Investigation on the efficacy of UV disinfection on *Cryptosporidium* in swimming pools and other recreational water facilities

By

Shun Yan Gladys Chong

Thesis
Submitted to Flinders University
for the degree of

Master of Environmental Health

College of Science and Engineering
05 December 2024

TABLE OF CONTENTS

ABSTRACT

Cryptosporidiosis outbreaks in swimming pools and other recreational water facilities, primarily caused by *Cryptosporidium parvum* and *Cryptosporidium hominis*, are responsible for most water-born gastroenteritis cases in Australia.

Cryptosporidium oocysts are notorious for their high tolerance to chlorination, allowing them to survive in well-maintained swimming pools for prolonged periods, posing a significant public health risk to swimmers. As of 1 September 2024, the number of cryptosporidiosis notifications from the National Notification Diseases Surveillance System (NNDSS) indicated a significant increase of confirmed cases in Queensland, New South Wales, and Victoria, implying an ongoing endemic outbreak.

Research demonstrated that UV disinfection was effective in inactivating *Cryptosporidium* oocysts in drinking water treatment and wastewater treatment. However, it remains uncertain if ultraviolet light could eliminate the *Cryptosporidium* oocysts in swimming pools and other recreational water facilities. A comprehensive systematic literature review was conducted to identify eligible literature before 08 March 2024 and found that recreational water facilities with chlorine-based disinfectants along with UV disinfection in other countries had cryptosporidiosis outbreaks. It is suggested that more scientific studies be conducted to fill any knowledge gaps.

Experiments were also carried out at four swimming pools in South Australia that used primary chlorination and secondary UV disinfection. Negative results of Colilert 18 testing were observed, suggesting primary chlorination with secondary UV disinfection was effective in eliminating *E.coli*. However, it was still unclear whether secondary UV disinfection with primary chlorination could eradicate *Cryptosporidium* oocysts efficiently. Future research using the reliable surrogate indicator is suggested for detecting *Cryptosporidium* oocysts in a swimming pool with secondary UV disinfection combined with primary chlorine disinfection.

As there is no available vaccination and limited approved drug for treating cryptosporidiosis in immunocompromised adults, prevention of cryptosporidiosis greatly relies on the environmental health approach. It is essential to emphasise healthy swimmer practices and good hand hygiene.

An extensive comparison of legislation, regulations, and guidelines related to cryptosporidiosis outbreaks in swimming pools and other recreational water facilities was undertaken. The findings indicated an inconsistency in the management of cryptosporidiosis outbreaks in recreational water facilities across Australia, particularly in the definitions for a cryptosporidiosis outbreak, guidelines related to CT value for hyperchlorination, recommendation for filter size and filtrate turbidity, recommendation for using UV as secondary disinfection, regular shock chlorine treatment in pools, and the legislative controls on using chlorine or bromine as primary disinfection and the

recommendation for new high-risk public swimming pools. It is recommended that a National Recreational Water Facilities Standard And Guideline be established to provide a proper legal protocol for recreational water facility operators and staff, health authorities, and the swimming pool industry, for supervising and monitoring the remedial actions to prevent a cryptosporidiosis outbreak. The guideline should provide daily operational requirements for a recreational water facility to minimise public health risks.

DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed: Shun Yan Gladys Chong

Date: 14 October 2024

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisors, Professor Kirstin Ross and Associate Professor Harriet Whiley for their invaluable guidance, insights, and support to me throughout this research project. Their mentorship and expertise have been essential for me to have a clearer understanding of the knowledge in Environmental Health. I am deeply grateful for their time, effort, and inspiration in guiding me in growth in the academic field.

I am deeply grateful to my parents and two sisters for their support and encouragement during my studies in Australia.

I also dedicate this work with heartfelt gratitude to my beloved husband, Kevin, and our young daughters, Emma and Mo Yin, for their love, understanding, accompaniment, and encouragement that motivates and sustains me through this challenging journey.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACT	Australian Capital Territory
AFR	Accidental Faeces Release
ANSI/NSF	American National Standards Institute and National Sanitation Foundation
AOP	Advanced Oxidation Processes
AS	Australian Standard
ASFB	Aerobic spore-forming bacteria
AS/NZS	Australian/ New Zealand Standards
BSES	Bi-national Food Surveillance and Enforcement Strategy
CDC	Centers for Disease Control and Prevention
CINAHL	Cumulative Index to Nursing and Allied Health Literature
cm	centimetre
CRYPTO	*Cryptosporidium*
Cryptosporidium spp.	*Cryptosporidium* species
CT	Concentration × Time
div	Division
E. Coli	*Escherichia coli*
EHA	Environmental Health Australia
EHO	Environmental Health Officer
FDA	Food and Drug Administration
FSANZ	Food Standards Australia New Zealand
g	gram

h	hours
ISO 9000:2000	International Organization for Standardization 9000:2000.
KAP	Knowledge, Attitudes, and Practices
LAMP	Loop-Mediated Isothermal Amplification
log10 units	logarithmic base 10 units
L/min	litres per minute
µL	microlitre
MAHC	Model Aquatic Health Code
$mgCl_2/L$	milligrams of magnesium chloride per litre
mg/L	milligrams per litre
mg·min/L	milligram minutes per litre
mg/mL	milligrams per millilitre
min	minute
mJ/cm^2	millijoules per square centimetre
mJ/s	millijoules per second
mL	millilitre
NHMRC	National Health and Medical Research Council
nm	nanometres
NNDSS	National Notifiable Diseases Surveillance System
NSW	New South Wales
NT	Northern Territory
NTU	Nephelometric Turbidity Units
PCR	Polymerase Chain Reaction

ppm	parts per million
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
pt	Part
qPCR	quantitative Polymerase Chain Reaction
qRT-PCR	quantitative Reverse Transcription Polymerase Chain Reaction
Qld	Queensland
SA	South Australia
sch	Schedule
s	Section
ss	Sections
Tas	Tasmania
USA	United States of America
UV	ultraviolet
UV 254	UV Absorbance at 254 nm
Vic	Victoria
W	Watt
WA	Western Australia
WHO	World Health Organization

1.0 INTRODUCTION

This chapter gives an introduction to *Cryptosporidium spp.* and cryptosporidiosis, the biological cycle of *Cryptosporidium spp.* in humans, the transmission pathway of cryptosporidiosis in swimming pools and recreational water facilities, cryptosporidiosis in Australia and the background information for this research.

1.1 *Cryptosporidium spp.* and cryptosporidiosis

Cryptosporidium spp. are enteric protozoan pathogens that are responsible for cryptosporidiosis in many species and humans (U. Ryan et al., 2021; Shrivastava et al.,2017). It is known that there are more than 44 *Cryptosporidium spp*. with more than 120 genotypes and the most common species for human infection are *Cryptosporidium parvum* and *Cryptosporidium hominis* (Fayer, 2010; U.M. Ryan et al., 2021).

Cryptosporidiosis, a kind of gastrointestinal disease, was first noted in humans with diarrhea in 1976 (Nime et al., 1976). It has been found in more than 40 countries (Kosek et al., 2001). Contraction of cryptosporidiosis can be symptomatic or asymptomatic (Checkley et al., 1997; Johansen et al., 2015; Jokipii & Jokipii, 1986; Moghaddam, 2007; Ng-Hublin et al., 2015; Vuorio et al., 1991). An infected person can have symptoms such as fever, watery diarrhea, dehydration, vomiting, and nausea (Desai et al., 2012). On-set of symptoms typically starts from Day 2 to Day 10 after contracting *Cryptosporidium spp***.** for up to 2 weeks (Desai et al., 2012). High-risk groups for cryptosporidiosis include immunocompromised individuals and children under five (Current & Navin, 1986; Desai et al., 2012; Huang et al., 2004). Risk factors account for the higher risk of infection in children below five years include low socioeconomic status, overcrowded living conditions, male gender, household with pets, unhygienic storage of cooked food, secondary infection of cryptosporidiosis from family members, consumption of unclean or untreated water, low birth weight, impaired growth and lack of breastfeeding (Desai et al., 2012).

A critical factor in a cryptosporidiosis outbreak is the rapid development of oocysts, which are ready to infect humans once they are excreted (Chalmers et al., 2016; Dillingham et al., 2002; Kiang et al., 2006; Newman et al., 1994; Utsi et al., 2016). Cryptosporidiosis is transmitted through ingestion of the oocysts on any contaminated household surface due to poor hand hygiene practice, intensifying the secondary infection of cryptosporidiosis in the household, hospitals, extended care institutions, farms, daycare centres (Chalmers et al., 2016; Dillingham et al., 2002; Kiang et al., 2006; Newman et al., 1994; Utsi et al., 2016). Secondary infection of *Cryptosporidium spp*. can also be caused by inadequate disinfection using chlorine-based household disinfectants (Boehmer et al., 2009a).

1.2 The biological cycle of *Cryptosporidium spp.* in humans

The biological cycle of *Cryptosporidium spp.* in human hosts includes a sexual stage and an asexual stage (Shrivastava et al., 2017; Tandel et al., 2019; Thompson & Ash, 2016). *Cryptosporidium* oocysts, usually about 4 to 6 microns in size and containing four sporozoites, are released into the extracellular environment in hosts' faeces (Shrivastava et al., 2017; Xiao et al., 2004). The *Cryptosporidium* oocysts are accidentally ingested by another healthy person (Shrivastava et al., 2017). Upon arriving at the digesting tract of the new host, the oocysts release spindle-shaped sporozoites that adhere to the intestinal epithelial cells (Shrivastava et al., 2017; Smith et al., 2005). Trophozoites then develop as parasitophorous vacuoles encapsulate the sporozoites (Aldeyarbi & Karanis, 2016; Certad et al., 2017; Clode et al., 2015; Heo et al., 2018; Shrivastava et al., 2017; Valigurová et al., 2008). Meronts are produced via the merogony of trophozoites, while two merogonies occurred in different generations consecutively, forming the first-generation meronts and the second-generation meronts (Cacciò & Putignani, 2014; Shrivastava et al., 2017). The asexual reproductive stage is then completed by reinfecting the nearby intestinal epithelial cell (Chalmers & Davies, 2010; Shrivastava et al., 2017). Sexual reproduction involves the differentiation of meronts to form male and female gametes microgamonts and fertilize themselves to undergo multiple divisions (English et al., 2022; Rosales et al., 2005; Shrivastava et al., 2017). The sporogony then produces oocysts with thickened walls that are excreted with faeces, while oocysts with thinner walls remain in the host to initiate autoinfection (Shrivastava et al., 2017).

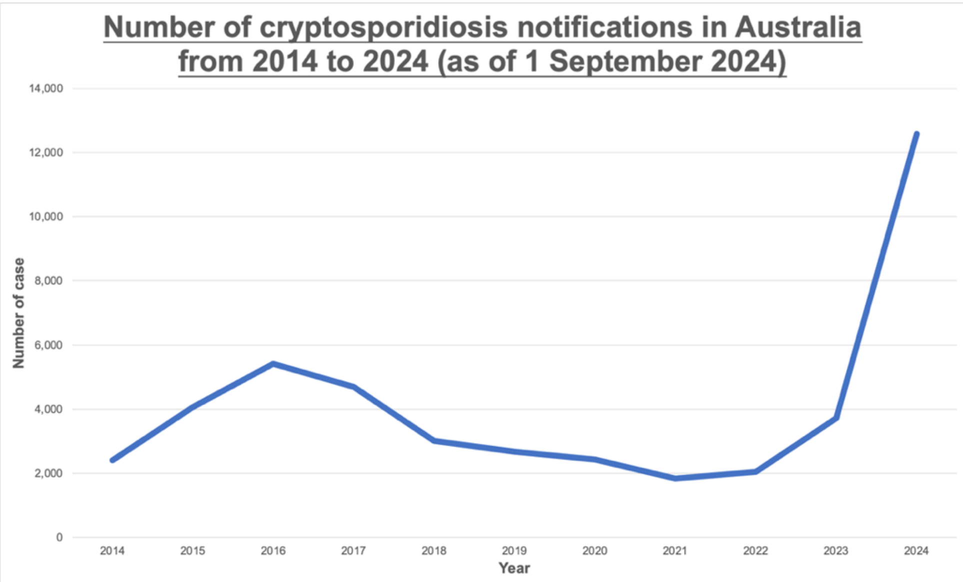
1.3 Transmission pathway of cryptosporidiosis in swimming pools and recreational water facilities

Cryptosporidium oocysts have a high chlorine resistance (Dillingham et al., 2002). The infectivity of oocysts was unchanged after being exposed to 10 ppm of chlorine for a period of 48 h, which is higher than the average level of chlorine in actual swimming pool practice (e.g. 2 ppm) (Carpenter et al., 1999; Dillingham et al., 2002). Transmission of cryptosporidiosis in recreational water facilities occurs through the faecel-oral route when an infected person sheds faeces with infectious oocysts into swimming pool that are swallowed by other healthy swimmers (Dillingham et al., 2002; Fayer et al., 2000; Gururajan et al., 2021; Shrivastava et al., 2017). Symptomatic individuals can excrete billions of oocysts inside their faeces and the situation continues for up to two weeks after the diarrhea symptom resolves (Jokipii & Jokipii, 1986). Studies showed that the infectious dose was found to be just 10 oocysts, thus causing a severe health risk to swimmers (Chappell et al., 2006; Dillingham et al., 2002; Jokipii & Jokipii, 1986).

1.4 Cryptosporidiosis in Australia

Cryptosporidiosis is one of the nationally notifiable diseases in Australia (Australian Government Department of Health and Aged Care, n.d.). It is monitored by the National Notification Diseases Surveillance System (NNDSS) (Australian Government Department of Health and Aged Care, n.d.). A review found that there are 78% of waterborne outbreaks of gastroenteritis were identified as related to recreational water facilities and 98% of the outbreaks were caused by *Cryptosporidium spp.* from 2001 to 2007 in Australia (Dale et al., 2010). Also, a review found that *Cryptosporidium hominis* was responsible for most of the outbreak cases in the swimming pools and recreational water facilities in Australia, which have a higher infective rate in humans than *Cryptosporidium parvum* (Garcia-R & Hayman, 2023; Ryan et al., 2022).

According to the data from the Department of Health and Age Care, the number of notifications of cryptosporidiosis in Australia for the year 2024 is 12,577 (as of 1.9.2024) which is more than triple the number of total cryptosporidiosis notifications in the year 2023 (e.g. 3,715) (Australian Government Department of Health and Aged Care, n.d.). The number of cryptosporidiosis notifications in Australia from 2014 to 2024 (as of 1 September 2024) is shown in **Figure 1.1.**



Diagnosis Year	Number of Notifications
2014	2,408
2015	4,064
2016	5,421
2017	4,694
2018	3,011
2019	2,679
2020	2,437
2021	1,844
2022	2,047
2023	3,715
2024	12,577

Figure 1.1 Number of cryptosporidiosis notifications in Australia (2014 - 2024) (as of 1 September 2024) (Australian Government Department of Health and Aged Care, n.d.)

