MANAGING RISK IN WATER REUSE: POLICY ANALYSIS

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Abstract
Water scarcity is an increasingly prevalent problem, with changing hydrological regimes due to climate change and human development taxing freshwater systems. One way to tackle this issue is through planned water reuse. This thesis explores the context of the agricultural application of treated wastewater in the European Union where Directive 2020/741 Minimum Requirements for Water Reuse was recently adopted. A document analysis was conducted of the EU Member States with the highest rates of water reuse who also had national level legislation governing water reuse for agriculture (Cyprus, France, Italy, Spain, Portugal), the EU's Regulation 2020/741 and international norm-setters in the water reuse space (California and Australia). It was found that the principles of risk assessment and risk evaluation are not consistently and thoroughly included in the policies analyzed. The policies reviewed use a combination of three risk evaluation factors: crop categories, water classifications, and irrigation method for operationalizing risk management strategies. All policies take risk reduction actions, however there is not consistency in what these are. These risk reduction actions appear to be designed with human health first and foremost in mind, potentially neglecting environmental health concerns. The uncertainties and complexity of water reuse are minimally alluded to in water reuse policies, but present significant challenges to managing risk.

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Summary

Water scarcity is an increasingly prevalent problem, with changing hydrological regimes due to climate change and human development taxing freshwater systems. One way to address this is through planned water reuse, which presents a more sustainable water management strategy – optimizing resource use and implementing circular economy principles (Maiolo & Pantusa, 2018; Smol et al., 2020). A document analysis of the water reuse policies of six Member States of the European Union (Cyprus, France, Greece, Italy, Portugal, and Spain), the recent EU Directive 2020/741, the American state of California, and Australia's water reuse risk management framework was conducted to understand the water reuse policy context. The *ISO 31000:2018 Risk Management – Guidelines* and the risk assessment framework laid out in Tehler (2020) were used to inform the analytical framework used in this thesis to analyze to what extent risk management is incorporated in the aforementioned policies.

It was found that risk management is only partially incorporated into the water reuse policies analyzed. Though policies incorporate risk management steps, they vary in the thoroughness of these. It is speculated that some of these steps may be covered in ancillary policies not analyzed as part of this thesis, thus the enabling environment for water reuse is complicated. As exemplified by the risk assessment guidance provided by the EU, there are a number of supporting policies for managing risks in water reuse. Though policies incorporate aspects of a risk management framework, because many of the policies are not framed as such, they are still incomplete and inconsistent.

Policies take different tactics with the level of detail in specifying jurisdiction and mandates. This is possibly due to the policy environment and that different levels of government were analyzed – sub-national, national, and supranational. Member States working at the national level provide more detailed language on setting roles, but all policies face the challenge of trying to manage risk throughout the entirety of the treated wastewater's life cycle. The knowledge and jurisdiction needed to carry out this task extends beyond the control of water treatment operators, who are the primary targets of compliance. It was found that policies rely heavily on end-user compliance for enacting risk-reducing actions.

Policies for water reuse in agriculture rely on three main factors to simplify risk evaluation – crop categories, water classifications, and irrigation methods. Most policies utilize a combination of these factors for governing the water quality of treated wastewater used in irrigation. It appears that this system is designed to mainly mitigate human health risks, with less weight given to the health of terrestrial environments. This is seen in how crop categories and water classes are centered around the human consumption of crops and the exposure pathways presented by agricultural products e.g., crops eaten raw, crops for industrial processing, dairy products, etc., as well as the dearth of monitoring parameters related to soil health, i.e., sodicity, salinity, and sodium absorption rate. Some policies state an overarching purpose that water reuse is addressing, providing insight into the values that undergird the creation of the policy. However, the values used for assessing and evaluating risks are usually not clearly stated in the policies, with the exception of Australia's disability adjusted life year tolerable risk level. Risk assessments and risk evaluations would benefit from more open inclusion of values.

Nearly all policies use treatment and non-treatment risk-reduction measures; however, the quantitative values of these treatment outcomes did not show consistent trends. The Greek and Portuguese policies are the only Member States whose quantitative treatment values meet

the EU’s minimum requirements. The lack of consistency and clear norms highlights a major challenge, i.e., the complex nature of water reuse and the uncertainties in characterizing and assessing risk make it difficult to know what risk sources to monitor. This potentially introduces undue harm to humans and the natural environment and threatens the stability of the internal market for agricultural goods within the EU.

Abbreviations

BOD – Biochemical Oxygen Demand

CECs – Contaminants of Emerging Concern

COD – Chemical Oxygen Demand

DALY – Disability Adjusted Life Years

EC – Electrical Conductivity

EEC – European Economic Community

EU – European Union

FAO – Food and Agriculture Organization

HACCP – Hazard and Critical Control Points

IPCC – Intergovernmental Panel on Climate Change

ISO – International Organization for Standardization

NTU – Turbidity

p.e. – People Equivalents

PCR – Polymerase Chain Reaction

RNA – Ribonucleic Acid

SAR – Sodium Absorption Rate

TSS – Total Suspended Solids

UN – United Nations

UWWTD – Urban Wastewater Treatment Directive

VOC – Volatile Organic Compounds

WHO – World Health Organization

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1. Introduction

The drivers and outcomes of climate change challenge the notion of humans as masters of linear natural processes. The growing application of systems thinking is apparent in the conceptualization of "nexuses" such as the energy-food-water nexus promulgated by the Food and Agriculture Organization (FAO) (Chojnacka et al., 2020). Making connections to bridge traditional silos will be important for adapting to a changing climate. The agriculture, livestock, and energy sectors consume 80% of the water that humans use, and as living standards rise and populations increase, this places more pressure on water resources through increased water demand (Fawell et al., 2016). This threshold will be especially challenging to meet through current practices as the Intergovernmental Panel on Climate Change (IPCC) predicts severe modification of the availability and quality of freshwater (Fawell et al., 2016). With some estimates placing increased global food demand as high as 70% by 2050, demand for fresh water to meet this need will also increase (Sunyer-Caldú & Diaz-Cruz, 2021). While emphasis is often, and rightly, given to the vulnerabilities of low-income and/or least developed countries, citizens in middle- and high-income countries will not be immune to the impacts either. Indeed, southern Europe is expected to be among the most affected areas in the world from the changing distribution and availability of freshwater (Fawell et al., 2016).

In some places within Europe, agricultural demand for water is already not being met. Maiolo and Pantusa (2018) estimated that farmers in southern Italy around Camigliatello Silano mountain were facing a 31% water deficit, forcing them to draw water from the nearby lake, exacerbating low environmental flows there. On a larger scale, "over the past 30 years, drought has caused losses of over 100 billion euros in [the European Union] and has covered almost 40% of Europe's area" (Chojnacka et al., 2020). Societies in arid regions have long coped with droughts and water stress; however, the severity, uncertainty, and variability brought on by climate change is pushing countries to search for new solutions.

Currently less than 0.5% of the European Union's (EU) annual freshwater withdrawals are met through reused urban wastewater (European Commission, n.d.). Agriculture is the main sector in which Member States of the EU are already implementing water reuse and have policies developed (Umwelt Bundesamt, 2021). Until recently, water reuse at the Union level was only briefly mentioned in passing under the Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater 'Urban Waste Water Treatment Directive' (UWWTD), which stated that treated urban wastewater could be used "whenever appropriate" (91/271/EEC Article 12(1)). However, further guidance on the definition of 'appropriateness' was left to Member States to decide. In practice, this led to Mediterranean countries with lower water availability enacting enabling legislation and more widely adopting the practice than their northern counterparts with higher water availability. Italy was the first country in Europe to have water reuse standards in 1977 for planned water reuse (Paranychianakis et al., 2015). Even though the practice is allowed and the first policy by a Member State was enacted nearly 25 years ago, the potential of wastewater as a resource is relatively underutilized. Estimates place the potential for water reuse in the EU at 6 times the present volume – from 1 billion cubic meters to 6 billion cubic meters of water annually (European Commission, n.d.). Though treated urban wastewater will not supplant the EU's need for freshwater withdrawal, it would relieve some pressure of agriculture and domestic users competing for freshwater resources. In 2018, the EU put forward the Proposal for a Regulation of the European Parliament and of the Council on Minimum Requirements for Water Reuse (COM [2018]337) for regulating wastewater reuse for agriculture irrigation to encourage further uptake of the practice, which entered into force in June 2020 as Regulation 2020/741 of the European Parliament and of the Council of 25 May 2020 on Minimum Requirements for Water Reuse. Yet there are significant social, economic, and environmental risks involved in water reuse including acute and chronic illness, pollution and quality degradation, distrust of authorities, and bans on agricultural products resulting in significant economic loss.[1]

Recognizing the growing need to shift the paradigm around water resources without jeopardizing environmental or human health, the EU enacted a risk-based approach to water reuse. In creating an EU-wide doctrine, there were multiple sources from which the EU could draw inspiration, however it was unclear to what degree these existing policies were informed by a risk-based approach, or if the EU waded into uncharted waters by enacting a policy based on a risk management framework. The extent to which a risk-based approach to water reuse was undertaken in Member States' policy was not extensively covered in the literature, nor was it discussed outside the context of water treatment how significantly the EUs policy could potentially alter the practices of Member States already engaged in water reuse for agriculture (Kirhensteine et al., 2016).This paper compares Regulation 2020/741 with the six Member States (Cyprus, France, Greece, Italy, Portugal, and Spain) who had national level water reuse policies prior to 2018 when the Proposal was put forward. Additionally, these are compared to the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risk* and Title 22 of the State of California's Code of Regulations, Division 4, Chapter 3 (NRMMC–EPHC–AHMC, 2006; 22 CCR 60304); as policies created by two of the major norm-setters in the space of water reuse (Kirhensteine et al., 2016; Alcalde-Sanz & Gawlik 2017).

