

CRANFIELD UNIVERSITY

TOM DOLAN

**WATER FRAMEWORK DIRECTIVE ARTICLE 7, THE
DRINKING WATER DIRECTIVE AND EUROPEAN PESTICIDE
REGULATION: IMPACTS ON DIFFUSE PESTICIDE
POLLUTION, POTABLE WATER DECISION MAKING AND
CATCHMENT MANAGEMENT STRATEGY**

SCHOOL OF APPLIED SCIENCES

ENGINEERING DOCTORATE (ENGD)

Academic year 2013

Supervisors

D. J. Parsons, P. Howsam, M. Whelan and L. Varga

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October 2013

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Abstract

The European Water Framework Directive (WFD) promotes increased awareness of catchment processes and challenges the established dependence on a ‘treatment-led approach’ for the supply of European Drinking Water Directive (DWD) compliant potable water. In particular, WFD Article 7 promotes a ‘prevention-led approach’ to DWD compliance, based on pollution prevention at source to reduce investment in new treatment. In this context the challenge of preventing diffuse pesticide pollution from agricultural sources is significant because metaldehyde (a molluscicide) and to a lesser extent the herbicide clopyralid are, despite current treatment, causing DWD non compliance for drinking water in a number of English catchments. Analysis presented here identifies that a successful transition from a ‘treatment-led’ to a ‘prevention-led’ approach will require collective action from, and shared mutual understanding between, a number of stakeholder groups. However, each of these groups has a unique perspective on WFD Article 7 and other elements of the currently uncoordinated legal and voluntary framework for diffuse pesticide pollution prevention. A toolbox of intervention options and a set of criteria to evaluate current catchment management actions are proposed to help the WFD competent authority facilitate WFD Article 7 compliance. Water suppliers need to improve their understanding of the reasons for pesticide use. Through consultation with pesticide agronomists, important drivers of pesticide use, a hierarchy of adaptation options available if a particular pesticide is restricted and key messages for catchment managers and regulators were identified. Based on this foundation a classification system to inform and prioritise water sector decision making for investment in catchment management was developed. Additionally, analysis presented here demonstrates that the DWD standard

for pesticides, which determines the level of catchment management required for WFD Article 7 compliance, is not itself consistent with European environmental policy principles, particularly the precautionary principle, and needs to be reviewed.

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List of Papers

Five Papers were produced as part of this Thesis:

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Notation

AA	Annual Average
AIC	Agricultural Industries Confederation
AICC	Association of Independent Crop Consultants
AMP	Asset Management Plan
BAU	Business as Usual
CAP	Common Agricultural Policy
CatchIS	Catchment Information System
CPA	Crop Protection Association
CPMP	Crop Protection Management Plan
CRD	Chemical Regulation Directorate
CTU	Chlortoluron
Defra	Department for Environment, Food and Rural Affairs
DPSIR	Drivers-Pressures-State-Impacts-Responses
DrWPA	Drinking Water Protected Area
DWD	Drinking Water Directive
DWI	Drinking Water Inspectorate

EA	Environment Agency
EC	European Commission
ECSFDI	England Catchment Sensitive Farming Delivery Initiative
EFSA	European Food Safety Authority
ELS	Entry Level Stewardship
EPA	Environmental Protection Agency
EPPO	European and Mediterranean Plant Protection Organisation
EQS	Environmental Quality Standards
ESTO	European Science and Technology Observatory
EU	European Union
FOOTPRINT	Functional Tools for Pesticide Risk Assessment and Management
GV	Guideline Value
H _a	Alternative Hypothesis
HLS	Higher Level Stewardship
H _n	Null Hypothesis
IPU	Isoproturon
LOAEL	Lowest Observed Adverse Effect Level

MAC	Maximum Allowable Concentration
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MSG	Metaldehyde Stewardship Group
NE	Natural England
NHMRC	National Health and Medical Research Council
NOAEL	No Observed Adverse Effect Level
NRMMC	Natural Resource Management Ministerial Council
Ofwat	The Water Services Regulation Authority (England and Wales)
OSR	Oil Seed Rape
PoMs	Programme of Measures
PPP	Plant Protection Products
PR	Periodic Review
PSD	Pesticide Safety Directorate
RBD	River Basin District
RBMP	River Basin Management Plan
RfD	Reference Dose

SDWA	Safe Drinking Water Act
TDI	Tolerable Daily Intake
UF	Uncertainty Factors
UKTAG	United Kingdom Technical Advisory Group
UN	United Nations
VI	Voluntary Initiative
WFD	Water Framework Directive
WHO	World Health Organization
WSP	Water Safety Plan
WTW	Water Treatment Works

Chapter 1: Introduction

Chapter 1: Introduction

1.1 Research Question and Objectives

1.1.1 Research question:

What are the implications of the Water Framework Directive and other relevant European legislation for the management of potable water quality with respect to pesticides?

1.1.2 Research objectives:

Objective 1: to analyse the legal framework for ‘raw’ water quality, potable water, pesticide use and approval.

Objective 2: to identify the agronomic drivers of pesticide use

Objective 3: to critique current water sector investment strategy processes

Objective 4: to develop a decision support process to (a) analyse implications of WFD Article 7 targets for ‘raw’ water quality at the point of abstraction; (b) plan for possible impacts of European pesticide approval legislation on the types and concentrations of pesticide active substances present in ‘raw’ water at the point of abstraction (c) assess the significance of any active substance to water supplier investment in pesticide management (treatment or pollution prevention)

1.2 Research focus:

The research is primarily focused on WFD Article 7 protected areas for surface water abstraction, diffuse pesticide pollution from agricultural sources, the current and future legislative context (European and Member State), the underlying agricultural context (European and Member State), and catchments in the Anglian Water region.

Where appropriate, findings from the research have been generalized to apply to any surface water WFD Article 7 protected area in Europe and the water suppliers abstracting from these catchments.

1.3 Research context

A number of interconnected themes linked to the research question create the need for the body of research presented in this thesis; an overview of each of these themes is given in sections 1.3.1 - 1.3.9.

1.3.1 Theme 1: The European DWD standard for pesticides

The DWD has been in place since 1980 (EC, 1980; EC, 1975) and was renewed in 1998 (EC, 1998), it takes the philosophical position that no pesticide active substance should be present in drinking water (Hey, 2006; Jordan, 1999), and regulates accordingly by setting a 0.1µg/l standard for individual pesticide active substances (a value of 0.03 µg/l is applied for the active substances aldrin, dieldrin, heptachlor and heptachlor epoxide), and a 0.5µg/l standard for total pesticides. These standards are maximum allowable concentrations (MACs) that require absolute compliance.

1.3.2 Theme 2: Diffuse pesticide pollution

Diffuse pollution from agricultural sources is a problem for water quality (Novotny and D'Arcy, 2005; Orr et al., 2007; Chon et al., 2012), WFD compliance (Heinz, 2008) and the supply of DWD compliant potable water (Keirle and Hayes, 2007). The Environment Agency of England and Wales identify 'diffuse pollution as a bigger threat to river water quality than point source pollution' (Environment Agency, 2007; National Audit Office, 2010). Often it is difficult to diagnose the cause of a known diffuse pollution problem, and difficult to regulate, prevent or mitigate even when the need for action is widely recognised (Glass et al., 2006; Garrod et al., 2007; Humphrey, 2007; Garthwaite et al., 2008; Wang and Yang, 2008; Yang and Wang, 2010).

1.3.3 Theme 3: Water Sector preference for treatment-led approaches to DWD compliance

Historically, in response to the risk posed by pesticide pollution, treatment has offered water suppliers a certainty of DWD compliance for pesticide parameters that catchment management cannot yet match. Therefore, investment has been based predominantly on treatment. For example, in the period 1984-89, Anglian Water Services (AWS) installed a high level of treatment based upon granular activated carbon (GAC) and ozone at all surface water treatment plants (Croll, 1995); some other English and Welsh water suppliers subsequently made similar investments (Evans et al., 2003).

1.3.4 Theme 4: Pollution prevention at source is a legislative and practical necessity

Legislative factors, primarily driven by WFD Article 7 and the presence of difficult to treat pesticides in raw water are increasing the importance of water supplier investment in catchment management to prevent diffuse pollution at source.

Legislation: Article 174.2 of the consolidated EU Treaty specifies the importance to Community environmental policy of preventative action and rectifying damage at source (EC, 2002). The European Water Framework Directive (WFD) (EC, 2000) embodies this approach. For drinking water supply WFD Article 7 prioritises a prevention led approach to compliance with the DWD (EC, 1998). In addition, European pesticide legislation through Directive 09/128/EC on the sustainable use of pesticides (EC, 2009b) and Regulation 1107/2009 concerning the placing of plant protection products on the market (EC, 2009a) make these principles explicit for pesticides by regulating pesticide use and pesticide approval respectively. Therefore, as a direct consequence of European legislation, catchment management to prevent pollution at source is of increasing importance to water suppliers and the catchments from which they abstract for drinking water supply.

Additionally, from an international perspective the World Health Organisation (WHO) promotes a drinking water safety planning (DWSP) approach (World Health Organisation, 2011) the aim of which is to increase understanding of and mitigate risks throughout the supply chain from catchment to customer (Breach, 2011).

Untreatable active substances: Two active substances, metaldehyde and clopyralid cannot be removed from 'raw' water using current treatment infrastructure in place at

AWS and other UK water suppliers. Water sector research indicates that currently no new treatment technology gives effective removal of these active substances (UKWIR, 2011; Autin et al., 2013; Tizaoui et al., 2011). Additionally, a number of other active substances have been identified as ‘at risk’ of causing DWD compliance problems for water companies with less installed treatment infrastructure (Kennedy, 2010).

1.3.5 Theme 5: The Water Framework Directive (WFD) creates uncertainty for water supplier investment planning

WFD Articles 1 and 4 (EC, 2000) require necessary measures to prevent deterioration in water quality and to deliver good chemical, ecological and hydromorphological status in all surface water bodies. Article 16 requires identification of priority substances and priority hazardous substances for inclusion in chemical status targets (EC, 2001; EC, 2008; EC, 2012) and Annex V requires identification of specific pollutants for inclusion in ecological targets (UKTAG, 2008b; UKTAG, 2012). At the present time relatively few approved pesticide active substances are included in these targets. Nevertheless, these targets may have some impact on pesticide concentrations in ‘raw’ water at the point of abstraction for potable water supply.

WFD Article 7 requires the creation of protected areas at all points of abstraction for potable water supply and sets targets to avoid deterioration of water quality and reduce the level of treatment needed to produce DWD compliant drinking water. These targets apply to all approved pesticide active substances and pollution prevention at source is required to achieve these targets. Who is responsible for these targets, how they will be delivered and how compliance will be measured remains

uncertain. Additionally, what level of action the competent authority will take when a catchment is failing to comply (Kennedy, 2010; Defra, 2012; Kennedy et al., 2009), whether 2015 is a fixed target date for compliance, and whether water suppliers can legitimately propose additional investment in treatment infrastructure (UKTAG, 2008a; DWI / EA, 2012) all remain unclear.

Therefore, WFD Article 7 is significant to water sector decision making because it has an influence on both the absolute level of investment required, and the relative allocation of such investment between catchment management and additional treatment infrastructure. Compliance with WFD Article 7 will lead to Drinking Water Directive (DWD) compliance. However, in the event of a Member State failing to deliver WFD Article 7 compliance in a catchment, the water supplier will be legally responsible for any failure to comply with the DWD.

1.3.6 Theme 6: The full impacts of European pesticide approval legislation remain unknown

European pesticide approval legislation is independent of the WFD. It requires all pesticide active substances to be reapproved on a ten year rolling basis and makes approval decisions based upon a set of criteria not defined by the WFD. As a consequence, European pesticide approval legislation is changing the baseline of pesticide active substance use from which WFD targets must be achieved. Therefore, water suppliers, their regulators and the competent authority for the WFD need to understand the significance of European pesticide approval legislation when planning actions for WFD compliance.

Regulation 1107/2009, part of the European thematic strategy on pesticides (EC, 2009a; EC, 2009b; EC, 2009c), specifies the criteria a pesticide active substance must satisfy before it is approved for use in Europe. Regulation 1107/2009 is more stringent than the previous approval Directive (91/414/EEC (EC, 1991)). Regulation 1107/2009 will, therefore, reduce the number of active substances available to agriculture. However, because endocrine disruptor criteria are yet to be defined (Kortenkamp et al., 2011; EFSA Scientific Committee, 2013), it is uncertain what the scale of this loss will be and which active substances will be lost (PSD, 2009; KEMI, 2008).

1.3.7 Theme 7: Catchment management is of uncertain and variable efficacy

Catchment management interventions to prevent pesticide pollution at source are subject to aleatory uncertainty caused by factors such as rainfall, and epistemic uncertainty caused by incomplete knowledge of the unique nature of diffuse pollution pathways in any catchment (Reichenberger et al., 2007; Brown and van Beinum, 2009; Tediosi et al., 2012; Tediosi et al., 2013).

In England and Wales, the development of catchment management to control diffuse pesticide pollution has been relatively uncoordinated. A range of schemes (Natural England, 2012; Environment Agency, 2013; National Demonstration Test Catchment Network, 2013) have been put in place and key learning points from these are beginning to be identified (Catchment Change Network, 2013; Cascade Consulting, 2013). However, in the majority of cases preventing the presence of pesticide active substances in ‘raw’ water at the point of abstraction has not been the primary purpose

of catchment management. Pesticides cause less visible problems than nutrients (nitrates and phosphorus), are rarely the cause of ecological or human health concerns in the aquatic environment, and with few exceptions not subject to WFD Ecological or Chemical status targets. As a consequence the efficacy of prevention interventions for diffuse pesticide pollution remains uncertain as do the reason for the variation in efficacy of interventions within and between different catchments.

There is, therefore, little track record of successful catchment management implementation for water suppliers to learn from and water suppliers lack complete knowledge of the sources and pathways through which pesticide active substances move to the point of abstraction. Water suppliers are, therefore, reluctant to commit resources to, or risk reputations on, unproven catchment management interventions.

It follows that before effective catchment management strategies can be developed, water suppliers need to characterise their catchments and identify the highest risk sources and pathways of diffuse pesticide pollution. To do this water suppliers may need to engage with agriculture to gain greater mutual understanding of the reasons for pesticide use and the problems pesticides cause water suppliers

1.3.8 Theme 8: Mutual understanding between water suppliers, agriculture and regulators is required to enable catchment management

In many catchments, the implementation of catchment management is beyond the direct control of a water supplier. This is mainly because the water supplier does not own the land, and cannot compel a land manager to change their behaviour. In such situations catchment management requires partnership working between land

managers, pesticide agronomists, water suppliers, pesticide manufacturers, and the WFD competent authority. A lack of established relationships between these groups can be a short term barrier to catchment management. Therefore, water suppliers need to build working relationships in their catchments to enable knowledge to be shared and mutually beneficial solutions for water quality problems to be identified and implemented.

1.3.9 Theme 9: Absolute compliance with the DWD standard for pesticide active substances is potentially inconsistent with pollution prevention at source

The DWD is referenced directly in WFD Article 7.2, and therefore, dictates the level of prevention actions required for WFD Article 7 compliance. Catchment management interventions to prevent diffuse pollution are by their very nature subject to epistemic and aleatory uncertainty. Therefore, a DWD standard based upon a maximum allowable concentration (MAC) that requires absolute compliance is perhaps inconsistent with the prevention-led approach promoted by WFD Article 7. It follows, that whether the standard remains consistent with European principles for environmental policy (as defined in Article 174.2 of the European Treaty) (EC, 2002), and the precautionary principle (European Commission, 2000) is an important debate if resources for pollution prevention at source are to be allocated to those pollutants for which they are most needed.

1.4 Thesis structure

1.4.1 Introduction

The research objectives gave rise to five Papers and outputs for AWS and the water sector (Figure 1.1). Together these Papers represent a co-ordinated body of research (Figure 1.2). Chapters 2 to 6 each present a Paper. Chapter 7 places the research in the industrial context. Chapter 8 integrates themes from each of the Papers.

1.4.2 Thesis structure

Chapter 1 Introduction

Chapter 2 Diffuse pesticide pollution of drinking water sources: impact of legislation and UK responses

Chapter 3 Impact of WFD Article 7 on DWD Compliance for Pesticides: Challenges of a prevention-led approach

Chapter 4 Is the EU Drinking Water Directive Standard for Pesticides in Drinking Water Consistent with the Precautionary Principle?

Chapter 5 Identifying Adaptation Options and Constraints: The Role of Agronomist Knowledge in Catchment Management Strategy

Chapter 6 Pesticide Active Substance Classification: A Systematic Approach to Potable Water Investment Decision Making

Chapter 7 Improving Knowledge and Processes: Commercial Significance of Research Outputs for Anglian Water Services Ltd

