bloom during a routine inspection at a managed beach or following a report of a suspected bloom at an unmanaged beach. A visual report triggers a series of steps that guide the response. For some jurisdictions a visual report will trigger a precautionary advisory to be issued, while in others it may trigger additional testing. Collection of field data and water samples for laboratory analysis may be recommended to further inform the response, such as updating or posting new advisories or additional warnings, advising against certain activities, closing beaches, or continuing to monitor for changes. Some decision protocols will also advise on when it is appropriate to rescind advisories and reopen closed beaches, guided by visual indicators, testing, or time elapsed.

Health Canada's 2022 *Guidelines for Canadian Recreational Water Quality – Cyanobacteria and their Toxins* includes a decision support flowchart that begins with visual identification, and only progresses if the suspected bloom is confirmed to be near a recreational area (Health Canada, 2022). If near a recreational area, a precautionary public notification is recommended until the bloom is confirmed to be cyanobacteria, after which testing against guideline values is recommended. The HC flow chart uses single-level guideline values for several indicators including the cyanotoxin, microcystins (MC, <10 μg/L), cyanobacteria cells (<50,000 cells/mL), cyanobacterial biovolume (<4.5 mm^3/L) and chl-a (<33 μg/L). Exceeding one or more of these guideline values can trigger an update to the public notification and continued monitoring until the bloom collapses.

Some jurisdictions have adapted the HC guidance into regional or local protocols. For example, the *Decision Protocols for Cyanobacterial Toxins in B.C.,* provides a similar decision tree for assessing cyanobacterial hazards in recreational waters (British Columbia Health Protection Branch, 2018). However, this decision tree differs from other approaches by using either visual indicators or nitrogen to phosphorus ratio (N:P < 23) as a trigger for further cyanotoxin testing, initially using a field kit for MC. If MCs are detected, a water sample is collected for laboratory testing of MCs, informing further responses. Other decision protocols informed by the HC guidance include Interior Health Authority's *Creating a Beach Safety Plan* (Interior Health Authority, 2024) and Halifax Regional Municipality's *Supervised Beach Water Quality Monitoring Protocol,* which assist with the interpretation of national and provincial guidance on managing bloom events (Halifax Regional Municipality, 2024).

Alert level frameworks

Alert level frameworks may be incorporated into decision protocols or used as standalone decision support tools. They use multi-level indicators of cyanobacteria or their toxins to inform risk assessment. Most frameworks use three alert levels, but some may use up to five. Terminology varies between risk levels, alert levels, danger thresholds, and many apply a traffic light classification for communicating risk, with progression from green to amber to red signalling increasing risk. Colour coding and the number of alert levels used in alert level frameworks can vary by jurisdiction.

The WHO's 2021 *Guidelines on recreational water quality* uses a framework with a pre-screening level, a vigilance level, and two alert levels (World Health Organization, 2021). For sites with intense recreational activity pre-screening indicators include: total P > 20 μg/L, Secchi depth < 2–3 m, and a previous history of blooms (Chorus & Testai, 2021). Vigilance level indicators include visual indicators (e.g. colour or clarity), presence of known toxin producers, or indicators of cyanobacterial biomass (e.g. biovolume or chl-a). Alert level 1 is triggered by exceeding guideline values for biovolume, chl-a, or cyanotoxins concentrations, and Alert level 2 is triggered by these indicators plus the presence of cyanobacterial scum.

