Drinking Water Inspectorate

RECOMMENDATIONS FOR THE MANAGEMENT OF CRYPTOSPORIDIUM IN WATER SUPPLIES

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APPENDICES

1 INTRODUCTION

The Group of Experts on *Cryptosporidium* in Water Supplies published a series of three reports (Bouchier, 1998; Badenoch, 1995; Badenoch, 1990), with the final one published in 1998. The three reports produced by the group have served as a standard of good practice for stakeholders within the water industry for the identification, mitigation, and management of *Cryptosporidium*. However, given that the last (third) report was published in 1998, there is a gap between the recommendations set out in the last Report of the Group of Experts and current knowledge of *Cryptosporidium*. For example, at the time of the third Report of the Group of Experts, *Cryptosporidium parvum* was the only species discussed in the report as this was the only species regarded to infect humans. There are now 48 species identified, of which 23 have been reported in humans with *Cryptosporidium hominis* and *Cryptosporidium parvum* most frequently reported in humans. Therefore, there is a need to update the recommendations to ensure that they take into consideration latest available knowledge and technology.

WSP undertook a literature review including UK and international research since the publication of the last Report of the Group of Experts (i.e. since 1998) and stakeholder engagement with water company representatives to understand the areas where such recommendations need to be updated or new recommendations need to be added.

To undertake the stakeholder engagement, a survey was developed to obtain information on the management of *Cryptosporidium* in water supplies in the topic areas of challenges, recommendations and guidance, treatment processes, detection and monitoring, and supply and storage. The survey was presented using Microsoft Forms. This was sent to water company representatives in June 2024. A virtual workshop was held in October 2024 to capture further insight from water company representatives on the management of *Cryptosporidium* in water supplies. The topics discussed in the workshop were *Cryptosporidium* removal and disinfection, management issues for NAV companies, monitoring and detection, and catchment management. Discussions were held in smaller groups using breakout rooms.

Using the information obtained from such evidence review, this report details the areas where recommendations need to be updated. A gap analysis was performed which is presented in Appendix A of this report. This provides information on the progression from the Group of Experts Reports to the current literature and stakeholder insights, and summarises the gaps identified. A notable point made by the stakeholders was that there should be reformation of an expert group to review best practice for the management of *Cryptosporidium* in water supplies.

This report is structured into the following thematic areas: species and infections, monitoring and detection, regulations, catchment management, treatment technologies, and reformation of expert group.

2 TOPIC FINDINGS AND UPDATES TO RECOMMENDATIONS

2.1 SPECIES AND INFECTION

2.1.1 GROUP OF EXPERTS REPORTS

At the time of the Third Report of the Group of Experts, *Cryptosporidium parvum* was the only species that was known to infect both humans and livestock. *Cryptosporidium parvum* was the only species discussed in the report.

The Third Report of the Group of Experts stated that the impact of an outbreak caused by a contamination event may be greater in areas that are supplied from normally high-quality sources compared to areas that are supplied from poorer quality sources. The report further notes that this is due to lower seroprevalence (presence of antibodies) indicating a lower level of prior and repeated exposure in populations served by normally high-quality sources.

2.1.2 LITERATURE REVIEW

There are now 48 recognised species and over 120 genotypes of *Cryptosporidium*. The following 23 species have been reported in humans: *Cryptosporidium hominis*, *Cryptosporidium parvum*, *Cryptosporidium meleagridis*, *Cryptosporidium canis*, *Cryptosporidium felis*, *Cryptosporidium ubuiquitum*, *Cryptosporidium cuniculus*, *Cryptosporidium viatorum*, *Cryptosporidium muris*, *Cryptosporidium andersoni*, *Cryptosporidium erinacei*, *Cryptosporidium tyzzeri*, *Cryptosporidium bovis*, *Cryptosporidium suis*, *Cryptosporidium scrofarum*, *Cryptosporidium occultus*, *Cryptosporidium xiaoi*, *Cryptosporidium fayeri, Cryptosporidium ditrichi* (Ryan, et al., 2021), *Cryptosporidium equi* (Huang, et al., 2023), *Cryptosporidium mortiferum* (Kváč, et al., 2025), *Cryptosporidium sciurinum*[1], *and Cryptosporidium wrairi* (Hernández-Castro, et al., 2022).

Cryptosporidium hominis and *Cryptosporidium parvum* are the species most frequently reported in humans. The main host species for *Cryptosporidium hominis* is humans and *Cryptosporidium parvum* has many host species including livestock, wildlife, companion animals and humans.

Infection with *Cryptosporidium* can be asymptomatic or can cause humans to develop a gastroenteritis-type illness called cryptosporidiosis with symptoms that can include diarrhoea, abdominal cramps, nausea, vomiting and low-grade fever (Horne, et al., 2017). *C. hominis* and *C. parvum* are responsible for the vast majority of cases of cryptosporidiosis in Europe

Studies have demonstrated that a small number of ingested *Cryptosporidium parvum* and *Cryptosporidium hominis* oocysts can result in cryptosporidiosis in an individual (Okhuysen, et al., 1999), although receiving higher doses of oocysts (in a study of healthy adults experimentally

[1] Documented in GenBank

infected with *Cryptosporidium hominis*) can result in more severe symptoms of the illness (Chappell, et al., 2006).

The main transmission risk factors for *Cryptosporidium hominis* infection are linked to contact with young children, people with diarrhoea, or consumption of water contaminated by human faeces or wastewater. The main transmission risk factors for *Cryptosporidium parvum* are linked to contact with farm animals or consumption of water or food contaminated by their faeces.

