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Bloomin' Ridiculous: Climate Change, Water Contamination and Algal Blooms in a Land Down Under

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Abstract: Climate and anthropogenic change, particularly agricultural runoff, increase blue-green algae/cyanobacteria blooms. This article researches cyanobacteria alert-level identification, management, and risk communication in Lake Hume, Australia. Two methods, document and content analysis, evidence contamination events and risk communication, reflect water governance and data management limitations. Results found that Lake Hume had amber or red alerts for only one week, December 2021–December 2022. This failed to prevent government tourism promotion of recreational usage, contravening water authority red alert advice. Lake-use restrictions lacked compliance enforcement. Events during amber alerts lacked risk communication to vulnerable populations (children). Lake Hume's governance by the Murray–Darling Basin Authority restricted risk communication to one authority that reproduced generic advice in minimal outlets/time points. Geophysical signage failed to address diversity needs (language, literacy, age, and disabilities). No risk communication was found for residents with diseases exacerbated by aerosolization. Despite WHO promoting cyanotoxin investigation, Australian research is absent in international literature. Further, Lake Hume cyanobacteria produce potentially carcinogenic microcystein. This coexists with census data revealing cancer rates higher than the national average in a waterside town. The results demonstrate the need to incorporate robust public health risk assessments, communication, and management into water management and advocate international legislation changes based on evidence-based research to reduce blooms and prevent agricultural runoff.

Keywords: agricultural run-off; algal blooms; blue-green algae; water quality; public health; cyanobacteria; environmental health; science communication

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1. Introduction

International scientific research predicts that climate change will significantly exacerbate public health issues arising from environmental contamination. Global hospital and mortality data evidence increasing temperatures and exposure to environmental pollutants exacerbate respiratory and cardiovascular diseases [1–3]. In Europe, climate change has prompted physician associations to incorporate environmental education into medical training, reduce health industries' ecological impact, and prepare doctors to treat patients adversely affected by environmental factors. Comparatively, Australia, the world's driest continent and research location, lacks climate change action. This article presents an analysis of Lake Hume's blue-green algae blooms to reveal the urgent need for environmentally responsible water management, pollution legislation, and public health risk reduction through information and education provision.

Broadly, the study contributes to multidisciplinary global climate change research. It reveals that cyanobacteria lack attention for their public health implications by organizations managing and governing water to prioritize economic, political, and hydrological foci. Technically, in scientific literature, cyanobacteria are prokaryotic (bacterium which

contain cyanotoxins) and not usually considered algae; 'algae' is a term for photosynthetic eukaryotic species. This contrasts with common parlance using 'blue-green algae' in the researched communities. The analysis illustrates how competing human interests and environmental factors combine to create water quality conditions that pose increased public health risks from cyanobacteria exposure. Cyanobacteria worsen cardiovascular and respiratory diseases, which have been shown to exist at higher than national averages in the research area. Additionally, the article contributes to the dearth of cyanotoxin research, alerting of human and animal health risks posed by current practices. It documents a failed attempt at collaborative water management and identifies vulnerable social groups across local communities who may lack health literacy tools to support informed decision-making. Finally, it expands prior research applying a socio-hydrological lens to the Murray–Darling Basin (MDB) in Australia by transcending foci on resource management and anthropomorphic impacts on water systems [4]. This is achieved by exploring how water management conditions affect incidental users (recreational water users) and those unwittingly exposed (residents and visitors) to contaminated water, specifically cyanobacteria. Thus, it applies a novel social science lens to consider how environmental and anthropogenic factors may affect public health.

Recreational water users are neither the targeted users of Lake Hume's water management protocols nor do they significantly impact its water quality or volume. Would-wide, however, recreational water users substantially contribute to waterside areas' economic health through tourism [5]. Globally, rural tourism research increasingly focuses on environmental sustainability [6]. While rural-regional Australian communities illustrate concern about environmental sustainability and agricultural production [7], water tourism promoters exhibit a laissez-faire approach towards water safety from blooms, and water authorities focus on other priorities. Many socio-hydrological factors contribute to this situation. Rural-regional Australia's technological capacity and testing constraints may prevent source identification of agricultural contaminants (nitrogen, phosphate, and organic matter [8]) in recreational water. Limited enforcement of recreational water users' compliance with guidelines and insufficient legislation restricting environmental contaminants of agricultural activities causing water and soil nutrification that promote cyanobacteria growth also increase public health risks.

More frequent and intense blooms occur in nitrogenated water and are precipitated by climate change. Climate change contributes to increased blooms locally [9,10] and globally [11]. Where climate change induces hotter, drier environments and increased water temperatures, agriculture's need for increased water consumption competes with environmental watering needs created by reduced waterflows [12]. This situation is most apparent in the MDB. The MDB encompasses more than 1 million km^2 weaving through four Australian states. It supports crop irrigation of cotton, rice, almonds, and grapes, plus pastures for grazing livestock [13], and contributes an estimated AUD 22 billion annually to Australia's economy [14]. The socioeconomic practice of irrigators drawing directly from rivers, and increasingly from floodplain harvesting, to supply large inland reservoirs has drastically altered seasonal waterflows critical for the environment, system health, and water quality [15,16]. In 2012, the contentious Murray–Darling Basin Plan (MDBP) was introduced, partly to promote more equitable water sharing across stakeholders, including the environment [15]. This ambitious multiple-state, multiple agency initiatives failed to reach key water availability targets, resulting in the Australian Government extending the due date for states to achieve adequate environmental waterflows [17]. Water quantity (total flow and timing) is arguably the most contentious issue. Aggressive local farming lobby groups secured politically backed water rights that reduced environmental watering to significantly less volume than water management experts recommended (using evidence-based targets that originally were agreed as required to achieve goals) [18]. Consequently, 95% of water consumed serviced the 3% of landmass used for irrigation, far insufficient for environmental and flow patterns conducive to water quality maintenance [15].

In addition to the MDBP's susceptibility to political power and individual career interests, its risk management structure also contributed to its failure [15]. The compounded risks from localized interests and actions driving the vast multiple stakeholder organization managing the MDB (a large, complex natural entity affected by climate change) became evident when environmental considerations were usurped by local, compartmentalized actions 'upstream' impervious to 'downstream' consequences [15,16,19]. The most visual example is Menindee's massive fish deaths occurring when drought affected water levels were further reduced by upstream irrigation [19]. The MDBP's planning and management failure also extends to greater water removal from the system due to global technical irrigation advances in efficiency, facilitating irrigators to be able to afford to irrigate more land [15].

Low waterflows are one of two facilitators of blooms related to irrigation. The other is nutrients carried in return flows. Although the diffusion of nutrient sources challenges quantification, research demonstrates irrigation is the largest contributor to nutrification in the system [20]. The World Health Organization's (WHO) latest guidelines for recreational water management specifically identify agricultural runoff as a key cause of eutrophication supporting blooms [21]. Recently, the New South Wales (NSW) state government acknowledged MDB's increased nutrification from agricultural activities [22]. Historically, this was recognized by managers in the adjacent state of Victoria [23].