Climate change, economic development, and population growth are adding pressure on freshwater resources. Therefore, society needs to move towards a more integrated and holistic approach to managing water resources. This will require directing technological, social, and regulatory changes in tandem. Policy level decisions will impact how feasible and effective uptake of water reuse will be moving forward, both in the EU and beyond. Risk management strategies are a facet of this enabling environment. Comparing risk management strategies may provide cross-context learning opportunities, as well as insight into the conceptualization and concerns of risk stemming from water reuse in agriculture. The EU is not the only region of the world where water scarcity is a concern; however, the decisions taken by the EU and its Member States could influence the technology, research, and knowledge available to other regions and countries who may be less well resourced.

[1] Multi-country bans on importing Spanish cucumbers in 2011 because of fears of *E. coli* contamination cost Spain 200 million euro per week, contributing to a 11.3% decrease in agricultural income for the Murcia region for the 2010-2011 growing season (COM 2018[337]).

1.1 Purpose

The purpose of this thesis is to understand the risk management policy context of the agricultural application of treated wastewater in the EU by looking at the extent to which aspects of risk management are operationalized in water reuse policies.

2. Theoretical Framework

This thesis builds upon the following concepts which help to position this inquiry in the fields of water treatment and risk management.

2.1 Concepts

2.1.1 Wastewater

In the context of this thesis, wastewater refers to water that has been collected in systems that are treated by urban water treatment plants and reclamation facilities. Therefore, it includes precipitation runoff, domestic and commercial water, and potentially treated industrial effluent, if these sources are collected in urban treatment and reclamation facilities.

2.1.1 Water Reuse

Unplanned or indirect (de facto) water reuse occurs when downstream communities draw water from rivers which have received treated wastewater discharges upstream. While unplanned water reuse is common throughout the world, planned water reuse receives much more scrutiny and is not as widely practiced (Dingemans et al., 2020). Water reuse is sometimes also referred to as water recycling, water reclamation, or fertigation. This paper will use "water reuse" to denote the act or acts of treating wastewater for additional uses before it is released back into the environment. Since Regulation 2020/741 is restricted to agricultural applications, this paper limits its scope to treated wastewater used for agricultural purposes and does not include aquifer recharge, industrial reuse practices, greywater, fecal sludge management, etc.

2.1.2 Water Treatment

There are four levels of treatment in wastewater processes: preliminary, primary, secondary, and tertiary (Chojnacka et al., 2020). The treatment chains, or types of processes employed for each step can vary; however, their overall effect on the quality of water is what qualifies them as a certain treatment level. Preliminary treatment results in the removal of large foreign objects such as sticks or litter that have entered the sewage system. Primary treatment removes most suspended solids, while secondary treatment removes the majority of organic pollutants (expressed by Chemical Oxygen Demand [COD] or Biochemical Oxygen Demand [BOD]) (Chojnacka et al., 2020). Secondary treatment may include biofiltration, aeration, or oxidation ponds (Bloganica, 2017). Tertiary treatment removes biogenic compounds, specifically nitrogen and phosphorus (Chojnacka et al., 2020). Disinfection processes are used to kill any remaining parasites, bacteria, or viruses (CDC, 2022). Chemical disinfectants, ultraviolet light, or ozone may be used for completing this process.

2.1.3 Hazard and Risk

Hazard is an event or action that could cause harm. The definition provided within Regulation 2020/741 is “a biological, chemical, physical or radiological agent that has the potential to cause harm to people, animals, crops or plants, other terrestrial biota, aquatic biota, soils or the general environment” (Article 3 p. 20). Tehler (2020) refers to hazards as risk sources. Risk encompasses the degree of exposure to a hazard and sensitivity to the hazard. An acceptable risk level is defined as a “level of risk judged to be outweighed by corresponding benefits or one that is of such a degree that it is considered to pose minimal potential for adverse effects” (GEMET, n.d.).

2.1.4 Precautionary Principle

The precautionary principle is enshrined in Article 191 of the Treaty of the Functioning of the European Union as one of the principles underpinning EU environmental policy (Bourguignon, 2015, p. 5). Though there is no universal definition, the main interpretation of the principle is that the absence of absolute scientific certainty should not preclude taking action to reduce or mitigate harm, this is “to avoid causing adverse impacts in situations of scientific uncertainty” (Bourguignon, 2015, p. 6).

2.2 Analytical Framework

The *ISO 31000:2018 Risk Management – Guidelines* provide an overarching framework for entities to manage risk across any sector. ISO 31000:2018 is a global 3rd-party standard that informs best practice across organizations, sectors, and risks; risk management is described as an iterative process starting from the leadership and commitment for integrating, designing, and implementing risk management into the organization to evaluating and improving the process. The ISO standards encompass a number of aspects that are relevant to the overall process of risk management; however, they also could be seen as including behavioral components outside the bounds of a document analysis. To fully conduct an analysis based on the entire ISO 31000:2018 framework would require a different methodology than the one undertaken in this thesis, such as including interviews. Furthermore, because the guidelines aim to be applicable to a variety of contexts, the framework is kept very general. To narrow down the analysis of this thesis, behavioral and organizational aspects of risk management were omitted. This thesis was informed by the following sections of ISO 31000:2018:

- 6.3 Scope, Context, Criteria;
- 6.4 Risk Assessment;
- 6.5 Risk Treatment; and
- 6.6. Risk Monitoring.

The risk assessment framework laid out in Tehler (2020) provided additional guidance to the data collection and analysis process, as it reinforced aspects of the ISO 31000:2018 sections mentioned above and provided additional explanation. The six steps of the framework from Tehler (2020) include:

- Identifying values and goals;
- System description;
- Events and scenarios;

- Uncertainty and consequences;
- Risk presentation; and
- Risk evaluation.

These were used to narrow the scope of analysis and inform the coding processes as compared to the general broad language of ISO 31000:2018. Risk presentation was omitted from the analysis as it was expected to be a level of detail unlikely to be covered at the policy level. Tehler (2020) also includes different views and definitions of risk as well as major concepts in the discussion of risk theory. The Tehler (2020) framework on its own, however, is too focused on sections 6.3 and 6.4 from ISO 31000:2018 and does not include other core aspects of risk management such as risk treatment and monitoring. This thesis therefore was informed by both frameworks but did not use either one in its entirety. These frameworks were chosen as they are independent of any sector and entity in this research.

3. Methods

Document analysis is an analytical procedure of appraising and synthesizing data (Bowen, 2009, p. 28). This thesis engaged in a content analysis which is the "process of organizing information into categories related to the central questions of the research" (Bowen, 2009, p. 32), in this case, to what extent is risk management operationalized in water reuse policies? Information was organized into major themes based on a manual open and iterative coding process, such that documents previously analyzed were re-analyzed to determine the presence of new categories as these arose in the data, thereby filling "underdeveloped categories and [narrowing] excess ones" (Bowen, 2009, p. 37). The analytical framework (see Section 2.2 above) was used as a coding guide such that *system description*, *hazard identification, risk assessments*, *risk evaluation*, etc. were used as initial pre-figured coding categories (Creswell, 2013). From there, informed emergent codes were created to flush out the types of risk management tasks, e.g., public health or environmental risk assessments, cost benefit analysis, emergency management, etc. Some categories, such as *system description* and *risk evaluation*, needed multiple words or sentences to describe a process. While for the categories of *hazard and risk identification*, the words "hazard" or "source," and "risk" (or their translated equivalent) were required to be used in the language of the policy to be coded for this category. This was done to minimize the researcher ascribing distinctions or false understandings to these two key concepts, though the process of coding policies is inherently subjective.