A scan of other examples of alert-level frameworks used in Canada (Health and Social Services Haldimand and Norfolk, 2024; North Bay Parry Sound District Health Unit, 2024; Renfrew County and District Health Unit, 2024; Windsor-Essex County Health Unit, 2024), the United States (Nevada Division of Environmental Protection, 2024; New Jersey Department of Environmental Protection, 2020; State of California, 2024; United States Environmental Protection Agency, 2019b; Utah Department of Environmental Quality & Utah Department of Health, 2021; Washington State Department of Health, 2008; Wisonsin Department of Health Services, 2019), Australia (Australian Capital Territory Government, 2014), New Zealand (Puddick et al., 2022), Uruguay (Gangi et al., 2022), and the Netherlands (Schets et al., 2020), revealed a range of terminology to describe alert levels (Table 2) and various indicators used for triggers. Some frameworks use the lowest alert level to describe safe conditions, whereas others use it to denote the first indicators of health risks, or caution levels. Descriptions of alert levels range from basic to those providing more detailed descriptions, linking trigger levels to possible health effects and actions to protect public health.

Caution should be used in comparing responses from agencies using different alert level frameworks due to variations in the terminology used. For example, some frameworks use “Action” level to refer to a middle alert level, initiating posting of advisories or further testing, whereas other frameworks use “Action” to refer to a higher alert level, signaling more serious health risks and higher levels of response such as beach closure. The numbering of levels is also not comparable between frameworks, with some using “0” to refer to the lowest alert level, and others using “1” for the lowest alert level.

Characteristics of the scum alone is sometimes used to determine the alert level. *The Netherlands Cyanobacteria Protocol* describes three scum categories based on appearance, coverage of a bloom, and proximity to recreational use areas. Category 1–2 scums initiate water sampling, whereas category 3 scum initiates elevation to the highest alert level (Schets et al., 2020). Some Ontario health units also use visual categories 1–3 to describe a bloom, with the lowest category indicating initial visual indicators and possible risks to children during swimming. Categories 2 and 3 indicate a more significant bloom and could result in recommendations against swimming (Haliburton Kawartha Pine Ridge District Health Unit, 2024; North Bay Parry Sound District Health Unit, 2024; Renfrew County and District Health Unit, 2024).

When to rescind advisories and reopen

The WHO advises that it is important to rescind warnings when it is safe to do so to allow healthy outdoor recreational activity to resume and to avoid warning fatigue, which could cause beachgoers to ignore posted advice (World Health Organization, 2021). Determining how long a health hazard persists following a bloom can be challenging and regular monitoring is recommended to assess whether a hazard remains, worsens, or diminishes (Health Canada, 2022). Toxins can persist in the environment after a bloom has collapsed, even after visual indicators have dissipated (Draper et al., 2013), and environmental variables can affect regrowth, degradation or dilution of toxins, or dispersion of a bloom away from recreational areas.

Some decision protocols and alert level frameworks provide guidance on decision making for rescinding advisories and reopening beaches, but detailed advice is often limited or absent altogether. Decisions may be based on cyanotoxin concentrations, visual indicators, biological indicators, conditions for growth, or a combination of indicators, over differing timeframes. The review of protocols and alert level frameworks identified a range of practice, with examples of the criteria used summarized in Table 3. Cyanotoxin concentrations are most often used to inform reopening decisions, followed by visual indicators.

Health Canada guidance advises that the responsible authority should determine the conditions for removing advisories. This should ideally be based on evidence that the bloom has dissipated and cyanotoxins are below the guideline value. Limited resources for reinspection or testing may prevent frequent cyanotoxin testing for some locations, and decisions may be based on visual inspections and local knowledge of past bloom events to inform decisions.

Where toxin testing is not available, Health Canada recommends that sufficient time should be given after the bloom has dissipated to allow any toxins to be diluted or degraded, but no specific guidance on an appropriate length of time is provided. Some agencies advise waiting just 24 hours after a bloom has disappeared and water is clear to resume recreational activities, whereas other recommend testing for toxins or other indicators days or weeks apart, as shown in Table 3. Two consecutive samples are often recommended to confirm concentrations of toxins are below guideline values. Some jurisdictions take a precautionary approach, where any new visual indicators or positive toxin results restart the monitoring period again, initiating additional days or weeks of monitoring (Sereshk & Kuchmak, 2017).