Lake Hume's water quality affects human and animal health. Health risks, however, surpass water contact during large blooms. Research increasingly indicates cyanobacteria levels below water management triggers can pose public health risks to those with underlying health conditions and/or chronic exposure, such as those living adjacent to bloom-prone water [24]. For example, nasal swabs from people near blooms, without direct water contact, tested positive [25]. Cyanobacteria cyanotoxins also can become aerosolized in vapor by wind, rain, and water-disturbing activities (e.g., jet-skiing or powerboating), traveling up to 30 km [26]. They can be present in dust blown into homes and carried on clothing and shoes [27]. Thus, evaluating related public health risks is complex because of technical aspects in toxin detection and high degrees of variation in toxin production relative to variants of the same bacteria species, impact of water temperature, water quality, synergistic relationship between toxins/bacteria, and presence of unknown toxins in a bloom [28]. Knowing prevalent species or toxin levels may be irrelevant because individual susceptibility varies in a non-dose-dependent manner, including at very low levels [29]. Current dose-related guidelines also may be too high. Recent research found daily exposure below WHO's recommended levels to cyanotoxins can cause metabolic and renal impairments [30]. Further, toxicity is relevant to the transmission route. Insufficient toxicology knowledge exists about the inhalation of known toxins [31] or chronic exposure [32,33].

MDBP's structure puts water management decisions affecting public health under the remit of water authorities. Authorities assess safe exposure levels using criteria that may or may not be most relevant. MDB water testing is restricted to specific areas, lacks regularity, is seasonally contingent, and is driven by visual indicators, namely bloom presence [29]. Gaps between water inspection and test results, or the dominance of species that do not produce characteristic blooms, may expose humans and animals to health risks. Risk communication to the public only occurs when a threshold is reached relevant to the presumed toxicity of the assumed species' composition and potential impacts on healthy individuals directly engaging in or on the water. There is no requirement for water managers to communicate cyanobacteria presence at lower levels, and communication typically relates to users directly engaging with water sources [29]. Thus, susceptible persons (i.e., with conditions known to be exacerbated by exposure, such as asthma) would be unaware of the risks they are exposing themselves to when swimming or sailing in water contaminated below threshold levels that trigger public risk communication. Health decision-making remains an individual problem informed by available information and issue awareness. This article next explores the materials and methods used to research

cyanobacteria levels, risk communication, and recreational activity at one of the MDB's largest reservoirs, Lake Hume.

2. Materials and Methods

2.1. Research Design

A community-based research (CBR) design was utilized to investigate the existence and communication of health alerts for cyanobacteria contamination by Australian authorities to recreational water users. CBR seeks to identify issues of community concern and construct investigations that will benefit 'real-world' communities, in addition to advancing academic knowledge necessary for achieving social and policy change goals [34]. This CBR commences establishing the extent to which blooms constitute a public health threat in the research location by investigating policy, governance, and scientific management processes surrounding outbreak identification and communication.

The research design employed social science research methods to holistically examine the research topic using qualitative methodology [35]. Community issues represent complex social, and this case environmental, problems involving multiple, potentially competing, stakeholders requiring analysis of multiple data sources [34]. Content analysis of secondary data was employed to analyze organizational policy documents, social and news media about blooms, technical reports, communications made by water authorities, and census data in the research location. The entire dataset was publicly available. Census data was used only to collect population metrics to permit demographic description of disease rates, compared with the national population, that cyanobacteria exposure may exacerbate in nearby communities.

2.2. Research Location

The research location, Lake Hume, is a water catchment area near the regional cross-border towns of Albury–Wodonga (within 20 km), where the researchers reside. Their combined population is approximately 100,000 people. Lake Hume, locally termed the 'Hume Dam', was chosen because it is a water catchment area serving numerous divergent stakeholder activities. This reservoir is one of the largest storage sources in the MDB. The two states it borders are Victoria and NSW, Australia's two most populous states. Each state has its own water management body in addition to a MDBP branch.

Figure 1 shows Lake Hume's location relative to surrounding communities. The three townships surrounding Lake Hume's edge are Bellbridge, Bonegilla, and Tallangatta. The water catchment area contains native and plantation forests and grazing land. It is also home to a residential 'yacht club' serving sailors, school groups, and tourists that hosts classes and runs a yearly regatta, attracting visitors from other regions. Additionally, it is a site for Australian powerboaters' Grand Prix circuit, annual cycling challenges, and fishing competitions, drawing interstate anglers and associated promotors.

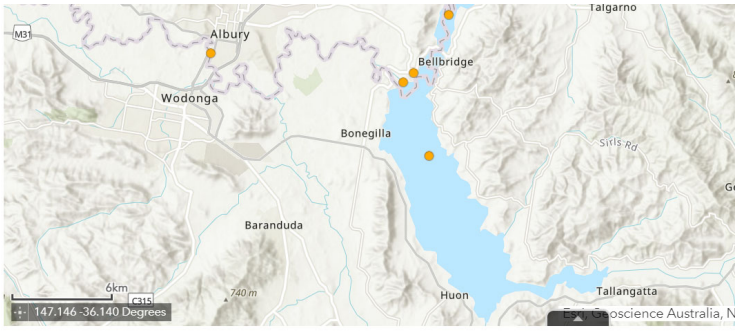

Figure 1. Lake Hume, local communities, and water parameter sensor locations. Source: www.waternsw.com.au/water-services/water-quality/algae-alerts (accessed on 2 June 2023).

2.3. Research Timeframe, Sampling, and Data Analysis

2.3.1. Research Timeframe

The research period chosen for data sampling was December 2021 to December 2022. This timeframe was selected because it occurred shortly after one of Australia's strictest COVID-19 'lockdown' periods. Australian state governments restricted interstate travel between Victoria and NSW for most of 2021 to contain COVID-19 population transference. Travel restrictions prevented widespread community access and event organization around Lake Hume. Roads crossing state boundaries were strongly guarded by police to prevent interstate travel. These barriers remained in place until November 1, 2021. Thus, to research Lake Hume's recreational access and use, data collection began one month after the Victorian Government lifted its travel ban preventing most Victorians from traveling into NSW. The second criterion guiding sampling is related to Australia's climate. Because water contamination events correlate with temperature, the research timeframe sought to collect data across all four seasons.

2.3.2. Identifying Cyanobacteria Contamination Data and Alert Rating Processes

To identify how Australian water and governmental authorities identify Lake Hume bloom events, and subsequently understand the governance process and contamination criteria they utilize to issue community alerts about lake use, a two-step procedure was followed. First, an Internet search was conducted to locate *who* is officially responsible for managing Lake Hume's water quality. Selection criteria included only organizations (and corresponding websites) related to water quality testing, reporting, or management of cyanobacteria in the research location. This revealed a complex governance process informed by legislation and guidelines across multiple levels of government and traversed several management bodies according to location and remit. Although publicly available, establishing the water quality reporting process and acquiring the data identifying Lake Hume's water quality demanded expansive literacy in governance, policy, legislation, and science.