Quantitative content analysis was also undertaken for the presence or absence of quality parameters. These were used to probe deeper into the hazards and the risks that water reuse poses which may be assumed or unstated by the policies but reflected in the choice for monitoring hazards. As documents are context specific, the original purpose(s) of the documents were considered in the analysis as reflecting the values underpinning the need for policy (Bowen, 2009).

The documents chosen represent the EU Member States with the highest rates of water reuse who also had national level legislation governing water reuse for agriculture, the EU's Minimum Requirements for Water Reuse (Regulation 2020/741) and international norm-setters in the water reuse space. Relevant international guidelines and standards were chosen based on their incidence in the literature. This initially yielded:

- The Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (NRMMC–EPHC–AHMC, 2006);
- The California Code of Regulations;
- The International Standards Organization (ISO) 16075-2015: *Guidelines for treated wastewater use for irrigation projects;* and
- The World Health Organization (WHO) *Guidelines for the Safe Use of Wastewater, Excreta and Greywater* (2006).

Alcalde-Sanz & Gawlik (2017) discusses ISO 16075-2015 as a main pillar of evidence; however, these standards have since been withdrawn and replaced with ISO 16075-2020. The ISO standards were not included in this thesis as they are not intended for certification purposes and are aimed at the users of treated wastewater. During the process of drafting COM(2018)337, the EU sought WHO input as well as the standard practice of public comment from Member States. Since the EU solicited input from the WHO in drafting COM(2018)337, the WHO (2006) was not reviewed as this may double count the WHO's influence.

Alcalde-Sanz and Gawlik (2017) and other EU commissioned documents (Rebelo et al., 2018; Wicke, Vosse, & Miehe, 2019) were used to guide the process of cross-checking the selection of EU Member States. Though these documents were not included in the analysis, they were used to confirm the names or registry numbers of relevant national documents. FOALEX (FAO legislative and policy database), Ecolex (UN supported repository of environmental law), EUR-Lex (official website of EU law) and national level registries (France and Greece) were used to obtain primary documents. Although Malta has high rates of water reuse for agriculture irrigation, there was no national level legislation at the time of this research, therefore, Malta was excluded from this analysis.

Countries and the documents reviewed:

Cyprus: Το περί Ελέγχου της Ρύπανσης των Νερών (Κώδικας Ορθής Γεωργικής Πρακτικής για Περιορισμό της Νιτρορύπανσης) Διάταγμα του 2007 (Κ.Δ.Π. 263/2007).

> **Translation:** Water Pollution Control (Code of Good Agricultural Practice) Order, 2007 (P.I. 263/2007).

France - Arrêté du 25 juin 2014 modifiant l'arrêté du 2 août 2010 relatif à l'utilisation d'eaux issues du traitement d'épuration des eaux résiduaires urbaines pour l'irrigation de cultures ou d'espaces verts. JORF n°0153 du 4 juillet 2014. NOR: AFSP1410752A

> **Translation:** Order of June 25, 2014 modifying the order of August 2, 2010 relating to the use of water from the treatment of urban waste water for the irrigation of crops or green spaces.

Greece - ΚΥΑ οικ. 145116/2.2.2011 (ΦΕΚ 354/Β/2011) «Καθορισμός μέτρων, όρων και διαδικασιών για την επαναχρησιμοποίηση επεξεργασμένων υγρών αποβλήτων και άλλες διατάξεις»

Translation: Definition of measures, conditions and procedures for the reuse of treated wastewater (354/B/2011) and related provisions. Greek Government Gazette 354/B/2011

Italy - Decreto Ministeriale 12 giugno 2003, n. 185 «Regolamento recante norme tecniche per il riutilizzo delle acque reflue in attuazione dell'articolo 26, comma 2, del D.Lgs. 11 maggio 1999, n. 152». (G.U. 23 luglio 2003, n. 169)

Translation: Ministerial Decree 12 June 2003, n. 185 "Regulation laying down technical standards for the reuse of waste water in implementation of the article 26, paragraph 2, of Legislative Decree 11 May 1999, n. 152" (Official Gazette 23 July 2003, n. 169)

Portugal – Decreto-Lei n.º 119/2019 Estabelece o regime jurídico de produção de água para reutilização, obtida a partir do tratamento de águas residuais, bem como da sua utilização

Translation: Decree-Law No. 119/2019 "establishing the legal regime for producing water to be reused, obtained from wastewater treatment"

Spain - Real Decreto 1620/2007, de 7 de diciembre, por el que se establece el régimen jurídico de la reutilización de las aguas depuradas.

Translation: "Royal Decree 1620/2007 of 7 December which sets the legal framework for the reuse of treated wastewater Amends 2001 Water Act"

Australia – National Water Quality Management Strategy: Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) 2006. NRMMC–EPHC–AHMC, 2006

California – Title 22 of the California Code of Regulations, Division 4 Environmental Health, Chapter 3 Water Recycling Criteria. In keeping with best practice, citations will read "22 CCR 603##" to specify the section of the Code.

3.1 Limitations

Due to resource constraints, Google Translate was the primary mode of translation. Except in the instance of Spain where an official English translation is provided by Mujeriego and Hultquist (2011) on an informational basis for interested readers. This could lead to misrepresentation in the coding and an incorrect understanding of the meaning of the documents. There are numerous policy contexts that overlap with or could have bearing on the implementation of water reuse schemes. It was outside the time and resource scope of this paper to analyze all of these at the national and EU levels. This mosaic in itself may pose a barrier to implementing a unified risk management strategy across and within countries. The choice to analyze nine policies broadly, instead of performing a comprehensive case study was a choice that limits the representativeness of the conclusions drawn. Furthermore, the results are not generalizable beyond the documents reviewed.

4. Results and Analysis

This section presents the combined results and analysis of the documents reviewed above and is broken into three sections. The first part presents how risk management strategies are incorporated across the policies and what components are lacking. The second section delves into the risk evaluation factors of water reuse. The final section looks across all of these to answer the question whether there are clear trends in risk reduction.

4.1 Coverage of Risk Management Strategies

Risk management tasks are not systematically found throughout the policies reviewed and even among the norm-setters there are incomplete risk-based strategies (Table 1). When risk management-based approaches are not explicitly used to frame policies, there is the possibility of inadequate control measures. Table 1 presents the results of which risk management tasks were identified in the policies analyzed. These are discussed in more detail below.

Table 1

Risk Management Tasks

		Cyprus	France	Greece	Italy	Portugal	Spain	EU	Australia	California
Identification of Values		x	x		x	x		x	x	
Characterization of water reuse system			x	x			x	x		
Identification of hazards		x				x		x	x	
Risk Assessments	Public Health	x[a]	x			x	x	x	x	
	Environment		x			x	x	x	x	
Risk evaluation	Risk Matrix									
	Cost benefit				x		x			
	Comparison to expected solution		x	x	x	x	x	x		x
Risk Reducing Measures	Non-Treatment	x	x	x	x	x	x	x	x	x
	Treatment		x	x	x	x	x	x	x	x
Emergency Management Planning			x				x	x		x

[a] Sometimes, depending on the type of irrigation

4.1.1 Identification of Values

At the beginning of the policies, the purpose of the document is laid out, justifying its creation and legal standing. The purpose stated in these beginning sections are the closest policies come to stating the values on which they are founded. Many of the policies specify protecting human (France, Italy, Portugal, EU, Australia) and environmental (Cyprus, France, Italy, Portugal, Australia) health. This is usually left in broad terms, though policies occasionally highlight specific aspects such as soil and plants (Italy), protecting agriculture production (France), or water bodies from agriculture pollution (Cyprus). Additional values driving policies is increasing the uptake of water reuse as a practice (Portugal and EU) as water savings measures (Spain and Greece).

4.1.2 Characterization of Water Reuse Systems

The policies that describe the total water reuse system are not consistent in the steps they identify. Greece and France both specify providing information about the physical area to be irrigated, including the crops and distance to water bodies, but the latter policy takes this a step further by also requesting the annual irrigation schedule and equipment specifications. The EU envisions this as the first step in risk management planning – gathering information to understand the system. The French and Greek policies include this as a step in the application for water reuse permits – not a step in systematic risk strategy, per se. This step is assumed to occur in risk assessments (Portugal and Australia) but is not found as an independent step to gain an overview of the water system prior to conducting said risk assessments. A notable discrepancy is that Australia and the EU both make mention of including the source of the water, but Portugal does not.

4.1.3 Identification of Hazards

Hazards are the variables that could potentially cause harm. Hazards could exhibit multiple consequences depending on what or whom is being harmed, as exemplified by multiple risks shown in the relationships Australia explains between sodium and salinity.