With regard to the distribution of cryptosporidiosis notifications as of 1 September 2024, Queensland has the highest cryptosporidiosis notifications (5,924); followed by New South Wales (3,105) and Victoria (1,964). The number of cryptosporidiosis notifications across States and Territories in Australia from 1.1.2024 to 1.9.2024 was summarized in **Table 1.1** (Australian Government Department of Health and Aged Care, n.d.).

Table 1.1 The number of cryptosporidiosis notifications across States and Territories in Australia from 1.1.2024 to 1.9.2024 (Australian Government Department of Health and Aged Care, n.d.)

States or Territories	Australian Capital Territory	New South Wales	Northern Territory	Queensland	South Australia	Tasmania	Victoria	Western Australia
Number of C*ryptosporidium* notifications	229	3,105	42	5,924	626	77	1,964	610

In February 2024, Queensland Health issued media releases to report that there is a rapid increase in cases of cryptosporidiosis in Queensland (Queensland Health, 2024a). Meanwhile, the NSW Government also issued a cryptosporidiosis alert in February 2024 to remind the public about the outbreak situation in New South Wales (NSW Health, 2024a).

The data of cryptosporidiosis notifications extracted from NNDSS strongly supports a current ongoing endemic outbreak of cryptosporidiosis in Australia, with an unexpected surge in cryptosporidiosis notification numbers particularly in Queensland and New South Wales.

1.4.1 Most susceptible groups for cryptosporidiosis in Australia

For the distribution by age groups for cryptosporidiosis notifications in Australia as of 1.9.2024, it is found that the age group under 5 has the highest infected individuals for cryptosporidiosis; followed by the age group from 24- to 44 years old. These age group data are consistent with previous studies of cryptosporidiosis, indicating age group under 5 is the most susceptible group for cryptosporidiosis, and parents or carers between 24-to 44 years old are likely to have secondary infection if the child is contracted with cryptosporidiosis (Cacciò & Chalmers, 2016; Khalil et al., 2018; Lal et al., 2016; Lal et al., 2015; Tombang et al., 2019). The distribution by age groups for cryptosporidiosis notifications in Australia as of 1.9.2024 was summarized in **Table 1.2.**

Table 1.2 shows the distribution by age groups for *Cryptosporidium* notifications in Australia as at 1.9.2024 (Australian Government Department of Health and Aged Care, n.d.)

Age	Male	Female	Not stated / Inadequately described/ No information provided	Total
00-04	1,898	1,374	9	**3,281**
05-09	1,035	822	1	**1,858**
10-14	363	261	0	**624**
15-19	103	105	0	**208**
20-24	121	264	0	**385**
25-29	225	544	0	**769**
30-34	477	1,020	1	**1,498**
35-39	546	983	1	**1,530**
40-44	347	564	1	**912**
45-49	187	183	0	**370**
50-54	89	129	0	**218**
55-59	44	136	0	**180**
60-64	54	186	0	**240**
65-69	64	154	1	**219**
70-74	45	99	0	**144**
75-79	28	55	0	**83**
80-84	11	20	0	**31**
85+	9	17	1	**27**
Total	**5,646**	**6,916**	**13**	**12,577**

1.5 Background information of this research

The representative of a company called HealthySwim attended a meeting with the Public Health Special Interest Group of Environmental Health Australia (EHA) on 2nd April 2024, stating its evidence-based patent UV treatment with an ozone system *could inactivate Cryptosporidium spp*.. Despite its adoption in Queensland, cryptosporidiosis cases have surged dramatically in 2024. An investigation on the efficacy of UV disinfection on *Cryptosporidium spp*. in swimming pools and other recreational water facilities was conducted as concern was expressed by one of the councils in South Australia.

2.0 SYSTEMIC LITERATURE REVIEW

This chapter presents a systemic literature review about the efficacy of UV disinfection on *Cryptosporidium* in swimming pools and other recreational water facilities using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

2.1 Search Strategy and Databases

Adhering to the guidelines from PRISMA, keyword searches were conducted in the databases Scopus, Web of Science, and CINAHL to find any matched results of literature written in English before March 2024.

2.2 Search Keywords

The three databases were preliminarily searched with a set of keywords using Boolean operators "AND" and "OR", namely “CRYPTO* AND (UV OR Ultraviolet)”. Subsequent refined searches in search results were carried out by using another set of keywords, namely “Pool OR spa OR recreational OR spray OR splash OR spring”.

2.3 Inclusion Criterion

The refined results from the three databases were then examined and regarded as eligible for this systemic literature review if they related to “any field studies or cryptosporidiosis outbreak reviews in swimming pools or recreational water facilities equipped with ultraviolent light disinfection systems”, “any laboratory studies that assess the efficiency of innovative disinfection methods involving ultraviolent light in swimming pools” or “any studies that review the regulations regarding the design of UV disinfection systems in swimming pools”.

2.4 Exclusion Criterion

Exclusion criteria for this systemic literature review were defined as “any study not related to swimming pools or any other recreational water facilities”, “any study not related to UV disinfection on *Cryptosporidium*” or “any study was not specifically discussing *Cryptosporidium*”. In cases where a screened result falls within any one of the exclusion criteria, it would be regarded as ineligible for this systemic literature review.

2.5 Search Result

There were 379 initially retrieved articles after applying the inclusion criterion and exclusion criterion. Distribution of these 379 initially retrieved articles were 32 journals from CINAHL, 279 journals from SCOPUS, and 68 journals from Web of Science. There were 46 initially retrieved articles that were excluded because of duplication. The remaining 333 articles were screened by examining the journal title; if the title was relevant, then its abstract was examined in detail. There were 305 records being excluded according to the irrelevance of content in their abstract. Therefore, 28 records were being sought for retrieval. However, there was a record that could not be retrieved for its full text and was excluded. As a result, the remaining 27 articles were further examined by reading their full manuscript. After considering both inclusion and exclusion criteria, only 8 eligible articles were found and included in this systemic literature review. Figure 2.1 demonstrates the PRISMA flow diagram for the screening of searched records from the three databases (Haddaway et al., 2022).

Figure removed due to copyright restriction.

Figure 2.1 A PRISMA flow diagram demonstrating the screening of searched records from CINAHL, SCOPUS, and Web of Science in this research (Haddaway et al., 2022).

2.6 Result

The key findings from the included literature that are related to UV disinfections on *Cryptosporidium* oocysts in swimming pools or recreational water facilities were summarised at Table 2.1.

Table 2.1 presents the key findings from the included literature that are related to UV disinfections on *Cryptosporidium* oocysts in swimming pools or recreational water facilities.

		Reference
Types of literature	Outbreak review	Boehmer et al., 2009; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013
	Lab study	Busse et al., 2019
	Fieldwork test	Ekowati et al., 2019; Petterson et al., 2021
	Regulation review	Paccione et al., 2017
Country of cryptosporidiosis cases in swimming pools or recreational water facilities that involved UV disinfection	USA	Boehmer et al., 2009; Iverson et al., 2018; Paccione et al., 2017
	Canada	Hopkins et al., 2013; Lu et al., 2013; Petterson et al., 2021
	Information not available	Busse et al., 2019; Ekowati et al., 2019
Types of filtrations involved	High-rate sand filtration	Boehmer et al., 2009
	Rapid sand filtration	Ekowati et al., 2019
	Diatomaceous earth filtration	Hopkins et al., 2013; Lu et al., 2013
	Neptune Filtration, Hydrobotanic Filtration, and Submerse Filtration	Petterson et al., 2021
	Information not available	Busse et al., 2019; Iverson et al., 2018; Paccione et al., 2017
Installation point for UV disinfection	After filtration and before chlorination	Boehmer et al., 2009; Ekowati et al., 2019; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021
	Information not available	Busse et al., 2019

		Reference
Method for enumeration of *Cryptosporidium* oocyst	Testing of bulk stool samples from infected cases by polymerase chain reaction	Boehmer et al., 2009
	Plate counting of infectious foci with an epifluorescence microscope	Busse et al., 2019
	Testing of stool sample with initial screening with auramine-rhodamine fluorescent stain, followed by the confirmatory testing by safranin stain or formalin-ether concentration	Hopkins et al., 2013
	Information not available	Ekowati et al., 2019; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021
Strain / Species / Serovar of *Cryptosporidium*	*Cryptosporidium hominis* subtype *IbA10G2*	Boehmer et al., 2009
	Cryptosporidium parvum	Busse et al., 2019
	Cryptosporidium hominis	Hopkins et al., 2013; Petterson et al., 2021
	Cryptosporidium hominis subtype *IfA12G1*	Iverson et al., 2018
	Information not available	Ekowati et al., 2019; Lu et al., 2013; Paccione et al., 2017
The wavelength of UV involved in the disinfection process	UV with wavelength 254 to 330 nm	Busse et al., 2019
	UV with wavelength exactly at 254 nm	Ekowati et al., 2019
	Information not available	Boehmer et al., 2009; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021

		Reference
UV Disinfection System Installed After Filtration and Before Chlorination	Four amalgam low-pressure 180 W UV lamps inside a reaction chamber	Ekowati et al., 2019
	A medium-pressure UV light system	Hopkins et al., 2013
	UV reactor at 40 mJ/cm^2	Paccione et al., 2017
	Information not available	Boehmer et al., 2009; Busse et al., 2019; Iverson et al., 2018; Lu et al., 2013; Petterson et al., 2021
UV Effectiveness to *Cryptosporidium* oocyst	Inactivation of 1.1 log10 units *Cryptosporidium* oocyst at UV 254 with a dose of 2.0 mJ/cm^2	Busse et al., 2019
	Information not available	Boehmer et al., 2009; Ekowati et al., 2019; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021
Presence of other disinfectants	Chlorination	Boehmer et al., 2009; Hopkins et al., 2013; Iverson et al., 2018
	Ozone and chlorination	Ekowati et al., 2019; Lu et al., 2013
	Halogen-based compounds	Paccione et al., 2017
	Information not available	Busse et al., 2019; Petterson et al., 2021
Chlorine residue level	1–3 ppm	Boehmer et al., 2009
	0.3 $mgCl_2/L$	Ekowati et al., 2019
	1 mg/L	Lu et al., 2013
	Information not available	Busse et al., 2019; Hopkins et al., 2013; Iverson et al., 2018; Paccione et al., 2017; Petterson et al., 2021

2.6.1 Types of Literature

After assessing the inclusion and exclusion criteria, eight literatures were eligible and included in this systemic literature review. Four included articles reported a past cryptosporidiosis outbreak in swimming pools or other recreational water facilities that involved UV disinfection (Boehmer et al., 2009; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013). Two included articles described fieldwork that involved the UV disinfection on *Cryptosporidium* oocysts in swimming pools (Ekowati et al., 2019; Petterson et al., 2021). One article reported a lab study (Busse et al., 2019), and the remaining one article reported a regulation review that consisted of UV disinfection on

Cryptosporidium oocysts in swimming pools or other recreational water facilities (Paccione et al., 2017).

2.6.2 Country of cryptosporidiosis cases in swimming pools or recreational water facilities that involved UV disinfection

It was found that there were three articles described cryptosporidiosis cases in swimming pools or recreational water facilities occurred in the USA (Boehmer et al., 2009; Iverson et al., 2018; Paccione et al., 2017), and three articles described such cases in Canada (Hopkins et al., 2013; Lu et al., 2013; Petterson et al., 2021). The remaining two articles did not mention such details (Busse et al., 2019; Ekowati et al., 2019).

2.6.3 Types of filtrations

There are two articles mentioned the use of diatomaceous earth filtration in the swimming pool (Hopkins et al., 2013; Lu et al., 2013). One article described the use of high-rate sand filtration (Boehmer et al., 2009), one article described the use of rapid sand filtration (Ekowati et al., 2019), and one article mentioned the use of Neptune filtration, Hydrobotanic, and Submerse filtration (Petterson et al., 2021). The remaining three articles did not provide any information on the types of filtration involved in the swimming pools (Busse et al., 2019; Iverson et al., 2018; Paccione et al., 2017).

2.6.4 Installation point for UV disinfection

Except for one article did not describe the installation point for UV disinfection, the remaining seven articles mentioned that the installation point of UV disinfection was located after the filtration process (Boehmer et al., 2009; Ekowati et al., 2019; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021).

2.6.5 Method for enumeration of *Cryptosporidium oocyst*

With regard to the method for enumeration of *Cryptosporidium* oocysts, one article mentioned *Cryptosporidium* oocysts were enumerated from the bulk stool samples by PCR (Boehmer et al., 2009), one article mentioned using an epifluorescence microscope to count the number of infectious foci (Busse et al., 2019), and one article mentioned that stool samples were initially screened with auramine-rhodamine fluorescent stain, followed by safranin stain or formalin-ether concentration (Hopkins et al., 2013). The remaining five articles did not have details for enumeration of *Cryptosporidium* oocyst (Ekowati et al., 2019; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021).

2.6.6 Strain / Species / Serovar of *Cryptosporidium*

Four articles mentioned that *Cryptosporidium hominins* were being enumerated (Boehmer et al., 2009; Hopkins et al., 2013; Petterson et al., 2021; Iverson et al., 2018), with one of them further revealed *Cryptosporidium hominis* subtype IbA10G2 was involved (Boehmer et al., 2009), and another one of them pointed out *Cryptosporidium hominis* subtype IfA12G1 was enumerated (Iverson et al., 2018). There was one article revealed *Cryptosporidium parvum* (Busse et al., 2019). The remaining three articles did not mention the strain of *Cryptosporidium* involved (Ekowati et al., 2019; Lu et al., 2013; Paccione et al., 2017).

2.6.7 Wavelength of UV involved in the disinfection process

There was one article that mentioned the application of UV with wavelengths 254 nm to 330 nm in the study (Busse et al., 2019). Another fieldwork article revealed the use of UV with wavelength of 254 nm in the study (Ekowati et al., 2019). The remaining six articles did not mention such details (Boehmer et al., 2009; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021).

2.6.8 UV disinfection system installed after filtration and before chlorination

A fieldwork article revealed four amalgam low-pressure 180W UV lamps were placed inside a reaction chamber (Ekowati et al., 2019). One outbreak review revealed a medium-pressure UV light was installed in the recirculation system (Hopkins et al., 2013), while an article also described the installation of a UV reactor at 40 mJ/cm^2 (Paccione et al., 2017). The remaining 5 articles did not mention such details (Boehmer et al., 2009; Busse et al., 2019; Iverson et al., 2018; Lu et al., 2013; Petterson et al., 2021).

2.6.9 UV effectiveness on *Cryptosporidium* oocyst

Only one laboratory study revealed that *C. parvum* was inactivated at 1.1 log10 units with a UV 254 dose of 2.0 mJ/cm^2 (Busse et al., 2019). The remaining seven articles did not mention such information (Boehmer et al., 2009; Ekowati et al., 2019; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021).