Second, content analysis of the secondary documents obtained from step one was conducted. This qualitative analysis followed a 'realist approach', whereby the information found was understood as able to give insight into the "social reality" about "'who', 'when', 'where', and 'what'" water authorities, legislation, and processes are followed for Lake Hume's water testing and alerting [36] (pp. 293–294). Since cyanobacteria reporting and governance processes were created by those with governmental authority to issue official warnings, the validity of the sample is high. Likewise, the reliability of the document analysis, in other words, its capacity to qualitatively reproduce the same findings if conducted by other researchers, is high if reproduced in Australia because state and national legislation binds local governance processes to follow NHMRC water quality testing guidelines. Although variation likely will exist by historical period, and organizational changes affect water governance and policy, as a method, content analysis of documents permits reliable identification of legislation and bodies responsible for determining Lake Hume's levels of water contamination and management [34–36]. Hence, the social science research methods employed are suitable and effective for yielding valid and reliable data to answer the first research question, *Q1: Who is responsible for managing data and alert designation of Cyanobacterial levels for Lake Hume?*

After commencement, the initial sampling framework required modification when it was discovered organizational reports typically are published following the Australian financial year cycle. This cycle runs from 1 July to 30 June. Hence, the final sample was guided by data and report availability once the researchers determined who was responsible for guiding community knowledge and decision-making about public health risks for Lake Hume's recreational users. Collectively, steps one and two contributed to locating data to answer the second research question, *Q2: How is cyanobacteria contamination determined?* This began with the first author, a microbiologist, closely reading water quality guidelines and data provided by the organizations identified in step one. Data sources

included national, state, and local documents containing water quality testing details. The 'alert' rating criteria presented in the results are informative for understanding the type of community guidelines water authorities used for issuing contamination warnings. Results presented in Section 3.1 explicate the organizations, reports, and alerts produced during the research period related to Lake Hume's water management.

2.3.3. Communicating Cyanobacteria Contamination Alerts to Communities

The third and final step undertaken in the sampling and analysis process was created for its capacity to answer the last two research questions, *Q3: How are Cyanobacteria risks communicated to lakeside communities and the broader public by water management authorities?*, and *Q4: What public-health risks are/are not presented in this communication?*

Following a progressive research design, findings from answering the first two research questions informed the sampling framework to guide data collection for the second half of the investigation. First, governing bodies had to be identified to explore how water authorities responsible for Lake Hume's management communicate public information about bloom alerts. Two authorities, the MDBA and Goulburn–Murray Water (whose remit is the management of the Victorian side of Lake Hume), plus the third-party entity, WaterNSW, were identified on government websites. These organizations were included in the sample to investigate bloom communication. Second, samples of community 'bloom alert' communications were drawn from three community communication platforms: news media, social media, and authorities' websites.

Since WaterNSW was found responsible for communicating about Lake Hume's safety, the keyword 'Lake Hume' was used to search for all public communication available on its website during the research timeframe. This yielded four communications. WaterNSW's contamination alert communications appeared to prompt social media postings on Facebook by three local organizations: Albury City Council, Visit Albury–Wodonga, and Albury–Wodonga Yacht Club. Given the cross-state location, Wodonga City Council also was sampled. The keyword 'Lake Hume' was used to search these four organizations' Facebook pages to find bloom alert posts. This yielded a sub-sample (n = 14) of postings that were added to the sample for content analysis. To further locate mass communication about Lake Hume bloom alerts during the research timeframe, all Australian news media were searched. This followed the same keyword search process, using the Factiva database to search all local, state, and national Australian media between December 2021 and December 2022. The keywords used were 'algae' or 'algal alert' and 'Hume'. This produced a second sub-sample (n = 4) of articles published in three news media outlets: *The Border Mail*, *Australian Broadcasting Corporation*, and *Public: Private Company News*.

The final sample (n = 18) was analyzed independently by both authors for latent and overt content [37]. The second author, a sociologist, reviewed the first author's analysis, providing additional analytical suggestions about data code development and content analysis. Using an iterative process of interrater reliability and co-reading, code modification continued until the team found no new content or codes emerged from further analysis [36]. Results were compiled and organized by data source to answer the third and fourth research questions. These results appear in Section 3.2. Finally, results from Sections 3.1 and 3.2 were considered alongside community population metrics to epidemiologically explore ramifications and formulate suggestions proffered in the Sections 4 and 5.

3. Results

Results contribute to the broader research objective of enhancing academic and community understanding of governance, scientific, and communication processes guiding Lake Hume's cyanobacteria identification, management, and response to inform and minimize public health risks posed by blooms. The next section presents findings that answer the first two research questions.

3.1. Identifying Lake Hume Cyanobacteria Testing, Compliance, and Community Alert Processes

Lake Hume's geographic location in the MDB makes it part of the MDBP. Historically, the need for systematic evidence-based bloom management across the MDB preceded the MDP plan. The Algal Management Strategy in the MDP was established in 1994 after a series of major blooms occurred the prior year [16]. The Regional Algal Coordinating Committee (RACC) monitors the management of blue-green algae/cyanobacteria in the MDBP. RACC is responsible for Lake Hume meeting public health needs [38]. The committee includes diverse stakeholders, mostly government departments at the state and local levels, privatized water providers, and an irrigator group titled 'Murray Irrigation Limited'. RACC does not have a prevention role. The administration of activities, relative entity management, and public communication responsibility rests with WaterNSW [38]. Management consists of predicting bloom incidences (from environmental conditions), monitoring water quality (using sensors and visual inspection driven by historic incidences and seasons) and responding.

Lake Hume's natural resource management is governed by the Murray–Darling Basin Authority (MDBA) under the *Water Act of 2007*. This national legislation created the MDBA. Commonwealth legislation mandates water quality reporting to the Bureau of Meteorology under the *Water Regulations Act of 2008* as part of the *Water Act*. Problems emerge, however, for identifying and understanding water quality measurement and reporting of cyanobacteria because legislation does not include biological contaminants. This extends to *E. coli*, the standard indicator of fecal contamination of water.

According to the MDBA, there are two state government authorities governing Lake Hume's water quality. These are WaterNSW and Goulboun-Murray Water. Members of the public seeking water quality information about Lake Hume are referred to WaterNSW. WaterNSW provides an "algae alert" webpage that advises information is collected by RACC [39]. It also notes water quality guidelines used to create alerts are the national, Australian governing guidelines created by NHMRC (2008). These "Guidelines for Managing Risks in Recreational Water" were under revision during the data collection period.

NHMRC's water quality guidelines are presented within the context of the National Water Quality Management Strategy (NWQMS). NWQMS seeks to facilitate effective water quality management through nationally agreed-upon policies, guidelines, and tools to assist relevant governments and organizations with their water quality management relative to local conditions. NWQMS also was recently revised. One outcome was producing water quality plans and annual reports. The plans were finalized in 2020, and the first reports produced covered the 2021–2022 period. Table 1 presents the publicly available 'first' report produced for Lake Hume and all publicly accessible alert level information for Lake Hume during the research period not covered in the yearly report.

Table 1. Cyanobacteria alert-level information sources, July–December 2022.