There is a gap in many of the policies when it comes to identifying hazards as a distinct task in a risk-based approach. Cyprus and Australia, neither of which include systems characterization, provide the clearest identification of hazards considered for the local context. In the Cyprus policy this is borne from a concise purpose the policy sets out to address (identification of values and goals under Tehler [2020]), while Australia's policy identifies nine key environmental hazards and two types of human health hazards. The main risks associated with these individual hazards are elaborated on, drawing a clear line between hazard and risk(s).[2]

Australia has a comprehensive risk management policy in regard to certain tasks related to the analytical framework (hazard and risk identification) but not to the framework as a whole. The Australian policy is based off the risk management strategy of Hazard and Critical Control Points (HACCP). As summarized by the Australian policy, HACCP is a risk management strategy from the food industry which provides a framework for creating risk management plans. The first step is to identify any potential hazards and the second is to identify particular points – these are the critical control points – along the systems where actions can be taken to reduce or eliminate the likelihood that the hazards will occur. Within this strategy, and therefore the Australian policy, there is a heavy emphasis on identifying potential hazards.

4.1.4 Risk Assessments

[2] The nine key environmental hazards identified by the Australian risk framework are: boron, chloride, sodium, cadmium, chlorine, salinity, sodium phosphorus, nitrogen, and water logging. The main human health hazards are pathogenic microorganisms and harmful chemicals.

As with hazard identification, there is little direct guidance on how to perform risk assessments or which hazards to consider, except in the Australian policy. Australia provides risk characterizations broken into two levels per hazard – residual and maximum risk, to provide a ranking of what risk to focus on (NRMMC–EPHC–AHMC, 2006). No other policy reviewed provides this breakdown of risk.

The French, Spanish, Portuguese, EU, and Australian policies include language for environmental and public health risk assessments. Although the Cyprus policy is concerned with environmental degradation, it does not include environmental risk assessments, and only sometimes requires public health assessments in the case of applying for additional forms of irrigation methods. In Section 8, the French policy provides examples of what receptors, "infrastructure, housing, rain, crops, etc.," to perform risk assessments in relation to but does not provide the same guidance for what are the risk sources. The French policy places public health and environmental risk assessments together in the same language. The Spanish policy stipulates that health assessments be carried out by public health authorities, while environmental health assessments are left under the purview of the Water Basin Authority. Spain is unique in specifying who is to carry out risk assessments, delineating mandates within the body of the policy. The EU lists Directives and Regulations which constitute the minimum requirements and obligations from which risk assessments should be derived, showing the overlapping nature of risk management.

Consideration for environmental health is strongest in relation to water bodies. This is seen directly in the purpose of some policies, e.g., Cyprus's policy addresses groundwater and surface water pollution from agricultural practices, or adjacent environmental concerns such as the Italian and Greek policies promoting water saving measures to address water scarcity. Vulnerability to nitrate pollution is a separate EU policy Member States must be in line with that results in having environmental considerations for vulnerable water bodies such as stricter concentration limits (Italy and Greece provide clear examples of this). Although Italy has factors about soil and terrestrial health, these are superseded by regulations about surface water discharge. Within the 14 Directives and Regulations to be considered for risk assessments in Regulation 2020/741, the first seven are related to water health. Four others are related to food for human consumption, and the final remaining Directive is for soil protection in the event of sewage sludge application – a different application than water for irrigation.

4.1.5 Risk Evaluation

The one risk management component found throughout nearly all policies is the use of routine monitoring. Routine monitoring is an example of risk evaluation, where samples are compared to predefined concentration levels. The parameters monitored, the frequency of sampling, and type of sampling all vary by policy, which will be detailed further on in Section 4.4.3. Neither Australia nor Cyprus provides acceptable concentration levels within their policies though Australia very clearly has tolerable risk levels that are used to illustrate concentration levels in case examples.

Other examples of risk evaluation methods are cost-benefit analyses and risk matrices. The EU, France, and Portugal present tables that provide guidance similar to that found in traditional risk matrices, however, there are not distinctions between acceptable and unacceptable risks. Cost-benefit analyses are mentioned in the Italian and Spanish policies. Italy requires an economic analysis of water protection and cost-benefit analysis of reused water to other sources – which could be related to the purpose of addressing water scarcity. Nutrients from reused water and fertilizer must be taken into consideration together with anthropogenic pressure on water resources, such as abstraction and pollution load, when considering water reuse. While in Spain, economic and financial analyses of water reuse infrastructure are to accompany environmental assessments.

Though the EU has guidance on what elements to include in risk assessments, there is no clear next step on what to do with these, e.g., how to operationalize results from risk assessments. Where the EU does provide guidance for decision making is in the form of applying the precautionary principle when there is "scientific uncertainty" in the risk assessment or risk evaluation process (see section 2.1.4). An interesting addition from Portugal is clarifying that qualitative risk assessments are acceptable when there is not sufficient data to support quantitative assessments.

One way the EU could provide further guidance for Member States to operationalize risk management strategies would be in setting acceptable risk levels, as Australia does. The Australian policy is derived from using a standard tolerable risk level for human health, set at 10^{-6} disability adjusted life years (DAYLs) per person per year.[3] Guidance is issued around setting quality limits to stay within the tolerable risk level regardless of parameter, crop, or irrigation strategy, though this only applies to human health.

4.1.6 Risk Reduction Measures

Nearly all policies make use of both treatment and nontreatment measures to reduce the likelihood of risks. The exceptions to this being Australia, California, and Cyprus, the first two which only stipulate treatment measures and the latter that only includes non-treatment actions in the policy analyzed. Though all policies make use of some form of reduction actions, there are significant differences in practices undertaken, these are discussed in depth in Section 4.3.

4.1.7 Emergency Management

Although emergency management (including contingency planning) was not part of either framework used to create the initial analytical framework of this thesis, it evolved through the emergent coding process. Though the policies reviewed are ostensibly about managing some form of risk, emergency planning is mentioned in approximately half of the policies. The Member States with risk assessments, except Portugal, include emergency planning as part of their policies. California is a notable outlier for the inclusion of contingency plans without mention of prior risk assessments.

[3] DALY considers the severity of disease rather than solely the likelihood of disease or death. "The basic principle of the DALY is to weight each health impact in terms of severity within the range of zero for good health to one for death. The weighting is then multiplied by duration of the effect and the number of people affected by the effect. In the case of death, duration is regarded as the years lost in relation to normal life expectancy" (NRMMC–EPHC–AHMC, 2006, p. 84).

Though emergency management is included in policies, there are still gaps in how these are conceptualized, for example, section 7 of the French appendix requires a risk analysis that includes “methods for detecting and managing malfunctions in the treatment and distribution chain.”

4.2 Risk Evaluation Factors

A key step after identifying risks, is creating a systematic way to evaluate and compare the risks either to pre-defined acceptable risk levels and/or to other risks, thus beginning the process of taking preventative action to minimize risks. There is a trend among policies to essentially utilize a matrix where the type of crop, irrigation method, and quality of water are factors in assessing and reducing risk. Some policies utilize all three factors, as seen in the EU, Portuguese, Spanish, and French policies, while others use a combination of two (Cyprus, Greece, and California), only one (Australia) or none (Italy) (Table 2). These are not expressed as traditional risk matrices where there are differing levels of consequence or likelihood. Yet they are being used to make decisions judging whether the risks posed are acceptable or not.

Table 2

Risk Evaluation Factors for Water Reuse

	Cyprus	France	Greece	Italy	Portugal	Spain	EU	Australia	California
Crop Categories	x	x			x	x	x		x
Water Classes		x	x		x	x	x		x
Irrigation Method	x	x	x		x	x	x	x	

4.2.1 Crop Categories

Crops are assessed by their relation to how humans consume them. The language used for classifying crops varies slightly, but on the whole most types of crops are allowed across all the policies reviewed. Cyprus is the most restrictive, not allowing leafy green vegetables, roots, or tubers which are eaten raw to be irrigated with treated wastewater. The descriptions of crops vary, but generally are grouped by vegetables and fruits, roots and tubers, orchards/tree crops, fodder/cereal crops, and crops intended for industrial processing. Cyprus and Portugal also place additional restrictions on the type of pasture for which irrigation is allowed, barring dairy producing animals and swine respectively. In the policies which utilize crop categories there is general agreement about which crops require more strict water quality requirements, e.g., those consumed raw with thin or no protective layers for the portion eaten. Except in the case of Cyprus, crop categories are paired with water classes for setting the quality requirements of crop categories.

4.2.2 Water Classes

All the policies, except Australia, Cyprus, and Italy, use water classes for setting restrictions on irrigation use and defining quality parameters. The highest water quality classes are those with the strictest quality parameters and are often tied to irrigating crops that are in contact with the edible portion of crops and/or those eaten raw. The exception to this is Greece, whose water classes are unique because rather than being paired to crop categories they are tied to public access. Though the three initially mentioned countries do not include water classes, all perform some extent of water treatment and routine monitoring of predefined water quality parameters. Italy has an extensive list of quality parameters, but these do not vary based on any use cases, except occasional caveats such as in areas vulnerable to nitrate pollution.