2.6.10 Presence of other disinfectants

Regarding the presence of other disinfectants being used with UV disinfection, three articles mentioned chlorination was used (Boehmer et al., 2009; Hopkins et al., 2013; Iverson et al., 2018); two articles mentioned both chlorination and ozone were used (Ekowati et al., 2019; Lu et al., 2013), and one article mentioned halogen-based disinfectant (either chlorination or bromine) was used (Paccione et al., 2017). The remaining two articles did not mention such details (Busse et al., 2019; Petterson et al., 2021).

2.6.11 Chlorine residue level

One study revealed residual chlorine levels at 1 to 3 ppm in a swimming pool with UV disinfection (Boehmer et al., 2009). Another fieldwork study mentioned 0.3 $mgCl_2/L$ of free residual chlorine within the pool (Ekowati et al., 2019). An outbreak study reviewed mentioned 1 mg/L free residual chlorine in the pool (Lu et al., 2013). The remaining five articles did not reveal the chlorine residue in the pool (Busse et al., 2019; Hopkins et al., 2013; Iverson et al., 2018; Paccione et al., 2017; Petterson et al., 2021).

2.7 Discussion

Among the four included articles that reported a past cryptosporidiosis outbreak in swimming pools or other recreational water facilities that involved UV disinfection, all of them indicated that there was chlorination as a primary disinfectant (Boehmer et al., 2009; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013). This indicates that the possibility of a cryptosporidiosis outbreak still exists even when a swimming pool is equipped with both primary chlorination and secondary UV disinfection. The introduction of unintentional faecal matters with *Cryptosporidium* oocysts from infected bathers remains to be the major cause of an outbreak at a swimming pool (Lu et al., 2013).

It is found that seven articles mentioned the installation point of UV disinfection was located after the filtration process and before the point for chlorination (Boehmer et al., 2009; Ekowati et al., 2019; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013; Paccione et al., 2017; Petterson et al., 2021); these actual arrangements are consistence with scientific studies that the efficiency of UV is lowered by the high turbidity of waterbody and UV could decompose dissolved chlorine (Gómez-Couso et al., 2009; Örmeci et al., 2005). Therefore, the point of UV disinfection should be after the filtration process and before chlorine is added to the swimming pool waterbody (Gómez-Couso et al., 2009; Örmeci et al., 2005).

The systematic literature review demonstrates there is insufficient scientific studies on the performance of UV disinfection on inactivating *Cryptosporidium* oocysts using an actual swimming pool and more future scientific efforts are required to identify and fill the knowledge gaps.

3.0 HEALTHYSWIM

This chapter discusses the validity of claims about a patented Advanced Oxidation Processes (AOP) system from the representative of a company named HealthySwim to a Public Health Special Interest Group of Environmental Health Australia (EHA) on 2nd April 2024.

On 2nd April 2024, a representative from a company called HealthySwim attended the meeting of a Public Health Special Interest Group of EHA, stating its evidence-based patent UV treatment system could inactivate *Cryptosporidium* (Environmental Health Australia (South Australia) Inc., n.d.). The representative revealed to EHA in the meeting that the UV component of their AOP system could create UV over 60 mJ/cm^2 at a flow rate of 750 L/min, aiming to inactivate *Cryptosporidium* oocysts with reference to the scientific literature of Adeyemo et al. (2019) and Morita et al. (2002). (Environmental Health Australia (South Australia) Inc., n.d.).

There was no such content about *Cryptosporidium* from the literature of Adeyemo et al. (2019) and Morita et al. (2002). Adeyemo et al. (2019) only mentioned a few previous scientific studies that found UV radiation at 20 to 40 mJ/cm^2 was efficient in eradicating 99% of *Giardia* cysts (Adeyemo et al., 2019). Concerning UV light at 20 mJ/cm^2, it had a higher efficacy in killing *Giardia* than in *Cryptosporidium* (Adeyemo et al., 2019). In addition, the graphic included in Adeyemo et al. (2019) only showed about 5 percent viability for *Cryptosporidium at* 20 to 40 mJ/cm^2, which was only equal to 1.3 log inactivation of *Cryptosporidium* (Adeyemo et al., 2019). NSW Health *Cryptosporidium* risk assessment suggested that a 5-log inactivation *Cryptosporidium* should be achieved for complete eradication of *Cryptosporidium*; while a study revealed that a UV dose of 40 mJ/s can attain a minimum 2-log inactivation of oocysts (Cotton et al., 2001; NSW Health, 2023). Therefore, it could be reasonable to regard that UV radiation at 20 to 40 mJ/cm^2, leading to 1.3 log inactivation of *Cryptosporidium* oocysts, could not eliminate *Cryptosporidium* oocysts completely (Adeyemo et al., 2019).

Besides, Morita et al. (2002) mentioned there was still a 1±1% of viable *Cryptosporidium* at UV 83.2 mJ/m^2 and 2% of viable *Cryptosporidium* after UV 83 mJ/cm^2 (Morita et al., 2002). Therefore, it is questionable whether the AOP system with over 60 mJ/cm^2 at a flow rate of 750 L/min could effectively inactivate the *Cryptosporidium* (Morita et al., 2002).

A study conducted by Korich (1990) mentioned that 1 ppm of ozone in a period of 5 minutes could have inactivated over 90% of *Cryptosporidium* oocysts (Korich et al., 1990). Another study mentioned hydroxyl radicals with a CT value of 0.000093 mg·min/L could achieve 2-log *Cryptosporidium parvum* inactivation in drinking water (Cho & Yoon, 2008). However, the representative of HealthySwim did not disclose the ozone concentration and the hydroxyl radical concentration in the AOP system during the meeting. Thus, it was still unknown if the ozone applied, and hydroxyl radicals' concentration was enough to inactivate any *Cryptosporidium* oocysts.

The literature that the representative of HealthySwim quoted was either using a waste treatment plant sample or a drinking water sample (Adeyemo et al., 2019; Morita et al., 2002). There were insufficient scientific investigations on the efficacy of inactivating *Cryptosporidium* in swimming pool water using a UV light system, or ozone with a UV light system. As wastewater treatment plants or drinking water treatment plants were enclosed systems, while a swimming pools or recreational water facilities were constantly being polluted by the introduction of organic matter and faecal matter from the bathers or patrons (Lu et al., 2013). Therefore, it is reasonable to say that the data or scientific findings of disinfection methods on *Cryptosporidium* in drinking water plants or wastewater treatment plants may not be able to be applied to the case of swimming pools (Lu et al., 2013). It remains uncertain whether the patent AOP system from HealthySwim can effectively minimise the health risk of *Cryptosporidium* oocysts to swimming pool patrons (Adeyemo et al., 2019; Cho & Yoon, 2008; Cotton et al., 2001; Korich et al., 1990; Morita et al., 2002; NSW Health, 2023).

4.0 A COMPARISON OF LEGISLATIONS, REGULATIONS, AND GUIDELINES RELATED TO CRYPTOSPORIDIOSIS OUTBREAKS IN PUBLIC SWIMMING POOLS AND RECREATIONAL WATER FACILITIES OF ALL STATES IN AUSTRALIA

Given that all states in Australia have their separate legislation, regulations, and guidelines, this chapter presents a comparison of those legislation, regulations, and guidelines regarding cryptosporidiosis outbreaks in public swimming pools and recreational water facilities and includes a brief suggestion for necessary changes in legislation or regulation for each state.

4.1 Comparison of the definition of a cryptosporidiosis outbreak at a public swimming pool or recreational water facilities

There are only four states that have defined clearly the meaning of a cryptosporidiosis outbreak. In New South Wales, an outbreak was defined as two or more confirmed cryptosporidiosis cases notification related to a swimming pool or pool complex from NSW Health (NSW Health, 2024b). In Queensland, a cryptosporidiosis outbreak was defined as an observation of a significant rise in confirmed cryptosporidiosis cases number within a certain area or a recreational water facility compared to past records (Queensland Health, 2024b). In South Australia, a cryptosporidiosis outbreak was defined as any confirmed presence of *Cryptosporidium spp.* in a public swimming pool or a history of infected patrons using a public pool during the infectious period (SA Health, n.d.). In Victoria, a cryptosporidiosis outbreak was defined as two or more unrelated cases of infected cryptosporidiosis patrons who swim at the same swimming pool within 12 days since exhibiting a sign of symptoms, and at the same time, there are not more than 28 days between their onset of symptoms (Victoria State Government Health and Human Services, 2018).

There is no definition of a cryptosporidiosis outbreak at a swimming pool or aquatic water facility in the Australian Capital Territory, Northern Territory, Tasmania, and Western Australia (ACT Department of Health, n.d.; ACT Department of Health, 1999b; ACT Department of Health, 1999a; Government of Western Australia Department of Health, 2020; Government of Western Australia Department of Health, 2023; Government of Western Australia Department of Health, 2024; Northern Territory Government Department of Health, 2006; Tasmanian Department of Health, n.d.; Tasmanian Government Department of Health, 2007)

4.2 Comparison of the CT value for hyperchlorination against a cryptosporidiosis outbreak at a swimming pool

The CT value is the product of the duration of contact in minute (min) and the residual chlorine level in milligrams per litre (mg/L) when taking the residual measurement (NSW Health, 2022a). It is used to estimate the residual chlorine concentration, and the action time required to inactivate a specific pathogen (NSW Health, 2022a).

New South Wales, South Australia, and Victoria have the same approach towards CT value for hyperchlorination against a cryptosporidiosis outbreak at a swimming pool, which recommends to hyper-chlorinate the swimming pools at a CT value of 15,300 mg·min/L to inactivate *Cryptosporidium* oocysts (NSW Health, 2022b; SA Health, n.d.; Victoria State Government Health and Human Services, 2018). In cases where the swimming pool water has cyanuric acid, the affected swimming pools should be hyper-chlorinated at a CT value of 31,500 mg·min/L (NSW Health, 2022b; SA Health, n.d.; Victoria State Government Health and Human Services, 2018).

In Queensland, upon a suspected cryptosporidiosis outbreak in a swimming pool or spa, a CT value of 15,300 mg·min/L should be attained for inactivating *Cryptosporidium* oocysts (Queensland Health, 2019). However, if a recreational water facility has an existing validated system to treat the risk of cryptosporidiosis and could provide valid evidence that such a system has been in operation within its validated parameters before and since the outbreak event, it may not require hyperchlorination as a remedial measure (Queensland Health, 2019).

In Western Australia, it is recommended to carry out hyperchlorination for all filters and pool water using free chlorine level at 20 mg/L (ppm) for up to 13 hours to attain a CT value of 15600 mg·min/L upon a suspected cryptosporidiosis outbreak in a swimming pool (Government of Western Australia Department of Health, 2023).

In Tasmania, there is no information about the CT value for hyperchlorination against a cryptosporidiosis outbreak at a public swimming pool or recreational water facilities (Tasmanian Government Department of Health, 2007).

On the other hand, the Australian Capital Territory and Northern Territory have a completely different requirement on the CT value for hyperchlorination upon a cryptosporidiosis outbreak at a public swimming pool or recreational water facilities when compared with other states in Australia (ACT Department of Health, 1999b; Northern Territory Government Department of Health, 2006). In the Australian Capital Territory, Part B of the Code of Practice recommended a CT value of 7,200 mg·min/L or hyperchlorination by either chlorine or chlorine dioxide upon a cryptosporidiosis outbreak at a public swimming pool or recreational water facilities with the assumption that chlorine at such level could attain 90% inactivation of *Cryptosporidium* oocysts at normal temperature and pH value (ACT Department of Health, 1999b). In the Northern Territory, the guideline states a CT value of at least 8,400 mg·min/L should be reached to inactivate 99.9% of the *Cryptosporidium* oocysts upon a suspected cryptosporidiosis outbreak in a swimming pool or spa (Northern Territory Government Department of Health, 2006).

4.3 Comparison of the legislations that regulate the use of chlorine or bromine as a primary disinfectant

New South Wales, South Australia, and Victoria have more legislative controls, which clearly state that primary disinfection with either chlorine or bromine must be applied in a public swimming pool.

In New South Wales, Section 3(2) in Schedule 1 of *Public Health Regulation 2022* (NSW) states that a pool must be disinfected with chlorine or bromine (*Public Health Regulation 2022* (NSW), sch 1 s 3(2)). An Environmental Health Officer who acts as an authorized officer can issue an improvement notice or a prohibition order to the proprietor of the swimming pool with a fee of $295 for the period from 1 July 2024 to 1 July 2025 according to Schedule 5 of *Public Health Regulation 2022* (NSW) (*Public Health Regulation 2022* (NSW), sch 5). Re-inspection of the swimming pool due to a prohibition order would cost an hourly fee of $225 to the proprietor of the swimming pool as stated in Schedule 5 of *Public Health Regulation 2022* (NSW) (*Public Health Regulation 2022* (NSW), sch 5). For any failure to adhere to a prohibition order for a public swimming pool or spa pool, the penalty would be $1,100 for individual offenders and $2,200 for corporations according to Schedule 6 of *Public Health Regulation 2022* (NSW) (*Public Health Regulation 2022* (NSW), sch 6).

In case there is a reasonable ground related to a risk to public health, a temporary closure order in written form according to Section 28(1) and Section 28(2) of *Public Health Regulation 2022* (NSW) would be served to the occupier of a spa pool or a public swimming pool; and any non-compliance to such temporary closure order would lead to a maximum penalty of 20 penalty units to the occupier that the temporary closure order was served according to Section 28(3) of *Public Health Regulation 2022* (NSW) (*Public Health Regulation 2022* (NSW), ss 28(1) – 28(3)). According to Section 28(4) of *Public Health Regulation 2022* (NSW), the occupier who is served with a temporary closure order is required to display a copy of the order in a prominent space or near the swimming pool entrance; or else a maximum penalty of 10 penalty units would be charged (*Public Health Regulation 2022* (NSW), s 28(4)). Besides, as stated in Section 29 of *Public Health Regulation 2022* (NSW), a written notice could also be issued to the occupier of a public swimming pool or spa pool with clear directions for proper disinfection or appropriate actions taken to eradicate public health risk; and the maximum penalty would be 20 penalty units for any non-compliance to such notice without reasonable grounds (*Public Health Regulation 2022* (NSW), s 29).