Governing Body	Reporting Site	Data Range	Data
NSW Government Department of Planning and Audit	Murray Valley Annual Surface Water Quality Report: 2021–2022	December 2021–30 June 2022	Weekly alert-levels
Regional Algal Coordinating Committee *	The Murray and Sunraysia Combined Blue-Green Algae Report: 28 November 2022	1–14 November 2022	Alert-level and dominant species of cyanobacteria
Regional Algal Coordinating Committee *	The Murray and Sunraysia Combined Blue-Green Algae Report: 21 November 2022	29 October–7 November 2022	Alert-level and dominant species of cyanobacteria
Regional Algal Coordinating Committee *	The Murray and Sunraysia Combined Blue-Green Algae Report: 14 October 2022	27 September–10 October 2022	Alert-level and dominant species of cyanobacteria

Table 1. *Cont.*

Governing Body	Reporting Site	Data Range	Data
Regional Algal Coordinating Committee *	The Murray and Sunraysia Combined Blue-Green Algae Report: 17 December 2021	1–6 December 2021	Alert-level and dominant species of cyanobacteria
WaterNSW	Website–Current alert-level posted, with history of prior 6 readings	December 2022	Alert-level
WaterNSW	Facebook–Alert post for Lake Hume	24 December 2021 11 October 2022 22 November 2022 13 December 2022	Red alert-level commencement

* Available RACC reports were those archived by third parties using the Wayback Machine service (accessed on 2 June 2023: https://balranald.nsw.gov.au/algae-reports-for-the-region/).

The Murray Valley Annual Surface Water Quality Report contains weekly alert levels, but no information about the dominant species of cyanobacteria present. The latter is available from retrieving RACC reports. Current RACC reports for Lake Hume are hosted by the Balranald Shire Council. According to WaterNSW's webpage, RACC and WaterNSW collaborate in water quality management. WaterNSW's role includes serving as a public informant. Since RACC does not maintain a public website, the URL of the publicly available RACC report (June 2023) permits searching Internet archives [40] using the Wayback Machine [41]. While RACC reports do not seem to be included in automated archive activity, four reports fit the research timeframe that was archived by a third party. Further, the December 2022 alert level appeared on the WaterNSW "algal" information website, which reports the current and past five alert levels at each site.

Lake Hume's cross-border geographical location means water testing is conducted in NSW and Victoria. Hence, this involves two RACCs: NSW Murray RACC and Victorian Sunraysia RACC. The frequency of Lake Hume's water testing and corresponding designation of community alert level is completed in accordance with NHMRC's guidelines for managing risks in recreational waters [29]. These guidelines were developed from the now superseded, World Health Organization's 2003 guidelines for safe recreational water [42].

Content analysis of latent communication found the level of water contamination hazard for cyanobacteria is determined using qualitative and quantitative measures. Measurements relate to criteria for cell count, cyanobacteria biovolume, and predominance of known toxin-forming species. Public health risks for Lake Hume are considered relative to the nature of expected activities from ingesting water while swimming, physical contact from non-immersive activities, such as fishing, and non-contact activities, such as boating. Aggregated results are calculated to produce a 'traffic light' alert rating system. 'Green' is the surveillance level, where there is no perceived risk, although some cyanobacteria may be present. To identify if routine monitoring is recommended, local conditions and data on historic blooms are used to predict what monitoring may be needed.

An 'amber' alert level for monitoring is triggered when total cyanobacteria biovolume is >0.4–<10 mm^3/L, or >0.4–<4 mm^3/L if a known toxic species is predominant. This prompts increased surveillance and notification to relevant official stakeholders (e.g., local council). In regard to public health risk, the Murray and Sunraysia RACCs describe the amber-level as an "alert mode":

> "Blue-green algae may be multiplying, and the water may have a green tinge and musty or organic taste and odour. The water should be considered unsuitable for potable use, and alternative supplies or prior treatment of raw water for domestic purposes should be considered. The water may also be unsuitable for stock watering. Generally suitable for water sports, however, people are advised to exercise caution in these areas, as blue-green algal concentrations can rise to red alert levels quickly under warm, calm weather conditions." [43]

When upper thresholds are exceeded, the alert level changes to 'red'. A red alert indicates 'action' is necessary. It is at this level that the public are informed, and a broader range of authorities, including health authorities. Lake Hume alert-level information is publicly available on the WaterNSW webpage. WaterNSW also takes responsibility for public communication when a red alert is triggered. A red alert indicates "action mode" activation:

> "These alert levels represent 'bloom' conditions. Water will appear green or discoloured, and clumps or scums could be visible. It can also give off a strong, musty or organic odour. Algae may be toxic to humans and animals. Contact with or use of water from red alert areas should be avoided due to the risk of eye and skin irritation. Drinking untreated or boiled water from these supplies can cause stomach upsets. Alternative water supplies should be sought or activated carbon treatment employed to remove toxins. People should not fish when an algal scum is present. Owners should keep dogs away from high alert areas and provide alternative watering points for stock." [43]

Understanding how governmental and scientific processes of alert-raising translates into community action for Lake Hume's usage is the second major contribution of this article. This commences in Section 3.2's content analysis (for latent and covert meaning) of communication surrounding blooms during the research timeframe. Results contribute to answering the third and fourth research questions.

3.2. Alert Levels and Community Communication

Table 2 shows all communication found relating to Lake Hume during the research period.

Table 2. Community communication: Lake Hume blooms December 2021–December 2022.

Organization	Communication Mode & Sample Size	Quantity of Communications	Communication Date
Albury City Council	Facebook (n = 6)	1	24 December 2021
Wodonga City Council		0	
Albury–Wodonga Yacht Club		4	13 October 2022
Visit Albury–Wodonga		1	
Australian Broadcasting Corporation	News media (n = 4)	1	24 December 2021
The Border Mail (n = 2)		2	13 October 2022 14 December 2022
Public (n = 1)		1	11 October 2022
WaterNSW	Website and Facebook (n = 4) TOTAL (n = 14)	4	24 December 2021 11 October 2022 22 November 2022 13 December 2022

Across all organizations, fourteen discrete community communications about bloom outbreaks were found between December 2021 and December 2022.

3.2.1. Albury City Council, Wodonga City Council, and WaterNSW Official Bloom Communication

No public communications were found for Wodonga City Council regarding Lake Hume blooms. Albury City Council posted one message on its Facebook site, advising, "An algae alert has been issued by WaterNSW for Lake Hume. This means we should avoid contact with the raw water in the weir, but it is important to note that Albury City's water supply will remain completely safe to drink, regardless of conditions in the lake". The

Council's communication reflects greater concern with its safe drinking water provision remit, than involvement with communicating cyanobacteria exposure or ingestion risks posed to its constituents. The Council made no communication about 2022 red alerts.

WaterNSW made one website posting in 2021 and three in 2022 (including one Facebook post) about high alert blooms. Dates appear in Table 2. On 24 December 2021, it advised, "A red alert level warning (high alert) for potentially toxic blue-green algae has been issued for Hume Dam, following algal testing undertaken by WaterNSW". This warning further explains the need to avoid recreational activities involving direct Lake Hume water contact, listing swimming, showering, washing, and drinking by humans and animals, as well as not consuming mussels, crayfish, or "any internal organs" of fish. Noting the erection of public signage "at key recreational areas and [that] will remain in place while high levels of blue-green algae are present", WaterNSW indicates the impossibility of predicting red alert duration. The left photograph in Figure 2 shows a warning sign at one of the lake's boat ramps and public access points. The right image displays WaterNSW's official Facebook posting of another red alert on 13 December 2022.

Figure 2. Geophysical and digital high, red alert for cyanobacteria at Lake Hume.