2.1.3 STAKEHOLDER ENGAGEMENT

The insight regarding the *Cryptosporidium* species from the stakeholders focused on how this translates to risk in the catchment. As there are different species and different hosts, the risk may not be the same depending on the species present (i.e. if it is a species that does not typically infect humans). This also feeds back to discussions regarding the now-rescinded treatment standard, raising the question over whether the treatment standard should be a blanket value for all species of *Cryptosporidium* oocysts or whether it should consider that the human infectivity potential of different *Cryptosporidium* oocysts varies.

2.1.4 UPDATES TO RECOMMENDATIONS

Since the Reports of the Group of Experts, there has been a big leap in the understanding of *Cryptosporidium* species. A recommendation update is to consider the species diversity and differences in potential for human infectivity when reviewing if a regulatory treatment standard should be reintroduced.

2.2 MONITORING AND DETECTION

2.2.1 GROUP OF EXPERTS REPORTS

The reports of the Group of Experts noted that most water treatment companies did not undertake routine monitoring of treated water supplies for *Cryptosporidium* oocysts. The reports advise on a monitoring strategy for *Cryptosporidium*, stating when the monitoring should be undertaken. They advised that monitoring for *Cryptosporidium* should be undertaken following significant contamination of water sources by agricultural pollution or sewage; during transitional periods during changes in the treatment process; when treatment processes are operating abnormally; if turbidity readings or indicator organisms deviate from normal range; and / or if an outbreak of cryptosporidiosis in the community is suspected as being linked to a water supply. Additionally, if a waterborne outbreak is suspected, the report advises that water companies will need to implement investigative monitoring for oocysts covering source waters, the water treatment works, and the distribution system. For monitoring within the treatment works, high-risk sites should have continuous turbidity monitoring and continuous sampling for *Cryptosporidium* with analysis times linked to turbidity monitoring results; or sampling triggered by turbidity events. Random spot sampling is unlikely to be effective for operational monitoring.

For detection purposes, the recovery of *Cryptosporidium* oocysts is described by the Third Report of the Group of Experts specifying the use of membrane filtration, cartridge filtration or chemical flocculation. For the identification of *Cryptosporidium*, flow cytometry and the use of antibodies are methods described in the report. The identification described is to the genus-level and does not include species determination. Species determination is usually referred to as genotyping.

2.2.2 LITERATURE REVIEW

Monitoring and detection for *Cryptosporidium* can be done indirectly by monitoring for surrogates, through turbidity monitoring and particle counting. For turbidity monitoring, this can be undertaken using nephelometric sensors which utilise light scattering to provide a turbidity reading. These can be handheld or can be used as online monitoring systems. They will not indicate what the cause of the change is but can indicate if further investigation is needed. Tube testing and Secchi disks are other options for turbidity monitoring which both involve using an apparatus to approximate turbidity. For particle counting, options include particle counters, which use a sensor to determine the size and quantity of particles; and / or flow cytometry, which measures the physicochemical properties of particles. Such indirect methods do not specifically detect *Cryptosporidium* oocysts.

Monitoring and detection for *Cryptosporidium* can also be done directly and specifically, by sampling for the *Cryptosporidium* organism through monitoring for oocysts or their DNA using molecular methods. For oocyst counting, the standard practice in the water industry is the EPA 1.623 / blue-book method (The Envionment Agency, 2010). This involves filtration, elution, centrifugation, immunomagnetic separation, and immunofluorescent microscopy to observe and count oocysts. Flow cytometry is not included in the Blue Book. Identification of the species of *Cryptosporidium* is not achieved using the Blue Book oocyst count method but can be achieved through further processing of the microscopy slides and use of molecular methods ("slide genotyping"). Molecular detection methods are not included in the Blue Book but include amplification methods (e.g. Polymerase Chain Reaction (PCR), Loop-mediated Isothermal Amplification (LAMP), Recombinase Polymerase Amplification (RPA) followed by probes or sequencing methods with high-throughput sequencing. Molecular methods also allow for *Cryptosporidium* species identification.

New trends for detection are the use of miniaturised detection methods. Various options are optical detection techniques, mass-based detection techniques, surface plasmon resonance, molecular diagnostics and existing total analysis systems, and electrical methods. A benefit of these is that they can be undertaken on site and be rapid and automatable. Although such methods are not yet validated or widely adopted.

2.2.3 STAKEHOLDER ENGAGEMENT

Stakeholders shared the monitoring and detection methods that are implemented in their organisations. These included a range of indirect methods such as manual, online and / or laboratory turbidity monitoring; particle counting; sampling for indicator organisms. Direct methods are also used including oocyst counts, and PCR and sequencing to speciate positive detections.

Stakeholders also flagged that there are many challenges associated with monitoring and detection of *Cryptosporidium*. These were mainly related to cost, the fact that monitoring is time-consuming and resource-heavy, their lack of capability to confirm if oocysts are viable; inconsistencies around monitoring frequency and locations between different organisations or sites; accuracy of monitoring; and that more modern technology is not being implemented. It was discussed that whilst there is much research ongoing in the field of monitoring and detection, there is yet a significant challenge to translate the research findings into easy-to-use reliable and accurate methods that can be used in practice.

The stakeholders wanted some clarification on what is considered to be a safe health level for *Cryptosporidium*. They noted that there is not a clear link between the number or concentration of oocysts and impact on public health, and no permitted concentration or value. Reporting limits on *Cryptosporidium* detections and how they may be related to health risk, for example microDALY was also identified as a challenge.