In South Australia, Section 8(1)(a) and Sec 9(1)(a) of *South Australian Public Health (General) Regulations 2013* (SA) respectively state that a public swimming pool or spa pool must apply chlorination or other disinfection method as stated in the Standard for the Operation of Swimming Pools and Spa Pools (*South Australian Public Health (General) Regulations 2013* (SA), ss 8(1)(a) & 9(1)(a)). Meanwhile, the Standard for the Operation of Swimming Pools and Spa Pools outlines approved disinfection methods, which include chlorine, chlorine stabilized with cyanuric acid, UV plus hydrogen peroxide, bromine, and bromamine formation (SA Health, 2013b). It is an offence for any non-compliance to either Section 8(1)(a) or Section 9(1)(a) of *South Australian Public Health*

(General) Regulations 2013 (SA), and the owner or occupier of the public swimming pool or the spa pool is subject to a maximum penalty of $5,000 and an expiation fee of $ 315 as stated in Section 8(6) and Section 9(7) of *South Australian Public Health (General) Regulations 2013* (SA) respectively (*South Australian Public Health (General) Regulations 2013* (SA), ss. 8(6) & 9(7)).

In Victoria, Section 54(1) of *Public Health and Wellbeing Regulations 2019* (Vic) states a swimming pool or an interactive water feature must use either chlorine-based or bromine-based disinfectant (*Public Health and Wellbeing Regulations 2019* (Vic), s 54(1)). The penalty for this offence would be 20 penalty units (*Public Health and Wellbeing Regulations 2019* (Vic), s 54(1)). The value for each penalty unit would be $197.59 from 1 July 2024 to 30 June 2025 (Victoria State Government Justice and Community Safety, 2024). Therefore, the penalty for this offence would be $3952 (rounded up to the nearest dollar) from 1 July 2024 to 30 June 2025 (Victoria State Government Justice and Community Safety, 2024).

On the other hand, the remaining five states use requirements in their respective guidelines to control the primary disinfection with chlorine or bromine in public swimming pool and spa pools. In the Australian Capital Territory, there is a recommendation of using chlorine or bromine with or without ozonation as stated in Annexures B or C of A Code Of Practice To Minimise The Public Health Risks From Swimming / SPA Pools (ACT Department of Health, 1999a). In the introduction part of A Code Of Practice To Minimise The Public Health Risks From Swimming / SPA Pools, it is only mentioned that owners of swimming pools who fail to maintain the pool to be operated correctly or allow any non-compliance with the standards would face legal proceedings (ACT Department of Health, 1999a). An Environmental Health Officer can thus issue an improvement notice to the occupier of the swimming pool regarding the non-compliance of primary chlorine-based or bromine-based disinfectant in the pool water according to Division 3.6, Section 57 of *Public Health Act 1997*(ACT) (*Public Health Act 1997*(ACT), div 3.6 s 57). According to Division 3.6, Section 57 of *Public Health Act 1997*(ACT), any party served with an improvement notice and failing to comply may face a maximum penalty of 100 units for an individual or 2000 units for a utility. (*Public Health Act 1997*(ACT), div 3.6 s 57). Moreover, according to Division 3.7, Section 66(4)(a) and (b) of *Public Health Act 1997*(ACT), any party to whom a prohibition order was served and failed to comply with the order in the specified time duration or could not comply the specification stated in such order within the listed period would be subjected to 100 penalty units, a year of imprisonment or both for the individual; or 2000 penalty units, a year of imprisonment or both for a utility (*Public Health Act 1997*(ACT), ss. 66(4)(a) & (b)).

In the Northern Territory, the Public Health Guidelines For Aquatic Facilities recommended that chemical disinfection at recreational water facilities must involve chlorine or bromine and be used along with secondary disinfectants such as UV and ozone (Northern Territory Government

Department of Health, 2006). The Public Health Guidelines For Aquatic Facilities do not mention any consequences or legal responsibility that an occupier of a swimming pool shall bear in case of any non-compliance with the standards or requirements listed in such guidelines (Northern Territory Government Department of Health, 2006). There are also no legislation related to non-compliance with public swimming pool requirements listed in The Public Health Guidelines For Aquatic Facilities in both *Public And Environmental Health Act 2011*(NT) and *Public And Environmental Health Regulations 2014* (NT) (*Public And Environmental Health Act 2011*(NT); *Public And Environmental Health Regulations 2014* (NT)). In the circumstances that an immediate risk to public health is caused by a business or an activity, the Chief Health Officer can issue a written Public Health Order to the occupier according to Section 32(1)(b) of *Public And Environmental Health Act 2011* (NT) (*Public And Environmental Health Act 2011* (NT), s 32(1)(b)). It is an offence if the occupier of a business or an activity that a Public Health Order is served could not comply with the Public Health Order and the maximum penalty for such offence is 20 penalty units according to Section 35(1) of *Public And Environmental Health Act 2011* (NT) (*Public And Environmental Health Act 2011* (NT), s 35(1)). In case the local court agrees the person could not comply with the Public Health Order, the court can order the defendant to settle a penalty of 500 penalty units to the Territory or make other orders or payments that are justified to the Court according to Section 36(4) of *Public And Environmental Health Act 2011* (NT) (*Public And Environmental Health Act 2011* (NT), s 36(4)).

In Queensland, it is recommended that filtration should be used together with primary disinfection using chlorine or bromine as stated in Chapter 4 of Water Quality Guidelines For Public Water Facilities (Queensland Health, 2019). The guideline does not mention any legal consequences if an occupier of a swimming pool does not comply with this requirement (Queensland Health, 2019). In case of public health risk caused by non-compliance with primary disinfection in a swimming pool or spa pool, an Environmental Health Officer can issue a written public health order to the occupier of the pool to conduct necessary actions within a certain time frame to eliminate the public health risk according to Part 3, Division 1, Section 21 of *Public Health Act 2005* (Qld) (*Public Health Act 2005* (Qld), pt 3, div1, s 21). The occupier who receives the public health order must comply or face a maximum penalty of 200 penalty units according to Section 23(4) of *Public Health Act 2005* (Qld) (*Public Health Act 2005* (Qld), s 23(4)). According to Section 61C of *Public Health Act 2005* (Qld), any recreational water facilities must have a water risk management plan, or they may be subjected to 500 penalty units at maximum (*Public Health Act 2005* (Qld), s 23(4)). According to Section 61G(1) of *Public Health Act 2005* (Qld), the responsible person of a swimming pool should ensure the pool complies with its water risk management plan, or face 500 penalty units at maximum (*Public Health Act 2005* (Qld), s 61G(1)). As per Sec 61G(2) of Public Health Act 2005, the responsible person must implement all necessary measures to ensure compliance with the water risk management plan by all obligated parties during pool operation or face 200 penalty units at maximum (*Public Health Act 2005* (Qld), s 61G(2)).

In Tasmania, the Recreational Water Quality Guidelines 2007 specify that public recreational water facilities must operate within the limit for free chlorine, total chlorine, and bromine set out in Appendix F (Tasmanian Government Department of Health, 2007). In case of a risk to Public Health related to recreational water facilities, the controlling authority shall issue public health advisories to the public and erect a public health warning where necessary (Tasmanian Government Department of Health, 2007). As mentioned in the Definition part of Recreational Water Quality Guideline 2007, any individual or occupier of a spa pool or public swimming pool who fails to comply with the requirements in Recreational Water Quality Guideline 2007 would result in a penalty (Tasmanian Government Department of Health, 2007). According to Part 1, Section 3 of *Public Health Act 1997* (Tas), any recreational water is referred to as a kind of “water” in the Act (*Public Health Act 1997* (Tas), pt 1, s 3). According to Section 128(1) of *Public Health Act 1997* (Tas), any person or occupier of public swimming pool or spa pool who are failed to comply with the requirements in Recreational Water Quality Guideline 2007 would be subjected to a penalty not more than 100 penalties unit which equals to $20200 for the financial year 1 July 2024 to 30 June 2025 (*Public Health Act 1997* (Tas), s 128(1); Tasmanian Government Department of Justice, 2024).

In Western Australia, The Code of Practice For Aquatic Facilities recommends that all interactive water features or water spray facilities should have a residual primary disinfection with UV light (Government of Western Australia Department of Health, 2020). The guideline does not mention any legal consequences if an occupier of a swimming pool does not comply with this requirement (Government of Western Australia Department of Health, 2020). However, according to Section 19(1) of *Health (Aquatic Facilities) Regulations 2007* (WA), any aquatic facility operator should comply with all the requirements stated in the Code of Practice For Aquatic Facilities, except a variation of the requirement was endorsed by the Chief Health Officer (*Health (Aquatic Facilities) Regulations 2007* (WA), s 19(1)). The Chief Health Officer or an Environmental Health Officer can issue an improvement notice to the occupier of a recreational water facility if such facility cannot comply with the requirements stated in the Code of Practice For Aquatic Facilities according to Section 22(1) of *Health (Aquatic Facilities) Regulations 2007* (WA) or a closure order as per Section 23 of *Health (Aquatic Facilities) Regulations 2007* (WA) (*Health (Aquatic Facilities) Regulations 2007* (WA), ss. 22(1) & (23)). Section 31 of *Health (Aquatic Facilities) Regulations 2007* (WA) states that any non-compliance of requirements stated in the Code of Practice For Aquatic Facilities, non-compliance of improvement order or closure order are an offence, and the penalties are as follows:

(a) A penalty ranging from $100 to $1000 for the first contravention (*Health (Aquatic Facilities) Regulations 2007* (WA), s 31).
(b) A penalty ranging from $200 to $1000 for a second contravention (*Health (Aquatic Facilities) Regulations 2007* (WA), s 31).
(c) A penalty ranging from $500 to $1000 for a third contravention (*Health (Aquatic Facilities) Regulations 2007* (WA), s 31).

(d) A daily penalty ranging from $50 to $100, or part thereof, for any continuing offence (*Health (Aquatic Facilities) Regulations 2007* (WA), s 31).

4.4 Comparison of the legislation that is related to keeping testing records

Three states, including New South Wales, South Australia, and Victoria, have clear legislation related to the keeping of pool water testing records (*Public Health and Wellbeing Regulations 2019* (Vic), s 61(2); *Public Health Regulation 2022* (NSW), sch 1, s 11; *South Australian Public Health (General) Regulations 2013* (SA), s 8(3)). Section 11 in Schedule 1 of *Public Health Regulation 2022* (NSW) states the duration for keeping testing results is at least half a year (*Public Health Regulation 2022* (NSW), sch 1, s 11). In South Australia, Section 8(3) of *South Australian Public Health (General) Regulations 2013* (SA) states the duration for keeping testing results is two years (*South Australian Public Health (General) Regulations 2013* (SA), s 8(3)). In Victoria, Section 61(2) of *Public Health and Wellbeing Regulations 2019* (Vic) states the duration for keeping testing results is one year (*Public Health and Wellbeing Regulations 2019* (Vic), s 61(2)).

On the other hand, the remaining five states set up a requirement in their respective code of guidelines to bind the duration that a pool water testing record shall be kept (ACT Department of Health, 1999a; Government of Western Australia Department of Health, 2024; Northern Territory Government Department of Health, 2006; Queensland Health, 2019; Tasmanian Government Department of Health, 2007). In the Australian Capital Territory, the Code Of Practice states that all chemical results, dates, and times of testing should be recorded and kept on-site (ACT Department of Health, 1999a). In the Northern Territory, the Public Health Guidelines For Aquatic Facilities recommend a record of water testing results and maintenance details should be kept for at least two years and can be produced to an Environmental Health Officer upon request (Northern Territory Government Department of Health, 2006). In Queensland, the Water Quality Guidelines For Public Water Facilities recommended records to be kept at least 1 year (Queensland Health, 2019). In Tasmania, the Recreational Water Quality Guidelines 2007 recommended that a record of swimming pool water testing should be kept on-site (Tasmanian Government Department of Health, 2007). In Western Australia, the Code of Practice For Aquatic Facilities recommends the duration for keeping water testing record is at least two years (Government of Western Australia Department of Health, 2024).

4.5 Comparison of the recommendation for filter size

With regard to the size of the filter being installed in the pool filtration system, the Water Quality Guidelines For Public Water Facilities from Queensland and the Water Quality Guidelines for Public Aquatic Facilities Managing Public Health Risks from Victoria both recommend the filter should be able to remove any particulates 4 microns in diameter (Queensland Health, 2019; Victoria

Government Department of Health, 2020). Meanwhile, the Australian Capital Territory and New South Wales have more rigorous controls on the size of the filter stated in their respective guidelines, both of which recommend that the filter should be able to remove any particulates 1 micron in diameter (ACT Department of Health, 1999b; NSW Health, 2022a).

However, there is no recommendation on the filter size for the remaining states, including Northern Territory, South Australia, Tasmania, and Western Australia (Government of Western Australia Department of Health, 2020; Northern Territory Government Department of Health, 2006; SA Health, 2013a; SA Health, 2013b; Tasmanian Government Department of Health, 2007).

4.6 Comparison of the recommendation for turbidity for removal of *Cryptosporidium* oocysts

With respect to the recommendation for turbidity, the NSW Guidelines for Public Swimming Pools and Spa Pools recommended the turbidity should remain under 0.2 Nephelometric Turbidity Units (NTU) and not surpass 0.5 NTU (NSW Health, 2022a). In Queensland, the Water Quality Guidelines For Public Water Facilities stated that the filtrate turbidity should not be more than 0.5 NTU (Queensland Health, 2019). In Victoria, the Water Quality Guidelines for Public Aquatic Facilities Managing Public Health Risks stated that the filtrate turbidity should be less than 0.2 NTU (Victoria Government Department of Health, 2020). There is no suggestion or recommendation on the filtrate turbidity in the respective code of guidelines in the Australian Capital Territory, Northern Territory, South Australia, Tasmania, Western Australia (ACT Department of Health, 1999b; Government of Western Australia Department of Health, 2020; Northern Territory Government Department of Health, 2006; SA Health, 2013a; SA Health, 2013b; Tasmanian Government Department of Health, 2007).

4.7 Comparison of the recommendation related to UV disinfection

Apart from Tasmania, the other seven states have their details for using UV as secondary disinfection as recommended in their respective code of guidelines.

In the Australian Capital Territory, as stated in the Code Of Practice To Minimise The Public Health Risks From Swimming / SPA Pools, either primary residual disinfection using chlorine or hydrogen peroxide could be used with secondary UV disinfection (ACT Department of Health, 1999a). For an indoor pool with such disinfection installation, the maximum indoor pool capacity is 500,000 litres (ACT Department of Health, 1999a). The dosage of the UV disinfection should be 30 mJ/cm^2 with a meter clearly showing the duration of each UV light tube being operated in hours (ACT Department of Health, 1999a). Each UV light tube should be replaced on or before the usage of 7500 hours (ACT Department of Health, 1999a). The reading of the UV intensity on the meter through the water body should be clearly visible to an operator or an Environmental Health Officer (ACT Department of Health, 1999a). In case the UV dosage falls below 30 mJ/cm^2, the entire UV disinfection system should be automatically ceased with an alarm with an audible sound that is installed at an obvious location (ACT Department of Health, 1999a).