Chapter 8 Integrated Discussion

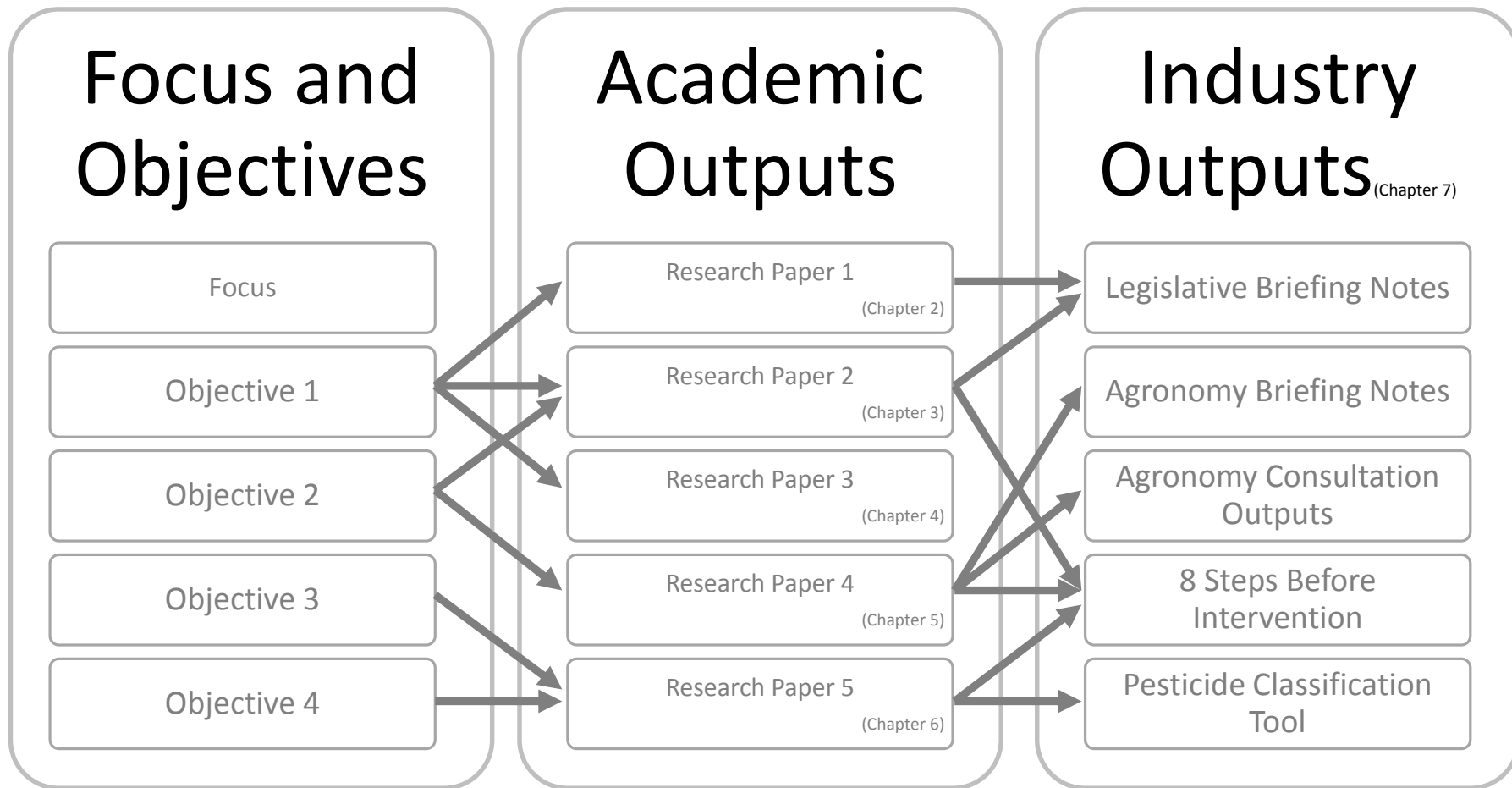
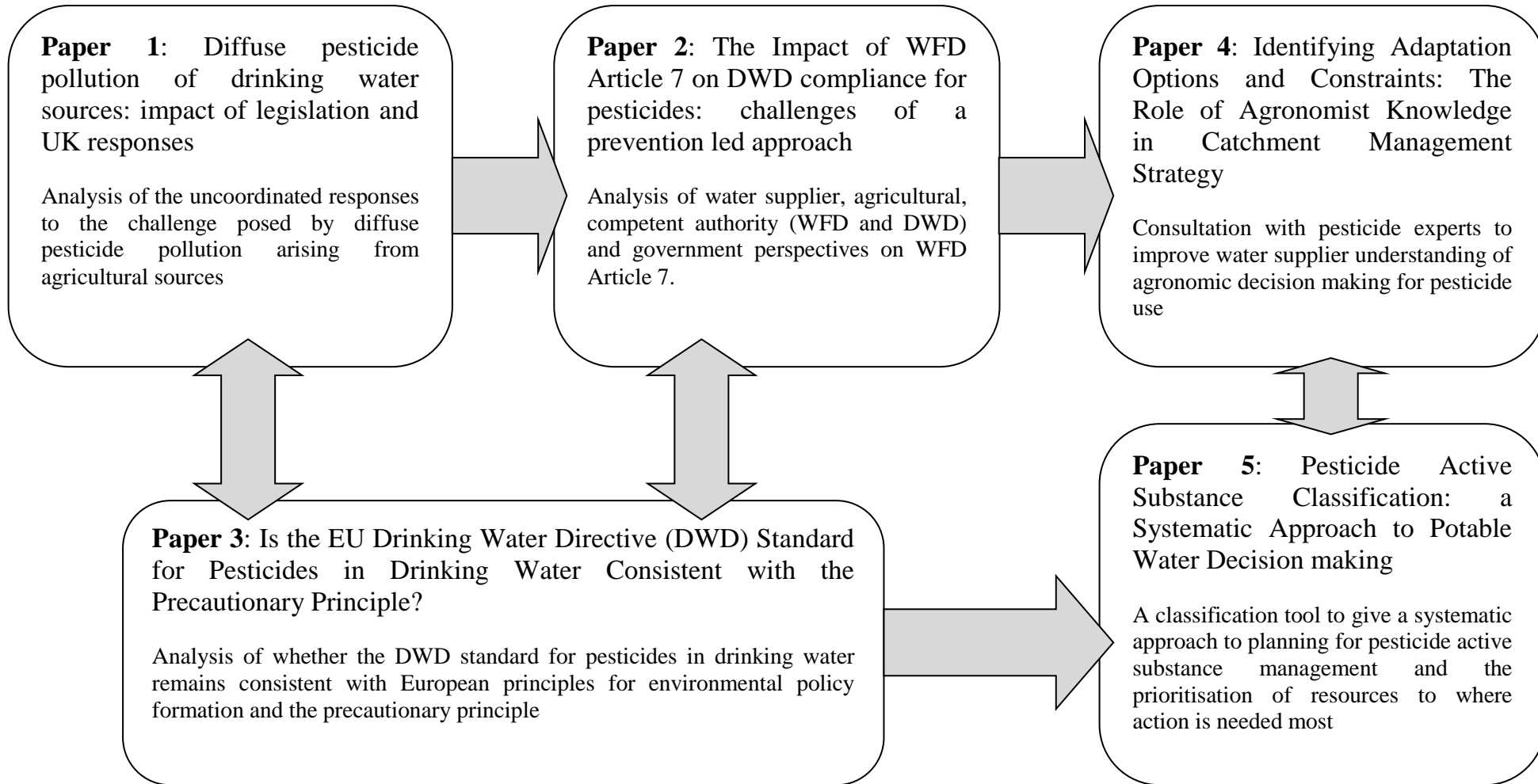


Figure 1.1 Research overview

Figure 1.2 Connections between Papers



1.4.3 Literature review

Literature review is integrated into each of the Papers to support the analysis presented. For this reason, no Chapter is dedicated to the presentation of a literature review.

1.4.4 Research methods

A variety of research methods were applied as part of the research. Relevant details of these research methods are integrated into the Papers.

1.4.5 Student declaration

The Papers presented in Chapters 2-6 of this thesis are the work of the research student. In all cases the content and concept for the Paper were developed by the research student and the Paper was written by the research student. Project supervisors are included as named authors on all five papers.

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**Chapter 2: Diffuse Pesticide Pollution of Drinking
Water Sources: Impacts of Legislation and UK
Responses**

Chapter 2: Paper 1

Sections 2.2 - 2.8 of this Chapter were originally published by IWA Publishing in *Water Policy*: The official journal of the World Water Council:

Dolan, T., Howsam, P. and Parsons, D. J. (2012b), "Diffuse pesticide pollution of drinking water sources: impact of legislation and UK responses", *Water Policy*, vol. 14, no. 4, pp. 680-693. DOI: 10.2166/wp.2012.147

2.1 Preface

2.1.1 Context

The Paper presented in sections 2.2 - 2.8 of this Chapter was written to analyse the role that the WFD (EC, 2000), European pesticide legislation (EC, 2009a; EC, 2009b; EC, 1991) and Member State responses have to play in preventing diffuse pesticide pollution, improving the quality of ‘raw’ water and reducing the level of treatment required to produce potable water to DWD standards (EC, 1998). In so doing the Paper responds to research objective 1, addresses a number of key questions not answered elsewhere in the literature (Table 2.1) and lays a foundation for the research presented in subsequent Chapters of this thesis.

Table 2.1 Questions addressed in paper

In what ways are WFD targets (chemical status, ecological status and Article 7) relevant for pesticides?
In what ways are WFD targets relevant to water quality at the point of abstraction?
What actions are going to be initiated to achieve WFD compliance for pesticides?
Which active substances are subject to both the independent action of European pesticide approval regulation and WFD status targets (ecological or chemical)?
Can European pesticide approval legislation be used as a mechanism to withdraw an active substance causing WFD status or Article 7 problems?
Will additional pesticide active substance withdrawals be required at the Member State level to achieve WFD targets?
What impact will WFD targets for pesticides have on planning by water companies for DWD compliance?
Do the requirements of the Sustainable Use of Pesticides Directive (Dir. 128/09/EC) (EC, 2009a) support WFD Article 7 targets for water quality at the point of abstraction?
Will the Sustainable Use of Pesticides Directive compliance require action over

and above the voluntary, and statutory good practice currently in place in England?

The level of treatment required for DWD compliance is considered in WFD Article 7; is this also a criterion in the European pesticide approval process?

2.1.2 Review of analytical techniques

A systems engineering ‘Inputs - transformation process – outputs’ model (The Open University, 2013), The DPSIR (Driving Forces – Pressures – State – Impacts – Responses) Framework (Gabrielsen and Bosch, 2003; Kristensen, 2004) and the Source-Pathway-Receptor model (Gormley et al., 2011) are used in the Paper to frame the analysis.

Use of these techniques in combination allowed the problem of diffuse pesticide pollution in the potable water supply to be conceptualised on a range of levels. The systems thinking conceptual model presented potable water supply as an industrial process. The source-pathway-receptor model provided a lens to examine processes at the catchment level and add catchment based risk assessment and management to the front end of the potable water supply process. The DPSIR framework provided a strategic overview of those factors taking place at ‘source’ in the source-pathway-receptor model and, therefore, provided insight into the underlying causes of diffuse pesticide pollution and possible responses to mitigate the problem. Super-imposing the ‘response’ element of the DPSIR framework onto the source-pathway-receptor model made it possible to analyse at what level in the catchment actions designed to reduce diffuse pesticide pollution were most likely to act.

Where a clearly defined research question can be identified, comparative content analysis provides a rigorous method to compare the text of two or more technical documents and is particularly useful for evaluating legal ambiguity (Robson, 2002). This technique was applied throughout the Paper to analyse legislative and technical documents and address many of the questions stated in Table 2.1.

2.1.3 Significance to thesis

Analyse undertaken for, and conclusions drawn from, the Paper presented in this Chapter provide justification for further analysis of stakeholder perspectives on WFD Article 7 (Chapter 3), the logical basis of the European Drinking Water Directive standards for pesticides (Chapter 4) and for consultation with agronomists to understand more about the drivers of pesticide use by agriculture (Chapter 5).

2.2 Abstract

Diffuse pesticide pollution is a problem for the environment, but it also presents a challenge for water companies managing treatment infrastructure to produce potable water. The legal framework for this context has three main components: that dealing with pesticides and pesticide use, that dealing with environmental water quality and that dealing with drinking water quality. The study set out to identify, interpret and assess the impact of the legal framework related to this challenge. The study found that the current policy and legislation do not provide a coordinated legal framework and some changes are warranted. For example the Water Framework Directive (WFD) sets environmental quality standards for some, but not all, pesticides. Article 7 provides special protection of water bodies used as sources for drinking water supply, but it is not clear whether the UK will achieve full compliance by 2015. This is a problem for water companies planning investment, because the WFD and Drinking Water Directive remain legally distinct. Further uncertainty arises from the application of Regulation (EC) 1107/2009 and the extent that restricted availability of pesticides will drive changes in agricultural practice and pesticide use.

2.3 Introduction

The presence of pesticides in “raw” water is a challenge for water companies producing potable water. Historically, a water company has applied the necessary level of treatment to remove pesticides and comply with Drinking Water Directive (DWD) (EC, 1998) standards for potable water. Protection of surface waters used for drinking water supply has been afforded under Directive 75/440/EEC (EC, 1975), but in 2000 the Water Framework Directive (WFD) (EC, 2000) changed the emphasis away from investing in treatment infrastructure to preventing pollution at source.

Special attention is given to water abstraction points, designated as Drinking Water Protected Areas (DrWPAs) in the UK. WFD obligations and targets have increased awareness of diffuse pesticide pollution and driven increased catchment management activity to prevent it. The Voluntary Initiative (VI) is one of many examples and, in parallel since 2005, Environmental stewardship schemes have increasingly encouraged land managers to consider the environment, including water quality, when making decisions. In 2009, following three years of discussion, the EU thematic strategy on pesticides was published making the criteria for pesticide approval more stringent and promoting sustainable use of all pesticides throughout Europe. This comprised Regulation (EC) 1107/2009 concerning the placing of plant protection products (PPPs) on the market (EC, 2009b), and Directive 09/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides (EC, 2009a).

The combined impact of these developments on the level of pesticides found in “raw” water needs to be examined. Important questions include the meaning of WFD targets for pesticides and how they might be achieved, whether additional pesticide withdrawals will be required and what impact WFD targets for pesticides will have on planning by water companies for DWD compliance. To answer these it is necessary to consider the impact of Regulation (EC) 1107/2009 on future pesticide use patterns, the extent to which the Directive 09/128/EC complements existing UK efforts to deliver WFD targets and whether agri-environment schemes, such as Entry Level Stewardship (ELS), can be used to deliver WFD targets for pesticides. Previous research has considered many of these issues in isolation; (Garratt and Kennedy, 2006; Garrod et al., 2007; Glass et al., 2008; PSD, 2009; Humphrey, 2007; Hodge and

Reader, 2010; Posthumus and Morris, 2010) but there has so far not been an assessment of the whole framework.

This paper analyses the role that the WFD, European pesticide legislation, and UK driven responses such as the voluntary initiative and environmental stewardship have to play in preventing diffuse pesticide pollution, improving the quality of “raw” water and reducing the level of treatment required to produce potable water to DWD standards. Additionally, the impact of these responses on long term planning for water treatment work (WTW) investment by water companies is assessed.

2.4 Potable water production and diffuse pesticide pollution

2.4.1 Potable water production

Water companies manage a transformation process, illustrated as a conceptual model in Figure 2.1, in order to produce drinking water to clearly defined standards under the Drinking Water Directive (DWD) from raw materials of unknown and variable quality.

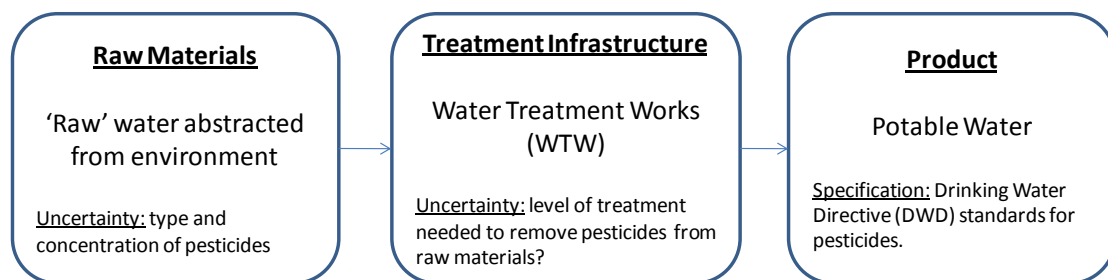


Figure 2.1 Conceptual model for potable water production

Unlike many industries, the water sector cannot define the specifications for the raw materials they work with. Instead they abstract “raw” water from the environment and operate a treatment infrastructure capable of managing variation in a broad number of

substances (e.g. nitrate, phosphate, sediment, heavy metals, pathogens and pesticides) to ensure the finished product, potable water, complies with quality standards for water intended for human consumption.

2.4.2 Diffuse pesticide pollution

Diffuse pollution (pollutant transport from land to water) is a major problem for “raw” water quality in many UK drinking water supply catchments. The Environment Agency of England and Wales now regards diffuse pollution as a bigger threat to river water quality than point source pollution (Environment Agency, 2007). This is, in no small measure, due to the difficulty of regulating or preventing diffuse pollution and the need for additional action to address the issue has been widely recognised (Garrod et al., 2007; Humphrey, 2007; Garthwaite et al., 2008; Glass et al., 2006). The largest source of diffuse pesticide pollution in most catchments is believed to be agriculture, particularly where arable agriculture is the major land use. However, in some catchments amenity use, for example on roads and railways, represents a potentially significant source of diffuse pesticide pollution. One of the most challenging diffuse pollution issues currently facing a number of water companies in the UK is the presence of pesticides such as metaldehyde and clopyralid, at levels that cannot easily be reduced by current WTW infrastructure to the potable water standards defined by the DWD.

In principle, the best strategy to tackle diffuse pollution of any type is catchment management. Catchment management requires appropriate interventions at source to manage application of pesticides and to reduce the risk of flow through each pathway into a DrWPA. The principles of catchment management for pesticides are supported

in European legislation through the WFD and the pesticide sustainable use directive (Directive 09/128/EC) (EC, 2009a). In England and Wales, the issue is addressed by the Environment Agency (EA), the Government's water strategy for England (Defra, 2008), the Government pesticide strategy and water action plan (Defra, 2006b; Defra, 2007) and government and industry partnerships such as the VI in the agricultural sector and the Amenity Forum (The Amenity Forum, 2011) in the amenity sector. Further initiatives include the England Catchment Sensitive Farming Delivery Initiative (ECSFDI), the code of practice for using plant protection products (Defra, 2006a) and guidance provided by industry bodies including the Metaldehyde Stewardship Group (MSG) and Water UK.

Figure 2.2 presents a targeted use of the driving forces–pressures–state–impact–response (DPSIR) framework to assess the problem of diffuse pesticide pollution from agriculture in the context of producing potable water to DWD standards.

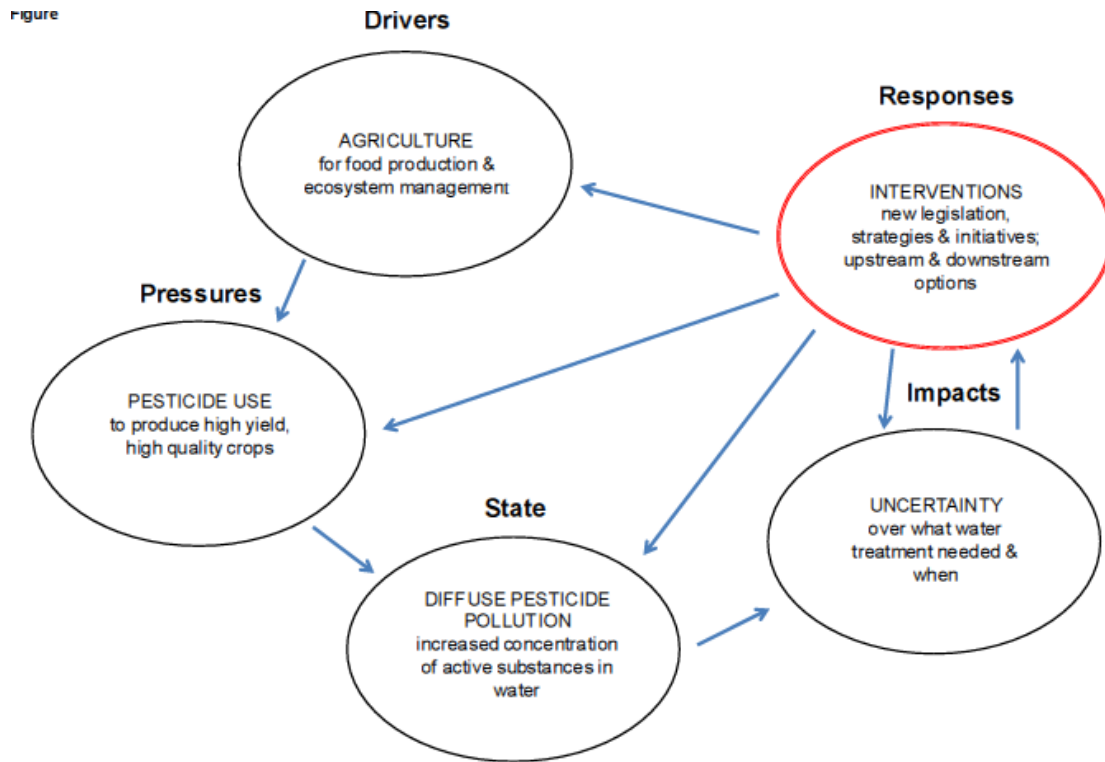


Figure 2.2 DPSIR analysis of diffuse pesticide pollution by agriculture (adapted from Kristensen, 2004)

The response element of the DPSIR framework is central to this paper because it includes all EU and UK driven responses to reduce pesticide use, pesticide availability and to influence pesticide user behaviour. The aim of these responses is to reduce diffuse pesticide pollution and improve the quality of “raw” water in the water environment; this paper assesses how effectively these responses deliver these objectives.

The Source-Pathway-Receptor model in Table 2.2 helps to identify where responses or interventions should be targeted. It illustrates the complexity of managing diffuse pesticide pollution, because pollution can arise from a number of sources and can pass through the environment by many routes before reaching the receptor, in this case the “raw” water abstraction point.