2.2.4 UPDATES TO RECOMMENDATIONS

Following the literature review and stakeholder engagement, recommendation updates for monitoring and detection are focused on improving guidance in this area. Specifically, guidance is needed on the following: testing frequencies including how these can be optimised and prioritised based on risk; standardisation of monitoring, e.g. a standard for what is considered “heavy rainfall”, any such standards need to be reviewed by industry experts; guidance should address the economic balance between treatment costs and detection, ensuring efficient use of resources across prevention, monitoring, and treatment; informing on what detection and monitoring options are available; and how monitoring results should be translated into actionable mitigation and control practices. Guidelines on health-based limits should be included and how to evaluate health risk associated with oocyst detection.

2.3 REGULATIONS

2.3.1 GROUP OF EXPERTS REPORTS

It was proposed in the third Report of the Group of Experts that there should be a treatment standard of less than one oocyst in ten litres based on continuously sampling 1,000 litres of treated water per day. The Water Supply (Water Quality) Regulations in 1999 set a treatment standard of an average of less than one oocyst in 10 litres of water supplied from a treatment works. This has since been deregulated (2007) and there is no treatment standard in the regulations. A water safety plan and risk assessment approach is now used.

2.3.2 LITERATURE REVIEW

Information on treatment standards was obtained as part of the literature review. The Water Services Association of Australia (WSAA) developed a ‘Manual for the application of Health-Based Targets for Drinking Water Safety’ (WSAA, 2015). In this, water sources are categorised based on their microbial risk. For each of the four categories, specific log-removal values (LRV) for protozoa (and bacteria and viruses) are provided. The LRVs are used as a benchmark for all water treatment systems in Australia and are now regulated as part of the Australian Drinking Water Guidelines (ADWG) which is used as a legislative framework to ensure accountability of drinking water suppliers in Australia. The USEPA introduced the Long Term 2 (LT2) Enhanced Surface Water Treatment Rule aimed to supplement existing regulations by targeting additional *Cryptosporidium* treatment requirements to higher risk systems. Under the LT2 rule, water sources are placed in one of four treatment categories based on the monitoring results and systems classified in higher bins must provide additional water treatment to further reduce *Cryptosporidium* levels (USEPA, 2006).

2.3.3 STAKEHOLDER ENGAGEMENT

The topic of whether a treatment standard should be in the regulations was discussed with stakeholders. The following suggestions were made:

- There should be a standard approach across companies.
- As there can be *Cryptosporidium* outbreaks with either high or low number of oocysts detected anything other than 0 cannot be a safe standard.
- The species of *Cryptosporidium* should be taken into consideration given not all species cause infection in humans. Although it is noted that the species detected can help inform the risk but needs to be interpreted with other information e.g. animals known to be in the catchment. The species detected may also not be the only species present.
- The group identified the need to define “safe” in the context of drinking water supply, as well as the importance of classifying the risk levels for which an action is required by the water companies. The stakeholder also noted that financial infeasibility and practical challenges are a concern in this context.
- Whether the standard should be limited to the boundaries of the treatment works, or also extended to the customer tap needs to be considered.

2.3.4 UPDATES TO RECOMMENDATIONS

Following the literature review and stakeholder engagement, it is understood that the lack of regulatory standard leads to an inconsistent approach to risk assessment and management between water companies. Therefore, a recommendation update is for there to be a standardised approach in terms of determining acceptable *Cryptosporidium* levels to be followed by water companies.

2.4 CATCHMENT MANAGEMENT

2.4.1 GROUP OF EXPERTS REPORTS

The Report of the Group of Experts highlighted scenarios and practices in the catchment that increase the risk to health as a result of *Cryptosporidium*. The Third Report of the Group of Experts described the risk assessment at the catchment level that should be in place. The risk assessment for water catchments and treatment works should cover anything that has the potential to result in *Cryptosporidium* entering raw water. This includes the type of water source, agricultural activity in the catchment, animals in the catchment, sewage contamination, water treatment factors and operational procedures for abstraction. In the Third Report of the Group of Experts, the catchment control recommendations mainly related to preventing, reducing and controlling contamination of manure and sewage effluent and sludge.

2.4.2 LITERATURE REVIEW

The two main risks of *Cryptosporidium* contamination in drinking water sources arise from agricultural activity and nearby wastewater effluent discharge. It was highlighted in the literature that there has been considerable movement towards the increasingly efficient and sustainable operation of both industries to minimise the impact on the environment, which also presents opportunities to reduce *Cryptosporidium* contamination.

In the agricultural sector, farm practices include the inactivation of oocysts through using heat when composting, storage of faecal waste on farms in slurry tanks, fencing livestock away from watercourses, using water troughs, and using vegetated buffer strips. It was also highlighted for water companies to regularly inspect water catchments and engage with livestock farmers regarding the application of such measures.

For wastewater treatment works (WWTW), studies have shown the presence of oocysts in effluent (Hemati, et al., 2022) and in a particular example, the regular, direct contamination of a reservoir and associated water supplying a Water Treatment Works (WTW) (Lamb, 2015). This demonstrates the need for effective catchment management by either improving oocyst removal at the WWTW or protecting the drinking water catchment from potential contamination.

For groundwater, in the UK, rural aquifers are more affected by contamination compared to part-rural and part-urban (although these are also affected). Contamination in chalk aquifers is the most prominent but this observation may be explained by their extensive exploitation as a water resource (Morris & Foster, 2000).

2.4.3 STAKEHOLDER ENGAGEMENT

In the responses to the stakeholder engagement survey, catchment management was raised as an issue by the stakeholders. The main challenges associated with catchment management are that there are catchment and external factors that are outside of the water company's control; agricultural practices; land use change; being able to identify catchment changes in a timely manner; and the changing climate and extreme weather events.