New South Wales, Queensland, and Victoria have the same recommendations for the use of UV as secondary disinfection (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020). As stated in the NSW Guidelines for Public Swimming Pools and Spa Pools, the Water Quality Guidelines For Public Water Facilities from Queensland, and the Water Quality Guidelines for Public Aquatic Facilities Managing Public Health Risks from Victoria, a validated UV disinfection system for full flow for any interactive water facilities should attain a 3-log inactivation of *Cryptosporidium* oocysts (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020). For other kinds of recreational water facilities, the validated UV disinfection system should attain a minimum 2-log inactivation of *Cryptosporidium* oocysts (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020). The point of UV disinfection should be before chlorination or bromine disinfection (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020). In case the water facilities use ozone disinfection, the chlorine and bromine levels should comply with the standards stated in Schedule 1 of Public Health Regulation 2022 (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020). The UV light device should be used within the limits recommended by its manufacturer, and its sleeves must be cleaned at regular intervals (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020).

In the Northern Territory, there is a requirement in Public Health Guidelines for Aquatic Facilities stating that chlorine or bromine disinfection should be used together with UV or ozone disinfection (Northern Territory Government Department of Health, 2006).

In South Australia, as stated in the Standard for the Operation of Swimming Pools and Spa Pools, UV disinfection combined with hydrogen peroxide can be used in indoor swimming pools, hydrotherapy pools, spas, and interactive recreational facilities with an upper limit of 500,000 litres (SA Health, 2013b). The UV disinfection combined with hydrogen peroxide must be operated for 24 hours per day. The UV light dosage should not be less than 30 mJ/cm^2 and the flowing water column should pass through the point of UV disinfection at a maximum rate of 150 litres per minute. The concentration of hydrogen peroxide should be at least 40 mg/L (SA Health, 2013b).

In Western Australia, all water spray facilities or interactive facilities must have a validated UV secondary disinfection with a dosage of at least 40 mJ/cm^2. The UV disinfection system should comply with any or more of the below standards:

a) Australian/ New Zealand Standards (AS/NZS) 4348 (Government of Western Australia Department of Health, 2020).
b) ISO 9000:2000 (Government of Western Australia Department of Health, 2020).
c) American National Standards Institute and National Sanitation Foundation (ANSI/NSF) Standard 50 (Government of Western Australia Department of Health, 2020).

In case there is any UV dosage failure, system malfunctioning, or absence of UV protective sleeves, the entire UV disinfection system should be automatically ceased with an alarm (Government of Western Australia Department of Health, 2020). The reading of the UV dosage, intensity, and flow rate should be shown on a readable meter that is placed inside an enclosed unit to avoid the operator from any electric shock or excessive UV radiation (Government of Western Australia Department of Health, 2020). A spare UV lamp should be available on-site for installation by a qualified technician when needed (Government of Western Australia Department of Health, 2020).

4.8 Comparison of the recommendation for all newly constructed high-risk public swimming pools, spa pools, or pools being upgraded that are prone to *Cryptosporidium spp.* contamination

In New South Wales, it is recommended that new high-risk recreational water facilities include a secondary disinfection system with a filter capable of removing impurities 4 microns or smaller, including *Cryptosporidium* oocysts. (NSW Health, 2022a). For the filtrate turbidity, it is also recommended to maintain below 0.2 NTU and not above 0.5 NTU (NSW Health, 2022a). It is also recommended that secondary disinfection methods should be included in all new swimming pools or spa pools (NSW Health, 2022b). Easily accessible showers are recommended to be in a way that bathers need to enter the change room with showers before entering the swimming pool or recreational water facilities to encourage bathers to have a shower before getting into the pool water bodies (NSW Health, 2022a). Easily accessible toilets are also recommended to be designed at proximate locations to the swimming pool or recreational water facilities (NSW Health, 2022a).

In the Northern Territory, it is recommended that the design should direct all patrons to pass through a warm shower installed with a temperature monitoring device before entering the pool water (Northern Territory Government Department of Health, 2006).

In Queensland, it is recommended that new recreational water facilities with conventional media filters should include a secondary disinfection method (Queensland Health, 2019). In case the new recreational water facilities use ultrafine precoat filters that are evaluated to remove any *Cryptosporidium* oocysts when functioning correctly, it is not a must to have secondary disinfection (Queensland Health, 2019).

In Victoria, it is recommended new high-risk recreational water facilities should equipped with a filter size of 4 microns or below, along with a secondary disinfection system (Victoria Government Department of Health, 2020). The new filtration system is also recommended to maintain less than 0.2 NTU for the filtrate turbidity (Victoria Government Department of Health, 2020). Easily accessible showers are recommended to be in a way that patrons need to pass through the changing room that equipped with showers before entering the pool bodies (Victoria Government Department of Health, 2020). Toilets are recommended to situate in a near position to the swimming pool or recreational water facilities (Victoria Government Department of Health, 2020). There are no such recommendations in the respective code of guidelines in the Australian Capital Territory, South Australia, Tasmania, and Western Australia (ACT Department of Health, 1999b; Government of Western Australia Department of Health, 2020; SA Health, 2013a; SA Health, 2013b; Tasmanian Government Department of Health, 2007).

4.9 Comparisons of the recommendation for regular shock chlorine treatment in commercial pools or public pools

Among all the states in Australia, it is found that only the Australian Capital Territory and the Northern Territory have their recommendation for regular shock chlorine treatment in a commercial swimming pool or public swimming pool. In the Australian Capital Territory, it is recommended to carry out regular shock chlorine dosing at 40 mg/L for three hours overnight each week in peak season which the CT value equals 7,200 mg·min/L (ACT Department of Health, 1999b). Sodium thiosulphate should be used to lower the chlorine level to a normal level after shock chlorine dosing (ACT Department of Health, 1999b). In the Northern Territory, it was recommended to carry out regular shock chlorine dosing at 10 mg/L for at least 8 hours weekly or biweekly when there are no bathers, which the CT value for a period of 8 hours equals 4,800 mg·min/L (Northern Territory Government Department of Health, 2006).

4.10 Suggestions for changes to different states' legislation, regulations, or guidelines

4.10.1 Australian Capital Territory

With respect to the definition used in the guidelines in New South Wales, South Australia, and Victoria, a definition for cryptosporidiosis outbreak is suggested to be included in Part B of A Code Of Practice To Minimise The Public Health Risks From Swimming / SPA Pools giving a clear direction for health authorities to classify suspected cryptosporidiosis outbreaks, execute effective remedial interventions at incriminated swimming pools or aquatic facilities before any further secondary cryptosporidiosis transmission within a local community and ensure limited health treatment resources are implemented preciously (Scully, 2004).

Shields et al. (2008) have shown that the effective CT value for a 99.9% reduction in the total amount of viable *Cryptosporidium* oocyst was 15,300 mg·min/L and this CT value has been adopted by Centers for Disease Control and Prevention (CDC) as a revised recommendation in response to an Accidental Faecal Release (AFR) at the swimming pool to inactivate *Cryptosporidium* oocyst since February 2008 (Centers for Disease Control and Prevention, 2008; Shields et al., 2008). Therefore, it is recommended that the CT value for inactivation of *Cryptosporidium* oocyst stated in the Public Health Risks From Swimming/Spa Pools Part B: Information On The Control Of *Cryptosporidium* and *Giardia* should be changed from 7,200 mg·min/L to 15,300 mg·min/L to achieve a 99.9% reduction in the total amount of viable *Cryptosporidium* oocyst in the swimming pool (ACT Department of Health, 1999b; Shields et al., 2008). A previous study showed that the CT value required for a 99.9% reduction in *Cryptosporidium* oocyst in swimming pool water, with cyanuric acid concentration at a range of 16 to 17 mg/L, would be 31,500 mg·min/L (Murphy et al., 2015). Thus, it is suggested Australian Capital Territory align with the guidelines in New South Wales, South Australia, and Victoria and state the CT value for swimming pools with cyanuric acid to be 31,500 mg·min/L with a concentration of cyanuric acid 15 mg/L or less in the Public Health Risks From Swimming/Spa Pools Part B: Information On The Control Of *Cryptosporidium* and *Giardia* (Murphy et al., 2015; NSW Health, 2022b; SA Health, n.d.; Victoria State Government Health and Human Services, 2018).

The World Health Organization (WHO) recommended that the turbidity of pool water should be at most 0.5 NTU to have adequate disinfection (World Health Organization, 2006). In Australia, the National Health and Medical Research Council (NHMRC) recommended the filtrate turbidity of drinking water should be lower than 0.2 NTU and at the same time not exceed 0.5 NTU to minimize the risks to human health including cryptosporidiosis (National Health and Medical Research Council, 2022). It is suggested that the Swimming and spa pools Part A: General guidelines should include a recommendation for filtrate turbidity lower than 0.2 NTU with maximum turbidity not above 0.5 NTU, following the recommendation for filtrate turbidity for swimming pools and spa pools in New South Wales (NSW Health, 2022a).

It is recommended to include legislation with clear penalty units in the *Public Health Act 1997*(ACT), stating that the pool operators shall comply with all the requirements stated in A Code Of Practice To Minimise The Public Health Risks From Swimming / SPA Pools (ACT Department of Health, 1999a*; Public Health Act 1997*(ACT).

With regard to the new high-risk water facilities, it is recommended to take statements from the guidelines of New South Wales, Victoria, and North Territory to add a recommendation to include secondary UV disinfection with a filter size of 4 microns in diameter, a new filtration system capable of maintaining filtrate turbidity under 0.2 NTU and not surpassing 0.5 NTU; an easily accessible toilet and the design should require all bathers to pass through a warm shower before going into the pool body (Northern Territory Government Department of Health, 2006; NSW Health, 2022a; Queensland Health, 2019).

As mentioned in 4.9, the Public Health Risks From Swimming/Spa Pools Part B: Information On The Control Of *Cryptosporidium* and *Giardia* recommended a regular shock chlorine dosing with CT value of 7,200 mg·min/L overnight each week in peak season (ACT Department of Health, 1999b). However, CDC suggested a CT value of 15,300 mg·min/L for swimming pools without cyanuric acid (Centers for Disease Control and Prevention, 2008). Therefore, it is suggested to increase the CT value for periodic shock dose chlorine from 7,200 mg·min/L to 15,300 mg·min/L in the guideline as per the CDC's latest recommendation (Centers for Disease Control and Prevention, 2008).

4.10.2 New South Wales

It is recommended to include a regulation in Schedule 1 of *Public Health Regulation 2022* (NSW) stating that the pool operators shall comply with the requirements stated in Schedule 1 and the requirements in NSW Guidelines for Public Swimming Pools and Spa Pools with the relevant penalty unit upon any non-compliance.

4.10.3 Northern Territory

With respect to the definition used in the guideline in New South Wales, South Australia, and Victoria, a definition for cryptosporidiosis outbreak is suggested to be included in the Public Health Guidelines for Aquatic Facilities.

As mentioned in 4.10.1, a clear definition of cryptosporidiosis outbreak would be beneficial with respect to prompt remedial action for the health authority and also a better allocation of health treatment resources for the local community (Scully, 2004).

As mentioned in 4.10.1, the CDC has amended the CT value for the inactivation of *Cryptosporidium* oocyst to 15,300 mg·min/L (Centers for Disease Control and Prevention, 2008; Shields et al., 2008). Thus, it is suggested that the CT value for inactivation of *Cryptosporidium* oocyst stated in the Public Health Guidelines for Aquatic Facilities should be changed from 8,400 mg·min/L to 15,300 mg·min/L to achieve a 99.9% reduction in the total amount of viable *Cryptosporidium* oocyst in swimming pool (Northern Territory Government Department of Health, 2006; Shields et al., 2008).

The size of *Cryptosporidium* oocysts ranges from 4 to 6 microns in diameter (Cacciò & Widmer, 2014). As the Public Health Guidelines for Aquatic Facilities does not have any recommendation on the filter size in swimming pools, it is suggested to include a recommendation for a filter with a size 4 microns or smaller in the guideline that aligns with the guidelines from Queensland and Victoria (Queensland Health, 2019; Victoria Government Department of Health, 2020).

With regard to filtrate turbidity, it is suggested that the Public Health Guidelines for Aquatic Facilities should include a recommendation for filtrate turbidity lower than 0.2 NTU with a maximum turbidity not above 0.5 NTU, following the recommendation for filtrate turbidity for swimming pools and spa pools in New South Wales (NSW Health, 2022a). The rationale for this recommendation has been discussed in 4.10.1.

With regard to the dosage for UV disinfection, it is recommended to include a validated UV disinfection with a dosage that attains a 3-log inactivation of *Cryptosporidium* oocysts for interactive water facilities and 2-log inactivation for other types of recreational water facilities, with reference to the guideline in New South Wales, Queensland and Victoria (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020).

It is recommended to state clearly that non-compliance with the recommendations described in the Public Health Guidelines For Aquatic Facilities would cause the operator of the swimming pool to bear legal consequences. Besides, it is also recommended to include a regulation in *Public And Environmental Health Regulations 2014* (NT) stating the pool operators shall comply with the recommendations stated in Public Health Guidelines For Aquatic Facilities at all times when the pools are in operation and stating the penalty unit that a pool operator shall bear in case of any non-compliance of requirements listed in Public Health Guidelines For Aquatic Facilities. Besides, it is suggested to refer to the guidelines of New South Wales, Queensland, and Victoria and include a requirement that all aquatic interactive water facilities should have a validated UV disinfection as secondary disinfection archiving 3-log inactivation *Cryptosporidium* oocysts together with residual primary disinfection with chlorine-based or bromine-based disinfectant; and a validated UV system as secondary disinfection that achieve 2-log inactivation of *Cryptosporidium* oocysts for other types of recreational water facilities (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020).

As mentioned in 4.9, the Public Health Guidelines For Aquatic Facilities recommended a regular shock chlorine dosing with a CT value of 4,800 mg·min/L weekly or biweekly when there are no bathers (Northern Territory Government Department of Health, 2006). It is suggested to update the value of shock chlorine dosing from CT value of 4,800 mg·min/L to 15,300 mg·min/L according to the CDC latest recommendation for hyperchlorination at recreational water facilities without using cyanuric acid (Centers for Disease Control and Prevention, 2008).

4.10.4 Queensland

Regarding the definition of a cryptosporidiosis outbreak in a swimming pool, Queensland would define it as an observable increase in confirmed cryptosporidiosis in a particular swimming pool or recreational water facility cases using past historical outbreak records as the reference (Queensland Health, 2024b). Given the highly infectious nature of *Cryptosporidium* oocysts as ingestion of only ten oocysts could be enough to infect a healthy patron (Chappell et al., 2006; Jokipii & Jokipii, 1986), it is reasonable to say the definition by comparison of past outbreak numbers would be an abstract comparison and may cause a delay in the judgment of an ongoing outbreak, seriously hindering public health at the same time (Scully, 2004). Therefore, it is advised that the definition should be revised as confirmation of a definite number of confirmed cases, concerning the definition adopted by New South Wales and Victoria that defines a cryptosporidiosis outbreak in a swimming pool as two or more cryptosporidiosis confirmed cases or the definition of cryptosporidiosis outbreak in swimming pool adopted by South Australia that include any confirmed cases (NSW Health, 2024b; SA Health, n.d.; Victoria State Government Health and Human Services, 2018). These definitions adopted by New South Wales, Victoria, and South Australia would be a more stringent and effective approach for classifying a suspected cryptosporidiosis outbreak and allocating the health treatment resources appropriately (Scully, 2004).