WaterNSW's two official website communications, 11 October 2022 and 22 November 2022, and its corresponding Facebook post on 13 December 2022, reproduce its 24 December 2021 advice. The Facebook post only displays detailed information if one follows the "read more" link shown in Figure 1. Although WaterNSW maintains a webpage showing the current alert level for all water bodies it manages, community members would need to be aware of this organization and its communication practices to obtain information. Additionally, the public would need to be aware of blooms, know they pose health risks, and be seeking information related to Lake Hume, perhaps after encountering a physical sign. Compared with WaterNSW's red alert description in formal document reporting [43], which appears in Section 3.1, WaterNSW's official public communication provides expansive cautioning of risks and adverse public-health consequences:

> "...the public should avoid coming into physical contact with untreated water at the site until the red alert warning is lifted. This advice includes recreational activities such as swimming, along with any activity that brings the user into direct physical contact with untreated water. Blue-green algae is potentially toxic and may cause gastroenteritis in humans if consumed, while skin and eye irritations can also occur after contact. Boiling the untreated water does not remove algal toxins. This red alert warning applies only to untreated water at Hume Dam and will remain in place until monitoring and test results confirm that the risk is sufficiently diminished. People who suspect they have been affected by blue-green algae should seek medical advice. Contact with untreated water subject to a red alert can also pose a risk to livestock and pets, and livestock owners are advised to check stock water supplies and remove stock from foreshores where surface scum is visible or blue-green algae is suspected. It is not possible to predict how long the algae will remain at high levels. Regular monitoring will continue, and

the alert will be lifted as soon as the high levels of algae dissipate. For information regarding treated drinking water supply, the public should contact their local council or local water utility. People should not consume mussels or crayfish from red alert warning areas. Before consumption, any fish caught in an area subject to red alert should be cleaned and washed thoroughly in uncontaminated water. Blue-green algae is naturally occurring and can reproduce quickly in favourable conditions where there is still or slow-flowing water, abundant sunlight and sufficient nutrients."

A web link and toll-free phone number are provided for updates and further information.

3.2.2. Albury–Wodonga Yacht Club, Visit Albury–Wodonga, and News Reporting

Four communications appear on the Albury–Wodonga Yacht Club's (AWYC) Facebook site relating to Lake Hume's cyanobacteria contamination during the research timeframe. The first communication appeared on October 13, 2022, two days following WaterNSW's official communication. The post identifies WaterNSW's red alert issuance, stating, "At red alert level, a waterbody should not be used for primary recreation. WaterNSW advises that extreme care should be exercised, and contact with water in Lake Hume should be avoided" [44]. The actions AWYC communicated it undertook in response to this alert are "reviewing all scheduled sailing activities". AWYC also provides WaterNSW's website address.

The next Facebook posting relates to the alert appearing the next day, October 14, then none appear until 7 November 2022, and 30 December 2022 (Figure 3). The WaterNSW link in Figure 3 takes readers to its real-time reading using an algal alert map. Thus, it is impossible to ascertain what information readers saw during the research period using publicly accessible data. The post on the left in Figure 3 advises AWYC to take its "duty of care seriously" and cancelled training exercises and recreational experiences until February 2023. This same action approach appears in their 7 November 2022 post, noting the intended postponement of a sailing regatta due to the bloom.

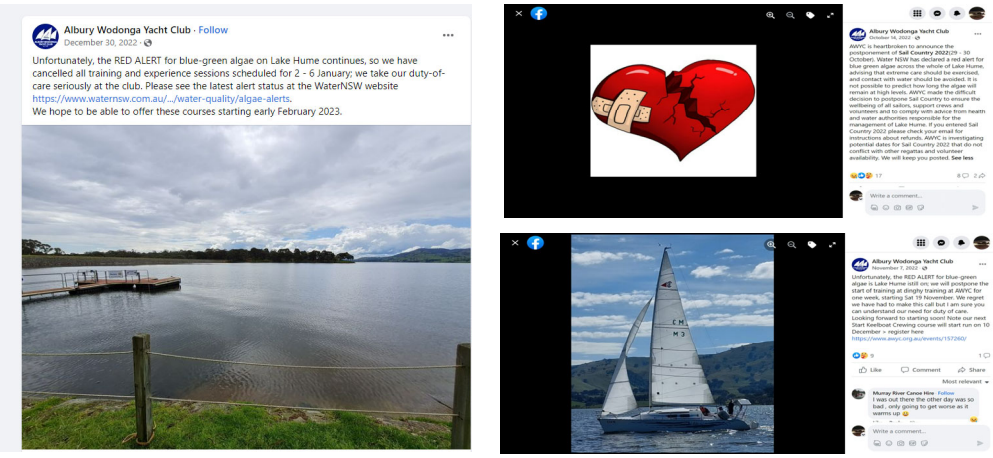

Figure 3. Albury–Wodonga Yacht Club's Facebook communication: Lake Hume's cyanobacteria contamination December 2021–December 2022.

Contrastingly, during this cyanobacteria outbreak, no communication was made by the tourism-promoting organization, Visit Albury–Wodonga, alerting the community or visitors of health risks from recreational activities or otherwise. Searches for all posts containing 'Lake Hume' returned marketing photographs of kayakers paddling in water and others sitting lakeside with bare, exposed skin. The text encourages fishing, swimming, and to "get on the water", while another advertisement promotes water-skiing to entertain children during "summer holidays" (Figure 4).

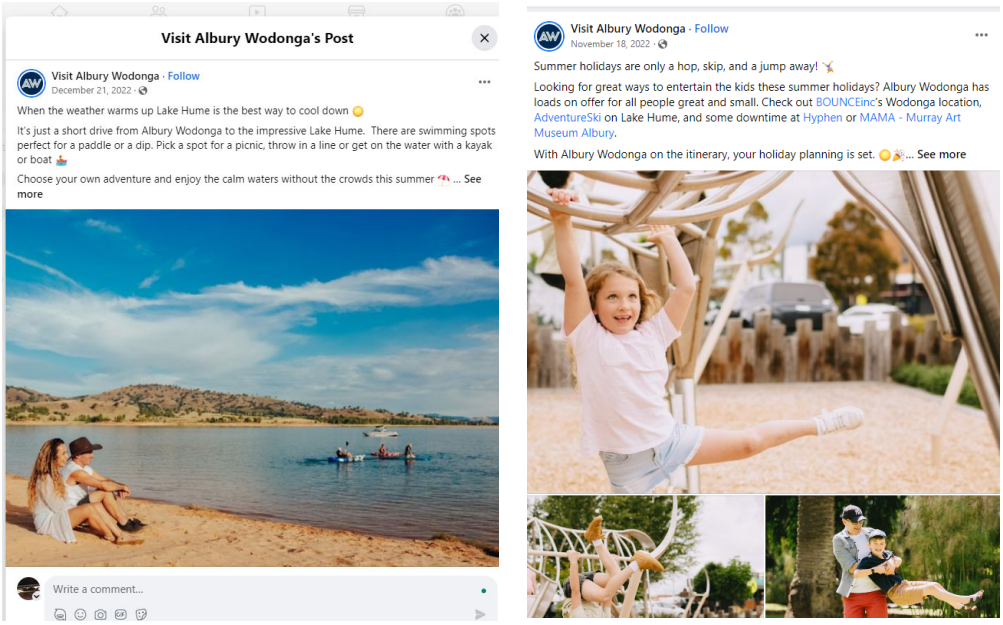

Figure 4. Marketing Lake Hume during a high Cyanobacteria outbreak, 2022.