The challenges associated with catchment management were explored further in the stakeholder workshop. Keeping in mind that a water company cannot have full control of the catchment, improvements that could be made were discussed. The identification of land use change was identified as being important with regards to helping improve water quality at the source. This included early warnings of changes in land applications, clear agendas and regular updates on changes in the catchment. A further suggestion was that there should be a formal procedure in place for the notification of land use changes in the catchment.

2.4.4 UPDATES TO RECOMMENDATIONS

From the literature review and stakeholder engagement, land use change is a key concern in relation to its impact on water quality. A recommendation update is for the development and implementation by the most appropriate authority of a formal procedure to notify the water company of land use changes. A further key issue identified from the stakeholder engagement was the changing climate and how this will impact water quality. Changes in water quality due to climate change should be considered in risk assessments.

2.5 TREATMENT TECHNOLOGIES

2.5.1 GROUP OF EXPERTS REPORTS

The treatment technologies available for *Cryptosporidium* removal at the time of the Third Report of the Group of Experts were solid-liquid separation technologies including rapid filtration and slow sand filtration; and chemical coagulation. The Report states that conventional physical and chemical water treatment processes such as coagulation, sedimentation, dissolved air flotation (DAF), rapid gravity filtration and slow sand filtration were not designed specifically for *Cryptosporidium* oocyst removal. However, these treatments can offer an effective barrier, provided that the appropriate level of treatment for the raw water source is in place and is operating properly. Membrane filtration methods were an emerging opportunity at the time of the Third Report of the Group of Experts.

For disinfection, the Reports of the Group of Experts acknowledge that chlorine is not suitable for oocyst deactivation given the high concentrations required. The Reports also state that chlorine dioxide is more effective than chlorine, but there are practicality, cost and safety issues associated with the dose level that would be required. At the time of the Report of the Group of Experts, ozone and ultraviolet (UV) disinfection were known to be options for disinfection but their practical application was in early stages.

2.5.2 LITERATURE REVIEW

Since the Third Report of the Group of Experts, there have been significant advancements in *Cryptosporidium* removal and deactivation technology within the water industry. This includes the improvement of technologies described in the Reports of the Group of Experts and technologies considered emerging at the time of their publication are now established. The World Health Organisation stress the need for a wholistic multi-barrier approach for managing *Cryptosporidium* risk in drinking water supplies. This includes implementing risk mitigating strategies through the entire supply chain from catchment to tap.

Solid-liquid removal technologies for *Cryptosporidium* are coagulation / flocculation; sedimentation; Dissolved Air Flotation (DAF), Dissolved Air Flotation – Filtration (DAFF), depth filtration, slow sand filtration; surface filtration; cartridge filtration; micro filtration; ultra-filtration; nano-filtration; reverse osmosis; and adsorption filters (granular activated carbon).

Disinfection technologies are ozone and UV disinfection. Chlorine dioxide can disinfect but has large challenges associated with it, such as the health risks posed by high concentrations and that it must be produced on site, due to it being explosive under pressure. Chlorine can also disinfect but in line with the Reports of the Group of Experts, it is not recommended in the context for *Cryptosporidium* disinfection due to the high concentration/time (Ct) values required.

Emerging technologies for *Cryptosporidium* removal are ballasted clarification (i.e. Actiflo®, Rapisand® and Comag®); ceramic membranes; coagulation/flocculation using natural substances; upflow direct filtration; and nature-based solutions – subsurface flow and free surface flow wetlands. Emerging technologies for deactivation are nanomaterial enhanced filtration; and ultrasonication.

2.5.3 STAKEHOLDER ENGAGEMENT

The stakeholders informed that risk assessments, change of risk, and water monitoring and quality results influence the barriers and treatment strategies that will be used. There are often many factors that will be assessed to determine the best approach. The solid-liquid removal technologies used by the stakeholders are coagulation, clarification, cartridge filtration, rapid gravity filtration, slow-sand filtration and membrane technologies (microfiltration and ultrafiltration membranes (polymeric and ceramic)). For disinfection, UV irradiation and ozone are often used.

The stakeholders shared their challenges and lessons learnt associated with certain treatment technologies. Challenges regarding the treatment of *Cryptosporidium* included: deciding appropriate sludge treatment, treatment optimisation, and applying updated knowledge on *Cryptosporidium* to existing assets.

2.5.4 UPDATES TO RECOMMENDATIONS

Following the literature review and stakeholder engagement, a recommendation update for treatment regards improving operational guidance. Stakeholders identified areas where guidance could be improved. Such suggestions for recommendation updates are: for the development of a UK-based guidance for UV treatment and membrane technologies; guidance on when treatment is required; and guidance following an event. A further suggestion for a recommendation update is for a review to be undertaken of existing practices and industry rules and an explanation of the science behind them (the example flagged by the stakeholders is the 10% recycling of wash water rule). It is noted that the DWI does not stipulate a specific percentage for recycled water, but requires water companies to conduct comprehensive risk assessments (Regulation 27) and obtain approvals for new water sources (Regulation 15). These assessments ensure that any recycled water introduced into the supply does not compromise water quality.

2.6 NETWORK MANAGEMENT

2.6.1 GROUP OF EXPERTS REPORTS

The Group of Experts Reports discuss the risks of contamination in the network during occurrences when pipes are at a lower pressure and via service reservoirs (particularly if grazing is occurring on grass-covered service reservoirs). The First Report of the Group of Experts also identified that chlorine disinfection procedures are not at a quantity that would be effective against oocysts and there is a need to review disinfection and sampling procedures to be applied if contamination is suspected in the network.

2.6.2 LITERATURE REVIEW

In line with the information set out in the Group of Experts Reports, low pressure events, leakages, cross-connections and mains breaks can present a health risk. Similarly, the construction, maintenance and repair of distribution networks pose a significant risk of contamination if strict hygiene practices are not followed (WHO, 2009).