Table 2.2 Source-pathway-receptor analysis of diffuse pesticide pollution

Source (diffuse pollution)	Pathway	Receptor
Agricultural application	<ul style="list-style-type: none"> • Surface runoff • Spray drift • Drainflow • Handling • Mixing • Storage • Disposal 	Surface water abstraction point
Professional amenity use		
Non professional amenity use		

Table 2.3 categorises these possible responses as interventions acting at source, pathway or receptor level. Source interventions are those that reduce the availability of pesticide active substances, pathway interventions are those that aim to reduce the concentrations applied and block pathways to the water environment and receptor interventions act once pesticides are in the “raw” water. The WFD is a significant response to water quality problems because, through Article 7, it sets targets for water quality at the receptor and then promotes the use of source and pathway interventions to achieve these.

Table 2.3 Source-pathway-receptor interventions to manage diffuse pollution

Source Interventions	Pathway Interventions	Receptor Interventions
Mixed methodology interventions		
Water Framework Directive (WFD)		
<p>Hard Regulation to limit pesticide availability</p> <ul style="list-style-type: none"> • Dir. 91/414/EEC • Reg. 1107/2009 • UK approval decisions 	<p>Catchment Management</p> <ul style="list-style-type: none"> • Dir. 09/128/EC • VI, ECSFDI • ELS, HLS, OELS, SPS • UK Pesticide Strategy 	<p>Treatment to remove pollutants from the water supply</p>

Predicting the impact of this mix of legal requirements and voluntary schemes is key to the long term planning for WTW investment by water companies.

2.5 Discussion–responses to improve water quality through reduced diffuse pesticide pollution

2.5.1 Water Framework Directive (WFD)

Introduced in 2000, the WFD is the main piece of EU legislation for the management of water quality and pollution at the river basin level. Chave (2001) describes it as “probably the most significant legislative instrument in the water field to be introduced for many years” and more broadly as “the most significant legal instrument adopted in the environmental field as it directs how an environmental sector is to be managed, institutionally and as a whole”

The first obligation under the WFD (Article 1 & Article 4) is to take all necessary measures to prevent deterioration in water quality and then to aim to achieve good status, for all bodies of water, with limited exceptions. For surface waters, status includes chemical, ecological and hydromorphological elements, whereas for ground waters only chemical and quantitative elements apply. Article 6 of the WFD requires the creation of a register of all protected areas already created under previous EU legislation as listed in Annex IV.

Article 7 requires the identification of “all bodies of water used for the abstraction of water intended for human consumption providing more than 10 m³/day as an average or serving more than 50 persons” and specifies water quality objectives for these protected areas that must be achieved by 2015 (Article 4.1c). In England and Wales

these areas have been designated as DrWPAs. These DrWPAs are subject to the objectives defined in Article 7.2 and 7.3. In effect Article 7 replaces the obligations of Directive 75/440/EC (as amended) concerning the quality required of surface water intended for the abstraction for drinking water, which was repealed in 2007.

Implementation of the WFD has led to the production of river basin management plans (RBMPs), under WFD Article 13. Each RBMP includes a programme of measures (PoMs), as required by Article 11, to specify how the objectives defined in Article 4 (no deterioration and achievement of “good” status, including special requirements for designated protected areas) will be achieved. In England, the PoMs make reference to actions from many stakeholders under existing legislation and ongoing UK initiatives to specify how progress toward status targets and protected area objectives will be delivered.

2.5.1.1 Pesticides in the WFD

A pesticide active substance can only affect achievement of status targets if it is subject to an environmental quality standard (EQS). To be subject to an EQS the active substance must be classified as a priority substance or a priority hazardous substance in WFD Annex X (EC, 2001) or be classed as a “specific pollutant” (SP) at Member State level. In the UK, the United Kingdom Technical Advisory Group (UKTAG) is responsible for identifying SPs and defining EQS for these (UKTAG, 2008b). Currently, in the UK only ten of the 278 approved pesticide active substances are subject to EQS as a priority substance or specific pollutant. This figure of ten includes six priority substances, four of which were proposed, but are yet to have EQS defined (EC, 2008), and one that is expected to be withdrawn under the new approval

regulation (Regulation (EC) 1107/2009) and four specific pollutants, three of which might be withdrawn under Regulation (EC) 1107/2009. Therefore, at most only 4% of currently available pesticide active substances can directly influence the achievement of good status targets. This is significant because the WFD as currently applied in the UK does not target all pesticides, in all water bodies; rather the WFD focus on pesticides is restricted to the protected areas (DrWPA) identified under Article 7. Furthermore, because EQS are not linked to DWD standards for pesticides, it follows that general action against pesticides is not designed to support the achievement of WFD Article 7 objectives. The main drivers in the WFD to reduce diffuse pesticide pollution and improve raw water quality are the objectives for DrWPAs, as defined in WFD Article 7 (EC, 2000). These are applicable to all pesticide active substances. For surface water DrWPAs, Article 7 objectives are additional to and do not affect the achievement of overall status targets, whereas a groundwater DrWPA cannot achieve good overall status if it is failing to achieve DrWPA objectives.

A briefing note from UKTAG (UKTAG, 2008a) provides the clearest guidance on how these objectives are interpreted in the UK. The following paragraphs reproduce Article 7.2 and 7.3 of the WFD and offer interpretation of their significance to diffuse pesticide pollution and potable water production.

Article 7.2 “.....Member States shall ensure that under the water treatment regime applied and in accordance with Community legislation, the resulting water will meet the requirements of Directive 80/778/EEC as amended by Directive 98/83/EC [the DWD].”

Article 7.3 “Member States shall ensure the necessary protection for the bodies of water identified with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water. Member States may establish safeguard zones for those bodies of water.”

Article 7.2 links Article 7 objectives for “raw” water in DrWPA to existing standards defined in the DWD. For pesticides, the DWD specifies that an individual pesticide cannot be present in drinking water at a concentration greater than $0.1 \mu\text{g l}^{-1}$ and that the total pesticide concentration must be below $0.5 \mu\text{g l}^{-1}$. Article 7.2 does not specify how DWD standards are to be met, simply that they must be met. Article 7.3 specifies the need for protection to avoid deterioration in the quality of “raw” water used for potable water production and sets the long term goal to reduce the level of treatment infrastructure. Together Article 7.2 and 7.3 imply that, in those DrWPA compliant with Article 7, a water company should be able to meet DWD standards for all pesticide active substances through continued and eventually reduced provision of existing water treatment work (WTW) infrastructure.

Given this interpretation, the achievement of Article 7 objectives for pesticides depends entirely upon the extent to which catchment management can be applied in and upstream of DrWPAs to improve “raw” water quality and prevent the presence of pesticides at concentrations that cannot be managed with the current treatment infrastructure. It follows that water company investment continually to improve the WTW infrastructure, as has historically been the case to ensure compliance with DWD standards, is against the spirit of WFD Article 7. Instead interventions should focus on stabilising and reducing pesticide concentrations in “raw” water in DrWPAs

to ensure that the current treatment infrastructure is sufficient to meet DWD standards.

Article 7.3 mentions safeguard zones as a tool to support Article 7 objectives, however no further details are provided in the WFD. In England, work is underway in partnership between the EA and water companies (personal communication with Simon Eyre, Anglian Water Services, 9th May 2011) to designate safeguard zones and produce catchment action plans in order to target measures at areas where the pollution that causes non-compliance with regard to Article 7 originates.

Where Article 7 cannot be achieved through catchment management and targeted use of safeguard zones, the willingness or otherwise of government to restrict use, or revoke approval, of those pesticide active substances causing Article 7 non-compliance will also be critical. Based upon the assumption that, using catchment management alone, the UK will be unable to comply with Article 7 (Clarke et al., 2009; Wynn et al., 2009) identify the possibility that WFD implementation of Article 7 objectives may require withdrawal of up to 13 widely used herbicide and fungicide active substances and many insecticide active substances. The WFD and the new pesticide approval Regulation 1107/2009 provide no mechanism for active substances to be withdrawn at EU level for reasons related to Article 7 objectives. Therefore, the loss of the active substances would have to be driven solely by UK decisions to withdraw an active substance to ensure Article 7 compliance.

The UK Government does have the authority to prohibit active substances, a power used when Isoproturon (IPU) was withdrawn in March 2007. The IPU decision was based upon reservations raised through the active substance approval process under

Directive 91/414/EEC (EC, 1991) and the status of IPU as a WFD priority substance, not over concerns about the ability to achieve Article 7 objectives.

In the UK no precedent exists for the withdrawal of a pesticide active substance for WFD Article 7 objectives. Therefore, for the prediction of pesticide withdrawal to become reality, the government would need to move away from the currently stated preference for voluntary and enhanced voluntary approaches, as embodied in the Voluntary Initiative, ECSFDI and the consultation on Directive 09/128/EC (Defra, 2010b; Defra, 2010a; House of Commons: Environment Food and Rural Affairs Committee, 2005) to a more statutory approach to diffuse pesticide pollution prevention. The government's willingness to withdraw pesticide active substances will be influenced by the level of compliance expected in 2015 and UK Government perception of the risk of infraction proceedings by the EC for failure to comply with Article 7 objectives.

2.5.1.2 WFD impact on water company investment

For a water company aiming to optimise investment in WTW infrastructure and catchment management initiatives and ensure compliance with DWD standards for potable water, the uncertainty generated by WFD Article 7 obligations and the Regulation (EC) 1107/2009 regulatory process is of crucial importance. WFD Article 7.2 makes explicit reference to the DWD but the two Directives remain legally distinct. In England and Wales, the Environment Agency (EA) is responsible for compliance with the WFD and water companies are responsible for DWD compliance. EA failure to comply with WFD Article 7 can jeopardise water company compliance

with DWD, but a water company cannot use WFD Article 7 failure to justify DWD non-compliance.

Article 7 implies that the risk of non-compliance with DWD standards using current treatment infrastructure, in compliant DrWPAs, is virtually zero. However, where compliance is not achieved, the water company risks non-compliance with DWD standards and must take action to manage this risk. In those DrWPAs where the likelihood of WFD Article 7 compliance can be quantified with confidence, water companies can plan the level of investment required for long-term DWD compliance. Therefore, water companies need to work closely with the EA to ensure that the risk assessment process for Article 7 non-compliance for pesticides, initiated in the RBMPs, is completed. In order to support long-term planning for DWD compliance, these assessments must also be shared with water sector regulators OfWat (The Water Services Regulation Authority) and the DWI (Drinking Water Inspectorate).

An additional complication for water sector investment is that the 6 year planning cycles for RBMP under the WFD are not synchronised with the 5 year periodic review and asset management plans investment cycles in the water sector. The next periodic review (PR14) must be finalised before 2014; from a risk averse perspective, investments planned in this cycle must be based upon current knowledge of raw water quality, rather than assumptions of full compliance with Article 7 in 2015. The same applies for PR19, where the best available evidence of WFD compliance will be data in 2015, rather than the promise of future compliance in 2021.

2.5.2 European pesticide thematic strategy

2.5.2.1 Introduction

The EU Thematic Strategy for Pesticides was published in June 2009. It comprises:

- Regulation 1107/2009 concerning the placing of plant protection products (PPPs) on the market and repealing Council Directives 79/117/EEC and 91/414/EEC.
- Directive 09/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides.
- Regulation 1185/2009 concerning statistics on pesticides (EC, 2009c).

Regulation (EC) 1107/2009 and Directive 09/128/EC will have an impact as drivers affecting the type and concentration of pesticide active substances present in DrWPAs.

2.5.2.2 Regulation 1107/2009

Under Directive 91/414/EEC all pesticide active substances had to be approved at the EU level before they could be used in a PPP. Regulation (EC) 1107/2009 (EC, 2009b) replaced Directive 91/414/EEC in June 2011 as the EU level approval mechanism for pesticide active substances. It will apply hazard criteria in addition to the risk criteria already in place. The approval of every active substance will be reviewed between June 14th 2011 and 2021 as current approval periods approach their end.

While Regulation (EC) 1107/2009 is not designed to address the issue of diffuse pesticide pollution, implementation of hazard criteria will reduce the availability of pesticide active substances. This in turn will influence the type and concentrations of

pesticide active substances in DrWPAs. Since Regulation (EC) 1107/2009 was first proposed in July 2006, many impact assessments have attempted to quantify the impacts at the level of active substance availability (PSD, 2009; KEMI, 2008; PSD, 2008a; PSD, 2008b; Rickard, 2009; Richardson, 2009a; Richardson, 2009b). The most recent of these (PSD, 2009) was completed after the final wording of Regulation (EC) 1107/2009 was agreed by an EU Parliament vote in January 2009. The scale of the impact remains uncertain; a minimum scenario will be the loss of the 26 list I active substances before 2021, with a further 60 identified as candidates for substitution (PSD, 2009). However, depending upon the interpretation of the endocrine disruptor criteria, more active substances may be withdrawn. How these endocrine criteria will be interpreted depends upon European Commission guidance which is currently under development.

Candidates for substitution are those substances identified under Regulation (EC) 1107/2009 as targets for replacement by low hazard active substances in the long term. Under Article 24, a candidate for substitution will be renewed for seven years rather than the standard 10 years. (Richardson, 2009b) states that multiple 7 year renewal periods will be available for these active substances. It follows that the timescale over which candidates for substitution will act remains uncertain. Furthermore, whether identification of candidates for substitution will produce innovative solutions by chemical companies, or a slow move by land owners towards non-chemical alternatives is another uncertainty arising from Regulation (EC) 1107/2009.

The restriction in the range of available pesticide active substances will drive behavioural adaptation amongst agronomists, farmers and chemical companies involved in EU agriculture. Alternative solutions, both chemical and non-chemical, will be needed to manage pest, weed and disease problems that were previously effectively controlled by available active substances. Thus the types of pesticide active substances and their concentration in the environment, and specifically in the “raw” water of DrWPAs, will change over time.

Anticipating the impact of Regulation (EC) 1107/2009 on pesticides in water is important to support planning for WFD Article 7 objectives, targeted investment for catchment management and pesticide monitoring actions. Furthermore, the change driven by Regulation (EC) 1107/2009 is important for long-term planning of optimal WTW treatment infrastructure investment for the removal of pesticides in order to produce potable water. At the time of writing no impact assessment of how Regulation (EC) 1107/2009 will affect water quality and WFD Article 7 compliance has been published.

2.5.2.3 Directive 09/128/EC

Directive 09/128/EC formally embodies many of the concepts enacted in the UK under the Voluntary Initiative and ECSFDI to promote pesticide-focused catchment management at the river basin level across the EU. The Directive prescribes the development of National Action Plans for pesticide use and specifies requirements relating to professional user training, point of sale information, public awareness, inspection and certification of application equipment, aerial application, protection of

drinking water and protected areas (DrWPAs), provision for integrated pest management and monitoring trends in pesticide use.

Much of the work required to meet the requirements of this Directive is already underway in the UK. The extent to which the UK currently meets the requirements of the articles of the Directive is laid out in a consultation document (Defra, 2010b) on the implementation of the Directive in the UK. Three implementation options were offered: business as usual (BAU) requiring no extension to existing statutory and voluntary frameworks; increased use of voluntary mechanisms, with statutory support, and stronger statutory action to ensure the UK exceeds the minimum requirements of the Article. It suggests that additional statutory options will be adopted only where voluntary actions cannot deliver the requirements of the Directive.

Article 11 of 09/128/EC makes specific reference to the WFD and drinking water, to specify that measures to deliver 09/128/EC must support delivery of WFD Article 7 objectives.

“Member States shall ensure that appropriate measures to protect the aquatic environment and drinking water supplies from the impact of pesticides are adopted. Those measures shall support and be compatible with relevant provisions of Directive 2000/60/EC and Regulation (EC) No 1107/2009.”

The government position on Article 11 and therefore WFD Article 7, is stated in (Defra, 2010a):

“The WFD will, however, require a reduction in the amount of pesticides detected in surface and ground waters and water abstracted for drinking water purposes. In many

cases, local approaches to local issues will be required. The government believes that this can be done using existing legal powers and through development of the existing controls. Consistent with the aim of minimising regulatory burdens, the government will primarily seek to work with the pesticide industry to enhance voluntary measures that improve knowledge transfer to pesticide users and to develop mitigation measures that can be adopted in areas where pesticides are causing problems. We will, however, keep the situation under review and will develop alternative controls using targeted regulatory powers if this proves to be necessary.”

This statement confirms that Directive 09/128/EC is seen as fully compatible with the current UK approach to voluntary measures for the control of diffuse pesticide pollution and reinforces the government belief that WFD Article 7 can be achieved without regulatory tools.

2.5.3 Voluntary Initiative, pesticide policy and other UK responses to diffuse pesticide pollution

In parallel with the WFD, a number of independent UK initiatives are ongoing to address the challenge of diffuse pesticide pollution. These include the Voluntary Initiative (VI), England Catchment Sensitive Farming Delivery Initiative (ECSFDI), the Metaldehyde Stewardship Group (MSG), government water policy, government pesticide policy and the water action plan for pesticides. Actions from many of these initiatives have been included in the WFD PoM because they can contribute to Article 7 objectives.

The VI, launched in April 2001, is a purely voluntary partnership between government, the Crop Protection Association (CPA), farming organisations, chemical

companies and water companies, to raise awareness of diffuse pesticide pollution and deliver actions to tackle it. The VI is based on three central themes: protecting water, benefiting biodiversity and changing pesticide user behaviour (Glass et al., 2006). Of these themes, changing user behaviour is the most important because it provides a foundation upon which progress towards the others can be built (Garrod et al., 2007; Humphrey, 2007). To measure how effectively the VI engages with the agricultural community, the VI sets behavioural targets for increased awareness of and participation in crop protection management planning (CPMP). Additionally, to ensure that VI actions are delivering observable results the VI sets long-term targets for reduced pesticide detections in the water environment.

In 2005, a House of Commons review identified the VI as “the most effective way of reducing environmental pollution associated with pesticides” (House of Commons: Environment Food and Rural Affairs Committee, 2005). This statement was qualified by criticism that (a) the behavioural and water environment targets were insufficiently ambitious and (b) the government had failed to support the VI by creating a national pesticide strategy. Following the review, the VI was extended for an additional 5 years and the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) was rolled out to 52 priority DrWPA catchments for targeted action against diffuse pesticide pollution in support of WFD DrWPA objectives. Additionally, in 2006 Defra published the UK pesticide strategy (Defra, 2006b); this was revised in 2008. The strategy has given rise to a number of action plans, including a water action plan (Defra, 2007; Health and Safety Executive, 2010) designed to “reduce contamination of surface and groundwater by pesticides” by building upon ECSFDI and VI actions, to integrate water protection policies with WFD requirements.

Reviews of the efficacy of the VI and, by association, of catchment management for pesticides (Garratt and Kennedy, 2006; Garrod et al., 2007; Humphrey, 2007; Glass et al., 2006; Lascelles et al., 2005) all identify that catchment management interventions (timing of application, buffer zones, no spray zones, changed handling practices, spraying good practice, biobeds) can be effective. However, all state that efficacy will vary, because of pesticide properties, local environmental variables (climate, geography and soil) and implementation at the farm level. Therefore, UK experience of catchment management of pesticides demonstrates the uncertainty surrounding catchment management intervention and the scale of the challenge to identify catchment management interventions to deliver WFD Article 7 objectives for pesticides.

2.5.4 Role of agri-environment schemes as a response to diffuse pesticide pollution

In the UK, the impact of the 1947 Agricultural Act and the 1962 EU Common Agricultural Policy (CAP) combined to create strong economic incentives to make agriculture more efficient and improve productivity. Together these policies drove changes to agricultural practice and delivered “a 180% (weighted by value) increase in productivity, between the early 1960s and mid 1980s” (Angus et al., 2009). CAP reform from 1986 onwards began a move away from incentives for increased productivity towards greater consideration of environmental priorities and led to the emergence of agri-environment schemes (Hodge and Reader, 2010; Posthumus and Morris, 2010; Evans, 2010).