Throughout the entire red alert cyanobacteria outbreak in November and Decembe, 2022, Visit Albury–Wodonga continued promoting visiting not only Lake Hume but also high-risk activities (Figure 5) involving water contact–paddleboarding, fishing, jet skiing–at the same time, WaterNSW advised the public to "avoid. . .physical contact", including "recreational activities such as swimming, along with any activity that brings the user into direct physical contact with untreated water". Visit Albury–Wodonga does not mention WaterNSW's red alert nor advise visitors about the algae's toxicity potential since consumption can cause gastroenteritis, contact can cause irritations, and fish "should be cleaned and washed thoroughly in uncontaminated water" prior to ingesting.

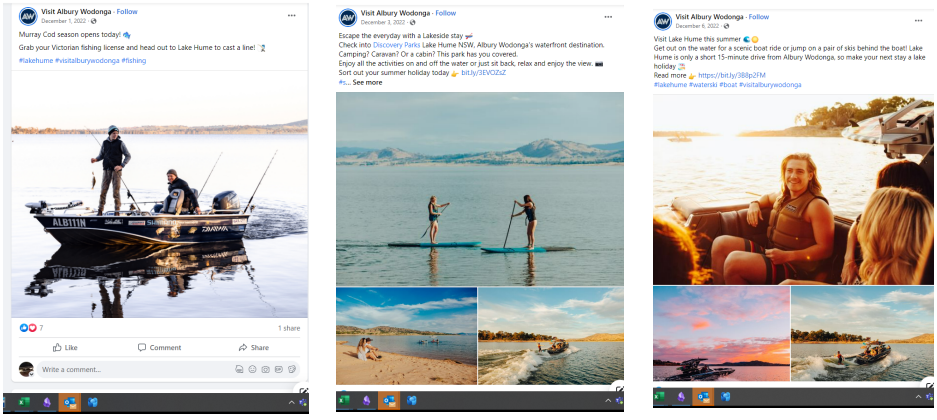

Figure 5. Albury–Wodonga tourism's failure to disclose Lake Hume contamination or public health risks during WaterNSW red alert.

When "Sam FreeSpirit" responds to a marking photograph with a direct enquiry about the bloom, thus constituting the only posting containing the search keywords, Visit Albury–Wodonga's response reveals their awareness of the contamination event by citing WaterNSW's 6 January 2023 update and noting the "warning". This appears without mentioning the high-risk or 'no contact' public health recommendation that was "still" in effect. Instead, they recommend an alternative "unaffected" water body (Figure 6). Where the culpability of managing such negligence by a governmental organization in terms of allowing tourism marketing of unsafe recreational waters for human and animal use, and

actively advising the public where and how to enter the "swimming spot" that the same employee knew was contaminated lie beyond this article's scope.

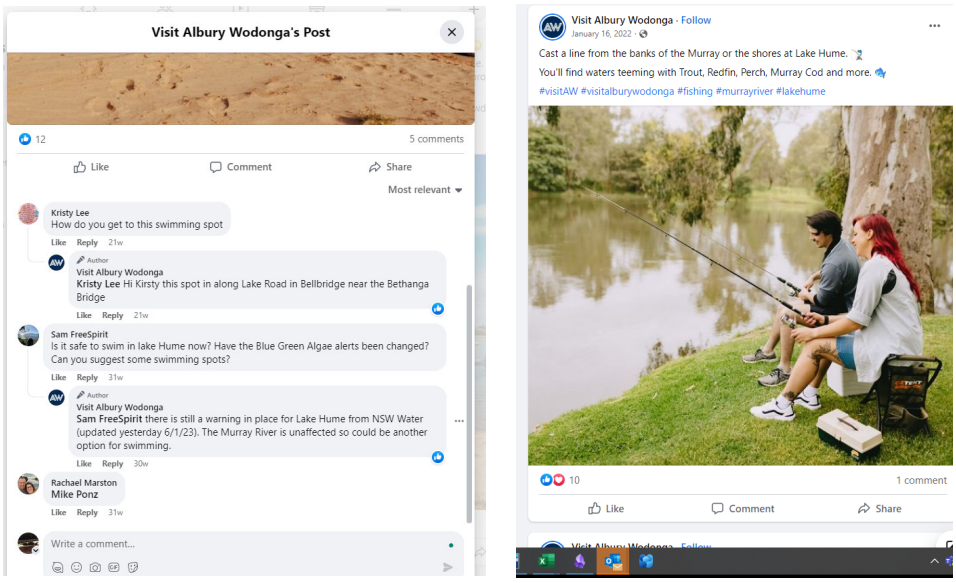

Figure 6. Public awareness of algae alerts in lieu of voluntary governmental disclosure.

Lastly, four articles represent all the news reporting of multiple high alerts for Lake Hume during the research period. Chronologically, the first of four news articles is WaterNSW's media release of its official red alert for Lake Hume on 11 October 2022. No further news articles appear until a summer travelling warning issued by the Australian Broadcasting Corporation (ABC) on Christmas Eve advising of "a surge in mosquito numbers and algae blooms, following the detection of Ross River virus and blue-green algae" across Victoria and NSW. The ABC reproduced WaterNSW's phraseology in its official communication, revealing this standard communication practice as exhibited by the other government bodies and organizations sampled. This finding suggests that WaterNSW exercises total control of responsibility for public communication about Lake Hume's public-health safety.

Albury's local newspaper, The Border Mail, published two articles. This news reporting was limited to directly quoting WaterNSW's official media releases for the first bloom occurring in October 2021, which lasted for over a month, and the second bloom in December [45,46]. News article headlines, "Don't touch the water: Blue-green algae red alert issued for Lake Hume" and "Avoid the water: Blue-green algae red alert issued for Lake Hume" clearly communicate Lake Hume ought not to be used for recreational activities at the time of reporting.

3.2.3. Population and Activity Metrics: Lake Hume Communities and Events

For red alerts, members of the genus *Microcystis* were a dominant component of the cyanobacterial blooms found during the Australian summer (December) of 2021 [47] and at 4 of 5 sites measured in summer 2022 [48]. *Dolichospermum* [48] was identified for the fifth site. Both *Chrysosporum* and *Dolichospermum* are genera within the *Aphanizomenonaceae*. In winter 2022 (July–August), similar conditions were detected [49]. Between December 2021 and June 2022, AWYC's activities included multiple courses attended by 332 participants. Of these, 286 participants were under age 18, with 64 primary school students generally under age 14 [50]. Thus, the analysis suggests varied levels of toxin exposure for children, and likely other vulnerable individuals, occurred without their awareness.

Exploration of the population metrics for age and four major diseases in the three rural communities closest to Lake Hume (Bellbridge, Bonegilla, and Tallangatta) suggest a need for improved communication of high cyanobacteria outbreaks, given age and disease

rates that may be compounded by socioeconomic status. Table 3 reveals two communities (Bellbridge and Tallangatta) are older than average Australians. These communities have comparable or higher levels of asthma, cancer, and heart disease than Australia's population. Despite Bonegilla's lower median age, its asthma rates exceed national averages.

Table 3. Population metrics and health status as % of residents with medical conditions in three rural waterside towns compared with the national population.