2.6.3 STAKEHOLDER ENGAGEMENT

The stakeholders were asked in the survey if there are any particular network configuration or arrangements that pose a high risk. The stakeholders noted that networks with air valves presented an increased risk and their location influenced risk.

2.6.4 UPDATES TO RECOMMENDATIONS

The First Report of the Group of Experts discussed the need for the review of the protocols for disinfection and sampling procedures to be applied if there is suspected contamination in the network. The stakeholders suggested that there should be recommendations associated with network integrity failures and how to manage incidents of contamination of potable supplies. As such a recommendation update is for there to be the establishment of guidance on the procedures to follow if there is a network integrity failure, suspected contamination in the network and how to manage incidents of contamination of potable supplies.

2.7 REFORMATION OF EXPERT GROUP

During the stakeholder engagement, several stakeholders commented that the expert group should be reestablished to review best practice. It is noted that one of the recommendations of the Third Report of the Group of Experts is that the group should reconvene at two yearly intervals to consider, in light of experience, whether additional advice should be issued and identify topics where further research is needed.

3 CONCLUSIONS

Following the literature review and stakeholder engagement, areas where recommendations and guidance need to be further reviewed and updated have been identified. These cover several topic areas. Whether there should be a reintroduction of a treatment standard is an area for further review. There should be a consistent approach to be implemented across water companies. For catchment management, an improved communication and early notification of land use change would be beneficial and whether a formal procedure for such communication should be implemented is something to consider. The use of technology such as satellite imagery may be able a useful tool to inform on changing land use. For network management, further guidance is needed on network integrity failures and for incidents of contamination of potable supplies. For *Cryptosporidium* species, given the large diversity of species and their potential infectivity for humans, understanding the species involved in an incident could help in the decision-making process for subsequent action and the risk to human health. For monitoring and detection, guidance on standardisation, frequency, and location is required. Additionally, guidance on options available that can help address the challenges associated with costs and resources of monitoring and detection is required. For treatment technologies, a UK-based guidance on UV treatment is required and a review on the rationale behind existing rules and practices. Finally, it would be of use to reestablish an expert group for the management of *Cryptosporidium* in water supplies and applying lessons learnt from *Cryptosporidium* events and outbreaks of cryptosporidiosis is highly valuable going forward and developing further guidance.

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Appendix A

GAP ANALYSIS

Topic	Reports of the Group of Experts summary	Literature / data / regulations summary	Stakeholder views	Gap summary
Cryptosporidium events	The third report reviewed 25 UK outbreaks that were associated with public drinking water supplies that occurred between 1988 and 1998. • The majority of outbreaks were associated with increases in turbidity, but not necessarily above the regulatory standard for turbidity. • The majority of the outbreaks of waterborne cryptosporidiosis occurred where the treatment integrity was compromised or the treatment provided was not adequate. • Most incidents were reported during the late autumn to early spring period. • Three out of the 25 incidents were reported to be 'probably' associated with groundwater.	Between 2005 and 2022, a total of 168 *Cryptosporidium*-related events were reported to the DWI. • For events overall, the most frequent causes were 'insufficient treatment for corresponding catchment risk', 'faulty assets' and 'poor procedures or staff training' responsible for 24 %, 22 % and, 20 % of events, respectively. Events caused by 'contamination or vermin breach was relatively low at 6 %. • For serious and major events, these typically occurred in highly populated areas. The frequency of causes of serious and major events was similar to the causes of events overall. A notable point is that contamination and vermin breach is not particularly common, but the likelihood of it resulting in a serious or major event is high. • Species and sub-types responsible for recent outbreaks in England include: ○ In May 2024, a cryptosporidiosis outbreak occurred in the Brixham area due to *C. parvum* with the gp60 subtypes IIaA15G1R1 and	The recommendations need to be updated to reflect learning from incidents and research that have occurred since their publication. The main recommendations from the reports are still mostly valid but need to be expanded on to reflect advancements and current good practice.	The event root-cause analysis has shown that treatment insufficiently corresponding to catchment risk, faulty assets and poor procedures are key factors in the cause of events. Recommendations related to these are set out in the Reports of the Group of Experts. Going forward, more specific and detailed recommendations could be made for these factors given role they have in causing events.

		IIaA20G1R1. Multiple-Locus Variable number tandem repeat Analysis (MLVA) profiles included the alleles 5/6/Ø-12/13/Ø-3/Ø-10/13–18/Ø-9/13-24/25. ○ In December 2013, Alderney WTW had consecutive *Cryptosporidium* detections and raw water deterioration due to *C. hominis* with gp60 subtype IbA10G2. ○ In June 2008, an outbreak at Pitsford was declared due to *C. cuniculus* with gp60 subtype VaA18. ○ In November 2005, an outbreak was declared at Cwellyn due to *C. hominis* with gp60 subtype IbA10G2.		
Regulations and guidelines	At the time of the third report, the Department of the Environment, Transport and the Regions (DETR), (department since replaced), issued a consultation document entitled 'Preventing *Cryptosporidium* getting into Public Drinking Water Supplies'. The document proposed amendments to the Water Supply (Water Quality) Regulations 1989 (England and Wales). This proposed a treatment standard of less than one oocyst in ten litres based on continuously sampling 1,000 litres of treated water per day. The third Report of the Group of Experts says that the infective dose for humans is not known with any confidence but is thought to be quite low. The report also notes	The Water Supply (Water Quality) (Regulations 1999) required water companies to conduct *Cryptosporidium* risk assessments for each of their water sources and set a treatment standard of an average of less than one oocyst in 10 litres of water supplied from a treatment works. This proposed treatment standard is not included in The Water Supply (Water Quality) Regulations 2016. It was deregulated as a defined level at which it was not a risk to health could not be established. Although *Cryptosporidium* is encompassed in Regulation 4 (that the water does not contain any micro-organism (other than a parameter listed in Schedule 1) or parasite at a concentration or value which would constitute a potential danger to human health).	The stakeholders' views on a treatment standard for *Cryptosporidium* were that if a standard is to be brought back, research needs to be undertaken before the standard is decided. A challenge was noted that anything other than 0 cannot be a safe standard. The species of *Cryptosporidium* should also be considered. It was agreed among stakeholders that it would be good to have a standard approach across companies.	This represents a gap between the content of the third Report of the Group of Experts and the current regulation. The report discusses a treatment standard based on the infective concentration and the current regulation was amended as a level at which *Cryptosporidium* is not a risk to health could not be confirmed.