The most inclusive form of environmental stewardship, Entry Level Stewardship (ELS), is the first agri-environment scheme applicable to all farmers in England. By late 2008, 52% of the farmed area in England had joined ELS (Hodge and Reader, 2010). The stated objectives of ELS include consideration of biodiversity, landscape quality, character and history, public access and natural resource protection (including water quality). ELS allows farmers to choose the stewardship options, from an approved list of 60 options, that suit their farm operation and can be integrated into their land management practices.

The challenge for delivering reduced diffuse pesticide pollution in DrWPAs through ELS involves encouraging local action, where action is needed most and would not otherwise take place (Hodge and Reader, 2010; Posthumus and Morris, 2010). However, the design of ELS options must be careful not to undermine the willingness to take voluntary action as part of the VI, ECSFDI and Directive 09/128/EC. ELS has the potential to support the delivery of WFD Article 7 objectives for pesticides, but, like all catchment management interventions, the degree and timing of any impacts from ELS actions are difficult to quantify. This does not provide the certainty required by water companies to inform long-term investment in WTW infrastructure for pesticides.

2.6 Conclusions and recommendations

The current legislation does not provide a coordinated legal and regulatory framework and some changes are warranted in order to achieve the desired impact. Better coordination is needed between the key components of that framework, that is, that

dealing with pesticides and pesticide use, that dealing with environmental water quality and that dealing with drinking water quality.

To support the future achievement of Article 7 objectives and to allow water companies to optimise investment in WTW infrastructure and catchment management intervention, further research is needed:

- to quantify the impact of catchment management intervention in supporting predictive modelling of pesticide risk in DrWPAs and identification of timely catchment appropriate action to address Article 7 failures for pesticides;
- to identify high risk areas in catchments where diffuse pesticide pollution will cause Article 7 non-compliance. To enable: targeted catchment management action to prevent diffuse pesticide pollution in high risk areas; the design of ELS options for targeted use in high risk areas and; the examination of the impact of use restrictions on specific pesticide active substances causing WFD Article 7 non-compliance in high risk areas;
- to investigate how weed/pest/disease problems currently controlled by available active substance will be controlled following Regulation (EC) 1107/2009;
- to analyse possible chemical companies', agronomists' and farmers' responses to the reduced portfolio of pesticide active substances;
- to model the impact of reduced pesticide availability on the types and concentrations of pesticide active substance in "raw" water in DrWPAs;
- to research non-chemical replacements for those pesticides known to be lost under Regulation (EC) 1107/2009;

- to clarify how endocrine disruptor criteria will be applied and what this means for pesticides and water quality.
- to prepare targeted briefings for OfWat and DWI on the potential significance of Article 7 compliance and non-compliance on water company investment needs.
- to continue the development of risk assessments for Article 7 non-compliance and the preparation of safeguard zone action plans, to give clear visibility of those DrWPAs expected to not comply with Article 7 and, therefore, provide a robust base of evidence for water companies to use with OfWat when justifying the need for treatment or catchment management investment and with DWI when defending the failure to comply with DWD standards.

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**Chapter 3: Impact of European Water Framework
Directive Article 7 on Drinking Water Directive
Compliance for Pesticides: Challenges of a
prevention-led approach**

Chapter 3: Paper 2

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3.1 Preface

3.1.1 Context

Research presented in Chapter 2 identified Article 7 as the most significant element of the WFD affecting pesticide active substance concentrations in raw water at the point of abstraction for potable supply. However, the targets set by WFD Article 7 are ambiguous, and what the impacts of these will be for a range of catchment stakeholders depends on interpretation of the target, and the level of action taken by other catchment stakeholders. Member State government, water suppliers planning for DWD compliance, agricultural stakeholders using and supplying pesticides, and the competent authorities responsible for two independent European Directives, the DWD and the WFD, are the groups most affected by WFD Article 7. Each of these groups has a different perspective on how Article 7 should be interpreted and who should be responsible for implementing solutions to the challenges raised by Article 7.

The Paper presented in sections 3.2 - 3.10 of this Chapter examines the potential ambiguity in WFD Article 7 and provides analysis of different stakeholder perspectives on the challenges associated with WFD Article 7 compliance. This work builds on Chapter 2 by focusing on a specific element of the legal framework to answer a number of questions not previously tackled in the academic literature (Table 3.1).

Table 3.1 Questions addressed in paper

What actions (measures and mechanisms) are currently being implemented for WFD Article 7 compliance?
What actions (measures and mechanisms) will the competent authority implement

in the future?
How confident can stakeholders be that current actions will deliver the required improvement in raw water quality over the required timescale (by 2015)?
What will a drinking water protected area achieving WFD Article 7 compliance mean for a water supplier?
Given the possibility of WFD Article 7 non-compliance in a protected area, how significant is the distinction between legal responsibility for WFD and DWD compliance?
What role should water suppliers play in supporting WFD Article 7 compliance?
What actions should a water supplier take to minimise DWD non-compliance risk and support WFD Article 7 compliance?
Do the requirements of WFD Article 7 prohibit future water supplier investment in treatment infrastructure?
What adaptation options for diffuse pollution prevention are available to and preferred by agriculture?
Can WFD Article 7 compliance be achieved without a negative impact on pesticide availability and agricultural productivity?
What criteria must a programme of prevention interventions satisfy to deliver the required improvement in 'raw' water quality?
Is a prevention-led approach based upon prevention at source consistent with a requirement for absolute compliance with the DWD standard for pesticide active substances in drinking water?
Do the WFD and DWD competent authorities provide clear regulatory guidance to stakeholders affected by WFD Article 7?
How credible is the threat of European Commission infraction proceedings against non-compliant Member States?

3.1.2 Review of analytical techniques

The research reported in this Chapter involved a combination of literature review, comparative content analysis, informal meetings with water sector representatives, semi-structured consultation with the Environment Agency (WFD competent

authority for England and Wales) and the Chemical Regulation Directorate (CRD) (the body responsible for the approval of plant protection products in the UK).

This approach allowed identification of key unresolved questions (Table 3.1) and development of draft frameworks prior to expert consultation. Therefore, facilitating targeted in-depth discussion of issues central to the research in a way that grounded theory (Lansisalmi et al., 2004) could not achieve without placing greater demands on an experts time. This processes retained greater flexibility than use of a structured questionnaire and gave the expert an opportunity to flag significant issues. Draft conceptual frameworks, derived from literature review, were shared during the consultation to promote an open two way discussion. Sharing these conceptual frameworks gave the researcher credibility and allowed expert validation of research outputs (Table 3.3 Figure 3.2) prior to inclusion in the Paper.

Regular consultation with the project steering group and involvement with the pesticide strategy group at the sponsoring organisation allowed the concerns of water suppliers to be integrated into the research process. Additionally, the use of early outputs from the three stage semi-structured consultation with agronomists (Chapter 5) allowed agricultural perspectives to be reviewed in greater depth than that provided in academic or technical literature. Furthermore, comparative content analysis (Robson, 2002) was applied to update two elements of analysis from Chapter 2 following publication of new documentary evidence.

3.1.3 Significance to the Thesis

The Paper presented in this Chapter builds upon Chapter 2. Additionally, identification of the DWD standard for pesticide active substance as a key

determinant of the level of pollution prevention at source required by each stakeholder group provides further justification for examination of the logical basis of the European Drinking Water Directive standards for pesticides (Chapter 4). Furthermore, recognition that the challenges presented by WFD Article 7 are perceived in different ways by a range of stakeholder groups indicates the need for consultation, to increase understanding, between those stakeholders concerned with meeting legislative standards (water suppliers, The WFD and DWD competent authorities) and those using pesticides for agricultural purposes (Chapter 5).

3.2 Abstract

Article 7 of the European Water Framework Directive (WFD) promotes a prevention-led approach to European Drinking Water Directive (DWD) compliance for those parameters that derive from anthropogenic influences on raw water quality. However, the efficacy of pollution prevention interventions is currently uncertain and likely to be variable, which makes absolute compliance with the drinking water standard a significant challenge. Member State governments, the WFD competent authority, the DWD competent authority, water suppliers and agriculture are all affected by and have a different perspective on the nature of this challenge. This paper presents a discussion of these perspectives applicable to stakeholders in all European Member States; the analysis is supported with examples from England and Wales. Improved understanding of the challenges faced by each group is needed if these groups are to achieve the shared goals of WFD Article 7 compliance and DWD compliance without a disproportionately negative impact on agricultural productivity. In addition, the European Commission needs to be aware of and address a potential incompatibility between WFD Article 7 and the DWD. With this in mind, targeted recommendations for action are presented for each stakeholder group.

3.3 Introduction

While integrated water management is a widely accepted goal in many countries, a fully integrated legal framework to support this goal does not yet exist. For example, in Europe different regimes apply to environmental water quality and drinking water quality. Legislation to manage environmental waters (Water Framework Directive (WFD) (EC, 2000)), i.e. the source of the raw waters used in drinking water supplies, remains distinct from legislation on the quality of drinking water, defined in the European Drinking Water Directive (DWD) (EC, 1998).

In Europe, drinking water is produced to standards defined in the DWD, using water abstracted from the environment. Treatment to remove pollution and strategies to prevent pollution are used to ensure a wholesome supply of drinking water. The WFD was introduced “to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater” (WFD Article 1). Article 7 of the WFD is focused on bodies of water used for drinking water supply, meeting DWD standards through prevention of deterioration in raw water quality and minimising the extent to which additional treatment is necessary.

Using pesticides as an example, this paper describes how, for certain water quality parameters, WFD Article 7 is driving an increasingly prevention-led approach to DWD compliance, and examines the potential challenges faced by Member State governments, WFD competent authorities, DWD competent authorities, water companies and agriculture, when implementing this approach to DWD compliance.

In order to set the context for subsequent discussion, the paper includes an overview of DWD standards, an explanation of the significance of WFD Article 7 for all

pesticide active substances, and proposes a framework for assessing the efficacy of pollution prevention interventions. The paper concludes with targeted recommendations for stakeholders affected by WFD Article 7 and for the European Commission.

Throughout the paper, examples from England and Wales are used to support the analysis. The examples given are partially shaped by the underlying structure of the water industry in England and Wales, and a prevailing UK preference for environmental protection through voluntary actions. Nevertheless, the challenges illustrated are analogous to the situation in other European countries because the nature of the challenge is primarily driven by the need to comply with both the WFD Article 7 and the DWD.

While the focus of the paper is pesticides in the potable water supply, the analysis is also relevant for other parameters included in the DWD for which diffuse pollution is a significant contributor to the risk of non-compliance.

3.4 Water Framework Directive Article 7

The requirements for the protection of water supply abstraction points are often different to those for protection of aquatic biodiversity (Breach, 2011). WFD Article 7 on “Waters used for the abstraction of drinking water” (EC, 2000) recognises this distinction. Article 7.1 requires that “Member States identify all bodies of water used for the abstraction of water intended for human consumption”. Article 7.2 specifies “that under the water treatment regime applied, and in accordance with Community legislation, the resulting water will meet the requirements of Directive 80/778/EEC [EC, 1980] as amended by Directive 98/83/EC [the DWD]”. Article 7.3 specifies that

“Member States shall ensure the necessary protection for the bodies of water identified with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water”.

Therefore, in designated protected areas, WFD Article 7 promotes DWD compliance for certain key parameters through preventative actions to avoid deteriorating raw water quality, rather than through investment in additional treatment infrastructure or increased process intensity (operating demand). The competent authority for the WFD must achieve this compliance in all Article 7 protected areas by 2015 (EC, 2000). This cannot be derogated beyond 2015 (Kennedy et al., 2009).

In the protected areas designated under Article 7.1, known in the UK as drinking water protected areas (DrWPAs), WFD Article 7 applies to all pesticide active substances. For surface water bodies, the targets set by WFD Article 7 are independent of ecological, chemical, and hydromorphological status targets. Thus, it is possible for a surface water body to achieve “good status” while failing WFD Article 7 and vice versa. This is not the case for groundwater, where WFD Article 7 is not distinct from chemical and quantitative status targets.

Chemical status and ecological status targets apply to all surface water bodies.

However, only those active substances for which environmental quality standards (EQS) have been set can affect compliance. In 2015, at the end of the first River Basin Management Plan (RBMP) cycle, EQS values will apply to just six currently approved pesticide active substances. Two are the Article 4 priority substances chlorpyrifos and diuron (EC, 2008); EQSs for these will apply across all EU member states. The remaining four are the “specific pollutants” cypermethrin, dimethoate, 2–

4,D and linuron (UKTAG, 2008a), for which EQSs will apply in the UK only (unless other Member States also decide to classify them in the same way).

Under a European Commission proposal (COM(2011)876) on priority substances (EC, 2012), six additional pesticide active substances (cybutryne, aclonifen, bifenoxy, cypermethrin, heptachlor and quinoxifen) will be classed as priority substances with EQSs defined and applicable before the end of the second RBMP in 2021. In the UK, following a stakeholder consultation, the UK Technical Advisory Group (UKTAG) identified five further active substances – carbendazim, methiocarb, chlorothalonil, pendimethalin and glyphosate – as “specific pollutants”, for which EQSs will apply from the start of the second RBMP cycle in 2015 (UKTAG, 2012). Because “specific pollutants” are defined by each Member State, the range of specific pollutants subject to an EQS will vary across Europe but the total number of active substances subject to EQSs is likely to remain small relative to the 411 active substances currently approved in Europe under Regulation 1107/2009 (Directorate General for Health and Consumers, 2012), all of which are subject to WFD Article 7.

Furthermore, the pesticide active substances subject to WFD status targets are largely different from those “at risk” of causing WFD Article 7 non-compliance. In England and Wales, the Environment Agency (EA) has twice assessed pesticide active substances deemed to be at risk of causing non-compliance for WFD Article 7 in one or more surface water bodies. In the first assessment (Kennedy, 2010) the EA identified 41 active substances as at risk of causing WFD Article 7 non-compliance in one or more DrWPAs. Of these, 30 remain approved for use under European pesticide legislation (EC, 1991, 2009). Of these 30, metaldehyde, MCPA (2-methyl-4-

chlorophenoxyacetic acid), chlortoluron, mecoprop, carbetamide, 2,4-D, propyzamide and asulam, none of which has an EQS assigned, each cause “at risk” status in 10 or more DrWPAs in England and Wales. At the time of writing, results from the second EA assessment have yet to be published.

3.5 Drinking Water Directive

Annex I (part B) of the DWD (Directive 98/83/EC) (EC, 1998) specifies that all potable water supplied in Europe must not contain any individual pesticide active substance at a concentration greater than 0.1 µg/l at the point of consumption (a lower value of 0.03 µg/l is applied for four active substances – aldrin, dieldrin, heptachlor and heptachlor epoxide). Furthermore, the maximum concentration of total pesticides is 0.5 µg/l. Since these standards are maximum allowable concentrations (MACs) rather than annual averages or percentile values, they must never be exceeded. It follows that there is no concept of acceptable risk for pesticides in European drinking water.

These standards were first set for total pesticides in Directive 75/440/EEC (EC, 1975) and for individual pesticide active substances in Directive 80/778/EEC (EC, 1980).

When the standards were set, the EC adopted a precautionary approach, because little was known about chronic long-term effects of pesticides (Jordan, 1999). The purpose of the standard was to avoid the presence of pesticides in European potable water.

DWD standards are, therefore, not based on toxicological data (Croll, 1995) and are effectively surrogates for zero since 0.1 µg/l was typical of analytical limits of detection when the standard was first introduced (Knapp, 2005).

Despite a requirement for a rolling 5-year review in the light of scientific and technical progress (DWD Article 11.1), the standards for pesticides have remained unchanged from when they were first introduced. Although a further review is expected in 2013, a change in standards is not expected (see Dolan et al., 2013) and for the purpose of discussion in this paper it is assumed that any reference to the DWD in WFD Article 7 is to the 0.1 µg/l standard defined in the current Annex 1 of the DWD.

3.6 WFD Article 7, a prevention-led approach to DWD compliance

3.6.1 Introduction

Water suppliers are legally responsible for supplying DWD-compliant potable water. The need for 100% compliance with the precautionary standards in the DWD and the absence of a concept of acceptable risk create a ‘compliance/legal risk’ for potable water suppliers (Pollard et al., 2004). It follows that a water supplier will take action to minimise the risk of non-compliance as much as possible. Failure to do so would leave a water supplier at risk of non-compliance with DWD standards and the Member State potentially at risk of failure to comply with WFD Article 7.

There are two primary routes to ensure DWD compliance:

- (1) Water treatment to reduce active substance concentrations to below the MAC and
- (2) Prevention of pesticide movement to raw waters used for drinking water abstraction.

Treatment is an intervention that water companies can control. In some circumstances, the installation of sufficient treatment capacity can give a water supplier certainty that the risk of non-compliance with the DWD will be close to zero. By contrast, most pollution prevention strategies (which might include structural measures, such as designating buffer zones near to water courses or constructing attenuation ponds in the drainage ditch network, as well as non-structural approaches, such as changes in pesticide application regimes or crop rotations) are harder for water companies to implement because they have little experience of implementation, and minimal control over land use and agricultural practice in their catchments (Keirle and Hayes, 2007; Dolan et al., 2012). Furthermore, the efficacy of such measures are often uncertain and are likely to be variable temporally (e.g. with weather patterns) and spatially (e.g. with different soil types over a catchment) (Reichenberger et al., 2007). Additionally, it is especially difficult to ensure completely effective protection in larger, more complex catchments (Breach, 2011).

3.6.2 Preference for treatment

In practice, an approach to DWD compliance based primarily on treatment has historically been adopted by water suppliers. This approach is more resilient to variations in raw water quality caused by the actions of other catchment stakeholders or by fluctuations in weather conditions. In England and Wales, this preference for treatment was reflected in a high level of capital investment at many water treatment works (WTWs) during the first business cycle (1990–1995) after privatisation (The Director General of Water Services, 1991) and a bias toward capital expenditure in the regulatory system, leading to the promotion of treatment over catchment-based interventions (Ofwat, 2011).

It is important to note, however, that in some circumstances DWD compliance cannot be achieved through treatment alone. For example, this may be the case where high seasonal peak concentrations of a pesticide active substance are present in raw water above concentrations that are treatable with the installed treatment processes (UKWIR, 2011), or where difficult-to-treat active substances such as metaldehyde (Autin et al., 2013) and clopyralid (Tizaoui et al., 2011) are periodically present in raw water at concentrations which exceed the DWD MAC. In these cases, employing catchment management interventions may play a role in supporting existing treatment to achieve compliance.

3.6.3 Emphasis on prevention

WFD Article 7 challenges the preference for treatment interventions because, through Article 7.3, it promotes prevention in favour of treatment. WFD Article 7 objectives are achieved by delivering DWD compliance at tap (Article 7.2) provided none of the following actions which compromise Article 7.3 compliance (UKTAG, 2008b) has to be taken:

- *An abstraction (or planned abstraction) of water intended for human consumption has to be abandoned and an alternative used to provide the supply;*
- *Water abstracted (or planned to be abstracted) has to be blended with water abstracted from another source;*
- *Additional purification treatment has to be applied;*
- *The operating demand on the existing purification treatment system has to be significantly increased.*

The words in the bullet points above are a UK interpretation of WFD Article 7. It follows from this interpretation that, if a water supplier takes any of the above actions for DWD compliance, they will trigger a WFD Article 7 failure for the protected area.

By restricting the role which additional treatment (including blending of water from several sources) can play and giving priority to prevention, WFD Article 7 limits the ability of water suppliers to influence outcomes directly. By highlighting the importance of raw water quality at the point of abstraction, it implies that responsibility for DWD compliance should be shared between the WFD competent authority (the EA in England and Wales), water suppliers, all pesticide users in the catchment and the DWD competent authority (the Drinking Water Inspectorate in England and Wales).

In this paper, it is assumed that the UK interpretation of WFD Article 7 is consistent with that made in other European countries and that the challenges presented by WFD Article 7 and the DWD apply to all water supply undertakers across Europe.