Given the CT value stated in the Water Quality Guidelines For Public Water Facilities, it is recommended to include the CT value of 31,500 mg·min/L for swimming pools with cyanuric acid concentration of 15 mg/L or less to attain a 99.9% reduction in the total amount of viable *Cryptosporidium* oocyst (Murphy et al., 2015; Queensland Health, 2019). The rationale for the CT value in swimming pools with cyanuric acid concentration 15 mg/L or less has been discussed in 4.10.1.

As mentioned in 4.6, the Water Quality Guidelines For Public Water Facilities only stated that the filtrate turbidity should not be more than 0.5 NTU (Queensland Health, 2019). For better control of filtrate turbidity in pool water to minimize health risks to humans, it is recommended to achieve a filtrate turbidity lower than 0.2 NTU with an upper interval of 0.5 NTU in swimming pool (National Health and Medical Research Council, 2022; NSW Health, 2022a; World Health Organization, 2006). The rationale for this recommendation has been discussed in 4.10.1.

It is recommended to include a statement in the Water Quality Guidelines For Public Water Facilities that any non-compliance with the requirements in the guideline would result in legal proceedings to educate and remind swimming pool operators. Additionally, it is advised to mention in the guideline that it is an offence for a responsible person of the swimming pool to fail to comply with its water management plan when the pools are in operation according to Section 61G(2) of *Public Health Act 2005* (Qld) (*Public Health Act 2005* (Qld), s 61G(2)).

As mentioned in 4.2, the aquatic facilities in Queensland are not required to conduct any remedial hyperchlorination process if the aquatic facility operator can provide valid evidence that the facility has an existing validated system to treat the risk of cryptosporidiosis and there is valid evidence that this system has been in operation within its validated parameters before and since the outbreak event (Queensland Health, 2019). The guideline does not state clearly the definition or details of a validated system that is qualified for treating the risk of cryptosporidiosis (Queensland Health, 2019). The "2023 Model Aquatic Health Code (MAHC)" from the CDC has detailed information about definitions, qualifications, and validation standards for secondary disinfection to public health authorities and aquatic facility operators as a reference guideline (Centers for Disease Control and Prevention, 2023). To ensure a stricter use of discretion for not conducting hyperchlorination upon any cryptosporidiosis outbreak at pools in Queensland, it is suggested to include the details for the definition of a validated system, third-party validation and validation standard in the Water Quality Guidelines For Public Water Facilities for clear reference to aquatic facilities operators, public and the health authority.

4.10.5 South Australia

As the Standard for the Operation of Swimming Pools and Spa Pools and Guideline for the Inspection and Maintenance of Swimming Pools and Spa Pools do not have any recommendation on the filter size in swimming pools, it is suggested to include a recommendation for a filter with size 4 microns or smaller in the guidelines, aligning with the guidelines from Queensland and Victoria (Queensland Health, 2019; SA Health, 2013a; SA Health, 2013b; Victoria Government Department of Health, 2020).

With regard to filtrate turbidity, it is suggested that the Standard for the Operation of Swimming Pools and Spa Pools should include a recommendation for filtrate turbidity lower than 0.2 NTU with a maximum turbidity not above 0.5 NTU, following the recommendation for filtrate turbidity for swimming pools and spa pools in New South Wales (NSW Health, 2022a). The rationale for this recommendation has been discussed in 4.10.1.

Additionally, it is suggested to take content from the guidelines of New South Wales, Queensland, and Victoria and include a requirement that all aquatic interactive water facilities should have a validated UV disinfection as secondary disinfection archiving 3-log inactivation *Cryptosporidium* oocysts together with residual primary disinfection with chlorine-based or bromine-based disinfectant; and a validated UV system as secondary disinfection that achieve 2-log inactivation of *Cryptosporidium* oocysts for other types of recreational water facilities (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020).

It is recommended to add requirements for newly developed high-risk water facilities with reference to the guidelines of New South Wales, Victoria, and North Territory; details have been discussed in 4.10.1 (Northern Territory Government Department of Health, 2006; NSW Health, 2022a; Queensland Health, 2019).

4.10.6 Tasmania

With respect to the definition used in the guideline in New South Wales, South Australia, and Victoria, a definition for cryptosporidiosis outbreak is suggested to be included in the Tasmanian Recreational

Water Quality Guidelines 2007. The benefits of the addition of a definition for cryptosporidiosis outbreak have been previously discussed in 4.10.1 (Scully, 2004).

As there is no information in the current version of Recreational Water Quality Guidelines 2007 for the CT value for inactivation of *Cryptosporidium* oocyst, it is thus recommended to include a CT value of 31,500 mg·min/L for swimming pool with cyanuric acid concentration 15 mg/L or less and a CT value of 15,300 mg·min/L for swimming pool without cyanuric acid in the guideline regarding any AFRs or cryptosporidiosis outbreak in swimming pool (Centers for Disease Control and Prevention, 2008; Murphy et al., 2015; Shields et al., 2008; Tasmanian Government Department of Health, 2007). The rationale for setting up these CT values have been discussed in 4.10.1.

There is no information about the filter size in the Recreational Water Quality Guidelines 2007 (Tasmanian Government Department of Health, 2007). Therefore, it is suggested to include a recommendation for a filter with a size of 4 microns or smaller in the guidelines, aligning with the guidelines from Queensland and Victoria (Queensland Health, 2019; Tasmanian Government Department of Health, 2007; Victoria Government Department of Health, 2020).

With regard to filtrate turbidity, it is suggested that Recreational Water Quality Guidelines 2007 should include a recommendation for filtrate turbidity lower than 0.2 NTU with a maximum turbidity not above 0.5 NTU, following the recommendation for filtrate turbidity for swimming pools and spa pools in New South Wales (NSW Health, 2022a). The rationale for this recommendation has been discussed in 4.10.1.

It is recommended to include a statement in the Introduction Part of Recreational Water Quality Guidelines 2007, emphasizing that it is an offence for any person or occupier of a public swimming pool or spa pool to fail to comply with the requirements in the guideline as per Section 128(1) of *Public Health Act 1997* (Tas) (*Public Health Act 1997* (Tas), s 128(1)).

It is suggested to take reference to the guidelines of New South Wales, Queensland, and Victoria and include a requirement that all aquatic interactive water facilities should have a validated UV disinfection as secondary disinfection archiving 3-log inactivation *Cryptosporidium* oocysts together with residual primary disinfection with chlorine-based or bromine-based disinfectant; and a validated UV system as secondary disinfection that achieve 2-log inactivation of *Cryptosporidium* oocysts for other types of recreational water facilities (NSW Health, 2022a; Queensland Health, 2019; Victoria Government Department of Health, 2020).

It is recommended to add requirements for newly developed high-risk water facilities concerning the guidelines of New South Wales, Victoria, and North Territory; details have been discussed in 4.10.1 (Northern Territory Government Department of Health, 2006; NSW Health, 2022a; Queensland Health, 2019).

4.10.7 Victoria

As discussed in 4.6, it is found that the Water Quality Guidelines for Public Aquatic Facilities Managing Public Health Risks only state that the filtrate turbidity should be less than 0.2 NTU (Victoria Government Department of Health, 2020). Therefore, it is recommended to follow the recommendation from WHO and add the highest benchmark of 0.5 NTU for filtrate turbidity in the guideline (World Health Organization, 2006).

It is recommended to state clearly in the Water Quality Guidelines for Public Aquatic Facilities Managing Public Health Risks that any non-compliance with the requirements in the guideline would be an offence as the pool operator fails to fulfill their “Duty to minimise risks” as per Part 5, Division 3, Section 46 of *Public Health and Wellbeing Regulations 2019* (Vic) (*Public Health and Wellbeing Regulations 2019* (Vic), pt 5, div 3, s 46).

4.10.8 Western Australia

With respect to the definition used in the guideline in New South Wales, South Australia, and Victoria, a definition for cryptosporidiosis outbreak is suggested to be included in the Code of Practice For Aquatic Facilities. The benefits of the addition of a definition for cryptosporidiosis outbreak have been previously discussed in 4.10.1 (Scully, 2004).

The Code of Practice For Aquatic Facilities only has the recommendation of CT value of 15,300 mg·min/L for swimming pools without cyanuric acid during AFRs or cryptosporidiosis outbreaks (Government of Western Australia Department of Health, 2023). Therefore, it is recommended to include the CT value of 31,500 mg·min/L for swimming pools with cyanuric acid concentration of 15 mg/L or less to attain a 99.9% reduction in the total amount of viable *Cryptosporidium* oocyst in the Code of Practice For Aquatic Facilities (Murphy et al., 2015). The rationale for the CT value in swimming pools with cyanuric acid concentration of 15 mg/L or less has been discussed in 4.10.1.

There is no information about the filter size in the Code of Practice For Aquatic Facilities (Government of Western Australia Department of Health, 2023). Therefore, it is suggested to include a recommendation for a filter with a size 4 microns or smaller in the Code of Practice For Aquatic Facilities, aligning with the guidelines from Queensland and Victoria (Queensland Health, 2019; Victoria Government Department of Health, 2020).

With regard to filtrate turbidity, it is suggested that the Code of Practice For Aquatic Facilities should include a recommendation for filtrate turbidity lower than 0.2 NTU with a maximum turbidity not above 0.5 NTU, following the recommendation for filtrate turbidity for swimming pools and spa pools in New South Wales (NSW Health, 2022a). The rationale for this recommendation has been discussed in 4.10.1.

It is recommended to include a statement in the Code of Practice For Aquatic Facilities that it is an offence for any non-compliance of the requirements in the guideline, or any non-compliance of an improvement order or closure order issued as per Section 31 of *Health (Aquatic Facilities) Regulations 2007* (WA) (*Health (Aquatic Facilities) Regulations 2007* (WA), s 31)). Besides, it is also recommended to add requirements for newly developed high-risk water facilities concerning the guidelines of New South Wales, Victoria, and North Territory; details have been discussed in 4.10.1 (Northern Territory Government Department of Health, 2006; NSW Health, 2022a; Queensland Health, 2019).

5.0 AN EXPERIMENTAL STUDY OF FOUR SWIMMING POOLS IN SOUTH AUSTRALIA

This chapter presents an experimental study to investigate the efficiency of UV disinfection with chlorine residue on the swimming pool water quality using the Colilert 18 test. It also presents the materials and methods, the sampling procedure, the procedure for delivery of sample, the experimental procedure of using the Colilert 18, results, and discussion. In this experiment, samples were taken from four distinct swimming pools on 20th June 2024. These four pools were connected to their individual filtration and recirculation systems that involved a secondary UV disinfection combined with a primary chlorination. Samples were then delivered to the Environmental Health Laboratory at Flinders University for a Colilert 18 test on the same day.

5.1 Material and Method

5.1.1 Preparation of sodium thiosulfate pentahydrate solution

According to Section 4.3.1.2 of AS 2031-2012 Water quality — Sampling for microbiological analysis (ISO 19458:2006, MOD), it was suggested that the concentration of the sodium thiosulfate pentahydrate solution should be 18 mg/mL (Standard Australia, 2012). Section 4.2.3 of AS 2031-2012 Water quality — Sampling for microbiological analysis (ISO 19458:2006, MOD) suggested that every 0.1 mL of sodium thiosulfate pentahydrate solution can neutralize between 2 mg/L and 5 mg/L of free chlorine (Standards Australia, 2012). Therefore, the sodium thiosulfate pentahydrate solution was made by dissolving 4.5 g of sodium thiosulfate pentahydrate into exactly 250 mL of distilled water on 18th June 2024 as shown in **Figure 5.1** and **Figure 5.2**. The solution was then autoclaved to eliminate microbes.

Figure 5.1 shows exactly 4.5 g of solid sodium thiosulfate pentahydrate was weight

Figure 5.2 shows that 4.5 g of sodium thiosulfate pentahydrate was dissolved into exactly 250 mL of distilled water for the preparation of sodium thiosulfate pentahydrate solution (18 mg/mL).

5.1.2 Preparation of sampling bottles with sodium thiosulfate pentahydrate solution

After autoclaving, the sodium thiosulfate pentahydrate solution (18 mg/mL), 100 μL of the solution was added to each 100 mL sterile sampling bottle on 18th June 2024. The sampling bottles were carefully stored in an Esky at the Environmental Health Laboratory ready for sample collection on 20th June 2024.

5.2 Sampling Procedure

Swimming water samples were taken from four different swimming pools, including a competition pool, a dive pool, a program pool and a leisure pool, at hourly intervals for seven hours on 20th June 2024, following below sampling steps with reference to Section 6 in “Guidelines for the Inspection and Maintenance of Swimming Pools and Spa Pools” from SA Health and also “Aquatic Facilities Microbiological Water Sampling Guideline” from WA Health (SA Health, 2013a; WA Health, 2022) :

A. Each 100 mL sterile sampling bottle was labelled with the sampling date, sampling time, and type of pool.
B. A clean large flask was rinsed twice at the swimming pool inlet with the pool water.
C. The plastic flask was dipped into the swimming pool water near the inlet edge, moving parallel to the pool edge at 30 to 40 cm under the water surface. The sampling was taken at the inlet nearest to the injection point with stable residual chlorine concentration in theory.

D. The screw cap of the sterile 100 mL sample bottle was carefully removed and held. The inner side of the screw cap was not touched. The sample swimming water was then carefully poured into the sterile 100 mL sample bottle. 100 µL of the autoclaved sodium thiosulfate pentahydrate solution was previously put inside the sampling bottle. The sampling bottle was kept about 1-2 cm from the rim and the screw cap was tightly secured.
E. The sample was then immediately placed into a chilled Esky with ice packs at 1 to 4 degrees Celsius before delivery to the laboratory.
F. The estimated number of bathers at the swimming pool at the time of each sampling was recorded.

Step A to F was repeated for each sample collected at the four distinct swimming pools. The estimated number of bathers at the time of each sampling was recorded, as shown in **Appendix 1**, to eliminate the possible bather loading effect.

5.3 Procedure for Delivery of Samples

The 16 bottles of samples collected in the morning session (from 0 h to 3rd h) were transported to the Environmental Health Laboratory for refrigeration at around 1 pm on 20th June 2024. The remaining 16 bottles of samples collected in the afternoon session (from 4th h to 7th h) were transported to the Environmental Health Laboratory for refrigeration at around 1730 h on the same day. Both batches of samples were transported in an Esky with enough ice packs keeping the temperature at 1 to 4 degrees Celsius. They were all delivered to the Environmental Health Laboratory for proper refrigeration within 6 hours from the starting time of sampling (WA Health, 2022). The sampling time and delivery time were recorded and shown in **Appendix 2**.