Conclusions and future perspectives

The aim of this paper was to provide an overview of the approaches used to inform decision making on freshwater HAB responses. Of the decision support tools reviewed, many are adaptations of advice provided by the WHO, Health Canada, or the US EPA in the form of decision protocols, flowcharts, or alert level frameworks. Many protocols use non health-based indicators such as visual detection of scums, cell counts, biovolume, detection of toxic genes, or presence of chlorophyll-a or phycocyanin to inform responses, providing flexibility where access to testing for cyanotoxins is not readily available. Used in combination, these can provide reasonable indicators of a possible hazard, but risk assessment and responses could be improved with access to more rapid and cost-effective test methods for cyanotoxins (Codd et al., 2020).

Communities affected by HABs may experience more frequent or prolonged events in the future due to a changing climate and environmental pollution. Building resilience to HABs requires awareness of how climate events could affect bloom activity and ensuring that responses are protective of health and do not cause unnecessary lengthy closures or unintended harms to local communities. Decision support tools can guide public health responses to HABs but may require periodic review. Over time there may be a need to adapt approaches to local knowledge, site usage, environmental conditions, or occurrence of climate-related events. Access to historical records of bloom occurrence

Table 2: Variations in lower, middle, and upper alert levels used in frameworks.

Alert level	Variations on terminology	Common triggers	Health effects described	Variations on recommendations or actions
Low	• Green • Safe • Risk level 0 • Category 1 • Vigilance • Watch • Alert	• Visual – suspected bloom. • Water may be cloudy; Secchi depth <1–2 m; some discolouration.	• Biomass considered too low to be hazardous. • Health effects are unlikely and unexpected. • Possible allergenic or irritative health effects.	• Safe for swimming, recreation. • Beach remains open and accessible. • Additional monitoring may be recommended. • Watch for changes and use caution if a bloom is visible. • May recommend a precautionary advisory.
Middle	• Amber/yellow • Medium • Caution • Risk/alert/tier 1 • Category 2 • Advisory • Action	• Visual – likely bloom. • Change in cloudiness and colour; Secchi depth <0.5–1 m. • Exceeds middle level chemical or biological guideline values (cell count, chl-a, cyanotoxins).	• Cyanobacteria could be hazardous even without a scum present. • Moderate risk of health effect. • Sensitive individuals may experience mild symptoms, skin rash, eye irritation or gastrointestinal illness.	• Swim with caution, avoid swimming or primary contact activities. • Keep children out of the water. • Caution may be recommended for secondary contact activities. • Advice to rinse after water contact. • An advisory will be posted, and access may be limited. • Continued surveillance for scum or change to bloom appearance. • Additional testing (e.g. more sites, indicators, frequency).
High or extreme	• Orange/red • Moderate, high, or extreme • Risk/alert/tier 2 • Warning • Closure • Danger • Action	• Visual – confirmed intense bloom. • Presence of a scum. • Exceedances of higher level chemical or biological guideline values.	• High/very high probability of acute adverse health effects due to high toxin levels. • Symptoms could include irritation, nausea, vomiting, or diarrhoea. • Sensitive individuals may experience dermal rash or eye irritation. • Potential for long term illness at higher alert levels.	• Advise users to stay out of water. • Prohibition of swimming and other primary contact activities. • Advise against secondary contact activities and sports that can lead to scum contact. • Closure or danger advisory. • Beaches may be closed but accessible or closed including access to shoreline. • Continued testing to confirm when risks from toxins are abated.

Table 3: Examples of criteria used in decision making on rescinding advisories or reopening beaches following a freshwater HAB*.