Town	Population	Median Age	Asthma	Lung Conditions	Cancer	Heart Disease
Bellbridge	363	51	7.6	0	4.3	3.1
Bonegilla	610	26	9.3	0.7	2.0	3.1
Tallangatta	1175	48	9.4	2.7	3.2	7.3
Australia	25M	38	8.1	1.7	2.9	3.9

Specifically, 51% of Bellbridge's residents are over 50. This is considerably higher than the Australian average for that age group's community representation of 35.4% [51]. Compared with the Australian average of 23%, 36.25% are over age 60. With the median weekly household income at AUD 1413, this community is socioeconomically lower than the national average of AUD 1746 and, hence, was likely to be less formally educated. Similarly, Tallangatta has 35.9% of residents over age 60, compared to the Australian average of 23%, and 48.5% over age 50, compared to the national average of 35.4% [52]. Its median weekly household income, AUD 1149, is the lowest of the three rural communities. In contrast, Bonegilla is largely a military town, with 57% of residents employed by the Australian military, compared with the national average of 0.7%. This is reflected in the low median age of 26, with only 18.6% of residents over 60 compared to Australia's 23%, and higher than the Australian median weekly household income average of AUD 2104 [53].

4. Discussion

The MDBP is among the most reviewed water management systems in Australia, having been subjected to over 30 reviews in the past fifteen years, impacting the livelihoods of millions of community members traversing three Australian states [54]. Such reviews, however, fail to distill how the inherently *social process* of governing and managing cyanobacterial contamination, risk-level identification, and corresponding communication affect community toxicity exposure. This article answered four research questions to produce novel insights of practical import about how the timing, content, and mode for Lake Hume bloom alerts affect the public's ability to learn about and manage exposure risks. Results evidence Lake Hume, as part of the MDBP, lacks a cohesive quality management framework that prioritizes enforcement of known public health risks during bloom events.

During the research period, December 2021 to December 2022, there was only one week when Lake Hume was not designated an 'amber' or 'red' alert level. Visitors attended major events and spent time in and on the water, were subjected to aerosols from high-powered boats, and were exposed to cross-lake breezes. Anthropogenic and natural processes present multiple pathways for the aerosolization of algal species. For recreationalists attending organized events, such as the Australian Powerboat Grand Prix and children's sailing lessons, the responsibility for assuring safety rested with the organizing entity, not the government or water authorities. The content analysis found cyanobacteria risk management by organizers was dichotomized as red alert = no activity, not red = no restrictions. Only when WaterNSW designated Lake Hume a red alert did organizers cancel events. This alert actioning strategy reveals minimal compliance and risk-exposure effort by the researched organizations, as well as an overall failure to equip attendees with the health literacy required to make informed decisions relative to health status. For example, if an asthmatic has high public health literacy, they may choose to avoid symptom exacerbation when toxicity levels are high enough for an amber alert. Since many lake users were children, however, their science and health literacy likely requires

augmentation by those without vested economic interests in promoting profitable recreation and tourism events. Moreover, given Lake Hume's rural geographic location and that rurality, wealth, and education affect science literacy [55–57], the economic pressure on fledging rural businesses to promote Lake Hume's use compounds public health risks from contamination exposure.

Cyanotoxins are hazardous chemicals. The Royal Yachting Association in the UK includes blue-green algae in their risk assessment practices and recommends their clubs provide information to event participants, further giving maps of affected areas to support informed decision-making and noting, since children and vulnerable adults may be unable to assess risks, clubs must take responsibility [58]. This article strongly encourages Australian boating/sailing clubs to follow British practices.

The research found the primary, if not only, geophysical public-health risk management practice during Lake Hume's red alerts was erecting signage at strategic entrance locations. Lake visitors missing, ignoring, and/or unable to read signage (due to English language, literacy, and/or physical eyesight ability presuppositions) faced cyanobacteria exposure. Compliance (e.g., no swimming) was managed by self-regulation. No monitoring or enforcement was found. The content analysis found social media and website postings of WaterNSW's red alert instructions across organizations implied that health risk was relative to physical contact with water or ingestion. There was no mention of risks posed by exposure from aerosol or dried remnants on Lake Hume's edge. Nor was advice provided about increased risks of adverse health outcomes from any exposure (inhalation, contact, ingestion) type for the immunocompromised or those with chronic health conditions, including asthma and heart disease [59]. Organizational practices also failed to educate lakeside residents about aerosol risks from blooms that can adversely impact their health conditions even if they do not 'touch' the water or ingest fish organs. Although WaterNSW's advice supports the broader scientific opinion that it is best to avoid or exercise great caution when eating fish from contaminated water, recent American research found that eating fish flesh from water during algal blooms is safe [60]. Hence, scientific uncertainty exists regarding 'safe' exposure and points to a need for further research.

While quantifying how many of the additional >2000 residents from surrounding towns were exposed to Lake Hume's water during amber/red alerts is impossible, public health data noting 31% were aged $\geq$60 and had pre-existing health conditions susceptible to exacerbation by cyanobacteria exposure (Table 3) suggests need for improved community health risk management beyond signage and repetitive and limited communication observed. Census data revealed local residents had low socioeconomic status and low formal education, exempting the military community. Research evidence shows that high health literacy correlates with higher socioeconomic and education levels [55]. Augmenting community health and risk literacy related to cyanobacteria exposure from Lake Hume demands a community-focused approach tailored to literacy levels rather than organizational reliance on generic directives and signage, presuming comprehension and hoping for compliance. Creating a communication plan that acknowledges and addresses the diversity of local communities and lake visitors' needs may prevent exacerbating preexisting diseases.

The health implications of waterside residents' chronic exposure to cyanotoxins is an active research area in several countries, but not Australia [27]. WHO notes it is an area requiring investigation in its latest guidelines [21]. Even without definitive measurements, higher rates in Tallangatta of the two conditions known to be exacerbated by cyanotoxin exposure, asthma and heart disease, combined with existing aerosol spread research, suggests RACC may not be meeting their public health goals. Census data for the three towns revealed high cancer rates in the two towns with long-term residents. This was evidenced by age, compared with Bonegilla's younger and mobile military population. Higher cancer rates existing alongside the presence of *microcystein* in Lake Hume (which is classified as potentially carcinogenic by the International Agency for Research on Cancer [61]) may be coincidental or may warrant further investigation. For instance, prior research finding a cluster of above-average incidents enabled identifying the link, in multiple places, between

amyotrophic lateral sclerosis, a neurodegenerative disease, and living near water bodies that experience blooms [62].

Next, the finding that no health warnings were made for Lake Hume's amber alerts has several implications. First, only those aware of and interested in WaterNSW's website could become aware of amber alert levels. Second, organizations and local councils promoted and held powerboat races, fishing competitions, sailing regattas, and lake use at all times outside legislated compliance with red alert measures. This trans-organizational practice promulgated a false image of water safety. Third, although scientific research evidences the health risks from amber-level cyanobacteria exposure for sensitive populations, no public communication or education existed. This finding suggests government negligence in promoting inclusive and preventative public health measures. For example, given safe exposure modeling uses a 15 kg child, this means children under approximately 3.5 years (based on average weight by age) may be exposed to higher risks than caretakers might realize given the 'one-size-fits-all' approach to Lake Hume's risk exposure alerting practices [21]. Fourth, water authorities' failure to inform the public of exposure risks at the amber-level left water-skiers, October 2022 fishing competition participants, and February 2022 powerboat Grand Prix boaters personally responsible for learning about bloom risks from swimming, boat engine spray, etc. Since the Grand Prix immediately preceded Lake Hume's nine-week red alert closure, the drift of aerosol particles from motorized watercraft likely added to chronic cyanotoxin exposure experienced by lakeside residents from natural sources without a public health warning. Finally, since NHMRC guidelines were published, increased evidence of cyanotoxin inhalation risks from aerosolization has emerged [16].