5.4 Experimental Procedure Using Colilert 18

All 32 bottles of swimming water samples were taken to the laboratory for testing of Total Coliforms and *E. Coli* using Colilert 18 on 20th June 2024. Each exact 100 mL sample was mixed with Colilert 18 reagent, placed into a Quanti-Tray/ 2000, and then sealed with a Quanti-Tray Sealer. The sample was then incubated at 35± 0.5 degrees Celsius for 18 hours (IDEXX, n.d.).

5.5 Experimental Results

After incubation for 18 hours, all Quanti-Tray/ 2000 were taken out from the incubator to observe the results. It was observed that all the Quanti-Tray/ 2000 showed a very clear colour, indicating that negative results were achieved for all 32 swimming pool water samples for Total Coliforms, and *E. Coli*. Results of the Colilert 18 test for all 32 swimming pool water samples were recorded in **Appendix 3**.

5.6 Discussion

Currently, there is no existing experimental testing to verify the viability of *Cryptosporidium* oocysts (ACT Department of Health, 1999b). It was also documented that *Cryptosporidium* oocysts are highly chlorine resistant with sizes 4 to 6 microns (NSW Health, 2022a). Clinical enumeration of *Cryptosporidium* oocysts is mainly conducted by either testing of stool samples by PCR or screening with auramine-rhodamine fluorescent stain, followed by the confirmatory testing by safranin stain or formalin-ether concentration (Ahmed & Karanis, 2018; Boehmer et al., 2009; Busse et al., 2019; Hopkins et al., 2013; Mahmoudi et al., 2017; Pacheco et al., 2013; Yang et al., 2014). These methods for enumerating *Cryptosporidium* oocysts are time-consuming and expensive (Ahmed & Karanis, 2018).

On the other hand, testing for *E.coli* using Colilert 18 is more cost-effective (IDEXX, n.d.). Colilert 18 test is also easy to handle and fast for obtaining results (IDEXX, n.d.). Given that the four distinct filtration and recirculation systems with secondary UV disinfection combined with primary chlorination worked perfectly in the targeted four swimming pools, any finding of the absence of *E.coli* in waterbody does not mean that there are no *Cryptosporidium* oocysts in the same waterbody (Ligda et al., 2020). However, if the experimental result showed *E.coli* presence in the swimming pool water samples, there will be a high possibility that *Cryptosporidium* oocysts could exist in the swimming pool water as the whole UV disinfection system with primary chlorination could not even eradicate *E.coli,* which should be easier to kill.

Negative results were obtained for all the 32 swimming pool water samples taken, indicating that the four distinct filtration and recirculation systems with secondary UV disinfection combined with primary chlorination worked efficiently for *E.coli*. However, studies have shown that *E.coli* is an inappropriate surrogate indicator for *Cryptosporidium* oocysts (Edberg et al.,2000; Ligda et al., 2020; Nieminski et al., 2010). Therefore, it was still unknown if secondary UV disinfection with primary chlorination could eradicate *Cryptosporidium* oocysts efficiently. Moreover, a study revealed that *Giardia* cysts might be a more reliable surrogate indicator for *Cryptosporidium* oocysts due to the close correlation between their abundances. (Cheng et al., 2012). Further scientific field work or laboratory studies using a more reliable indicator are suggested for detecting *Cryptosporidium* oocysts in the swimming pool with secondary UV disinfection combined with primary chlorine or bromine disinfection to fill any knowledge gaps.

6.0 LIMITATIONS AND DISCUSSIONS

This chapter presents the various limitations for the prevention of cryptosporidiosis in swimming pools and other recreational water facilities and the discussion regarding the environmental health approach.

6.1 Limitations for prevention of cryptosporidiosis in swimming pools and other recreational water facilities

6.1.1 Long incubation period for cryptosporidiosis

In humans, cryptosporidiosis has a long incubation period, of four to twelve days, with a median of ten days (Jokipii et al., 1983). This hinders the time for identifying the source of contamination, causing a delay in the timeline for implementing any mitigation measures for cryptosporidiosis at the source to stop further transmission (Ryan et al., 2016).

6.1.2 Unavailability of reliable surrogate indicator for *Cryptosporidium* oocysts

Despite numerous scientific efforts in the search for a surrogate indicator for *Cryptosporidium* oocyst for use in laboratory or water quality monitoring, a reliable surrogate indicator has not yet been identified. A lab study showed that polystyrene beads with 4 to 6 microns diameter could be a reliable surrogate indicator of *Cryptosporidium* oocyst via physical filtration, with 1-log removal of the microsphere could resemble 1.040-log inactivation of *Cryptosporidium* oocysts (Li et al., 1997). Recent scientific studies pointed out that microplastics could not only cause irreversible effects on the natural environment and living organisms but also pose a hazard in the food chains and affect human health (Bouwmeester et al., 2015; Goodman et al., 2021; Lee et al., 2013; Lehner et al., 2019).

A study revealed that *Clostridium perfringens*, F-specific coliphages, and enterococci were not appropriate surrogate indicators for *Cryptosporidium* oocysts as they showed an unexpectedly high number of false-positive results for predicting the presence of oocysts (Harwood et al., 2005). A study demonstrated that *Giardia* cysts might be a more reliable surrogate indicator for *Cryptosporidium* oocysts in wastewater treatment due to the close correlation between their abundances. (Cheng et al., 2012). It is still unknown if *Giardia* cysts could indicate *Cryptosporidium* oocysts in an actual recreational water facility.

Garvey et al. (2013) demonstrated that *Bacillus megaterium* endospore and *Cryptosporidium parvum* oocysts shared a comparable pulsed UV light inactivation kinetic data with a UV dosage from 6.4 to 12.9 $\mu J/cm^2$, suggesting *Bacillus megaterium* endospore has a high potential to be a surrogate indicator to resemble the efficacy of UV inactivation on *Cryptosporidium parvum* oocysts (Garvey et al., 2013). Bradford et al. (2016) presented that *Bacillus subtilis* spores and *Cryptosporidium parvum* oocysts had a similar performance in transport and retention over certain physical and chemical conditions, and could sometimes act as a conservative indicator for *Cryptosporidium* oocysts depending on the specific environment (Bradford et al., 2016). Pereira et al. (2023) revealed that aerobic spore-forming bacteria (ASFB) performed better as a conservative indicator than the polystyrene microbeads with fluorescent properties, yielding a 1.2 to 4 log r removal of ASFB at direct filtration with turbidity at 3.7 NTU using lake water (Pereira et al., 2023). Despite aerobic spores and *Cryptosporidium oocysts* being similar in some biological aspect and their ability to survive in external environments, they are distinct in terms of their life cycle in nature, biological structure on their surface, and physical properties (Headd & Bradford, 2016). Headd & Bradford (2016) pointed out that not all species of aerobic spore can act as the surrogate indicator for *Cryptosporidium* oocysts due to the difference in their interaction with the surrounding environment, particularly opportunist aerobic spore would germinate upon suitable conditions (Headd & Bradford, 2016). Compared to aerobic spores, *Cryptosporidium* oocysts are larger in size and are much easier to be physically separated by filtration (Headd & Bradford, 2016). There are still uncertainties in ruling out a single species of aerobic spores suitable for being a surrogate indicator for *Cryptosporidium* oocysts (Headd & Bradford, 2016). More gaps in science are waiting to be filled before any discovery of a single species or a combination of species of aerobic spores that could be perfect to be a surrogate indicator for *Cryptosporidium* oocysts (Headd & Bradford, 2016).

A study in Japan demonstrated the algae, *Scenedesmus quadricauda*, could be the surrogate indicator for *Cryptosporidium parvum* oocysts to assess their filtration efficiency in sand filtration as they have similar behavior upon filtration (Kim et al., 2002). Another study in Japan also pointed out that the algae, *Selenastrum capricornutum*, was regarded to be a possible surrogate indicator of *Cryptosporidium parvum* oocysts in rapid sand filtration during the wastewater treatment process (Akiba et al., 2002). It is still uncertain if these two algae species could be used as a surrogate to evaluate the filtration efficiency of *Cryptosporidium parvum* oocysts in a swimming pool setting.

6.1.3 Lack of available swimming pool water testing method for *Cryptosporidium* oocysts

Currently, there is no existing viability testing for *Cryptosporidium* oocysts (ACT Department of Health, 1999b). Clinical enumeration of *Cryptosporidium* oocysts is time-consuming and expensive (Ahmed & Karanis, 2018; O'Leary et al., 2021). Cullinan et al. (2020) interviewed with several Environmental Health Practitioners (EHPs) from Victoria to investigate the study of the work-related barriers they encountered in managing cryptosporidiosis outbreaks in swimming pools and pointed out that routine chemical testing compliance does not quarantine the absence of highly chlorine-resistant *Cryptosporidium* oocysts in swimming pool water (Cullinan et al., 2020). Due to the latency in tracking the source and unavailability of fast-track testing for detecting *Cryptosporidium* oocysts in swimming pool water, EHPs revealed that there was reluctance from swimming pool operators to carry out hyperchlorination as scientific proof was absent for confirming the *Cryptosporidium spp.* was still in the water body after several weeks since the initial exposure at the suspected source of the outbreak (Cullinan et al., 2020).

Recent advances in *Cryptosporidium* oocysts testing includes the invention of the “Rapid-Crypto Colorimetric LAMP test”, which achieved 100% sensitivity for detecting faecal oocysts in calves, as reported by Karakavuk et al. (2024) and a novel “TaqMan qRT-PCR/qPCR assays” that gives a quantitative viability screening of *Cryptosporidium parvum* oocysts and *Cryptosporidium hominis* oocysts in lake water introduced from Wang et al. (Karakavuk et al., 2024; Wang et al., 2024). Despite these innovations, significant effort and time are still needed before any rapid and reliable detection of *Cryptosporidium spp.* or oocysts viability test in swimming pool water comes to actual practice.

6.1.4 Inconsistent remedial response toward suspected or confirmed cryptosporidiosis swimming pool

The non-mandatory nature of legislation or guidelines towards performing hyperchlorination in recreational water facilities led to an inconsistency remedial response during a cryptosporidiosis outbreak, as the facility operators are given discretionary power for conducting hyperchlorination (Cullinan et al., 2020). As there is a latency in confirming the source for cryptosporidiosis and a lack of advancement in fast-track *Cryptosporidium spp.* detection for swimming pools as previously discussed in 6.12, the recreational water facility operators refuse to follow the recommendation from Environmental Health Practitioners for hyperchlorination (Cullinan et al., 2020). Given this, revising the current obligation to mandate hyperchlorination in swimming pools with specified penalty units upon non-compliance should be widely discussed among the swimming pool industry, other stakeholders, legislative parties, health authorities, environmental health experts, and the general public before reaching to a decision.

6.1.5 Lack of Knowledge, Attitude, and Practice (KAP) for recreational water facility operators, swimmers, and Environmental Health Officers (EHOs)

An interview conducted with 40 staff working in the public swimming pool and 380 swimmers in Western Australia revealed that less than 27% of the interviewees knew about cryptosporidiosis, and none of the interviewees without children understood the importance of refraining from swimming for two weeks after diarrhea resolved, more than 97% of the parental patrons believed that their children need to avoid swimming for one week after diarrhea resolved; less than 40% of the interviewee knew the importance of taking shower before entering the water body (Braima et al., 2022). With regard to the knowledge of handling accidental faecal release (AFR) from children in swimming pools, only half of the parents reflected they would immediately notify the pool operators (Braima et al., 2022). These findings from the interview indicated an insufficient awareness of knowledge and healthy swimming practices among the staff and swimmers (Braima et al., 2022). The results of another interview conducted with swimmers and swimming pool staff in Victoria also indicated that there was limited knowledge about crytosporidiosis and unhygienic swimming practices in the swimming pool, highlighting the urgent need to raise the awareness of healthy swimmer behaviour for the local community and enhancing the basic knowledge regarding swimming pool maintenance, preventive measures against cryptospordioisis and remedial action during AFR (Cullinan et al., 2020). Some EHOs expressed they lacked hands-on experience in how to share information on cryptosporidiosis outbreaks, lacked practical training and expertise in addressing their queries following the review of the guidelines. Therefore relevant unions may consider launching sharing sessions from highly experienced EHOs or experts about handling a cryptosporidiosis outbreak (Cullinan et al., 2020).

6.1.6 Limited demographic information on National Notifiable Disease Surveillance System (NNDSS)

Cryptosporidiosis is a nationally notifiable disease and is monitored by the National Notifiable Disease Surveillance System (NNDSS) (Australian Government Department of Health and Age Care, 2022). The demographic information only includes gender and age, without listing the types of sources and the identification of *Cryptosporidium spp*. and the genotype (Australian Government Department of Health and Age Care, 2022; Ng-Hublin et al., 2017). Lal et al.(2015) pointed out that information on the geographic trend of disease transmission can identify specific local locations for high exposure, and risk factors for transmission routes within a community and implement targeted mitigation measures (Lai et al., 2015). The demographic information provided by NNDSS does not show the geographic information, which affects health authorities or experts in developing prompt target mitigation for preventing the further spread of cryptosporidiosis in the local community (Lai et al., 2015).

6.2 Discussions

6.2.1 UV disinfection in recreational water facilities

UV disinfection has been widely applied to wastewater treatment and drinking water treatment worldwide (Adeyemo et al., 2019; Campbell et al., 1995). Studies showed that UV light treated *Cryptosporidium spp.* could not undergo either light repair or dark repair of DNA to restore the infectivity; however, the UV radiation did not have any effect on the capability of oocysts to excyst (Morita et al., 2002; Oguma et al., 2001).

Cotton et al. (2001) revealed that UV disinfection is more cost-effective than ozone disinfection, with a UV dose of 40 mJ/s achieving a minimum of 99% inactivation of *Cryptosporidium spp.* (Cotton et al., 2001). Both medium and low-pressured UV demonstrated the same effectiveness on the inactivation of *Cryptosporidium spp.* when considering their germicidal dosage (Clancy et al., 2000; Craik et al., 2001; Linden et al., 2001). UV with wavelengths ranging from 250 nm to 275 nm can attain 99% inactivation of *Cryptosporidium spp.,* while UV wavelengths below or above this range are not as effective (Linden et al., 2001). Studies have also found that medium and low-pressured UV exerted the same level of inactivation ability on both *Cryptosporidium parvum* and *Cryptosporidium hominis* accounting for most of the confirmed cryptosporidiosis cases in humans (Chappell et al., 2006; Johnson et al., 2005).