Short duration indicators (1–2 days)
Activities can resume 24 hours after bloom disappearance (Gouvernement du Québec, 2023).
Visually clear for at least 1 day and MC < 4 μg/L (New York State Department of Health, 2024).
Two consecutive tests showing cyanotoxin concentrations below guideline levels, 24 hours apart (United States Environmental Protection Agency, 2019a).
Two consecutive water samples showing MC below guideline levels, within 48 hours of each other (British Columbia Health Protection Branch, 2018).
Caution ends when toxin levels are below advisory level for two consecutive tests (8–72 hours apart) (Colorado Department of Public Health and Environment, 2020).
Long duration indicators (1–2 weeks)
Criteria varies by the type of advisory/closure initially posted and whether a public beach is affected. Could include visual confirmation the bloom has dissipated, toxins are below threshold, phycocyanin is not detected (5 consecutive days) (New Jersey Department of Environmental Protection, 2020).
Precautionary advisories lifted if no toxic algae are detected; Closures lifted when no visible indicators are identified for seven consecutive days and MC <10 μg/L, confirmed by additional test strip in field (Halifax Regional Municipality, 2024).
Weekly monitoring for MC during active bloom, and two weeks after it has dissipated before removing signage (Interior Health Authority, 2024).
Monitor weekly; reopen if toxins fall below closure level and no visual confirmation of bloom (Arkansas Department of Energy & Environment, 2019).
Two successive samples collected a week apart, below the guideline values for cell count or toxin level (Commonwealth of Massachusetts, 2021).
Advisory based on identification of scum is lifted if cyanotoxins are below recreational use values (RUV); Advisory based on exceedance of RUV is lifted when toxins are < RUVs, and weekly sampling until the bloom is gone (or bloom is visibly gone) (Oregon Health Authority, 2024).
Visual indicators and/or cyanotoxin concentrations are below the de-posting criteria for two consecutive weeks (State of California, 2024).
At least two weeks of sampling data below threshold for cyanotoxins and cell counts (Utah Department of Environmental Quality & Utah Department of Health, 2021).
No specified time frame, or advice to maintain seasonal advisories
Two consecutive water samples below the alert level and conditions not conducive to growth (Australian Capital Territory Government, 2014).
First level advisories may remain posted through the season; Second level advisories remain until MC < 20 μg/L (Government of Manitoba, 2024).
Advisories may be posted for the whole season with weekly monitoring; Advisories lifted when temperature conditions no longer support growth (Alberta Health Services, 2020).
Downgrade to Warning level until MC < guidance levels; Do not lift advisory if weather is conducive to biomass accumulation (calm, little/no rainfall) (Trainer & Hardy, 2015).

*This table provides some examples of practice and is not exhaustive. Protocols or guidance may have changed since the publication of this document.

could improve understanding of the timing, location, or triggers for events, and prevalent cyanobacteria or cyanotoxin types. Additional advice on the importance of multi-point, multi-time sample collection to account for variability throughout the day and the water column could also improve understanding of possible hazards, and better inform timescales for monitoring, retesting, or lifting of advisories and closures (Cameron et al., 2024; Christensen & Khan, 2020).

Knowledge gaps exist in understanding the effectiveness of various decision support tools and determining the best approaches to lifting advisories or reopening beaches. Precautionary approaches are most protective against cyanotoxin exposure, but may restrict healthy outdoor activities, or cause local socioeconomic impacts. There has been no comprehensive research to evaluate the effectiveness of different decision protocols and alert level frameworks, which is limited by the absence of mechanisms for reporting of adverse health incidents linked to bloom events. Building up local knowledge of bloom occurrence and health surveillance for cyanotoxin-associated illnesses during bloom season could improve understanding of the burden of illness and how best to reduce possible harms. There may be greater need to expand monitoring efforts by involving citizens in collection of water quality data, improving data access, and sharing through interactive maps, or to explore remote monitoring tools such as phycocyanin detection in areas with limited monitoring capacity but frequent recreational use. Community involvement can improve local understanding of natural water assets and hazards and achieve other aims such as improved stewardship or involvement in mitigation strategies for HABs (Alfonso et al., 2022; Bos et al., 2019; Simon et al., 2023).

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