Australia recommends against using water classes, because this codifies a rigid system that is unable to operationalize the "fit-for-purpose" approach recommended in the risk framework. The Australian policy argues that water classes do not take into consideration the source of the water and push operators to rely on routine monitoring based on end-use cases, thus encouraging a reactive rather than proactive approach to risk management.

The Australian and Italian policies stand in contrast to one another, and to the EU. Where the Australian policy advocates the most context specific approach and evaluation of every use case and water system. The EU simplifies this into tranches where the water source is limited to a predefined quality and using water classes with crop categories to be "fit-for-use." The Italian policy is the least flexible, with little change or accommodation for different uses, potentially making it either the strictest or the most lenient for risk reduction.

4.2.3 Irrigation Method

The type of irrigation scheme is the third and most commonly used factor to differentiate risk levels and dictate usage. A fundamental principle which is seen even in some policies that do not have crop categories (Cyprus and Australia), is that limiting contact between water and the edible portion of the crop attenuates the risk(s). Drip irrigation is the most preferred irrigation method, as this provides the most control for targeted watering – minimizing the unintended movement of water and using the smallest amount of water needed. There also may be some assumptions of the movement through the soil-plant pathway attenuating risk to consumers. An example of irrigation being viewed as a risk reducing factor comes from the EU policy. Regulation 2020/741 has four water classes that are built around three crop categories, all of which require at least secondary treatment and disinfection. The second and third water class apply to the same crop category; however, the third water class is only acceptable with drip irrigation and has less strict values than the same crop class irrigated with any other type of irrigation system, i.e., the second water class. An even more extensive version of this can be found in the French policy, that creates a matrix of crops and water quality with footnotes explaining how irrigation methods are related to crops and quality standards.

In none of the tables used for risk evaluation are there discussions of the frequency of exposure to the hazard or likelihood of a consequence occurring. Though they provide a method for determining usage scenarios they do not explain what is considered an acceptable or unacceptable risk.

4.3 Risk Reduction Strategies

All of the policies reviewed rely on both treatment and non-treatment measures to reduce the potential of negative impacts from water reuse, except Cyprus (Table 1).

The structure and type of document that constitutes the Australian policy is quite different than that of the other documents reviewed; the Australian policy is entirely descriptive guidance for the six states and potential operators but is not prescriptive nor mandatory as the EU policy is for Member States.[4] The Australian document is essentially a handbook with justifications and explanations of how to use the document to create policies at the state level, providing advice for calculating and implementing quality standards in practice. Therefore, the results in this section related to Australia are the national level suggestions and not individual state requirements.

4.3.1 Non-Treatment Strategies

Restricting access to land irrigated with treated wastewater is the most common type of risk reduction strategy, with only Italy not providing some mention of this strategy (Table 3). Besides Italy, Member States rely on a mix of non-treatment strategies as do Australia and California. Australia and California are broadly in alignment for non-treatment measures except for California's use of water classes and Australia's recommendation to incorporate irrigation type. Nearly all the documents reviewed include requirements to explicitly label and include signage on pipes or fields where treated wastewater is in use. Most also issue guidance requiring distance minimums for agricultural fields from water sources or other fields as well as restricting personnel access. The EU requires fewer non-treatment actions than most policies reviewed, which could be related to jurisdiction and mandate constraints since Annex II Table 1 provides additional suggested strategies (Portugal incorporated some of these into its policy).

Table 3

Risk Reduction Strategies

	Cyprus	France	Greece	Italy	Portugal	Spain	EU	Australia	California
Signage	x	x	x	x	x			x	x
Distance setbacks	x	x			x		suggested	x	x
Restricted access	x	x	x		x	x	suggested	x	x
Irrigation method	x	x	x		x	x	x	x	
Crop categories	x	x			x	x	x		x
Routine monitoring of water treatment		x	x	x	x	x	x	x	x

[4] Australia's federal government does not have the authority to set prescriptive or mandatory guidance related to water (Radcliffe, 2022)

4.3.2 Water Treatment

Although all policies rely on treatment processes to decrease risk, there are not consistent routine monitoring requirements. There are a few similar groupings, but there is no strong alignment between Member States and established norm-setters nor between Member States themselves. For the purposes of this paper, routine monitoring parameters have been broken down into microbiological parameters (Table 4) and physical-chemical parameters (Table 5). These could either be hazards in their own right or indicators monitored in lieu of an identified hazard; except for Australia, policies do not provide consistent and thorough justification for the inclusion or exclusion of parameters to be monitored.

Table 4

Microbiological Parameters Monitored

	Cyprus[5]	France	Greece	Italy	Portugal	Spain	EU	Australia	California
E. coli		x	x	x	x	x	x	Not preferred	
Total Coliforms			x						x
Fecal enterococci		x							
F-specific RNA phage		x							x[b,c]
Helminths/ intestinal nematodes					x	x	x	Use protozoa	
Legionella spp.						x	x		
Sulfate reducing anaerobic bacteria spores		x							
Salmonella				x		x		Not preferred	

[b] For some use cases
[c] F-specific bacteriophage

E. coli is the most consistently used microbiological parameter for water quality, with nearly all Member States and the EU requiring monitoring. Of these, all have different concentration limits usually based on water classification, except those without water classifications; however, this belies large differences in the quantity limits allowed for between the water classes. Most monitoring requirements are based on logarithmic increases in acceptable concentration values; yet there are substantial differences in the concentrations allowed even where logarithmic increases based on water class are used. As an example, France has the most permissive values, in that the most restrictive water class already allows a higher concentration of *E. coli* than any of Greece’s water classes. *E. coli* is mentioned as actively not being a preferred microbiological parameter to monitor in the Australian context.

[5] Cyprus does not include water quality standards in Κ.Δ.Π. 263/2007 as this is governed by individual permits

The one parameter with the closest homogeneity between concentration limits is the monitoring for intestinal nematodes, which are capped at ≤1 egg/liter, again though there are differences within details. Spain specifies that both *Taenia saginata* and *Taenia solium* be tested for when irrigating pasture for milk- or meat-producing animals. The EU and Portugal do not specify further than “intestinal nematodes (helminth eggs)” and Portugal only monitors these when water is destined for pastures.

Table 5

Physical-Chemical Parameters Monitored

	Cyprus	France	Greece	Italy	Portugal	Spain	EU	Australia	California
Total Suspended Solids (TSS)		x	x	x	x	x	x[d]	x	
Turbidity (NTU)			x[b]		x[b]	x[b]	x[b]		x[b]
Biochemical oxygen demand (BOD)			x[d]	x	x		x[d]	x	
Chemical oxygen demand (COD)		x		x					
Electrical conductivity (EC)				x		x		x	
Sodium Absorption Rate (SAR)				x	x	x		x	
Heavy metals/metalloids				x	x	x		x	
Residual chlorine			x	x	x[e]			x	x

[b] For some use cases
[d] Reference 91/271/EEC
[e] Indirectly tested through monitoring Volatile Organic Compounds (VOCs)

Greece and Portugal are the only policies that monitors all the same physical-chemical parameters as the EU and whose concentration limits meet the minimum requirements under Regulation 2020/741. Spain and Italy test for two-thirds of the physical-chemical parameters required by the EU, none of which meet the EU standards.
Spain and Italy show an overlap in monitoring electrical conductivity, sodium absorption rate, and heavy metals/metalloids. They diverge with Spain’s lack of chlorine residual and biochemical oxygen demand though, this is where Portugal and Greece are in alignment with Italy.

When looking at water treatment processes, there is an interesting divergence between California and the EU. The California policy states that food crops consumed raw where the water touches the edible portion is to be tertiary treated plus disinfected, but for the equivalent water class in Regulation 2020/741 only secondary treatment plus disinfection is required. Tertiary treatment removes nitrogen and phosphorous, thus limiting the water’s potential as a fertilizer supplement. The EU’s decision to limit the requisite indicative treatment to secondary treatment, could be for encouraging water reuse to be viewed as an agricultural input by recognizing the valuable nutrients within wastewater as resources, a feature explicitly stated in the purpose of Regulation 2020/741.

Overall, when viewing both microbiological and physical-chemical parameters, there is no clear reliance on the monitoring policies of the norm-setters. Italy, and to a lesser extent Spain, are similar to Australia in regards to physical-chemical parameters but diverge when it comes to biological parameters.

4.3.3 Sampling and Monitoring Guidance

The lack of consistency among policies for risk reduction extends to the sampling and monitoring guidance as well. The Portuguese legislation is from 2019 and is incorporating the EU policy into the national context. There are minimal differences between the two policies in regard to overall risk management strategy. The largest difference in this regard is the point of compliance for monitoring. The Portuguese policy specifies that testing occurs "immediately before the point of delivery and at the water reuse application point" (Decreto-Lei n.º 119/2019). Whereas the EU specifies the point of compliance as being when the water treatment operator delivers water to the next actor in the chain. The French, Spanish, and Italian policies sample at the point of exit from the treatment plant as the point of compliance. Spain is similar to Portugal in also sampling at the points of delivery.