	that an infective concentration is at least an order of magnitude greater than one oocyst in ten litres.	The *Cryptosporidium*-specific risk assessment is also not included in The Water Supply (Water Quality) Regulations 2016 as it was in The Water Supply (Water Quality) (Amendment) Regulations 1999. Although a *Cryptosporidium*-specific risk assessment is not included, risk assessments to establish whether there is a significant risk of supplying water that could constitute a potential danger to human health or is likely to be unwholesome are a regulatory requirement (Regulation 27 and 28 of the Water Supply (Water Quality) Regulations 2016. In 2006, the USEPA introduced the Long Term 2 (LT2) Enhanced Surface Water Treatment Rule aimed to supplement existing regulations by targeting additional *Cryptosporidium* treatment requirements to higher risk systems. This meant that monitoring of all water sources was required for an initial 2 year-period to determine the specific treatment requirements. Water sources are placed in one of four treatment categories based on the monitoring results. The Water Services Association of Australia (WSAA) developed a 'Manual for the application of Health-Based Targets for Drinking Water Safety'. In 2022, large portions of the manual were integrated indirectly into the Australian Drinking Water Guidelines (ADWG) which is used as a legislative framework to ensure accountability of drinking water suppliers in Australia. The Health-Based Targets attempt to split all water sources		

		into four categories based on microbial risk.		
Catchment management	The first report notes that whilst small numbers of oocysts may occur occasionally in all environmental waters, the risk to health is when an unusually high amount of oocysts occur in the water source. • There is an increased risk of oocyst contamination following agricultural pollution of source water as well as following a period of heavy rain after a dry spell especially if slurry has recently been spread on agricultural land. Peaks have been noted in spring and autumn. • The second report notes that the best way to prevent the contamination of water supplies is through the through the relevant codes of practice (e.g. the Code of Good Agricultural Practice for the Protection of Water). Monitoring programmes undertaken by water companies are described in the second report. The monitoring strategy is based on assessment of risk, which takes into account catchment quality and control and usually includes raw water quality monitoring. Risk assessment at the catchment level should include anything that has the potential to allow *Cryptosporidium* into raw water.	The two main risks of *Cryptosporidium* contamination in drinking water sources arise from agricultural activity and nearby wastewater effluent discharge. Benefits to livestock health and welfare can be seen following the implementation of measures to control cryptosporidiosis in livestock. On farm practices to reduce the viability of *Cryptosporidium* oocysts include: • The proper composting of manure as heat (>60°C) will inactivate the oocysts; • Storage of faecal waste on farms in slurry tanks, as ammonia and low pH will help to inactivate oocysts; • Fencing of livestock away from streams and watercourses; • Provision of water troughs; and • Use of vegetated and riparian buffer strips, which can help to slow down the transfer of *Cryptosporidium* oocysts from livestock faecal matter into watercourses. For groundwater sources, in the UK, chalk aquifers are at the greatest risk of contamination compared to other aquifer types. Adit wells, collectors, springs and former mines with adits are particularly vulnerable.	The key views of stakeholders regarding catchment management related to receiving communication and warnings about land-use change.	Since the third report, there is now a better understanding regarding groundwater contamination risk. An extensive review of *Cryptosporidium* risk in UK aquifers and type of supply shows that chalk aquifers are the most prominent, but also present the greatest risk. Both rural and part-rural and part-urban catchments are affected, but rural are more affected. Adit wells, collectors, springs and former mines with adits are particularly vulnerable. Springs draining fracture-flow systems were the most common at-risk design type. A gap exists regarding communication. Stakeholders expressed that there should be a formal procedure for informing on land use change and improved collaboration for identifying pollution sources.

	Vulnerability to groundwater contamination is described in the third report. Water companies should be vigilant for the sudden influx of surface water into boreholes, wells and springs. Risk assessments should be undertaken for groundwater contamination which should include (but is not limited to): • Assessment of source, catchment and hydrogeological factors; and • The use of national groundwater vulnerability maps and source protection zoning schemes to identify extreme vulnerability.			
Network management	The first report discusses the potential contamination of *Cryptosporidium* in the distribution pipe network. Although normal management of the distribution should not present a hazard of *Cryptosporidium* oocysts. At times of low pressure, the danger of oocyst contamination must be recognised. The potential contamination of service reservoirs through rooves and air vents is described in the first report. The use of grazing by livestock on grass covered reservoirs can increase the likelihood of contamination. Leakage in of oocysts poses a particular risk to the population served by a treated water reservoir. The second report notes that the recommendation of ensuring livestock grazing does not occur on grass-covered service	Low pressure events, leakage, cross-connections and mains breaks are indicators of the presence of a health risk, even in the presence of a disinfectant residual. There are many barriers in the distribution network that prevent *Cryptosporidium* contamination. These include the integrity of the system, the water pressure and backflow prevention in the connections of the network to the domestic plumbing installations. The construction, maintenance and repair of distribution networks pose a significant risk of contamination if strict hygiene practices are not followed.	The stakeholders noted that networks with air valves present an increased risk. The location of air valves was also noted to influence risk. Air valves in rural areas were noted to be a particular risk.	Both the Reports of the Group of Experts and the literature recognise the factors leading to risk of contamination of the distribution network. The Reports of the Group of Experts note that disinfection protocols for such events need to be established. Following the Franklaw *Cryptosporidium* event in 2015, the water company installed UV treatment in the Service Reservoir outlets. The stakeholders expressed that they would like to see guidance on network integrity failures and how to manage incidents of contamination of potable supplies.