However, the validity of this assumption can be challenged, because WFD Article 7 is somewhat ambiguous and there is, thus, potential for slightly different interpretations of the no deterioration, treatment provision (including blending) and timescale criteria to be transcribed into Member State law. WFD guidance documents published by the European Commission (EC, 2013) do not define these criteria for surface water abstractions. This lack of clarity is, therefore, an issue that needs to be resolved by the European Commission to ensure that Article 7 is interpreted consistently across all Member States.

3.6.4 A Framework for Assessing Prevention Interventions

In most water supply catchments DWD compliance is already achieved for most parameters using the suite of treatment technologies currently in place. However, new diffuse-source water pollution problems sometimes arise. These occur either as a consequence of changes to one or more factors that influence pesticide use or simply because existing issues are identified via the introduction of new analytical methods to raw water monitoring programmes. In such cases, increased emphasis on pollution prevention creates the need for intervention programmes in catchments vulnerable to diffuse pollution issues. These interventions can act at both pollutant source and pathway level to improve raw water quality and, thereby, ensure DWD compliance is achievable with the current treatment provision (Dolan et al., 2012). If successful, they would deliver WFD Article 7 compliance.

Here, we propose a framework of five criteria (Table 3.2) that any programme of prevention interventions must satisfy in order to achieve the required improvements in raw water quality.

Table 3.2 A framework for assessing prevention interventions in terms of satisfying the requirements of the DWD and WFD Article 7

Criteria	Description
Scale	The programme of interventions must be capable of delivering the required improvement to raw water quality
Stability	The programme of interventions must deliver the required improvement to raw water quality under all weather conditions
Consistency	The programme of interventions must deliver a consistent behavioural change, such that the required improvement is

	delivered every year
Level of Engagement	To deliver the required improvement, the programme of interventions must engage with a sufficient, and probably very high proportion, of stakeholders involved with pesticide use in the catchment
Timeliness	The required improvements must be delivered by the programme over the timescale allowed by WFD Article 7 and DWD derogations

In addition to satisfying the criteria in Table 3.2, any programme of interventions must be cost-effective and distribute costs equitably between those stakeholder groups affected.

In water bodies where prevention cannot meet the criteria in Table 3.2, water suppliers may be vulnerable to DWD failure and the water body may be vulnerable to WFD Article 7 failure. This vulnerability arises from the absolute nature of the DWD, restrictions on increases to treatment provision under WFD Article 7, the fixed timescale of Article 7 and, perhaps most importantly, from aleatory and epistemic uncertainty regarding the efficacy of preventative measures. While some measures are likely to be successful, if implemented at the right scale (e.g. bans or restrictions in pesticide use), the success of others, such as changing the length of the crop rotation, changing cultivation practices, designating buffer zones or constructing attenuation features (e.g. ponds or wetlands on ditch networks), are likely to be variable. This can introduce considerable uncertainty into the probability that a set of measures will help to achieve compliance. This uncertainty is likely to increase in large catchments where a greater number of individual local actors need to engage in the right way in order to achieve catchment-scale success.

3.7 Stakeholder perspectives on the challenges of a prevention-led approach to DWD compliance

Member State governments and four stakeholder groups face particular challenges as a direct consequence of WFD Article 7 driving a prevention-led approach to DWD compliance (Figure 3.1). The discussion that follows considers each of these challenges from the perspective of each stakeholder group affected.

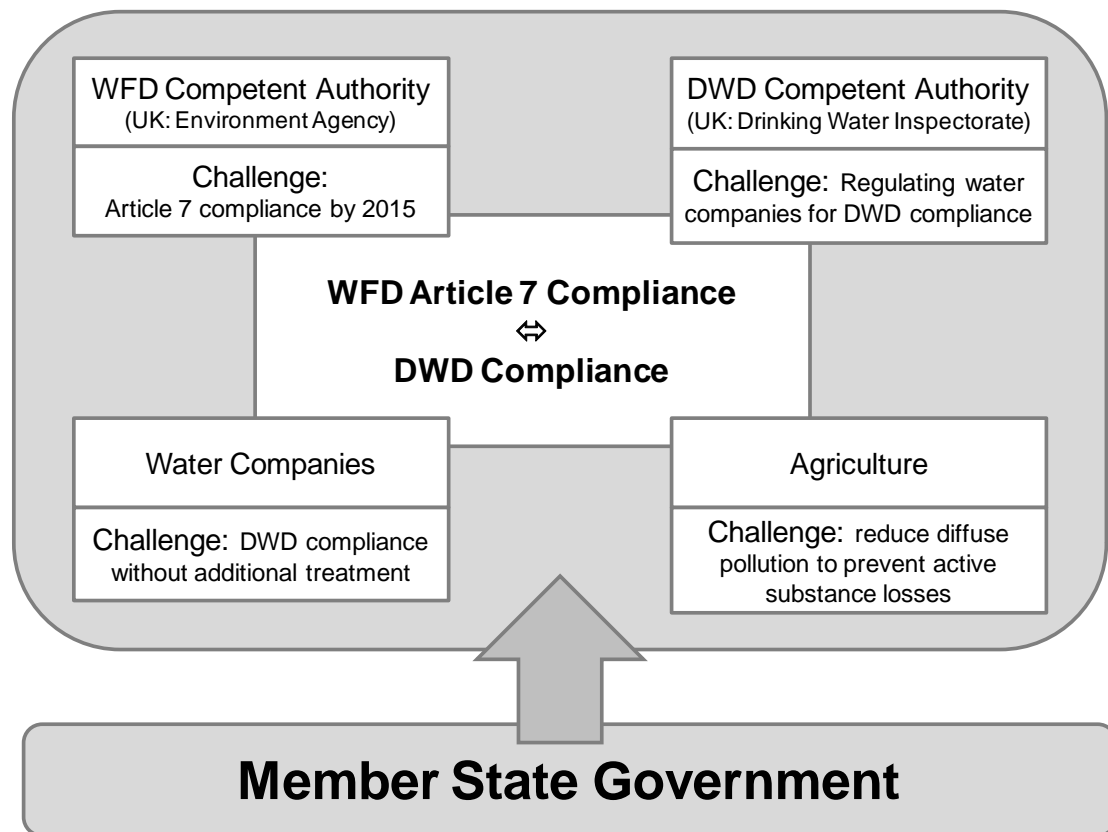


Figure 3.1 Important stakeholder groups and the challenges posed by an increasingly prevention-led approach to drinking water protection

3.7.1 Member State government

Although these challenges (Figure 3.1) arise from European Directives, the role of Member State governments in shaping and responding to them must not be overlooked. Each government transcribes European Directives into national law, and

is ultimately responsible for compliance. Governments have direct influence over all four stakeholder groups, in as much as they establish which authorities are responsible for the WFD and the DWD, they regulate or own the water suppliers and they determine agricultural policy. Government must, therefore, understand the significance of the challenges faced by each stakeholder group and take action to support them as appropriate. In particular, it is important to ensure that all stakeholder groups receive clarity and that conflicting objectives do not inhibit the collaboration between groups which may be required to achieve WFD Article 7 and DWD compliance.

3.7.2 WFD competent authority

The absolute nature of the DWD and the fixed timescale for WFD Article 7 compliance create challenges for any competent authority aiming to take a risk-based approach to the delivery of cost-effective pollution prevention interventions for WFD Article 7 compliance in catchments where diffuse pesticide pollution is an occasional cause of DWD non-compliance.

For each ‘at risk’ protected area, the competent authority needs to assess the nature and scale of prevention actions required for DWD and WFD Article 7 compliance, and assess whether current action can deliver results that meet the scale, stability, consistency, level of engagement and timeliness criteria in Table 3.2. Where it is believed that the current measures cannot deliver compliance, further action is required.

WFD competent authorities can choose whether to deliver interventions through statutory or voluntary measures. The need for interventions to be cost-effective and

for costs to be distributed equitably between stakeholders must be considered when determining the balance between voluntary and statutory action. Statutory measures will impose direct and indirect costs on one or more stakeholders in the catchment, and may have ramifications for all other activity in the catchment. For example, imposing catchment-specific statutory restrictions on land use or management practices may have a direct cost for farmers should their operating margins be affected but may also have an indirect effect on land value. Voluntary measures typically have lower costs to the stakeholder abating the pollution, but may require cooperation from all stakeholders involved with pesticide use. Regardless of whether the programme of interventions is led by voluntary actions or statutory actions, it needs to be capable of delivering the five criteria in Table 3.2, in order to satisfy the requirements of the DWD and WFD Article 7.

Assessing whether a particular set of interventions will deliver compliance is not a simple process. All protected areas are different in terms of their physical characteristics, and the spatial and temporal pattern of pesticide use. In addition, the level of prevention actions already initiated, the timescale over which these are expected to deliver and the shortage of information about the expected efficacy of interventions are factors that need to be considered by a competent authority to assess the level of compliance expected in 2015. Literature assessing the efficacy of prevention options highlights the complexity of designing a programme of interventions that satisfies the scale, stability, consistency, level of engagement and timeliness criteria (Table 3.2). Reichenberger et al. (2007) reviewed the effectiveness and feasibility of the mitigation strategies detailed in 180 papers and concluded that *“a compilation of the efficiencies of the mitigation measures available for the*

different pesticide input pathways is lacking so far.” In addition, where pesticides are transferred from land to surface water via drain flow (Brown and van Beinum, 2009; Tediosi et al., 2012; Tediosi et al., 2013) dependable mitigation options are limited to changes in application rate and timing, changes in crop rotation or restricted use of an active substance.

A correct assessment for a protected area will support cost-effective and timely delivery of compliance with WFD Article 7 through a combination of voluntary and, if necessary, statutory measures and mechanisms. It will also allow clear messages about required actions to be shared with water suppliers and with stakeholders involved with pesticide use. Incorrect assessment of the measures required may lead to either inaction or over-implementation of prevention actions.

Therefore, an iterative approach involving repeated phases of communication with catchment stakeholders, implementation of prevention actions and assessment of impacts may be required to satisfy the criteria in Table 3.2 and achieve an optimal balance between compliance and cost-effectiveness. A toolkit of well defined measures and mechanisms to implement actions for prevention, as required, would support this approach (Table 3.3 gives an example of this from England and Wales). In addition, research to close the knowledge gaps that exist regarding the efficacy of various prevention options would be useful. Communication is of vital importance because engagement and understanding are needed to support assessment, to identify possible solutions and to implement actions. It is also important that all stakeholders in the catchment are aware of the actions the competent authority is taking and the reasons for these actions.

3.7.2.1 Environment Agency (EA) in England and Wales

In England and Wales, there is a stated preference to achieve WFD Article 7 compliance through voluntary measures (Kennedy et al., 2009), and avoid increasing the regulatory burden (HM Government, 2011). For this reason the EA, as competent authority, has taken an approach similar to that outlined above. This preference places a constraint on the range of prevention options available to them. Table 3.3 shows the iterative approach to prevention actions currently being taken by the EA in England and Wales.

Table 3.3 An iterative approach for WFD Article 7 compliance in DrWPAs in England and Wales.

<p>Current Actions</p> <ul style="list-style-type: none"> • Voluntary actions to change behaviour (VI¹, MSG², ECSFDI³) • Water company catchment management
<p>Actions (under development)</p> <ul style="list-style-type: none"> • Safeguard Zone Action Plans. • Targeted provision of information (EA, MSG) • Characterisation of catchments • Defra research
<p>Possible Future Actions</p> <ul style="list-style-type: none"> • Additional non statutory measures from Defra research • Alignment of ELS⁴ options with WFD Article 7 objectives • Inclusion of specific drinking water considerations in current CRD⁵ processes

Future Statutory Actions

- The use of ‘Safeguard Zones’ to target enforcement action
- Water protection zones (EA prescribed land use where needed)
- Active substance bans

Actions to reduce pesticide pollution through behavioural change amongst pesticide users have been led since 2001 by the Voluntary Initiative (VI) (The Voluntary Initiative, 2011). This has had support in some DrWPAs, since 2006, from the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) (Natural England, 2012a) and, since 2009, by the Metaldehyde Stewardship group (MSG) ‘Get Pelletwise’ campaign for metaldehyde (Metaldehyde Stewardship Group, 2012). However, it is still not known whether these actions will improve raw water to the extent required to meet the scale, stability, consistency, level of engagement and timeliness criteria in Table 3.2. In particular, and importantly, there are doubts about the stability and consistency of these interventions under certain conditions and about whether the scale of reduction and level of engagement required can be achieved within the required timescale in all DrWPAs with potential pesticide issues.

In 2008, the EA examined a number of ‘beyond VI’ measures for possible use in ‘at risk’ DrWPAs (Kennedy et al., 2009). Subsequently, the UK Department for Environment, Food and Rural Affairs (Defra) commissioned further research (Defra, 2012) to identify and appraise cost effective policy instruments to tackle the impacts of pesticides. Furthermore, the EA, the VI and the MSG have identified that provision of simple and locally relevant information to *all* pesticide users and advisors in the

catchment is critical to delivering the level of engagement and scale of improvement required (The Environment Agency, 2012).

Currently, Safeguard Zone Action Plans, as specified in Article 7.3 (EC, 2000), are under development in 'at risk' DrWPAs. In the first instance, these action plans will support targeted deployment of voluntary interventions, provision of local pesticide water quality and catchment management advice and characterisation of catchments. This will improve understanding of what prevention interventions might be needed in each DrWPA.

If needed, fiscal incentives to encourage appropriate behavioural change in support of WFD Article 7 objectives could be made available. Delivery through an agri-environment scheme, such as Entry Level Stewardship (ELS) (Natural England, 2012b) would be one possible mechanism for this. Regardless of the delivery mechanism, fiscal incentives must avoid undermining willingness to participate in voluntary actions (Dolan et al., 2012).

Statutory interventions are seen as a last resort in England and Wales, and would only be used where the need is acute and where cost effective measures were sure to deliver a high certainty of success. However, there is currently little certainty over what statutory actions might be considered.

3.7.3 DWD competent authority

The challenge for the DWD competent authority is how to regulate water suppliers during the transition to an increasingly prevention-led approach. Of particular significance are those catchments where current treatment provision does not allow

DWD compliance for all active substances. Under Article 9 of the DWD, a derogation (known as an authorised departure) can be applied for non-compliance with the 0.1µg/l standard for a pesticide active substance, provided that it does not constitute a potential danger to human health. Derogations are for three years; extension by a further three years requires the Member State to communicate the grounds for the extension to the European Commission (EC, 1998).

The application of a water supplier for a derogation could be seen as indicative of a Member State being non-compliant with WFD Article 7. Therefore, using derogations, except as a temporary measure, is undesirable from the perspective of both the water supplier and the Member State. It follows that derogations are not a substitute for a programme of prevention interventions capable of meeting the criteria proposed in Table 3.2.

3.7.3.1 The Drinking Water Inspectorate (DWI) In England and Wales

In England and Wales, the Drinking Water Inspectorate (DWI) is the regulator responsible for ensuring that all water companies comply with the standards specified in the DWD and transcribed into English and Welsh law through The Water Supply (Water Quality) Regulations 2000 (HMSO, 2000). The DWI has the power under Regulation 19.1 to grant “undertakings” to allow an authorised departure where a non-trivial failure to meet the pesticide standard is likely to recur. Authorised departures allow temporary non-compliance and require water companies to perform a series of short, medium and long term actions to address each failure.

In some DrWPAs across England and Wales, undertakings are already in place for pesticide active substances (e.g. for metaldehyde and clopyralid). How to manage the

renewal of these undertakings in a way which is consistent with both WFD Article 7 and the DWD requirements represents a challenge for the DWI, along with the EA and the water suppliers, to address.

3.7.4 Water suppliers

The WFD and DWD are separate European Directives and, therefore, are legally distinct. Compliance with each Directive is the responsibility of a different competent authority. A water supplier has a legal obligation to be DWD compliant 100% of the time for the potable water they supply. WFD Article 7 appears to make a promise to water suppliers that they will be able to meet DWD standards for some catchment-derived pollutants without the need to make additional investment in treatment infrastructure for potable water production (Figure 3.2). However, a water supplier cannot be certain that the prevention-led approach, required for WFD Article 7 compliance, will satisfy the five criteria in Table 3.2 and give DWD compliance in all WFD Article 7 protected areas. Therefore, the absolute nature of the DWD, in combination with WFD Article 7.3 restricting treatment options creates a significant challenge for water suppliers.

This challenge should encourage water suppliers to increase investment in pollution prevention actions, such as catchment management, characterising catchments and understanding the agronomic drivers of pesticide use. The need for these types of interventions is further strengthened by the presence of those active substances for which available treatment is ineffective (e.g. metaldehyde and clopyralid), or where high peak concentrations prevent effective removal for DWD compliance.

However, the challenge also creates uncertainty for business planning. In each protected area a water supplier must now consider the consequences to their business of failure to achieve WFD Article 7 compliance (Figure 3.2), and consider how to mitigate these possible impacts when compiling their business plan. It is assumed here that all water suppliers, whether state or privately owned, undertake some form of business planning for DWD compliance. Therefore, the content of a water supplier's business plan will be inextricably linked to whether a WFD Article 7 protected area is expected to be compliant for pesticide active substances at the end of the first WFD river basin management plan (RBMP) in 2015. If the 2015 target is expected to be met, then minimal investment will be required by the water supplier (Figure 3.2). If the target is unlikely to be met, then additional expenditure will be needed (Figure 3.2). Therefore, in order for a water supplier to accurately allocate resources to additional treatment infrastructure, to catchment management plans and to actions as part of a safeguard zone management plan, it needs a clear indication, of whether WFD Article 7 compliance will be achieved by 2015.

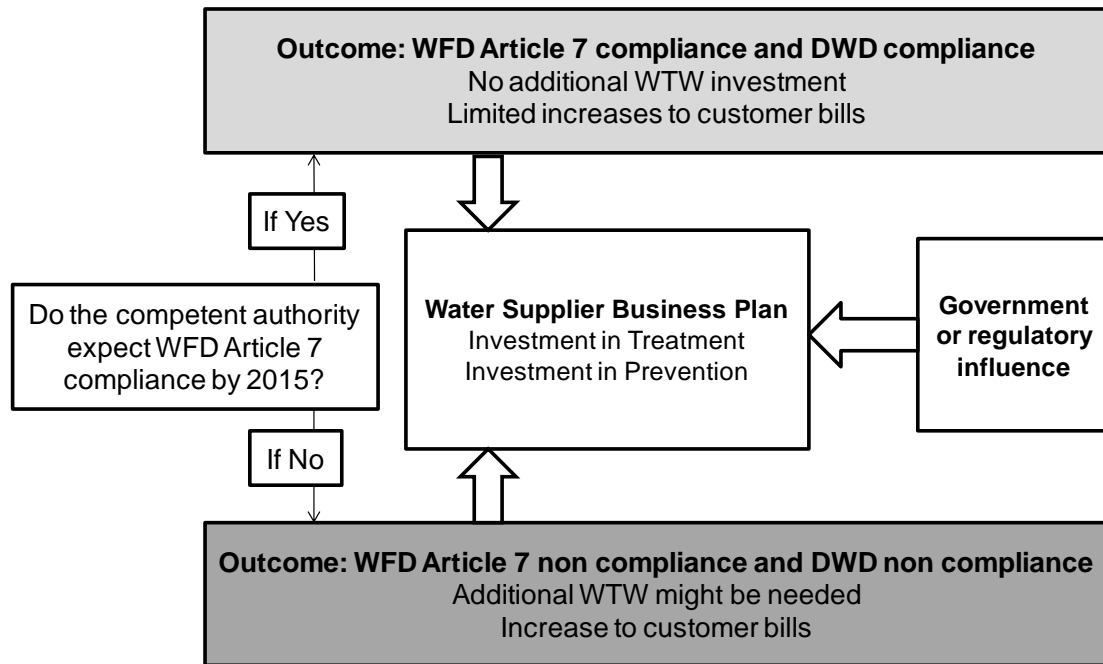


Figure 3.2 Relationships between WFD Article 7 compliance, DWD compliance and water supplier business planning

3.7.4.1 Water companies in England and Wales

In England and Wales, the privately owned, state regulated water companies are obliged to plan investment in five year cycles, known as asset management plans (AMP) and submit a business plan called a Periodic Review (PR) one year before the beginning of an AMP cycle. The next AMP cycle (AMP6) runs from 2015 to 2020, and the business plan for this cycle (PR14) must be completed early in 2014.