Human health risks appear in information linked to guidelines currently governing alert levels and actions. Interpretation of this information (in the context of a risk matrix, assumptions about who is at risk (which currently excludes residents), and likely, rather than actual, toxin composition used to predict health impacts) [63] is needed to better serve most Lake Hume visitors and residents. NHMRC guidelines assume general health and weight factors and that an acceptable annual load will derive from a 14-day annual exposure (equivalent to a 2-week summer holiday) by direct contact. These guidelines may be insufficient for residents of affected local communities. WHO's report supersedes NHMRC guidelines. This report places greater emphasis on toxin identification than cell counts, as even within a colony, toxicity ranges can vary considerably and under/over-assume actual risks using cell numbers [21].

Given the difficulties inherent to creating a national system suiting universal needs, it is worth reconsidering RACC's responsibilities. Local bodies have access to information about human interactions with natural resources, in this case, Lake Hume, cyanobacterial levels, and blooms' known precursory conditions (e.g., water temperature and nutrient levels largely derived from agriculture). The revised WHO guidelines provide a highly adaptable framework. Presently, however, RACC only has monitoring and response functions. WHO guidelines and others note the most effective management tool is prevention [21]. The MDBA holds managerial responsibility for greater engagement, namely with primary producers. This is problematic, as discussed next.

Global bloom research finds their increase is more a result of anthropocentric activities, namely agriculture, than climate change [11]. Lake Hume's future bloom management requires active engagement to reduce water nutrification (due to soil erosion and agricultural runoff from fertilizer and stock manure) and ensure adequate water flows to support cyanobacteria public health risks. This recommendation is congruent with the area's recent water quality technical report produced by the state government, which acknowledged the need to reduce nutrification from agriculture [22]. Likewise, it reproduces recommendations made in a localized report produced thirteen years earlier [23]. Evidence of active engagement with preventative measures to minimize adverse agricultural impact on water quality, however, is absent. Cattle still graze along Lake Hume's banks. The protection of agricultural activities is not unique to Lake Hume, despite evidence that altering them would create positive human and environmental health outcomes, and despite multiple or-

ganizations, including WHO [21], America's Environmental Protection Agency (EPA) [64], and Australian Productivity Commission [38] noting that managing nutrification, particularly from agricultural activities, is critical for bloom control. The US government's *Clean Water Act* exempted agricultural activity from direct regulation despite requests from the EPA [64]. Likewise, Australian and American regulators noted difficulties with accurately identifying diffuse sources of pollution (including farm runoff), choosing to address the issue with behavioral, rather than legislative, change by funding the EPA to educate and provide grants to primary producers to help them adopt more environmentally sound practices [64]. These measures were credited with decreasing blooms in northern states [11]. Water managers involved with American bloom management, however, are government and commercial entities rather than collectives that include agricultural representatives, as is the situation for Lake Hume and other water bodies the MDBA manages. In contrast to Australia, some American water managers noted their disproportionate responsibility for and cost of responding to blooms, while those largely impacting bloom production were not held accountable [64].

The United Nations General Assembly declared 2018–2028 the 'Water Action Decade' [65]. Water management in a time of climate change, increasing water scarcity, and global recognition of past mismanagement requires professional water managers capable and able to take a whole system approach to complex risk management. Australia has recent demonstrable success with government-supported education and program funding to enhance sustainable land practices that reduce erosion, movement of sediment, and waterway nutrification [66]. These measures have been instrumental in reducing pressure on the Great Barrier Reef and helping to preserve its World Heritage listing. Although the reef's potential loss of status was proclaimed a great international embarrassment by news media, it offered an opportunity to estimate the cost (e.g., an estimated AUD 900 million of State and Federal money [66]) of pro-environment actioning. Whilst similarly surrounded by farmland, those involved with the reef are not part of the MDB or MDBA governance or management. Thus, the reef offers an exemplar for possible adaptation for MDB waterway improvement broadly, and Lake Hume specifically.

Finally, questions related to governance and management model assumptions related to how cyanobacteria risks are communicated, which levels are deemed sufficient for public information dissemination, and who in the community is advised (when, how, and why), expose systemic limitations that require further investigation. The emergence of tropical cyanobacteria species in non-tropical areas [63], record-breaking rain and flooding events followed by drought [67], post-fire support for environment recovery [68], endangered species [69], P-nutrient stewardship [70], and effective large scale treatment of blooms [71] are elements that could be incorporated into a more holistic Lake Hume management plan. Likewise, international water management trends, such as incorporating professional engagement with *local* communities and using research by 'honest brokers' [72], might be considered. Lastly, Australia remains one of the few countries without national legislation protecting drinking water quality [73]. National guidelines are neither enforceable nor designed to permit individual states and territories to develop their own legislative tools. Subsequently, Lake Hume, as part of broader water systems, including the MDB, requires legislation to protect human and environmental health.

5. Conclusions

Cyanobacteria multiply when temperatures increase and reduce water quality. As climate change contributes to global warming, increased and longer-lasting blooms present public health risks in Lake Hume, Australia. This investigation found Lake Hume blooms receive inadequate public health education or management. High environmental health literacy is required to understand Lake Hume's water quality information [56,57]. Most Lake Hume water quality information lacks community access. The public health risk information water managers provide, through government and organizational distribution, fails to serve vulnerable populations identified at risk of cyanotoxin exposure. Suitable and

tailored information that is useful to guide decisions about living near, visiting, or recreationally using the lake is necessary. Results also found government tourism promoting Lake Hume and encouraging visitors to "get on" the water despite red alert contamination. Thus, community participation and the provision of information from trusted entities are necessary for safer water management. Further, enhanced water manager training and more effective communication practices, given local levels of environmental health literacy, are necessary to address these persistent, known problems [74].

Lake Hume residents and visitors are disadvantaged by not being given suitable advice to make informed decisions about how blooms affect their health. Anthropogenic and natural processes present multiple pathways for the aerosolization of algal species at Lake Hume. Vulnerable populations and/or those who experience illness from blooms may seek accountability from organizations failing to disclose known risks. While some individuals may act against provided bloom health risk advice, just as some choose to smoke, currently, the Australian Government legislates to reduce risk exposure by keeping workplaces and entertainment venues smoke-free. Conversely, government tourism promoting Lake Hume's usage, a key area for regional tourism development [75], and lack of legislation to prevent agricultural runoff from contaminating the environment support activities that increase blooms and exposure risks. Climate change and anthropogenic contributions affecting the quantity and severity of blooms illustrate the need for non-partisan legislative reform that prioritizes Lake Hume's water quality. European pro-environmental initiatives [76] and Australian legislative changes mandating the inclusion of First Nation voices in water issues and the provision of water for cultural reasons [77] present opportunities for current water authorities to learn from Indigenous knowledge of the country and recognize Lake Hume as part of the broader waterways requiring guardianship more than economic exploitation.

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