	reservoirs is not fully complied with in national parks, areas of natural beauty and common land. It also notes an issue that there is a potential for contamination of service reservoirs through air intakes as a result of grass cutting generating aerosols which contain faecal matter. The first report highlights that the disinfection protocols for contamination in the network needs to be revised as the chlorine protocols are at a concentration far lower than what is required to kill oocysts. The first report advises on the actions to undertake in the event of an outbreak. This includes remedial actions to remove *Cryptosporidium* oocysts in the network. Specific actions to consider include: • Contact tanks: inspect, clean out, ensure removal of all sludges. • Service reservoirs: repair roofs (e.g. by fitment of butyl rubber sheets) if rain water can seep in. • Distribution systems: introduce programme of flushing and / or scouring to remove suspect water and any contaminated mains deposits from system. The report notes that there is a need for the revision of the disinfection protocol as disinfection			

	procedures of 20 mg/l chlorine represent no safeguard if oocyst contamination is suspected.			
Cryptosporidium species	*Cryptosporidium parvum* was the only species known to infect humans. There was limited understanding of the species and sub-type diversity.	There are 48 recognised species and over 120 genotypes of *Cryptosporidium*. 23 species have been reported in humans. *Cryptosporidium hominis* and *Cryptosporidium parvum* and are responsible for the vast majority of cases of cryptosporidiosis in Europe, with particular sub-types being responsible for more infections. The main transmission risk factors for *Cryptosporidium hominis* infection are linked to contact with young children, people with diarrhoea or contamination of water by human faeces or wastewater. The main transmission risk factors for *Cryptosporidium parvum* are linked to contact with farm animals or consumption of water or food contaminated by their faeces. Molecular tools are used to understand both inter and intra-species diversity.	The stakeholders expressed that it may be useful to take into consideration the relationship between species and risk. I.e. if a species is detected, but it is not a species that is known to infect humans, should a different approach be taken when determining risk, compared to if a species known to infect humans has been detected.	Since the Report of the Group of Experts, the understanding of *Cryptosporidium* species and sub-type diversity has vastly increased. This increase in understanding is mainly due to advances in molecular research and tools allowing for improved inter and intra-species identification. There are two species (*Cryptosporidium hominis* and *Cryptosporidium parvum*) and sub-types within these species that are responsible for the most infections in humans. There are differences in the main transmission risk factors between the two species, but both can get into water supplies and cause waterborne outbreaks.
Detection and monitoring	The reports reinforce the importance of monitoring the passage of particles using turbidity or particle count monitoring. The third report advises that for high-risk sites, there should be continuous turbidity measurement on the outlet of each filter and on the final water using instruments capable of detecting changes of less than 0.1 NTU. Particle count monitors are encouraged to provide additional information to that provided by turbidity measurements. The first report advises that oocyst monitoring should be performed following significant agricultural contamination, during transitional	Numerous monitoring and detection methods are available: • Turbidity monitoring can be done using nephelometric sensors which can be handheld or can be used as online monitoring. Tube testing and secchi disks are other options for turbidity monitoring. • Particle monitoring can be done using particle counters or flow cytometry. Particle counters can be automated, are rapid and easy to use and can be multiplexed. Flow cytometry is fully automated and	Stakeholders expressed challenges associated with monitoring. Mainly that it is time-consuming, costly and often inefficient. There are inconsistencies across water companies. Stakeholders would like to see further guidance on monitoring, e.g. around standardisation of monitoring, frequency of monitoring, and location of monitoring.	Since the third Report of the Group of Experts, technological advances have increased the availability and suitability of monitoring and detection methods. The types of methods can be categorised into three main tiers: • Tier 1: Online monitoring of surrogate. • Tier 2: On-site analysis of sampled washwater. • Tier 3: Off-site expert lab analysis of washwater samples. The two prevalent Tier 1 methods are turbidity monitoring and particle monitoring. Continuous turbidity monitors are now commonplace at all water