Although there were studies that suggested UV disinfection used in drinking water and wastewater treatment plants were effective against *Cryptosporidium spp.* as the entire water cycle was enclosed, this finding may not be applicable to an actual recreational water facility practice as it is not an enclosed infrastructure (Adeyemo et al., 2019; Petterson et al., 2021). Infected patrons or any accidental faecal release that introduces *Cryptosporidium* oocysts to the swimming pool water is a significant human health risk (Lu et al., 2013). Residue halogen-based disinfections, either chlorine or bromine-based, are crucial for eliminating newly introduced *Cryptosporidium spp.* from bathers (Lu et al., 2013). As *Cryptosporidium spp.* are highly tolerant to chlorine disinfection, a combination of UV with chlorine-based disinfection can offer a shorter time required for inactivating the *Cryptosporidium* oocysts (Adeyemo et al., 2019). It is essential for health authorities to establish a requirement in the guideline stating secondary UV disinfection must be applied together with halogen-based disinfection in high-risk recreational water facilities as an additional barrier to mitigate the health risk of *Cryptosporidium* oocysts ("Cryptosporidiosis Outbreaks Associated with Recreational Water Use — Five States, 2006," 2007). Such a requirement is currently stated in the guidelines of most states in Australia except South Australia and Tasmania.

6.2.2 Emphasise the importance of residual halogen-based disinfectants as primary disinfection in recreational water facilities to pool operators

As discussed in 4.3, New South Wales, South Australia, and Victoria have legislation to make chlorine-based or bromine disinfectant a compulsory primary disinfection measure in recreational facilities (*Public Health and Wellbeing Regulations 2019* (Vic), s 54(1); *Public Health Regulation 2022* (NSW), sch 1 s 3(2); *South Australian Public Health (General) Regulations 2013* (SA), ss 8(1)(a) & 9(1)(a)); while the remaining States and Territories use their respective guideline for setting up the recommendation for using chlorine-based or bromine disinfectant as primary residual disinfection (ACT Department of Health, 1999a; Government of Western Australia Department of Health, 2020; Northern Territory Government Department of Health, 2006; Queensland Health, 2019; Tasmanian Government Department of Health, 2007). Violations of such legislations or non-compliance of such recommendations in guidelines would lead to relevant legal processing in respective states and details have been discussed in 4.3. In other words, recreational water facility operators are legally bound to use chlorine-based or bromine-based primary disinfection. Health authorities should emphasise the importance of residual halogen-based disinfectants as primary disinfection in recreational water facilities and the legal responsibility to recreational water facility pool operators, ensure the operators execute effective primary disinfection and risk-assessment plan in recreational water facilities, encourage operators to follow the swimming pool guidelines in the respective states, take any enforcement related to non-compliance of swimming pool guidelines (Mayne et al., 2011). It is recommended to include a requirement in the guidelines for a need to obtain written approval from the Health Authority before any attempt to change the primary halogen-based disinfection system to a new disinfection method in swimming pools to prevent any cryptosporidiosis outbreaks due to insufficient disinfection.

6.2.3 Prevention of cryptosporidiosis outbreak in recreational water facilities using an environmental health approach

Nitazoxanide, being the only Food and Drug Administration (FDA) approved medicine, is used to cure cryptosporidiosis in immunocompromised adults (Chavez & White Jr, 2018; Diptyanusa & Sari, 2021; Lenière et al., 2024). Meanwhile, there is no approved vaccine against cryptosporidiosis in humans (Lenière et al., 2024). The lack of available clinical treatment options in cryptosporidiosis and the high resistance of *Cryptosporidium* oocysts to chlorination in recreational water facilities highlight the importance of an environmental health approach towards a cryptosporidiosis outbreak (Centre for Disease Control and Prevention, 2024; Mofidi et al., 2001).

An infected person can shed faeces with billions of *Cryptosporidium* oocysts and the infective dose for contracting cryptosporidiosis is only 10 oocysts (Chappell et al., 2006; Jokipii & Jokipii, 1986). A person with symptoms resolved can still shed faeces with oocysts for 2 weeks while an asymptomatic person can shed oocysts for up to several weeks, posing a significant health risk to healthy swimmers in any accidental faecal release (Jokipii & Jokipii, 1986; Ng-Hublin et al., 2015; Victoria Government Department of Health, 2024). Therefore, it is essential for health authorities to implement health education measures for the general public, emphasizing refraining from swimming for 14 days after resolved from diarrhea (Mayne et al., 2011; Ng-Hublin et al., 2015; Polubotho et al., 2021). Additionally, signage to exclude swimming when having diarrhea symptoms should be placed at a prominent place within the recreational water facilities (Ng-Hublin et al., 2015). It is also important to remind the public to have healthy swimming practices at recreational water facilities, including maintaining good hand hygiene, washing both hands with soap after toileting, avoiding swallowing swimming pool water, and avoid wash hands using swimming pool water at poolside (Health Protection Program SA Health, n.d.; Vandenberg et al., 2012). In view of asymptomatic carriers can also shed oocysts in their faeces, it is essential to emphasise to the public about taking a pre-swim shower (Polubotho et al., 2021).

A study used five micrometre diameter microspheres as a substitute to for *Cryptosporidium* oocysts to evaluate the effectiveness of swimming nappies to hold oocysts in a hot tub without filtration and revealed 77% to 100% of the surrogate microspheres were all released into the water body after ten minutes of water-related activities, indicating swimming nappies could not prevent the leak of *Cryptosporidium* oocysts in faeces from either asymptomatic or symptom-resolved babies or toddlers (Amburgey & Anderson, 2011). Therefore, health authorities should deliver parental guidelines to the public not to allow nappy-needing children to swim if they have diarrheal symptoms (Amburgey & Anderson, 2011; Health Protection Program SA Health, n.d.; Vandenberg et al., 2012). Moreover, parents should be advised not to change their nappy at the poolside and properly wash their hands with soap after changing a nappy in the bathroom, and not to sit on splash feature structures (Health Protection Program SA Health, n.d.; "Outbreak of cryptosporidiosis associated with a splash park - Idaho, 2007," 2009; Vandenberg et al., 2012).

In the event of an endemic cryptosporidiosis outbreak, it is essential to utilize social media and press communication to inform the local community about the shared responsibility of swimmers to prevent the spreading of the disease, stressing the importance of the individual effort to practice good hygiene measures at the recreational water facilities and report any suspected accidental faecal release to the lifeguards or operators for prompt remedial action ("Cryptosporidiosis Outbreaks Associated with Recreational Water Use — Five States, 2006," 2007). Polgreen et al. (2012) found that in recreational water facilities for a “heterogenous populations”, including large public swimming pools and wading pools, accounted for a higher risk for cryptosporidiosis outbreak when compared with those only served particular “homogenous population” (Polgreen et al., 2012). Polgreen et al. (2012) further pointed out that suspension of one swimming pool that identified with confirmed cryptosporidiosis case would cause the swimmers go to another swimming pool and spread the disease to other healthy populations (Polgreen et al., 2012). Therefore, it is suggested that the health authority announce a temporary regional suspension for all the recreational water facilities within that area upon a large-scale endemic cryptosporidiosis outbreak and, at the same time, issue a compulsory order for hyperchlorination, CT value of 15,300 mg·min/L for those without cyanuric acid and 31,500 mg·min/L for those with cyanuric acid, in any swimming pools linked to the same filtration plant identified with confirmed cryptosporidiosis case (Murphy et al., 2015; Polgreen et al., 2012; Shields et al., 2008).

7.0 CONCLUSION

Cryptosporidium oocysts are highly infectious (Adeyemo et al., 2019). The limited availability of approved clinical treatment for cryptosporidiosis, no available vaccination against cryptosporidiosis in humans, and the high chlorine resistance of the *Cryptosporidium* oocysts in swimming pool water highlights that prevention of cryptosporidiosis outbreak in recreational water facilities rely on the environmental health approach (Centre of for Disease Control and Prevention, 2024; Chavez & White Jr, 2018; Diptyanusa & Sari, 2021; Lenière et al., 2024; Mofidi et al., 2001). While UV disinfection was found to be effective in drinking water treatment systems and wastewater treatment systems (Liberti et al., 2003; Parsa et al., 2021), it cannot guarantee a complete inactivation of *Cryptosporidium* oocysts in recreational water facilities due to the ongoing contamination of pool water with organic matter and faecal matters from patrons (Lu et al., 2013). This is consistent with the situations observed from the systematic literature review that there were cryptosporidiosis outbreaks that occurred in recreational water facilities with residual chlorine disinfection and secondary UV disinfection in other countries (Boehmer et al., 2009; Hopkins et al., 2013; Iverson et al., 2018; Lu et al., 2013). The actual contribution of UV disinfection on inactivating *Cryptosporidium* oocysts in a recreational water facility remains undetermined as there is inadequate scientific data on this, and future research needs to be conducted.

7.1 Establish a National Recreational Water Facilities Standard And Guideline

The findings of this study demonstrate an inconsistency in the management of cryptosporidiosis outbreaks in recreational water facilities across different states in Australia. As discussed in Chapter 4, it is recognized that the definitions for cryptosporidiosis outbreak, guidelines related to CT value for hyperchlorination, recommendations for filter size and filtrate turbidity, recommendation for using UV as secondary disinfection, regular shock chlorine treatment in pools, the legislative control on using chlorine or bromine as primary disinfection and the recommendation for new high-risk public swimming pools, spa pools or swimming pools that are going to have alterations varies across different states in Australia. Cullinan et al. (2020) reported the urgency expressed by working EHOs for recreational water facilities to be registered under local councils to enhance liability and create a similar legislative framework as the Food Act (Cullinan et al., 2020). Therefore, it is suggested to use the Australia New Zealand Food Standard Code as a model to develop a National Recreational Water Facilities Standard And Guideline. This guideline should include a standardized definition of a cryptosporidiosis outbreak, harmonized guidelines for managing recreational water facilities, and standardized responses to cryptosporidiosis outbreaks or accidental faecal releases, that are simpler to understand and adaptable to any new international standard or future scientific discoveries (Baines et al., 2003).

Similar to the development of the Evaluation Strategy in FSANZ, it is crucial to involve extensive engagement of external and internal stakeholders to maintain a high transparency for any assessment process and decision-making procedure, and at the same time remove unnecessary existing recommendations based on public health considerations (Baines et al., 2003). It is advised to establish a working group, with responsibilities similar to the Bi-national Food Surveillance and Enforcement Strategy (BSES) Working Group in FSANZ, to oversee the enforcement data regarding the non-compliance in the National Recreational Water Facilities Standard And Guideline in Australia, analyse and identify possible trends risking public health in recreational water facilities, and provide data-based recommendations for modifying future guideline (Baines et al., 2003). With the establishment and implementation of a national standard and guideline in Australia, there will be a proper legal tool that advises the swimming pool industry, health authorities and staff of recreational water facilities on the approach to prevent future outbreaks of cryptosporidiosis (Baines et al., 2003; Cullinan et al., 2020).

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APPENDIX

Appendix 1 showing the sampling time and the number of bathers at the time of sampling in four distinct swimming pool during the experiment conducted on 20th June 2024

Type of Pool	Competition Pool							
Approximate Time interval for Sampling	0 h	1st h	2nd h	3rd h	4th h	5th h	6th h	7th h
Sampling time	0926 h	1020 h	1121 h	1220 h	1324 h	1446 h	1519 h	1614 h
Number of Bathers	22	18	15	21	5	2	0	4

Type of Pool	Dive Pool							
Approximate Time interval for Sampling	0 h	1st h	2nd h	3rd h	4th h	5th h	6th h	7th h
Sampling time	0930 h	1025 h	1124 h	1221 h	1326 h	1449 h	1522 h	1616 h
Number of Bathers	19	5	6	14	8	9	8	29

Type of Pool	Program Pool							
Approximate Time interval for Sampling	0 h	1st h	2nd h	3rd h	4th h	5th h	6th h	7th h
Sampling time	0933 h	1025 h	1128 h	1226 h	1328 h	1451 h	1524 h	1619 h
Number of Bathers	47	30	25	11	26	26	9	22

Type of Pool	Leisure Pool							
Approximate Time interval for Sampling	0 h	1st h	2nd h	3rd h	4th h	5th h	6th h	7th h
Sampling time	0935 h	1028 h	1119 h	1227 h	1330 h	1452 h	1525 h	1622 h
Number of Bathers	59	78	91	14	66	8	7	76

Appendix 2 showing the sampling time and the sample delivery time to Environmental Health Laboratory at Flinders University on 20th June 2024.

Type of Pool	Competition Pool							
Approximate Time interval for Sampling	0 h	1st h	2nd h	3rd h	4th h	5th h	6th h	7th h
Sampling time	0926 h	1020 h	1121 h	1220 h	1324 h	1446 h	1519 h	1614 h
Sample delivery time	1300 h	1300 h	1300 h	1300 h	1730 h	1730 h	1730 h	1730 h
Less than 6 hours from the time of sampling to the time arriving laboratory	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Type of Pool	Dive Pool							
Approximate Time interval for Sampling	0 h	1st h	2nd h	3rd h	4th h	5th h	6th h	7th h
Sampling time	0930 h	1025 h	1124 h	1221 h	1326 h	1449 h	1522 h	1616 h
Sample delivery time	1300 h	1300 h	1300 h	1300 h	1730 h	1730 h	1730 h	1730 h
Less than 6 hours from the time of sampling to the time arriving laboratory	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Type of Pool	**Program Pool**							
Approximate Time interval for Sampling	0 h	1st h	2nd h	3rd h	4th h	5th h	6th h	7th h
Sampling time	0933 h	1025 h	1128 h	1226 h	1328 h	1451 h	1524 h	1619 h
Sample delivery time	1300 h	1300 h	1300 h	1300 h	1730 h	1730 h	1730 h	1730 h
Less than 6 hours from the time of sampling to the time arriving laboratory	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Type of Pool	**Leisure Pool**							
Approximate Time interval for Sampling	0 h	1st h	2nd h	3rd h	4th h	5th h	6th h	7th h
Sampling time	0935 h	1028 h	1119 h	1227 h	1330 h	1452 h	1525 h	1622 h
Sample delivery time	1300 h	1300 h	1300 h	1300 h	1730 h	1730 h	1730 h	1730 h
Less than 6 hours from the time of sampling to the time arriving laboratory	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Appendix 3 showing the pictures for the results of Colilert 18 test for all samples collected from 4 different swimming pools in South Australia on 20th June 2024.

Competition Pool	
0 h	
1st h	

Competition Pool

2nd h

3rd h

Competition Pool	
4th h	
5th h	

Competition Pool	
6th h	
7th h	

Dive Pool	
0 h	
1st h	

Dive Pool	
2nd h	
3rd h	

Dive Pool	
4th h	
5th h	

Dive Pool	
6th h	
7th h	

Program Pool	
0 h	
1st h	

Program Pool	
2nd h	
3rd h	

Program Pool	
4th h	
5th h	

Program Pool	
6th h	
7th h	

Leisure Pool	
0 h	
1st h	

Leisure Pool	
2nd h	
3rd h	

Leisure Pool	
4^{th} h	
5^{th} h	

Leisure Pool	
6th h	
7th H