In most policies, the frequency of sampling is linked to the quality parameter being monitored (Cyprus, Greece, California, EU, Portugal, Australia). Sampling is also contingent on water class for Greece, whereas for France sampling frequency is *only* contingent on the water class, with no differentiation based on the parameters being analyzed. Hence, suspended solids, chemical oxygen demand, and *E. coli* are monitored once per week for the highest class of water but are monitored once every 15 days for the second highest water. This shows a lack of consideration for the properties of the individual hazard, thus either setting unnecessarily strict monitoring based on the hazard of most concern, the hazard that exhibits the most variability, or not setting strict enough monitoring schedules.

The EU, Portugal, Spain, and Italy's monitoring plans are built around maximum allowable values, maximum deviation values, and a minimum percentage of samples that must meet this value. Greece differs slightly in not providing a maximum deviation value. California follows a different monitoring method with sampling based on median most probable number per 100 milliliters over a consecutive seven-day period as well as maximum allowance of most probable number for any one sample in a 30-day period.[6] Australia refrains from providing confidence intervals or numerical targets stating, "sampling should be sufficiently frequent to obtain meaningful information and statistical validity" as well as be informed by "the level of risk and confidence in preventive measures in place" (NRMMC–EPHC–AHMC, 2006 p. 57-58).

Portugal, California, and Spain are the only policies to specify the type of sampling. Portugal's default sample guidance is to take 24-hour composite samples. Portugal recognizes that composite sampling is not possible for all parameters and therefore the policy allows grab

[6] Most probable number is a statistical method for assessing the probability of the observed number occurring

samples in some cases, such as Volatile Organic Compounds (VOCs). California also specifies this type of sampling for turbidity but does not provide this same level of specification for total coliforms. Spain's sampling plan utilizes aliquot samples.[7] Australia provides general guidance on best practices for sampling (i.e., microbial is the most concerning for human health, while chronic chemical exposure is the major environmental health concern) but does not specify the method or frequency of sampling.

The type of sampling method could impact the ability of comparing results across contexts, even though operators are using best practices which address the uncertainty of representative sampling in different ways. Portugal, Spain, and California (for turbidity) address how to draw a sample that is likely to be evenly distributed and capture the hazards present. Whereas California's use of most probable number is related to how the analysis is interpreted. Although Australia leaves much of the sampling decision up to the operator, the guidelines recommend using deterministic analysis (instead of stochastic) because it is simpler and "does not involve the use of estimated or random values" however the downside is that it "does not address variability and uncertainty" (NRMMC–EPHC–AHMC, 2006, p. 227). Sampling decisions affect how uncertainty is accounted for in routine monitoring and risk management.

5. Discussion

This section elaborates on the results presented in the previous section. The first section considers the overarching policy context in which these documents exist and considers how this may affect the results presented in this research. The second section elaborates on the incorporation of risk management frameworks into policy and the difficulties that lie ahead for creating a unified strategy. The following three sections take a step back and consider universal concepts that inform the creation and assumptions underpinning risk management. Analyzing the values, perspectives on uncertainty, and consideration of complexity help fulfill the purpose of this research by exemplifying the challenges of managing risk with specific examples from the water reuse context.

5.1 Complicated Enabling Environment

The enabling environment of policy, jurisdiction, and mandates surrounding water reuse are complicated. There is a constellation of regulations that apply to water treatment operations, some of which overlap and others which intentionally omit relevant information that is supplied by an additional policy, as seen in the number of Regulations and Directives cited in Regulation 2020/741 for performing risk assessments. The EU and Greek policies directly refer to the Urban Waste Water Treatment Directive (UWWTD) within the monitoring requirements of their respective policies for biochemical oxygen demand and total suspended solids (Table 5). Whereas the Portuguese policy appears to overlap with the UWWTD, setting direct quantitative values into the policy that are in alignment with the UWWTD. Were the UWWTD to be amended, and become stricter, the Portuguese policy would need to be

[7] Aliquot sampling technique is where a single sample is drawn, then split into multiple samples which are then subsequently tested

updated to reflect these changes whereas the Greek and EU policies would continue to be applicable.

The mosaic of overlapping governance is not always clear to see, and a challenge includes finding all the documentation that is relevant. While the EU lays out the key legislation to take into consideration for risk assessments and directly includes the UWWTD for some quality parameters, other quality parameters may also be applicable for water reuse treatment standards but are not directly stated within Regulation 2020/741. In the results, the EU does not appear to have additional or separate monitoring requirements for chemical oxygen demand for agricultural water reuse purposes, but these parameters do have quality requirements that are potentially applicable from the UWWTD as general wastewater output requirements, though they are not referenced in Regulation 2020/741. Rebelo et al. (2018) include quality parameters from existing related legislation in their analysis of microbiological and physical chemical monitoring parameters, which shows a distinction between Member States with a number of parameters in ancillary policies (Portugal prior to the adoption of Decreto-Lei n.º 119/2019 and Spain) and those that did not rely on additional legislation for the parameters Rebelo et al. (2018) assessed (Italy, France, Cyprus). The pattern that emerges from the results could also apply to the norm-setters of Australia and California. It was surprising that California had minimal testing requirements since they are referenced in the literature as leaders in this space (Paranychianakis et al., 2015); however, the lack of requirements in the Code of Regulations (22 CCR 60304) could be due to ancillary policies.

By only reviewing the cornerstone policies expressly related to water reuse for agricultural irrigation, there may be governance mechanisms that this thesis missed. Thus, making it difficult to draw conclusions on the extent to which risk management tasks are considered in the EU context. Cyprus has two categories for wastewater treatment plants, those that serve agglomerations of less than 2,000 people equivalents (p.e.) and those that serve more. Wicke, Vosse, and Miehe (2019) report that water quality for agglomerations of less than 2,000p.e. is governed by K.D.P. no. 269 (2005) amended by K.D.P. no. 379 (2015); however, the author was unable to validate this assertion. For agglomerations of more than 2,000p.e., water quality is set out in individual treatment permits at the discretion of the Minister of Agriculture, Rural Development and Environment. Hence, the apparent lack of routine monitoring of biological and physical-chemical parameters presented in the results is misleading if taken at face value without considering the larger policy context.

Cyprus's reliance on discharge permits may show the strongest prioritization of context-based risk management, as advocated by Australia; however, it also highlights the challenge of explaining water reuse quality standards to the public. Though risks and risk assessments are context dependent, the inability of the public to locate or access regulation, such as K.D.P. no 379 (2015), may hinder efforts to increase acceptability and utilization of water reuse. Creating minimum requirements for the EU was driven by a concern of the negative economic effects from the interruption to the unified internal market for agricultural goods (Alcalde-Sanz & Gawlik, 2017; Regulation 2020/741). The EU has pertinent policies and guidance related to data sharing and public disclosure; water reuse in particular could benefit from incorporating risk communication principles when complying with these information and data sharing requirements[8] and incorporating dialogue and discursive strategies (see Aven and Kristensen [2019] for case example references).

An important function of policies is to enhance confidence, transparency, and traceability of goods and services (Mannina et al., 2021). Water reuse criteria set out in legislation affect the acceptance and economic viability of water reuse schemes (Fawell et al., 2016). Without robust legal structures, "uncertainty reigns, and there are no independently set performance objectives upon which to found risk management practices" (Fawell et al., 2016, p.567). This undermines public confidence in the safety and quality of the water, and places operators and end users in a precarious legal situation where they may potentially assume high financial risks. A failure to obtain trust in the EU's minimum requirements could limit the block's ability to adapt to climate change and address environmental degradation. Recognizing the challenges ahead, the EU published guidelines to support the application and adoption of Regulation 2020/741 shortly before the submission of this thesis (2022/C 298/01).

5.2 Knowledge Risk Management

Clear risk management plans help harmonize how risk is perceived and allows a coherent management and response operation (Tehler, 2020). When risk-based components are incorporated into policies in an ad-hoc manner, they may not be efficient nor effective. The French policy demonstrates this as it appears to a) conflate risk analysis with emergency management practices in Section 7, and b) list emergency management practices as occurring prior to risk assessments, which are listed in Section 8 (Appendix IV JORF n°0153). At a minimum, risk analyses should be undertaken prior to detailing emergency management plans since these plans should be predicated upon the identified hazards, their likelihoods, and impacts. The implications of this confusing ordering could lead to incomplete strategies, as not all hazards, exposure pathways, and reduction measures are explored.