When compiling the PR14 business plan, a water company must consider several uncertainties related to regulatory interpretation and competent authority policy. For pesticides, these include: the likelihood of WFD Article 7 non-compliance in a DrWPA; investment to support Safeguard Zones in AMP6; regulatory attitudes toward derogations for DWD non-compliance and additional water company investment in treatment.

Although DrWPAs ‘at risk’ of Article 7 non-compliance have been identified by the EA, the largely non-structured voluntary actions which have been implemented, thus far, have had uncertain success. In any DrWPA where WFD Article 7 non-compliance is expected in 2015 the EA can: (a) select from options in Table 3.3 in order to increase the probability of compliance; (b) set alternative objectives and extend compliance until 2021 or 2027, as is allowed for status targets under WFD Article 4 (EC, 2000); or (c) accept non-compliance for a short time period to give current actions time to deliver.

Expectation of which options are to be used will shape how water companies produce their PR14 business plans. Therefore, water companies would benefit from clear EA guidance regarding which of the above options is most likely for each DrWPA at risk of WFD Article 7 non-compliance for pesticide active substances. Similarly, where a safeguard zone action plan is a key component of EA plans for WFD Article 7 compliance in a DrWPA, and water company action and expenditure are needed to support implementation during AMP6, this must be made explicit to the water company as soon as possible, to allow inclusion of actions in PR14.

In addition, water companies need to know that the positions taken by sector regulators (the DWI and Ofwat in England and Wales) will be consistent with decisions taken by the EA. Specifically, water companies need:

- the DWI to define under what WFD Article 7 scenarios, and based upon what evidence, it will grant derogations and/or extend existing derogations for DWD failure for pesticide active substances; and

- Ofwat to specify under what circumstances it will allow a water company to invest in additional treatment infrastructure at PR14.

3.7.5 Agriculture

The fact that the DWD requires 100% compliance with precautionary standards (see Dolan et al., 2013) for pesticide active substances, the restriction imposed on additional treatment by WFD Article 7.3 and the time-bound nature of WFD Article 7 all present challenges to agriculture. Here, the term agriculture is used to cover farmers, agronomists, pesticide distributors and pesticide manufacturers.

Most current agricultural practices are intended to maximise productivity and gross margins using a range of pesticide active substances from those currently available and approved for use. Any reduction in pesticide availability will potentially have an impact on agricultural productivity. Consultation with agronomists performed as part of this research has identified the types of options potentially available to agriculture when an active substance is lost or restricted (Table 3.4). Which of these options are workable, and how far down the table agriculture needs to look for a solution is entirely dependent upon the context of the active substance lost or restricted. Typically, the further down the table the solution is found, the greater will be the impact on crop yield and gross margin.

Table 3.4 Hierarchy of potential responses from agriculture to the loss of a pesticide active substance

Action	Explanation
A direct substitute	An alternative active substance with equally efficacy, cost and timing.

A close substitute	An alternative active substance with lesser performance on one or more factors from efficacy, cost, timing of application, proven track record and environmental impact.
Treat at another stage in the rotation	Increased use of an alternative active substance at a different stage in the rotation.
Cultural control	The use of a cultivation practice, without a fundamental change to the rotation.
Change crop architecture	This intervention aims to maintain the rotation and maximise control by using targeted application of non selective pesticides to crops grown in wider rows.
Change the rotation	A change to land use based upon one or more of the following: crop type, crop frequency, growing season, use of fallow.

It is important that all stakeholders involved with WFD Article 7 and DWD compliance understand the agricultural perspective on potential restrictions or losses of pesticide active substances. Therefore, agriculture needs to communicate that in practice: (a) direct substitutes are rare; (b) apparent close substitutes or the option for treatment at another stage of the rotation are not only less effective, but in many cases already form a vital part of a resistance management strategy; and (c) non-chemical methods are complements to, rather than substitutes for, pesticide use, because they usually give comparatively poor control at a premium price (Moss, 2010).

3.7.5.1 Agriculture in England and Wales

In England and Wales all plant protection products (PPPs) must be approved by the Chemicals Regulation Directorate (CRD) before use. The CRD set maximum dose rates and have the power to ban any active substance. However, thus far, there is no

precedent for pesticide withdrawal in the UK for Article 7 reasons (Dolan et al., 2012), and the EA, as the WFD competent authority in England, view active substance bans as an action of last resort. Nevertheless, the concern remains that WFD Article 7 could cause reduced availability of active substances, with associated potential productivity losses for UK agriculture (Wynn et al., 2009; Clarke, 2009; Clarke et al., 2009).

Agriculture in England and Wales is, therefore, focused on (a) protecting the range of active substances currently available; (b) delivering water quality improvements through voluntary actions; and (c) ensuring that the WFD competent authority, other policy makers and water companies are aware of the expected impacts on productivity which a withdrawal or restriction of active substances for WFD Article 7 reasons might cause.

The Voluntary Initiative (VI), the England Catchment Sensitive Farming Delivery Initiative (ECSFDI), and Metaldehyde Stewardship Group (MSG) are all examples of where agriculture has led action to address problems relating to quality of raw water. It has not yet been possible to fully establish the impact of these actions, and whether they can deliver to the scale, stability, consistency, level of engagement and timeliness criteria (Table 3.2)

3.8 Conclusions and recommendations

3.8.1 Conclusion

WFD Article 7 favours a prevention-led approach to DWD compliance for diffuse source pollutants in catchments used for domestic water supply. The need for absolute

compliance with a surrogate zero standard for pesticides in drinking water (Dolan et al., 2013) and the uncertainties associated with the efficacy, costs, mode of implementation and equity of prevention interventions (together with the high number of potential actors) make this a significant challenge. Further work is needed to identify solutions in response to this challenge, and to some extent catchment management remains “experimental” because the extent to which a prevention-led approach is able to achieve the required certainty of compliance with respect to drinking water quality is currently unknown.

The successful transition to a prevention-led approach is the collective responsibility of all those groups involved with interpreting and implementing policy at the Member State level and the European Commission itself, as the body responsible for setting and reviewing legislation. At the Member State level, Government, the WFD competent authority, the DWD competent authority, water companies and agriculture are all affected by, and each have a different perspective on, this challenge. These groups need to share their perspectives and work together to achieve the shared goals of WFD Article 7 compliance, DWD compliance and minimal negative impact on agricultural productivity. At the European level the Commission needs to ensure that (a) the WFD and DWD are consistent with principles of European environmental policy; (b) targets for prevention at source are based on the precautionary principle and available scientific and technical evidence, (c) sufficient time is allowed for identification and implementation of catchment management solutions, and (d) the legislative framework does not impose disproportionate costs on agriculture or water suppliers.

3.8.2 Recommendations

The recommendations made in this paper are directed to these groups within each European Member State with the aim of supporting greater clarity, understanding and cooperation between them. The authors acknowledge that some of the recommended actions are already taking place in some Member States. In addition, five recommendations are directed to the European Commission.

Member State governments should:

- define clearly how they interpret the requirements of WFD Article 7, with regard to additional investment in treatment, increased use of existing treatment (including blending), abstraction abandonment and the timescale for compliance
- provide a flexible legislative framework to enable the WFD competent authority to implement bespoke programmes of targeted, cost-effective and equitable measures for pollution prevention, as appropriate, in each Article 7 protected area
- provide evidence to the European Commission should actions implemented for WFD Article 7 compliance directly increase water prices, reduce agricultural margins or result in other significant costs, including indirect effects such as reductions in land value
- engage with the Commission to explore the scientific basis and practicability for introducing a health-based (risk-based) DWD standard for pesticides in drinking water (cf Dolan et al., 2013).

The WFD Competent Authority should:

- provide clear guidance to water suppliers regarding the authority's position on WFD Article 7 compliance and investment in additional treatment (particularly a clearer definition of what this might include)
- follow an iterative approach, based upon repeated phases of communication, implementation and assessment, to secure WFD Article 7 compliance
- indicate to water suppliers which WFD Article 7 protected areas are expected to be non-compliant in 2015
- negotiate with water suppliers (and, where applicable, the sector's economic regulator) over the nature and level of investment required for catchment management and safeguard zones in water suppliers' business plans.

The WFD and DWD Competent Authorities should:

- facilitate consistent communication with water suppliers and agriculture by developing a mutually consistent position on those WFD Article 7 protected areas which are expected to be non-compliant in 2015.

The DWD Competent Authority should:

- define the DWD non-compliance conditions under which derogations will be granted to water suppliers to support the prevention-led approach promoted by WFD Article 7.

Water Suppliers should:

- consult with the WFD competent authority to identify those protected areas where there is the highest risk of Article 7 non-compliance
- support the prevention-led approach through targeted investment: to understand the risk of diffuse pesticide pollution; to identify the available

catchment management options (along with an assessment of their potential to achieve the required outcomes); to support safeguard zone action plans

- Seek guidance on the national position on WFD Article 7 and, particularly, the implications for WFD Article 7 compliance of any investments in new treatment intended to ensure DWD compliance.

Agriculture should:

- engage with and initiate industry-wide voluntary actions to support the prevention-led approach to DWD compliance for pesticide active substances
- highlight to Member State policy makers (including the WFD competent authority) and water suppliers the significance of key active substances for agricultural productivity, and the potential consequences should any of these substances be banned or restricted
- support actions by water suppliers or the WFD competent authority to characterise catchments, understand the risk of diffuse pesticide pollution and attempt to mitigate land to water pesticide transfers.

The European Commission should:

- provide clearer guidance on WFD Article 7 compliance particularly with respect to investment in additional treatment (including the extent to which blending should be interpreted as a form of treatment in the transposition of the directive into national law), whether the 2015 target for compliance can be derogated to 2021 or 2027 and the meaning of safeguard zones (7.3) for surface water abstractions

- review whether the interpretation of the DWD MAC as a “red line” (i.e. an absolute threshold which must never be exceeded) could be replaced by a statistical approach based on percentile compliance (e.g. Warn and Brew, 1980; Fristachi et al., 2009); this would be more consistent with the prevention-led approach of WFD Article 7 and the inevitably variable efficacy of catchment based interventions compared to conventional water treatment technologies
- re-examine whether the retention of a uniform DWD MAC standard for all pesticides (and their metabolites), regardless of their different toxicities and modes of toxic action in humans, continues to be consistent with European Treaty principles (Article 174) on environmental policy (Dolan et al., 2013); these principles, which include the precautionary principle, originally gave rise to the DWD standard for pesticides and are also embedded in the WFD
- investigate whether alternative approaches to regulation based on the peer-reviewed, risk-based, WHO guidelines for drinking water standards are consistent with European principles for environmental policy
- engage in dialogue with the authorities at Member State level which are responsible for implementing WFD Article 7 and a prevention-led approach to DWD compliance.

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**Chapter 4: Is the EU Drinking Water Directive
Standard for Pesticides in Drinking Water Consistent
with the Precautionary Principle?**

Chapter 4: Paper 3

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4.1 Preface

4.1.1 Context

WFD Article 7.2 makes direct reference to the DWD standard for pesticide active substances in drinking water. Based upon research presented in Chapters 2 and 3 it can, therefore, be argued that the DWD drives the scale of action required for WFD Article 7 compliance. However, the WFD and DWD remain legally distinct. It follows that WFD Article 7 cast fresh scrutiny on the DWD standard and whether this is fit for purpose. The Paper presented in sections 4.2 – 4.7 of this Chapter analyses whether the 0.1 µg/l standard remains consistent with principles for European environmental policy (EC, 2002) and the precautionary principle (UN Environment Programme, 1992; European Commission, 2000). In so doing the Paper raises profound questions about the logical basis of WFD Article 7 targets for pesticides in potable water.

4.1.2 Review of analytical techniques

The analysis in this Paper is framed around four questions that were identified during research for Chapters 2 and 3. In-depth review of academic literature, technical literature, European and international legislation is used to investigate these questions. The answers acquired, grounded as they are in the literature, provide a logical foundation from which to evaluate the central question ‘Is the EU Drinking Water Directive Standard for Pesticides in Drinking Water Consistent with the Precautionary Principle?’ This methodology makes explicit all analytical assumptions and so provides conclusions that can be replicated through equivalent desk based study.

4.1.3 Significance to the thesis

Because of the tight linkage between the WFD Article 7 and the DWD, the DWD standard for pesticides in potable water directly influences the level of catchment management and pollution prevention the WFD competent authority, water suppliers and agriculture (pesticide users, distributors and manufacturers.) are required to take. It follows that the credibility of the case for catchment management to achieve WFD Article 7 targets is inextricably linked to the logical basis of the DWD standard for pesticides in potable water. If this standard is inconsistent with the guiding principles of European environmental policy, it follows that WFD Article 7 is also inconsistent. The research presented in this Chapter highlights the need to re-evaluate the rationale for the current regulation of pesticides in drinking water. The outcome of any such re-evaluation may have an impact on the level of pollution prevention needed and as such is significant to agronomist behaviour (Chapter 5) and water company planning (Chapter 6).

4.2 Abstract

Regulations based on the precautionary principle should undertake a comprehensive assessment of all available scientific and technical data to identify sources of epistemic uncertainty. In the European Union (EU), environmental regulation is required to fulfil the principles established in Article 174 of the EU Treaty, such that it offers a high level of protection and is consistent with the precautionary principle. Pesticides in drinking water are currently regulated by the Drinking Water Directive using a maximum allowable concentration of 0.1µg/l. This standard (a surrogate zero) was consistent with the precautionary principle when it was originally set in 1980 and remained consistent when retained in 1998. However, given developments in EU pesticide and water policy, international experience in regulating pesticides and an increasing knowledge of pesticide toxicity, it can be argued that the level of epistemic uncertainty faced by regulators has substantially decreased. In this paper, we examine the extent to which such developments now challenge the basis of European drinking water standards for pesticides and whether, for substances for which there is good toxicological understanding, a regulatory approach based upon the World Health Organisation (WHO) Guideline Value (GV) methodology would be more consistent with the principles underpinning European environmental policy.

4.2.1 Graphical Abstract



A Graphical abstract was published in support of the Paper, the eight elements influencing European standards for drinking water are (clockwise from top): uncertainty, the precautionary principle, scientific and technical knowledge, European pesticide policy, European water policy, the WHO guideline value methodology for drinking water standards, international experience and perception (public and political)

4.3 Introduction

Article 174 (formerly Article 130r) of the 1992 Maastricht Treaty (EC, 2002) defines a set of principles for the formation of environmental policy in the EU. Central to Article 174 is the aim to provide a high level of protection for human health and to develop policy based upon available scientific and technical data, the precautionary principle, preventive action at source and the ‘polluter pays’ principle.

The revised Drinking Water Directive (DWD) (EC, 1998) was established in 1998 in line with the principles of Article 175 (formerly Article 130s1). Article 1.2 of the

DWD states: “The objective of this Directive shall be to protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean.”

To achieve this objective, the DWD sets maximum allowable concentration (MAC) values for several chemical parameters in drinking water. For pesticides, the MAC is 0.1 µg/l for any individual active substance (a 0.03 µg/l standard applies to four exceptions: aldrin, dieldrin, heptachlor and heptachlor epoxide) and 0.5 µg/l for the total pesticide concentration. The MAC of 0.1 µg/l was intended as a surrogate zero, since it was indicative of a typical limit of quantification for trace organic compounds when it was first established (1980) (Eureau, 2001; Jordan, 1999; Tye, 1997). Historically, compliance with these standards in mainly agricultural catchments used for water supply has been primarily achieved through the installation of water treatment infrastructure. However, Article 7 of the Water Framework Directive (WFD) (EC, 2000) is driving a prevention-led approach to compliance with drinking water standards, spreading responsibility for DWD compliance around all stakeholders in a catchment and aligning the DWD more closely with the polluter pays principle. WFD Article 7 has cast fresh scrutiny on the pesticide standard in the DWD, in part because the DWD MAC is applied absolutely with no allowance for low frequency periodic exceedence.

This paper examines whether a 0.1 µg/l MAC for every active substance is consistent with the principles of Article 174 and the precautionary principle. To do this, it addresses four key questions:

- What does the EU understand by the term precautionary principle, and is this consistent with the reasons to use the precautionary principle given in the academic literature?
- Why was a 0.1 µg/l MAC for pesticide active substances in drinking water set in 1980 and retained in 1998? Were these decisions compatible with the precautionary principle, available scientific and technical data, and with EU Treaty Article 174?
- Have advances in scientific understanding and the availability of technical data since 1998 been sufficient to undermine the original justification for the 0.1 µg/l MAC standard in terms of its consistency with Article 174 and interpretations of the precautionary principle?
- Are alternative regulatory options for protecting drinking water quality available to the EU, and are these compatible with Article 174?

4.4 Policy analysis

4.4.1 The EU interpretation of the precautionary principle and its use

What does the EU understand by the term precautionary principle, and is this consistent with the reasons to use the precautionary principle given in the academic literature?

There are many definitions for the precautionary principle (Aven, 2011; Sandin et al., 2002) and ‘a lively debate has arisen concerning its actual meaning and practical application’ (Vlek, 2010a; Vlek, 2010b). Therefore, it is important to define, for the purposes of this paper, the precautionary principle, the situations in which it is an appropriate risk management tool and the EU position regarding criteria for regulatory decisions based upon it.

In 1992, The Rio Declaration on Environment and Development (UN Environment Programme, 1992), declared 27 principles for sustainable development. Principle 15 defines the precautionary principle as follows:

“In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.”(UN Environment Programme, 1992)

Except for the addition of the term “cost effective”, this is the same definition as that agreed as part of the Bergen Declaration in 1990 (Sand, 2000).

4.4.1.1 The precautionary principle in the EU

In 1992, Article 174.2 of the Maastricht Treaty, which defined the principles for environmental policy in the EU, made the first reference to the precautionary principle in European policy:

“Community policy on the environment shall aim at a high level of protection It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay.” (EC, 2002)

However, despite having been written into primary EU Law, the precautionary principle is itself not defined in the EU Treaty (De Sadeleer, 2009). A European Commission (EC) communication on the precautionary principle (European Commission, 2000) is the clearest available guidance of its use in the EU. This communication recommends a structured approach to the analysis of risk, comprising assessment, management, and communication. It identifies the precautionary principle as a risk management tool that is appropriate where the risk assessment has identified scientific uncertainty. When invoking the precautionary principle, the rationale for a decision must be made transparent, the standards set may not be arbitrary and standards must be in keeping with the five principles of risk management shown in Table 4.1.

Table 4.1 Principles of risk management for precautionary principle policy design
(adapted from European Commission COM/2000/1 (2000))

Principle	Detail
Proportionality	Measures should be proportional to the desired level of protection.
Non-discrimination	Measures should not be discriminatory in their application.
Consistency	Measures should be consistent with the measures already adopted in similar circumstances or using similar approaches.
Examination of the benefits and costs of action	The measures adopted presuppose examination of the benefits and costs of action and lack of action. Benefit and cost evaluation may involve economic, efficacy and the socio-economic impact analysis, as well as evaluation of non-economic considerations.
Examination of scientific developments	The measures, although provisional, shall be maintained as long as the scientific data remain incomplete, imprecise or inconclusive and as long as the risk is considered too high to be imposed on society.