	periods in the treatment processes, if treatment is operating abnormally, if turbidity readings or indicator organism levels deviate from normal ranges and / or if an outbreak of cryptosporidiosis in the community is suspected as being linked to a water supply. The second report notes that each treatment plant should develop its own appropriate monitoring strategy for *Cryptosporidium* oocysts. This should be related to catchment risks and the nature of the treatment provided at the individual site. The third report advises for high-risk sites, continuous sampling for *Cryptosporidium* with analysis times linked to turbidity monitoring results; or sampling triggered by turbidity events. For *Cryptosporidium* recovery, membrane filtration, cartridge filtration and chemical flocculation are methods described in the third report. For identification, microscopy, flow cytometry and the use of antibodies are described. The third report recognises the need for a standard protocol for all water types for *Cryptosporidium* detection.	diversity indices give an indication of microbial community changes. • Oocyst monitoring using the USEPA 1623 or 'blue-book' method is extensively used in the water industry. • Molecular detection methods include the use of qPCR, ddPCR and LAMP for amplification and Restriction Fragment Length Polymorphism (RFLP) and high-throughput next generation sequencing (with high throughput sequencing generally replacing RFLP). • New trends include the use of miniaturised detection methods. These can be rapid and automatable. Various options are optical detection techniques, mass-based detection techniques, surface plasmon resonance, molecular diagnostics and existing total analysis systems, and electrical methods.		treatment sites regardless of perceived risk. Particle count methods have been further explored since the third Report of the Group of Experts and comprise particle counters and flow cytometry. Since the third Report of the Group of Experts, refinement and advances in the Tier 3 type methods can be seen. Oocyst monitoring using the USEPA 1623 or 'blue-book' method has been revised into a standard methodology. Advances in molecular techniques provide options for detecting *Cryptosporidium* at very low levels and, depending on the test setup, can inform on the species present. Species determination is currently a post-hoc test provided by slide genotyping. Miniaturised systems are emerging techniques that may offer a solution to the time-consuming efforts required when using other methods.
Treatment processes and technologies	The third report states that conventional physical and chemical water treatment processes such as coagulation, sedimentation, dissolved air flotation (DAF), rapid gravity filtration and slow sand filtration were not designed specifically for *Cryptosporidium* oocyst removal. However, these treatments can provide an effective barrier provided that the appropriate level	Established solid-liquid *Cryptosporidium* removal technologies are: • Coagulation / flocculation; • Sedimentation; • Dissolved Air Flotation (DAF); • Dissolved Air Flotation – Filtration (DAFF);	The stakeholders expressed that they would like to see UK guidance on the use of UV treatment. They would also like to see a review of existing practices and rules to be undertaken.	Regarding solid-liquid *Cryptosporidium* removal technologies: • Coagulation / flocculation is discussed in the third report of the Group of Experts. Coagulants have traditionally been iron or aluminium-based. More recently, natural coagulants have been explored as an alternative.

	of treatment for the raw water source is in place and is operating properly. If the treatment is compromised or inadequate, a significant quantity of oocysts can pass into the treated water supply. Bypassing of treatment can also lead to waterborne outbreaks. The report notes that the use of membrane technologies can further improve oocyst removal.	• Depth filtration; • Slow sand filtration; • Surface filtration; • Cartridge filtration; • Micro-filtration; • Ultra-filtration; • Nano-filtration; • Reverse Osmosis; and • Adsorption Filters (Granular Activated Carbon). Established disinfection technologies are: • Chlorination (although not recommended in the context of *Cryptosporidium* removal); • Monochlorination (although not recommended in the context of *Cryptosporidium* removal); • Chlorine dioxide; • Ozonation; and • Ultraviolet. Emerging *Cryptosporidium* removal / deactivation technologies are: • Ballasted Clarification (i.e. Actiflo®, Rapisand® and Comag®); • Ceramic membranes; • Coagulation / flocculation using natural substances;		• Sedimentation is discussed in the third report of the Group of Experts. Sedimentation configurations remain largely unchanged since this last report. A change that is noted is the more frequent use of lamella plates into existing sedimentation tanks to improve the solid-liquid separation of washwater streams. • At the time of the first Report of the Group of Experts, depth filtration was established for *Cryptosporidium* oocyst removal. Since the reports of the Group of Experts, there have been innovations in media types for depth filtration including recycled glass media (AFM®) and Filtralite®. • There have been no key innovations regarding slow-sand filters since the third Report of the Group of Experts. • The use of surface filters was not included in the Reports of the Group of Experts. • Membrane filtrations such as micro-filtration, ultra-filtration, nano-filtration and reverse-osmosis were considered 'novel' at the time of the third Report of the Group of Experts. These technologies are now established and effective in their removal of *Cryptosporidium*. Membrane materials are commonly made of polymers. Alternative membrane materials are also being utilised such as ceramic and stainless steel membranes.

		• Upflow direct filtration; • Nature based solutions: subsurface flow (SSF) and free surface flow (FSF) wetlands; • Nanomaterial enhanced filtration; and • Ultrasonication.		• For activated carbon adsorption, no significant advancements have been reported since the third Report of the Group of Experts. Regarding disinfection technologies: • The Reports of the Group of Experts note that standard chlorine disinfection practices are not suitable for *Cryptosporidium* removal due to the high concentrations required. Since these reports, chlorine is still not recommended for *Cryptosporidium* removal. • In the second Report of the Group of Experts, chlorine dioxide is identified as being more effective than chlorine, however safety issues regarding the concentrations required were noted. Since the Reports of the Group of experts, chlorine dioxide is an option for *Cryptosporidium* disinfection, but there are key operational aspects that need to be considered for its use. Chlorine dioxide in high concentrations can present acute health risks, therefore dosing control and monitoring are critical. Chlorine dioxide gas cannot be compressed or stored commercially because it is explosive under pressure. Therefore, chlorine dioxide gas is never shipped, but generated on-site. • The use of ozone was identified as a possible disinfection option in the Reports of the Group of Experts. Since the reports, ozone dosing technology has become cheaper and

				more efficient. Water quality parameters such as pH, suspended solids and bromide must be monitored for effective operation. It is slightly less effective compared to UV disinfection (discussed below). • The use of Ultraviolet (UV) disinfection was identified as a possible option in the Reports of the Group of Experts. In the third Report of the Group of Experts, they were considered to only be applicable to small-scale water supply systems. Since the reports, UV disinfection has been a popular solution to increase *Cryptosporidium* disinfection capability and reliability in recent years. Advancements in the technology have allowed it to be utilised in large scale applications, for example, it was used in the Franklaw event.

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