Incomplete risk management strategies and a complicated enabling environment can lead to conflicts in jurisdiction or a lack of oversight. However, implementing a risk-based policy does not immediately remedy this struggle, as the process can also be fraught with challenges in defining roles and mandates. The EU calls for a risk management approach to the whole water pathway, from treatment to end-user, however, "this generally exceeds the span of control of individual water providers or managers" (Dingemans et al., 2020, p. 5). As already mentioned, the point of compliance for the EU policy is where operators deliver water to the next actor in the chain, which could be at the point of exit from the water treatment plant (Regulation 2020/741). This raises concerns of where liability falls if the quality of water degrades in transit through the distribution network, since operators are only liable up to the point of compliance. This is a key concern raised by the German Environment Agency in its response to Regulation 2020/741 (Umwelt Bundesamt, 2021). Portugal addressed this concern by moving the point of

[8] Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC and Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE)

sampling from the point of exit from the treatment plant to the point of delivery and point of application. However, responsibility still sits with the water treatment operator, and/or network service provider in this case, without addressing how the responsible parties are to have knowledge or control of the water on its course through the environment. Redressing this concern, Spain places responsibility on the user for ensuring there is no deterioration between the point of delivery and point of use. Regardless, moving the point of compliance does not resolve the problem that the whole water pathway includes the movement through soil, plants, and potentially livestock. Moreover, it highlights that a strong emphasis on nontreatment risk reducing measures, especially irrigation method and crop categories, is heavily reliant on end-user compliance to function as risk prevention measures.

5.3 Values

The EU's definition of risk includes environments, populations, and individuals at risk, serving as a rudimentary acknowledgement of the values underlying the creation of the policy and its reference point(s) when evaluating risk. However, there appears to be more weight given to the latter two categories across the policies reviewed. Terrestrial environmental health risks do not seem to be as thoroughly considered as human health risks, as is demonstrated by risk hierarchies being predicated upon the relationship of agricultural products to human consumers. As noted previously, policies rely on three main factors to simplify risk evaluation, one being crop categories. Crop categories are not based on the relationships between the crops and their environment, nor between crops and their sensitives to hazards found in treated wastewater, such as heavy metals or salinity. Within the policies which disaggregate by crop, these ascribe to the assumption that factors about certain crops pose different risk levels to consumers. Policies rank crop categories with distinctions based on being eaten raw or after industrialized processes and in relation to contact between the edible portion of the crop and water, hence basing risk evaluation on human consumption. Within routine monitoring there is a paucity of physical-chemical characteristics related to soil and plant health, e.g., electrical conductivity, sodium absorption rate, heavy metals/metalloids, residual chlorine (Table 5).

Stating that environmental health should be taken into account does not set a unified risk-based approach. Although environmental risk assessments are an established practice in many fields, without additional guidance, such assessments may fall prey to diverging underlying and unstated assumptions (see Wassénius and Crona [2021] for a discussion of epistemological differences in quantifying risk). The complicated enabling environment with its myriad of relevant policies, may bring with it independent definitions of risk, tolerable risk levels, and risk management practices that are not founded on the same value weights. Competing industry understandings or standards could lead to an overestimation or underestimation of risks in the context of water reuse for agricultural irrigation. Rebelo et al. (2018) point out that in the Netherlands, it was legislation relating to the food industry that hindered water reuse for agricultural purposes, as treated wastewater was classified as a waste and not a raw material, placing additional regulations on its usage.

Though it is clear from the results that environmental risk assessments are required in a number of the policies reviewed, there is little to remedy the variety of analyses this entails.

The European Food Safety authority describes an "urgent need for harmonisation of environmental risk assessment in different scientific fields" (EFSA, 2018). Risk assessments could be conducted for the same hazard, but Member States may reach different conclusions, as hazards may pose several different risks. For example, sodium and salinity, two of the key environmental hazards raised in the Australian policy, present multiple risks (NRMMC–EPHC–AHMC, 2006). It is therefore surprising that the EU says nothing about either salinity and electrical conductivity, despite their relation to soil structure and plant health (Klopp & Bleam, 2021), or sodicity, despite it being a recurring concern raised in the literature (Chojnacka et al., 2020; NRMMC–EPHC–AHMC, 2006; Santos et al., 2017; USEPA, 2004). Although the characteristics of electrical conductivity and sodium absorption rate will be unique to the soils receiving the irrigation water, it is curious they are not mentioned as potentially requiring additional monitoring or consideration in risk assessments. This is potentially due to the diversity of contexts in which Regulation 2020/741 could be applied and the contrast in severity of consequences between these, e.g., Nordic and Mediterranean countries. Unjustified differences in judgement concerning the severity of consequences further bolsters the need to transparently state the values used to create and judge risk assessments (Tehler, 2020).

An important qualifier Tehler (2020) adds in the discussion of risk management is that "the purpose of [risk management] activities is (sic) to achieve purposeful protection of what is deemed valuable" (p. 32). Hence what is considered a risk is a value judgement related to what is being harmed (Aven & Renn 2009). Most policies have some acknowledgement of protecting human health as being a goal of the policy (section 4.1.1). Australia's use of DALY shows a concern for the quality of life and not just the presence of disease or death. It is less clear in the other policies how the burden of disease is considered. Signage, distance setbacks, and restricted access, all serve to protect people from contact with reused water; however, if risk is restricted to a traditional view of probabilities, then the social determinants of vulnerability may be overlooked. One such area of concern is the potential power imbalances between farm workers and those managing the farms, or if there are underlying inequalities placing some communities at higher exposure than others. Just as the social determinants of health are receiving increasing traction, the social determinants of vulnerability in risk should also be considered when discussing the risks posed by water reuse.

5.4 Complexity

While the enabling environment is complicated, the decisions regarding what to regulate, monitor, and treat exhibit complexity and uncertainty. Complex systems challenge the ability to set prescriptive criteria for evaluating risk and setting acceptable risk levels (Tehler, 2020). This could be why there are variations in the parameters monitored for within policies and why there are differences in concentration values for the same parameter.

A number of the policies reviewed monitor for residual chlorine levels. The EU has specifically been criticized for not including monitoring of residual chlorine, as well as leaving disinfection byproducts, pharmaceuticals, and contaminants of emerging concern (CECs) up to Member States' discretion (Dingemans et al., 2020; Umwelt Bundesamt, 2021).

It is likely that disinfection byproducts will become a higher priority as disinfection becomes more routine; especially in the water reuse context, since every water quality class in Regulation 2020/741 requires disinfection. However, there is not guidance on what the limits should look like for these additional hazards – nor what byproducts to be aware of, beyond that they may be of concern. Byproducts resulting from the treatment of wastewater (daughter substances) may have higher toxicity than the parent substances from which they derive, yet current monitoring is looking for the absence of parent substances and not what daughter substances are resulting from transformation during the treatment process (Deviller et al., 2019).

The latest estimates place the number of commercially available chemicals and chemical mixtures at over 350,000, many of which "remain publicly unknown because they are claimed as confidential (over 50,000) or ambiguously described (up to 70,000)" (Wang et al., 2020, p. 2575), therefore, it is not surprising that many of the sampling criteria target representative indicators. While Paranychianakis et al. (2015) call the effort to minimize all chemicals below detection limits "futile" (p. 1420), Narain-Ford et al. (2020) highlight that these compounds might already be in the environment but are not being monitored. Raising the possibility that a) treatment standards will not be strict enough, because the baseline assumed for risk assessments underestimates risks that have gone undetected, b) treatment abilities will not be able to attenuate the compounds to low enough levels because the baseline is already too high, and/or c) treatment operators will be penalized for contributing to a risk that was already present, jeopardizing their credibility. This could lead to negative public or environmental health outcomes, prohibit the adoption of water reuse technology, or undermine public acceptance of products irrigated with treated wastewater.

As mentioned above, the EU stops short of providing guidance on what are acceptable concentration limits of these compounds or which compounds to prioritize. This could be due to the fact that there are few long-term studies on persistent, toxic, mobile, or bio-accumulative substances (Narain-Ford et al., 2020). As such, there is insufficient data to quantitatively characterize the risks posed by these substances in treated wastewater (Revitt et al., 2021). It is difficult to incorporate CECs into wastewater management guidelines because it is hard to mimic all potential combinations and scenarios potentially found in real life into lab conditions. CECs and even other more well-defined substances can exhibit synergistic behavior, where two or more substances in tandem have a higher combined effect than they would on their own, conversely, substances might also mitigate or cancel out one another (Paranychianakis et al., 2015). Coupled with variations in concentration and flow behavior through wastewater, these factors and uncertainties make it difficult to draw valid conclusions on the risks posed by CECs to human and environmental health (Paranychianakis et al., 2015). The potential risks posed by water reuse for agriculture irrigation are interconnected, sometimes with poorly understood interactions, and differing types of uncertainty. Which exemplifies why full control of the risks present in complex systems cannot be achieved (Aven & Kristensen, 2019).