Therefore, it can be argued that, in the EU, once the decision has been made to invoke the precautionary principle in support of achieving a high level of protection, the standards set must be in keeping with the above principles. The environmental policy will then be compatible with the principles of both the precautionary principle and EU Treaty Article 174.

4.4.1.2 Application of the precautionary principle

Academic literature on the precautionary principle makes it clear that there should be no conflict between the precautionary principle and the scientific principles of risk assessment, and that its use in environmental policy formation can be consistent with a scientific approach (Aven, 2011; Vlek, 2010a; Vlek, 2010b; Klinke and Renn, 2001; Stirling and Gee, 2002). This is in line with the EC communication and the Rio Declaration, both of which recommend recourse to the precautionary principle when

scientific uncertainty is present. The subject of when recourse to the precautionary principle should be made is widely covered in the literature (Table 4.2).

Table 4.2 Synthesis of influential discussion of the precautionary principle in the literature

<p>Paper: Stirling and Gee (Stirling and Gee, 2002)</p> <p>Synopsis: Based upon risk as a function of likelihood and magnitude, Stirling and Gee distinguish between four states of incertitude: ‘risk’, ‘ambiguity’, ‘uncertainty’, and ‘ignorance’. These states are based upon the ability to define outcomes and assign probabilities to these outcomes. In these definitions, ‘risk’ is where outcomes are known and there is some basis to assign probabilities allowing ‘risk’ to be managed without recourse to the precautionary principle. Where uncertainty, ambiguity or ignorance exist they must be acknowledged, and policy based upon the precautionary principle is needed to avoid unexpected outcomes.</p>
<p>Paper: Klinke and Renn (Klinke and Renn, 2001)</p> <p>Synopsis: Klinke and Renn (Klinke and Renn, 2001) define three risk types ‘Normal’, ‘Intermediate’ and ‘Intolerable’, which are based upon knowledge of the ‘Extent of Damage’ ‘E’ and the ‘probability of occurrence’ ‘P’. ‘Normal’ risk types are those that can be managed using the conventional tools of risk management.</p> <p>Implementation of the precautionary principle is most strongly recommended to manage either intermediate or intolerable risk where the certainty of assessment for either E or P is low, or where there is believed to be high catastrophic potential, incomplete systematic knowledge or where the evaluation of risk has identified that regulatory decisions need to be made at the limits of human knowledge.</p>
<p>Paper: Aven 2011 (Aven, 2011)</p> <p>Synopsis: Aven 2011(Aven, 2011) critiques the position taken by Stirling and Gee with the argument that risk assessment can use both objective and subjective probabilities and, therefore, the term ‘risk’ as defined by Stirling and Gee is too narrow. Aven argues that the precautionary principle should only be used when faced with scientific uncertainty defined as epistemic uncertainty and arising from insufficient knowledge. He proposes two circumstances where the precautionary principle should be used in policy design to manage risks arising from epistemic uncertainty (incomplete knowledge). These situations are where it is:</p> <ul style="list-style-type: none"> • Difficult to specify a set of possible consequences or • Difficult to establish an accurate prediction model

Many authors distinguish two or more types of uncertainty. In the terminology used by Aven (Aven, 2011), epistemic uncertainty is defined as arising from insufficient knowledge and aleatory uncertainty is caused by natural random variation. Since it is generally agreed (Aven, 2011; Klinke and Renn, 2001; Stirling and Gee, 2002) that the precautionary principle should be invoked whenever there is epistemic uncertainty, the decision to invoke it should be preceded by a comprehensive assessment of available scientific and technical data in order to identify potential sources of such uncertainty. The level of regulation set under the precautionary principle must be sufficient to manage the epistemic uncertainty identified. These concepts are used later in the paper to assess whether current policy approaches to protecting drinking water quality are consistent with the precautionary principle.

4.4.2 Is the EU MAC for pesticides justified?

Why was a 0.1 µg/l MAC for pesticide active substances in drinking water set in 1980 and retained in 1998? Were these decisions compatible with the precautionary principle, available scientific understanding and technical data, and with EU Treaty Article 174?

The DWD sets a MAC of 0.1 µg/l for all individual pesticide active substances in drinking water at the point of supply (except for 0.03 µg/l for aldrin, dieldrin, heptachlor and heptachlor epoxide). The origin of this standard predates both the current DWD, and the decision to embody the precautionary principle in Article 174 (originally Article 130r) of the Maastricht Treaty. The 0.1 µg/l standard first appeared in 1980 in Directive 80/778/EEC (EC, 1980). Prior to this a 0.5 µg/l standard was set for total pesticides in Directive 75/440/EEC (EC, 1975). Both of these standards are

believed to have their origin in the philosophy of the first and second environmental action plans running from 1973-77 and 1977-81, i.e. that pesticides should not be present in drinking water regardless of the actual risks posed (Jordan, 1999; Hey, 2006).

In 1980, at the time the standards for pesticides in drinking water were adopted, relatively little was known about the impacts of pesticides on human health (Jordan, 1999), pesticides were poorly regulated in the EU and there was the perception that the scale of health impacts could be large. Therefore, when analysed against the reasons for recourse to the precautionary principle as given by Stirling and Gee (Stirling and Gee, 2002), by Klinke and Renn (Klinke and Renn, 2001) and by Aven (Aven, 2011), the decision to adopt 0.1 µg/l as a surrogate zero in order to prevent exposure to pesticides through drinking water can be justified.

In the language of Stirling and Gee (Stirling and Gee, 2002), policy makers were in a position of 'ignorance' because of insufficient knowledge regarding health outcomes from exposure. In other words the health risk from exposure could not be classified as 'Normal' because the certainty of assessment for both extent of damage and probability of occurrence was low (Table 4.2), and there was a perception of high catastrophic potential from exposure and the need for regulators to make a decision at the limits of human knowledge. Using the classification from Aven (Aven, 2011), the uncertainty present was epistemic, warranting recourse to the precautionary principle. Furthermore, the decision to set a standard as a surrogate zero could also be justified because, for many pesticides (but not all), the only exposure level where 'ignorance'/epistemic uncertainty could be replaced with scientific certainty was zero.

In 1998, Directive 80/778/EEC was replaced by the current Drinking Water Directive (98/83/EC). Following much debate, the decision was taken to retain the 0.1 µg/l standard for pesticides (Jordan, 1999). At the stage of this decision, pesticide active substances were beginning to be much more tightly regulated in Europe following the introduction of Directive 91/414/EEC (EC, 1991), but the pesticide review initiated by this Directive was not complete until 2009 (European Commission, 2001a). Therefore, in 1998 many pesticides remained available for sale despite significant uncertainty regarding their potential effects on human health. Furthermore, the EC had not formally stated its interpretation of the precautionary principle (De Sadeleer, 2009), EU chemical policy was still grappling with insufficient knowledge (European Commission, 2001b) and the WFD (EC, 2000) did not yet exist. It can be argued, therefore, that the judgement in 1998 to extend the 0.1 µg/l standard was also justifiable based upon a shortage of available scientific and technical data.

However, it is pertinent to point out that, at this stage, perception in the general public and amongst politicians was that the human health risks associated with pesticides were high. As a consequence of this prevailing negative public opinion about pesticides, it needs to be acknowledged that the decision in 1998 is likely to have had a political dimension.

A key question now is whether there has been a significant change in scientific understanding and available technical data since 1998 that might be sufficient to prompt a review of the DWD standard in terms of its consistency with the principles of European environmental policy (Article 174 and the precautionary principle).

4.4.3 Advances in policy and scientific understanding since 1998

Have advances in scientific understanding and the availability of technical data since 1998 been sufficient to undermine the original justification for the 0.1 µg/l MAC standard in terms of its consistency with Article 174, and interpretations of the precautionary principle?

Any case for the DWD pesticide standard to be reviewed must demonstrate that increased scientific understanding and technical knowledge is now available to address the epistemic uncertainty present in 1998. Scientific developments in the toxicology of pesticides occur periodically (Munro et al., 1992; Garcia et al., 2003; Silva and Carr, 2010). However, significant uncertainties remain, for example about mixture toxicity (Carpy et al., 2000; Lydy et al., 2004), which can sometimes be accounted for using conservative safety factors, and about the relevance of metabolites (Dieter, 2010). In addition, three factors have increased our knowledge of potential pesticide health impacts, chemical properties and use patterns, and improved the effectiveness of pesticide regulation since 1998. These are:

- Developments in EU Policy
- Increased application of the WHO GV method for regulating threshold chemicals in drinking water
- International experience in regulating pesticides

4.4.3.1 Developments in EU policy

Analysis of EU policy (Table 4.3), demonstrates that several policy barriers are now in place to control exposure to pesticides in drinking water. In all cases the strength of each barrier has increased since 1998. Thus taken together, these barriers decrease

dependence on a stringent drinking water standard for the protection of human health and increase the knowledge base from which drinking water quality can be regulated. The significance of each barrier is detailed below.

Table 4.3 EU policy as a multi barrier approach to pesticide regulation and drinking water policy

#	Barrier	Point of Action	Range of Influence
1a	EU Pesticide Approval Legislation Dir. 79/117/EEC, Dir. 91/414/EEC and Reg. 1107/2009	Source	Pathway Receptor Supply
1b	Member state plant protection product approval policy	Source	Pathway Receptor Supply
2a	WFD ‘No Deterioration Objective’ (Art. 1 and 4)	Receptor	Source Pathway
2b	WFD ‘EQS for Chemical Status’ (Art. 16)	Receptor	Source Pathway
2c	WFD ‘EQS for Ecological Status’	Receptor	Source Pathway
2d	WFD Art. 7 on waters used for the abstraction of drinking water.	Source	Pathway Receptor Source
3a	EU Dir 2009/128/EC on the sustainable use of pesticides	Source Pathway	Receptor
4	Drinking Water Legislation Dir. 75/440/EEC, Dir. 80/778/EEC, Dir 98/83/EC	Supply point	N/A

4.4.3.2 Barrier 1 – EU pesticide approval legislation

The first barrier to control the presence of pesticides in drinking water is the EU pesticide approval legislation. This legislation governs which chemicals can and cannot be marketed for use as pesticides. Initially, in the form of Dir. 79/117/EEC (EC, 1979), this barrier allowed any chemical to be marketed as a pesticide provided it did not contain mercury or one of eight persistent organo-chlorine compounds specified in Annex I of the Directive. In 1991, Dir. 91/414/EEC (EC, 1991) strengthened this barrier by introducing the need for all active substances to gain prior approval before they could be marketed as pesticides in Europe. Implementation took the form of a 16-year review, during which each active substance was subjected to a comprehensive evaluation of hazards posed to various end points and the likelihood of human and environmental exposure. This evaluation also included assessment of the propensity for land to water movement (Article 5) (EC, 1991). The data requirements for the evaluation were specified in Annex II of the Directive. The review was completed in 2009, at which point 26% of active substances had passed the review, 7% were not approved and 67% had been removed from the market prior to submission for review (European Community, 2009). The introduction of Dir. 91/414/EEC gave greater certainty about the chemistry and toxicology of those substances being used as pesticides, removed the most dangerous chemicals from the market, shifted the burden of proof to pesticide producers, and gave a knowledge-base from which pesticides could be regulated into the future. In addition, the review solved for pesticides the problem of different regulation for new and existing substances, which persisted in some areas of EU Chemical policy (European Commission, 2001b) until REACH (Regulation 1907/2006) (EC, 2006), the European

Community Regulation on general chemicals and their safe use, entered into force on 1st June 2007.

As part of the EU thematic strategy for pesticides, new legislation was introduced in 2009 (EC, 2009b). Regulation 1107/2009 (EC, 2009b) further increased the stringency of the prior-approval barrier put in place under Directive 91/414/EEC by introducing several hazard-based criteria (Annex II) (EC, 2009b), which have the intention of removing active substances with properties such as carcinogenicity, mutagenicity and reproductive toxicity (including endocrine disruptors) from the market, regardless of their potential for human or environmental exposure. All pesticide active substances scheduled for approval from 2011 onwards will need to satisfy the requirements of Regulation 1107/2009, as will all new active substances. Relevant metabolites, i.e. those judged to have comparable intrinsic properties to the active substance (European Commission, 2003), are also evaluated as part of the pesticide approval process defined in Directive 91/414/EEC and Regulation 1107/2009 and may prevent approval of an active substance.

In addition, Barrier 1b requires that any plant protection product containing an approved active substance must also gain approval at Member State or zonal level before the product can be used (Article 28 of Reg 1107/2009) (EC, 2009b).

4.4.3.3 Barrier 2 – The Water Framework Directive (WFD)

Various elements of the WFD (EC, 2000) can potentially have an impact on the concentration of pesticide active substances in ‘raw’ (untreated) water. The WFD can, thus, be considered as Barrier 2, which can be broken down into those elements acting at receptor (Barriers 2a-c) and those elements acting at source (Barrier 2d). The

primary purpose of Barriers 2a-c is not the protection of drinking water from pesticides, although they do, nevertheless, have some impact on the presence of pesticides in 'raw' water. Barrier 2a is the requirement for 'no deterioration' as specified in Articles 1 and 4 of the WFD: it is the starting point for the WFD objective to 'protect, enhance and restore' (Article 4.1a) all surface water bodies and to 'prevent or limit the input of pollutants into groundwater' (Article 4.2b). Barrier 2b is the requirement, in Article 16, for the identification of priority substances and priority hazardous substances, to enable assessment of the chemical status of a water body, in order to support the *'progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances'* (EC, 2000). Environmental quality standards (EQS) have been set for 11 pesticide active substances (EC, 2008). However, only one of these active substances remains approved for use (Dolan et al., 2012). The ability to designate priority substances ensures that any active substance considered a potential problem for water quality is identified and targeted under the WFD. That ten of the 11 pesticide active substances identified as priority substances or hazardous priority substances have now been removed from the market under the independent action of pesticide approval regulation is testament to the strength of Barrier 1 and its ability to prevent the release of highly hazardous substances into the environment. Barrier 2c is linked to the assessment of ecological status and involves the identification at Member State level of *'other substances being discharged in significant quantities into the body of water'* (Annex V) (EC, 2000). These 'specific pollutants' are distinct from the priority substances (Article 16) and environmental

quality standards (EQS) are set for these by the Member State in order to support compliance with WFD ecological status targets.

Barrier 2d is WFD Article 7, which refers to waters used for the abstraction of drinking water. It requires the creation of protected areas where water is abstracted, emphasizes the need for no deterioration in 'raw' water quality, and aspires toward DWD compliance without installation of additional treatment. Therefore, in WFD Article 7 protected areas the management of 'raw' water quality becomes a priority for river basin managers, water suppliers and all pesticide users. Although compliance with the DWD is measured at the point of drinking water supply to customers, the intention of WFD Article 7 is to create the incentive for action at the point of application (i.e. the primary pollution source), action to minimise movement to the water body (the pollution pathway) and action in abstracted water bodies (the pollution receptor) (Dolan et al., 2012) to reduce pesticide concentrations in 'raw' water to levels that can be removed by current treatment, thereby ensuring DWD compliant drinking water. Barrier 2d is an aspiration and it remains to be seen whether WFD Article 7 compliance will be achieved across Europe in 2015 for all pesticide active substances without the need for increased treatment.

4.4.3.4 Barrier 3 - EU Directive 2009/128/EC on the sustainable use of pesticides

The Sustainable Use Directive (09/128/EC) (EC, 2009a) is the second element of the EU thematic strategy for pesticides. It is intended to act at source to promote best practice for responsible pesticide use and along pathways to reduce the movement of pesticides to water. Many of the requirements of this Directive are very similar to the

good practice and responsible pesticide use recommended in the UK by voluntary industry-run schemes such as the Voluntary Initiative and the Metaldehyde Stewardship Group (Dolan et al., 2012). The Directive applies to the aquatic environment and drinking water through Article 11.1, and aims to deliver actions that strengthen Barriers 1 and 2. However, at time of writing the degree to which this Directive is likely to be effective remains uncertain, because the December 2011 deadline for transposition into Member State law has only recently passed.

4.4.3.5 Barrier 4 – The Drinking Water Directive

The DWD (EC, 1998) could now be seen as a final barrier acting at the point of supply to prevent the presence of pesticides in drinking water. However, the DWD standard for pesticides has its origins at a time before Barriers 1, 2 and 3 were in place and when insufficient scientific knowledge or technical data were available regarding the human health impacts of exposure to pesticides at any level. In addition, little was known about which pesticides were likely to be found in ‘raw’ water. For this reason, it regulates based upon the assumption that it is the only barrier and that all exposure to pesticides must be avoided.

4.4.3.6 World Health Organisation (WHO) guideline value (GV)

The WHO has published international standards for drinking water since 1958. In 1984, the WHO published the first edition of ‘Guidelines for Drinking Water Quality’, which was subsequently followed by further editions in 1993 (World Health Organisation, 1993), 2004 (World Health Organisation, 2008) and 2011 (World Health Organisation, 2011). The aim of these Guidelines is to “provide a scientific point of departure for national authorities to develop drinking water regulations and

standards appropriate for the national situation.”³⁸. The WHO Guidelines are recognized as representing the UN position on issues of drinking-water quality and health by “UN-Water” (World Health Organisation, 2008).

The most recent editions of the guidelines (World Health Organisation, 1993; World Health Organisation, 2008; World Health Organisation, 2011) include guidance on chemical aspects. This differentiates between threshold and non-threshold chemicals when determining a regulatory approach to protect human health. Non-threshold chemicals are substances that pose a theoretical risk to human health at any exposure level (e.g. genotoxic carcinogens) and should be regulated at source. Threshold chemicals are those where daily exposure below a certain level will have no adverse health effects and can, thus, be regulated with reference to guideline values (GVs) which are designed to prevent chronic health effects over a 70 year lifetime. A method for the calculation of guideline values was first proposed and applied in the second edition (1993); this has been applied to a broader range of chemicals in subsequent editions (2004 and 2011) of the guidelines.

For threshold chemicals, the GV methodology uses no observed adverse effect level (NOAEL) or lowest observed adverse effect level (LOAEL) data to calculate a tolerable daily intake (TDI). The TDI accounts for four sources of residual uncertainty in the toxicological data via uncertainty factors (UFs). These arise from: interspecies variations (the use data from animal studies), intra-species variation (difference between individual humans), data quality and uncertainty regarding the nature or severity of exposure above the NOAEL/LOAEL (Ritter et al., 2007). When calculating a GV from a TDI it is recognised that drinking water is not the only source

of daily exposure to a threshold chemical. The GV method is applicable to many chemicals, including pesticide active substances. Unlike the DWD MAC, it recognises that different active substances have different toxicities; i.e. at the same level of exposure not all pesticides pose an equal risk to human health.

4.4.3.7 International experience regulating pesticides

The WHO reports GVs for 32 pesticide active substances. Forty other active substances were evaluated, 27 of which were judged as ‘unlikely to occur in drinking-water’ and 13 of which were judged to ‘occur in drinking-water at concentrations well below those of health concern’, therefore GVs for these are not given. In Australia, the WHO method has been applied as part of the National Water Quality Management Strategy⁴¹ to calculate GVs for 154 pesticide active substances, including several pesticides judged ‘unlikely to be found in drinking water at levels that may cause health concerns’. The current Australian standards (NHMRC, 2011) include information on the derivation of the GV and include a full and transparent justification of all the assumptions made, including the selection of UFs and the fraction of exposure assumed to occur via drinking water.

In the USA, as part of the Safe Drinking Water Act, the Environmental Protection Agency (EPA) is responsible for the identification of contaminants for inclusion in national primary drinking water regulation. To be included in primary drinking water regulation, a contaminant must first be included on a contaminant candidate list (CCL) for further evaluation of health effects, occurrence and analytical methods (United States Environmental Protection Agency, 2012). If prioritised for inclusion in primary regulation, a Maximum Contaminant Level Goal (MCLG) is calculated for

the contaminant. To date, only 20 pesticide active substances have been subject to MCLG values in national primary drinking water regulation (EPA, 2012).