5.5 Uncertainties

Throughout the policies, there appears to be a reliance on the traditional, probability based, view of risk. Australia and California's traditional view of risk is displayed in the sampling analysis guidance of both policies. Australia recommends deterministic analyses, while California relies upon the assumption that it is possible to calculate the probability of an observed concentration level based on a normal distribution. From one perspective, it is possible "to calculate the probability distribution of the adverse outcome" (Wassénius & Crona, 2021 p.36) of water reuse, i.e., view risks as Knightian in nature.[9] This is based on the grounds that "exposure levels may also be predicted to some degree based on (expected) levels in wastewater, treatment efficiency, distribution and degradation in water, soil and air, and absorbance in plants" (Dingemans et al., 2020, p.4). However, limiting risk assessments to a probabilistic understanding of risk based on historical data could conceal or omit risks where there is uncertainty, especially if this uncertainty is related to ignorance (Aven & Kristensen, 2019). Policies provide a range of acceptable sample concentrations, maximum deviation, frequency of deviation, etc. This accounts for variability in real and observed concentration levels but does not address the state of knowledge operators have. Risk characterization is dependent on the extent of knowledge, and hence is also defined by uncertainty – which a probabilistic approach to risk has limitations in describing (Tehler, 2020).

Currently, the EU's guidance is to apply the precautionary principle when there are instances of "scientific uncertainty" (Regulation 2020/741). The precautionary principle is a contested approach; opinions are divided over its usefulness and effectiveness (see Bourguignon 2015 for a discussion). As there are multiple types of uncertainty (see Pelz et al., 2021; cf. Bradley & Dreschler, 2014) and large portions of risk management tasks are at the discretion of Member States, this could apply to several scenarios in agricultural irrigation. The precautionary principle is an approach for viewing and evaluating risk that can be judged based on a number of factors, including cost-benefit analyses, which as seen in the case of Spain and Italy, may have different starting points (Bourguignon, 2015). The precautionary principle is an acknowledgement of the existence of uncertainty; indeed, there is little else in the policies reviewed that openly acknowledges uncertainty and its role in risk.

Dingemans et al. (2020) point out that Directive 2020/741 inadequately considers technological innovation, specifically effect-based bioanalytical tools. As new tools and methods emerge, it is a question of how to coordinate and integrate these into risk management. Because water reuse intersects with many policy arenas and scientific disciplines, it is important to consider what happens as science and technology progresses. Articles written prior to 2018 mention the exciting possibilities and future research areas potentially on the horizon with the development of affordable polymerase chain reaction (PCR) testing (Paranychianakis et al., 2015). The possibilities realized by PCR testing were clearly on display with the widespread use of epidemiological surveillance of wastewater during the SARS-Covid-19 pandemic. Consideration of how rapidly scientific understanding can progress could have implications for how the precautionary principle is applied.

[9] A Knightian perspective defines risk as measurable uncertainty where the probability distribution of the adverse outcome can be measured (Wassénius & Crona, 2021)

The challenge of knowing what substances to monitor is a critical question for water reuse operations and “uncertainties are probably the major motivating factor prompting environmental and health authorities in the developed world toward conservative approaches” (Paranchankyais et al., 2015, p.1414). How then to reach the compromise Fawell et al. (2016) describe between excessive precaution and insufficient safety? One option is the inclusion of qualitative risk assessments such as the comparative seriousness matrix proposed by Revit et al. (2021) that provides a decision-making tool to circumvent the lack of quantitative information. Qualitative assessments help address ambiguity and ignorance when trying to assess risk, because it allows decision makers to move past the need for the same type of complete information for risks to be assessed. The comparative seriousness matrix judges risks against one another and not against an objective truth; allowing a variety of tests and tools to be combined. A second would be California’s operationally defined CECs screening framework that is separate from regulatory criteria (Drewes et al., 2018). Learnings from California show it is just as important to include a pathway for removing testing requirements as it is for adding additional restrictions, as three of the four 2010 health-based CEC indicators are no longer necessary to monitor for after long term monitoring revealed these three indicators were consistently lower than trigger levels (Drewes et al., 2018).

6. Conclusion

This thesis analyzed the water reuse policies of six Member States of the EU, the recent EU Directive 2020/741, the state of California, and Australia’s water reuse policies through a risk management lens. Though the state of California and Australia are cited as leaders in the water reuse sector (Kirhensteine et al. 2016; Alcalde-Sanz & Gawlik 2017), it does not appear that they have had significant impact on the risk management policies of EU member states or the EU. Though policies incorporate risk management steps, they vary in the thoroughness of these; potentially highlighting different tactics of the EU, California, and Australia in reducing the risks associated with water reuse. The EU included the greatest number of actions related to risk management, while California and Cyprus include the least. It is speculated that this stems from overlapping and interrelated policies, which contribute to a complicated enabling environment for water reuse operators. As exemplified by the risk assessment guidance provided by the EU, there are a multitude of supporting relevant policies for managing risks in water reuse. Though policies incorporate aspects of a risk management framework, because many of the policies are not framed as such, they are still incomplete and inconsistent. Not taking a deliberate risk management approach to water reuse leaves room for gaps and misunderstandings to occur, such as in France’s unclear ordering of risk assessments and emergency management plans. The deliberate risk informed approach of Regulation 2020/741 is an important contribution to the water reuse context in the EU.

Policies take different tactics with the level of detail in specifying jurisdiction and mandates. This is possibly due to the policy environment and the different levels of government that were analyzed – sub-national, national, and supranational. Member States working at the national level provide more detailed language on setting roles, but all policies face the challenge of trying to manage risk throughout the entirety of the treated wastewater’s life cycle. The knowledge and jurisdiction needed to carry out this task extends beyond the control of water treatment operators. It was found that policies rely heavily on end-user compliance for enacting risk reducing actions.

Policies for water reuse in agriculture rely on three main factors to simplify risk evaluation: crop categories, water classifications, and irrigation methods. Most policies utilize a combination of these factors for governing the quality of treated wastewater used in irrigation. It appears that this system is designed primarily to reduce human health risks, with less weight given to the health of terrestrial environments. This is seen in how crop categories and water classes are centered around the human consumption of crops and the exposure pathways presented by agricultural products (e.g., crops eaten raw, crops for industrial processing, dairy products, etc.), as well as the dearth of monitoring parameters related to soil health. Some policies state an overarching purpose that the water reuse policy is addressing, providing insight into the values that undergird the creation of the policy. However, the values used for assessing and evaluating risks are usually not directly stated in the policies. A notable exception is the Australian policy's use of DALY, yet this is only applicable to human health and again does not provide guidance for environmental health. Risk assessments and risk evaluations would benefit from more explicit detailing of values. Setting a tolerable risk level would also help counteract the lack of standardization and harmonization of risk assessment tools.

Nearly all policies use treatment and non-treatment risk-reduction measures; however, the quantitative values of these treatment outcomes are not consistent. The Greek and Portuguese policies are the only Member States whose quantitative treatment values meet the EU's minimum requirements. A challenge in the water reuse sector is knowing what parameters to monitor and at what concentration levels they pose risks. This is due to the complex nature of water reuse and the uncertainties inherent in risk. California's tactic to handle such challenges is through a separate policy that is operationally defined for monitoring CECs; however, no policy analyzed as part of this thesis included guidance for CECs, pharmaceuticals and personal care products, etc. The EU has been directly criticized for this lack of clarity and for leaving the choice of these additional monitoring standards to Member States' discretion without further direction. There are also varying degrees of guidance on sampling methods and analysis for routine monitoring. Most policies do not specify the type of sample or analysis method, which could lead to differences in how risks are assessed. There is also a poor inclusion of uncertainty in risk assessments and evaluation. In two clear cases, Australia and California, uncertainty is set aside in the analysis of samples. The policy that most clearly addresses uncertainty is that of the EU, which provides the guidance of applying the precautionary principle.

This thesis partially fulfils the purpose which it set out to, i.e., to understand the risk management policy context of the agricultural application of treated wastewater in the EU. Future research could look at how complexity and uncertainty are or are not incorporated in risk assessments and risk evaluations of water reuse. The field would benefit from an in-depth case study analysis encompassing additional policies and potential interviews with operators and other stakeholders involved in the process. Further research on the influence of Regulation 2020/741 on risk perception and public acceptance would also be beneficial. Both the EU and Australia lay out frameworks to guide states under their purview, however, it remains to be seen if the frameworks provide enough guidance to set a unified risk strategy, especially regarding the areas of complexity and uncertainty. The practices honed to manage risk have implications beyond the borders of the policies analyzed in this thesis and could shape the sector at large. Influencing the playing field for lower- and middle-income countries' climate adaptations.

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