The MCLG is equivalent to the WHO GV, and is calculated using a similar methodology (Ritter et al., 2007). NOAEL or LOAEL and UF (Ritter et al., 2007) values are applied to calculate a reference dose (RfD) (equivalent to a TDI.) The RfD is then converted to a MCLG using standard assumptions of adult body mass, daily water consumption and the level of exposure through potable water. Unlike the WHO GV process, an additional step is taken to derive a legally enforceable standard or maximum contaminant level (MCL). Whereas the MCLG is based purely on public health considerations, the MCL considers both best available treatment technology and cost, in order to set a standard which ‘maximizes health risk reduction benefits at a cost that is justified by the benefits’ (PSD, 2009). It is possible, therefore, for an MCL to be set at a higher concentration than the MCLG. However, like the WHO, for known carcinogens the US EPA reverts to the precautionary approach and sets the MCL at zero, because any exposure could present a cancer risk.

In the EU, all pesticide active substances currently on the market are regulated by the DWD, whereas GVs have been derived for just 32 substances by the WHO and for 154 substances in Australia. In the USA, MCLs have been derived for just 20 substances. Furthermore, the MAC is a more stringent standard than the equivalent GVs and MCLs for all substances (Table 4.4).

Table 4.4 Comparison of drinking water values for some common pesticide active substances

Active substance	DWD value (µg/l)	WHO (µg/l)	GV	USA (µg/l)	MCL	Australian Value (µg/l)
Metaldehyde	0.1		---		---	20
Propyzamide	0.1		---		---	70
Clopyralid	0.1		---		---	2000
Pendimethalin	0.1		20		---	400
Chlortoluron	0.1		30		---	---
Glyphosate	0.1		---		700	1000
Atrazine	0.1		2		3	20
Simazine	0.1		2		4	20

--- active substance not included in standards

With only six exceptions, the WHO GVs allow concentrations at least 20 times the DWD MAC. None of those exceptions (aldrin and dieldrin, chlordane, 1,2-dibromoethane, cynazine, endrin) is currently approved for use in the EU.

In Australia, with only seven exceptions, standards allow concentrations at least 10 times the DWD MAC. The exceptions are carbophenothion, fenamiphos, fipronil, parathion-methyl, pirimiphos-ethyl, profenofos and terbufos, each of which is allowed at concentrations at least 3 times the DWD MAC. Only two of these exceptions are approved in Europe, and these are expected to be candidates for substitution when reassessed under Regulation 1107/2009 (PSD, 2009). In the USA most MCLs are at least 20 times the DWD MAC.

In summary, the introduction of prior approval regulation for pesticides, and other developments in EU pesticide and water policy since 1998 have collectively increased

the stringency of legislation influencing which active substances can be used and, in principle, how these chemicals are managed. In addition, developments in toxicological understanding have reduced some of the scientific uncertainties which existed previously with respect to the risks associated with exposure to pesticides in drinking water. It follows that the assumption of total epistemic uncertainty regarding the human health impacts arising from any level of exposure to any pesticide active substance can no longer be justified. If this is the case, then it could be argued that a surrogate zero for pesticide active substance concentrations in drinking water is no longer consistent with the precautionary principle and EU Treaty Article 174. This is not in itself necessarily a justification for the revision of the DWD MAC for pesticides; it simply challenges the claim that this value is still based upon the precautionary principle.

The development by the WHO of a method for calculating guideline values to regulate exposure to threshold chemicals via drinking water and lessons from international experience of regulating pesticides in drinking water could form the basis of a DWD review. However, any such review should be careful to establish whether alternative regulatory approaches offer a sufficiently high level of protection to human health and are themselves consistent with the precautionary principle and EU Treaty Article 174. The compatibility of the WHO GV and EPA MCL approaches with the precautionary principle and EU Treaty Article 174 are analysed in the next section of this paper.

4.4.4 Regulatory alternatives to the surrogate zero

Are alternative regulatory options for protecting drinking water quality available to the EU and are these compatible with Article 174?

The regulatory approach taken by the WHO and EPA does not tolerate any level of exposure to non-threshold chemicals. For threshold chemicals, these approaches assume the existence of two levels of exposure: one level at which risk can be managed and one at which epistemic uncertainty regarding human health outcomes must be acknowledged and regulated for. In this respect, both approaches are in keeping with the precautionary principle.

The DWD, on the other hand, assumes epistemic uncertainty for all pesticide active substances at any level of exposure greater than zero. It then applies the precautionary principle to invoke a surrogate zero (0.1µg/l), to prevent significant exposure via drinking water. If the assumption of total epistemic uncertainty is not valid, then the standard is no longer justified by the precautionary principle, although it may still be justified on other grounds.

Thus, although both the WHO and DWD approaches recognise the existence of epistemic uncertainty, the WHO approach is more in keeping with EU Treaty Article 174 and the precautionary principle. This is because it acknowledges the existence of available scientific and technical data, recognises the heterogeneity of active substances, sets non arbitrary standards in a transparent way and is consistent with the five principles of risk management in the EC communication on the precautionary principle (European Commission, 2000) (as presented in Table 4.1).

In the USA, the approach taken by the EPA to calculate a level of exposure below which no adverse effects will occur (the MCLG) uses available scientific and technical data in the same way as the WHO GV calculation. However, the next step, converting the MCLG to a legally enforceable MCL, has the potential to set an MCL above the MCLG, thereby allowing exposure at a level where epistemic uncertainty is known to exist. It follows that the EPA approach is not fully compatible with the precautionary principle.

4.5 Discussion

In the absence of available scientific understanding and technical data, a surrogate zero for pesticides in drinking water can be justified under the precautionary principle and is in keeping with both EU Treaty Article 174 and DWD Article 1.2. The decision to use a surrogate zero standard in the 1998 DWD can be justified based upon the state of scientific and technical knowledge at the time this Directive was agreed. However, since 1998 there have been advances in available scientific understanding and technical knowledge (see Section 2.3) as well as significant developments in EU pesticide and water policy, which have essentially strengthened protective barriers and reduced overall risks to human health arising from exposure to pesticides. Therefore, whether the change in available scientific understanding and technical data since 1998 is sufficient to prompt a review of the DWD standard in terms of its consistency with the principles of European environmental policy (Article 174 and the precautionary principle) becomes a key question. It can be argued that the WHO GV method for pesticide regulation, like the DWD standard, also offers a high level of protection to prevent adverse effects of pesticides on human health, but, unlike the DWD, makes explicit use of available scientific and technical data to set regulatory standards in a

way that is consistent with the principles of EU Environment policy as defined in Article 174.

Given continuing scientific and legislative developments, it can be argued that a review of drinking water quality standards in the EU is required. A future regulatory approach could better utilize scientifically robust toxicological understanding, where this exists, and still be consistent with the precautionary principle. Where relevant (i.e. where a NOAEL or LOAEL can safely be established through toxicological studies), revised regulation could be based on the WHO GV method. In some cases (for highly toxic compounds) this may, in principle, actually reduce the MAC. The 0.1 µg/l MAC would be retained for those active substances for which reliable NOAEL or LOAEL values were not currently available. In addition, all non-threshold active substances would be banned under the independent action of EU pesticide approval Regulation 1107/2009. We suggest that this would be a more accurate reflection of Article 174 principles and the precautionary principle than using the same surrogate zero for all active substances.

The primary purpose of the observations made in this paper is to open an objective debate about whether the current standard for pesticides in drinking water remains consistent with the principles of European Environmental Policy (Treaty Article 174 and the precautionary principle) that originally gave rise to the standard. To be objective, this debate should focus solely upon how available scientific understanding and technical data can be most effectively used to develop environmental policy that is consistent with both Article 174 and the precautionary principle. Where current policy is inconsistent with these principles and where robust scientific evidence exists

to support regulatory change, alternatives may need to be formulated. Of course, a key factor in reopening the debate will be whether or not any apparent relaxation of environmental and public health protection (real or not) is acceptable to the public and to interest groups. This is beyond the scope of this paper, but could be critical for any ultimate changes in the regulation regardless of the scientific arguments.

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**Chapter 5: Identifying Adaptation Options and
Constraints: The Role of Agronomist Knowledge in
Catchment Management Strategy**

Sections 5.2 - 5.9 of this chapter were originally published online on 05/01/14 by Springer in *Water Resources Management*. In addition, Section 5.10 provides details of four 'Online Resources' submitted for publication alongside the Paper.

Dolan, T., Parsons, D. J., Howsam, P., Whelan, M. J. and Varga, L. (2014), "Identifying Adaptation Options and Constraints: The Role of Agronomist Knowledge in Catchment Management Strategy", *Water Resources Management*, vol. 28, no. 2, pp. 511-526. DOI: 10.1007/s11269-013-0498-6

5.1 Preface

5.1.1 Context

The agronomist consultation presented in sections 5.2 – 5.9 of this Chapter was undertaken to increase water sector understanding of the major agronomic drivers of pesticide use, the factors that influence these, and how they will evolve as legislation is implemented (pesticide, water and agricultural legislation) at EU and UK level. Conclusions and recommendations from Chapters 2 and 3 justify the need for water suppliers to develop such understanding.

The consultation took place in the Anglian region of the UK (see Figure 5.1 for the location of the Anglian region and Figure 5.2 for a map of the surface water catchments in the Anglian region). Outputs from the consultation are aimed to enable any water supplier to engage more effectively with catchment stakeholders, plan investment responses to support WFD Article 7 targets and deliver their legal responsibilities under the DWD.

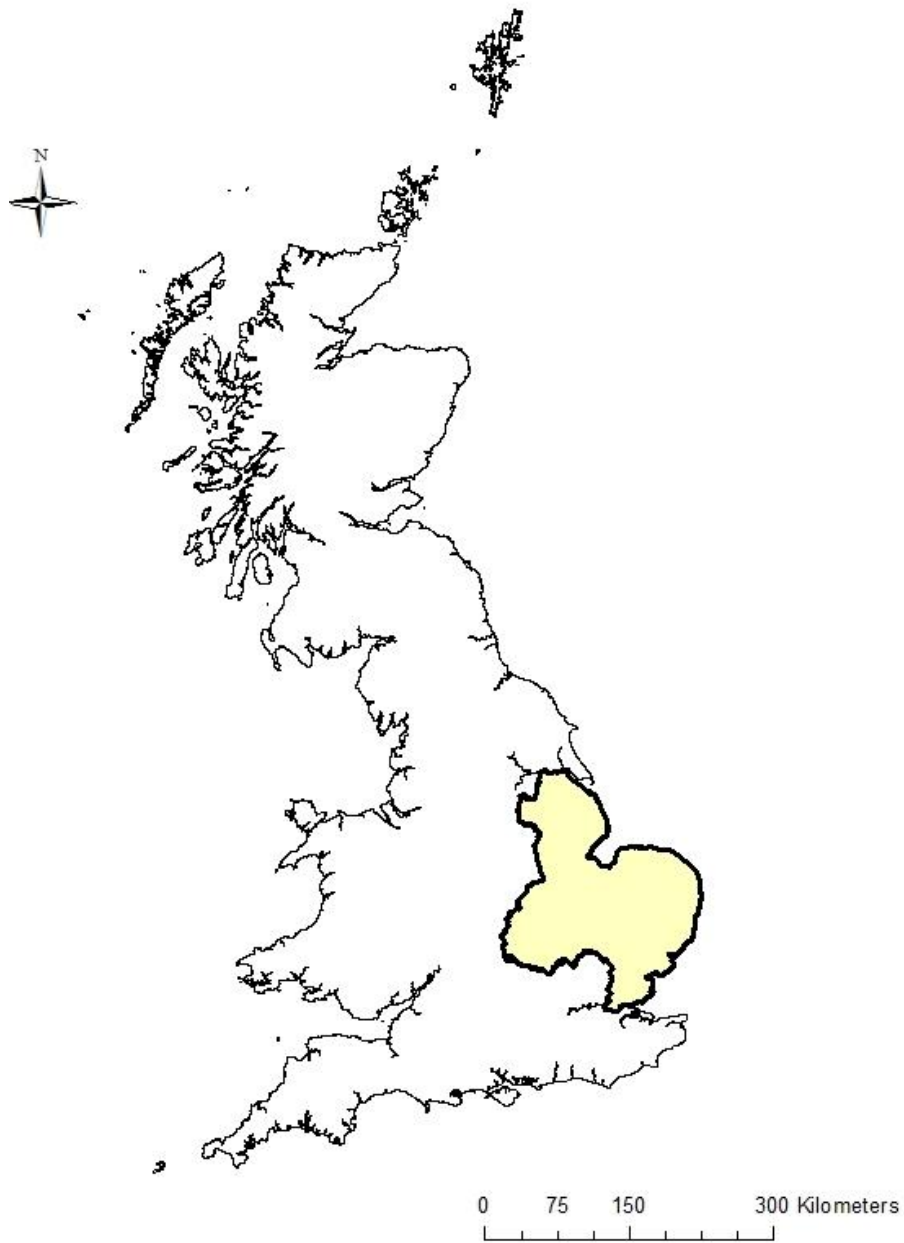


Figure 5.1 Anglian Region of the UK

Contains Ordnance Survey data © Crown Copyright and database right [2013]

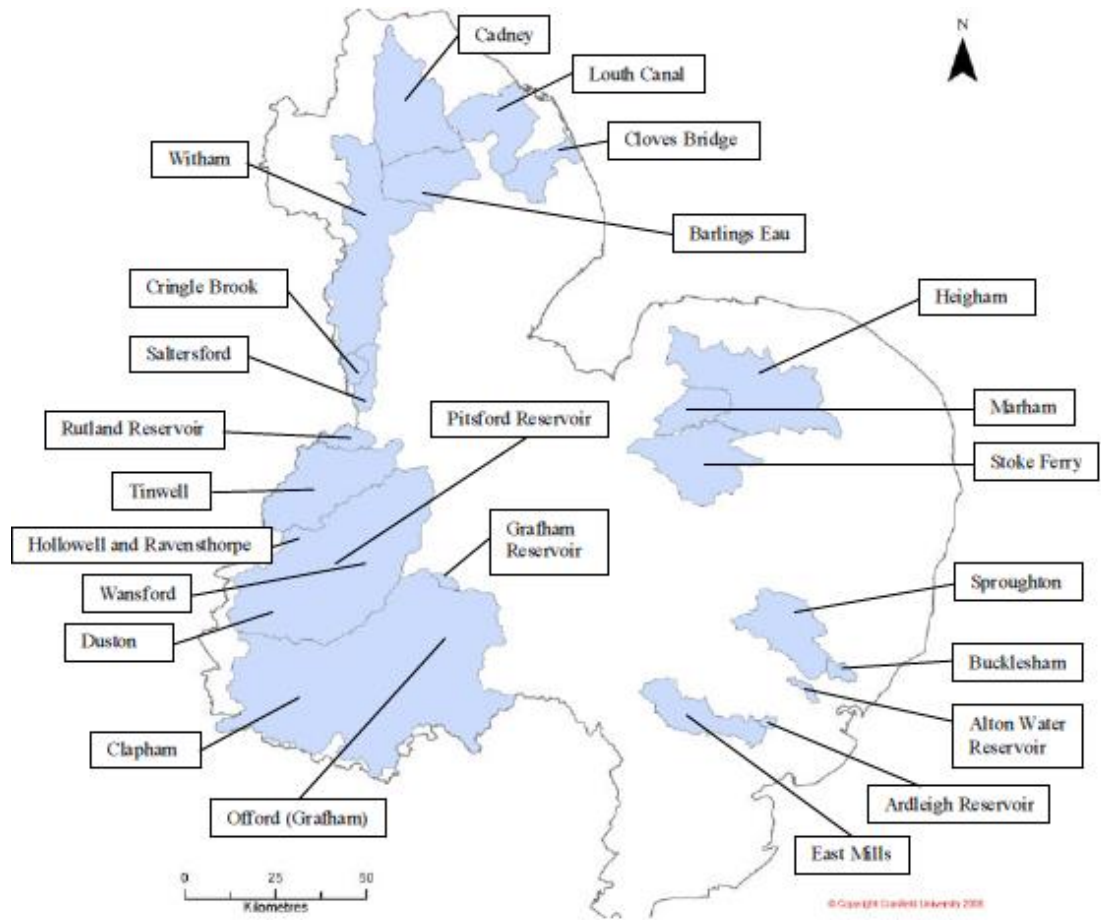


Figure 5.2 Surface Water Catchments in the Anglian Region

(adapted from Cranfield University, 2013)

5.1.2 Review of analytical techniques

An approach using expert consultation with agronomists working in the field and at a strategic level was selected because expert insight into the key drivers of pesticide use and challenges WFD Article 7 creates for agriculture is not currently available in academic or industry literature. The consultation is based upon two stages of semi-structured interviews and a third stage using a Likert survey. This approach was selected in order to maximise the level of expert engagement and then validate emerging themes against a larger population of respondents. Full details of and justification for the consultation method are provided in section 5.4 and appendix 5.3.

An approach based upon open interviews and grounded theory analysis (Lansisalmi et al., 2004) was rejected in order to provide focus to the consultation process and make best use of respondent's time. Similarly, a fully structured survey was not used until Stage Three of the consultation to allow key issues relevant to the context of the consultation to emerge through the consultation process.

5.1.3 Significance to thesis

Chapters 2 and 3 identified systematic gaps in water sector knowledge that reduce the ability of water companies to engage effectively with catchment stakeholders. The consultation methodology and results presented in this Chapter begin to address these knowledge gap. The consultation methodology is suitable for use by any European water supplier, to engage catchment stakeholders and begin the processes of improving understanding of the diffuse pesticide problems that may occur at catchment level. However, engagement with agronomists to improve understanding of pesticide use needs to be supported by a systematic method to convert knowledge

gained into evidence to support investment decisions for DWD compliance. It follows the agronomist consultation together with elements of research from Chapters 2 and 3 inspired, and provided essential insights for, the development of the pesticide classification system presented in Chapter 6.

5.2 Abstract

Water suppliers in parts of Europe currently face occasional Drinking Water Directive compliance challenges for a number of pesticide active substances including metaldehyde, clopyralid and propyzamide. Water Framework Directive (WFD) Article 7 promotes a prevention-led (catchment management) approach to such issues. At the same time, European pesticide legislation is driving reduced active substance availability. In this context, embedding agronomic drivers of pesticide use into catchment management and regulatory decision making processes can help to ensure that water quality problems are addressed at source without imposition of disproportionate cost on either agriculture or potable water suppliers. In this study agronomist knowledge, perception and expectations of current and possible future pesticide use was assessed and the significance of this knowledge to other stakeholders involved with pesticide catchment management was evaluated. This was then used to provide insight into the possible impacts of active substance restrictions and associated adaptation options. For many arable crops, further restrictions on the range of pesticides available may cause increased use of alternatives (with potential for "pollution swapping"). However, in many cases alternatives are not available, too costly or lack a proven track record and other adaptation options may be selected which catchment managers need to be able to anticipate.

5.3 Introduction

The European Water Framework Directive (WFD) Article 7 (EC, 2000) promotes a prevention-led approach to Drinking Water Directive (DWD) (EC, 1998) compliance (Dolan et al., 2012; Dolan et al., 2013a; Dolan et al., 2013b). This is philosophically consistent with the World Health Organisation (WHO) drinking water safety planning (DWSP) approach (World Health Organisation, 2008; Breach, 2011a), which aims to increase understanding of and mitigate risks from catchment to consumer (Breach, 2011b). For water quality parameters that are influenced by diffuse source pollution, this usually implies a catchment management approach to address the causes rather than just the symptoms of a water quality problem. For agricultural diffuse pollution of 'raw' (untreated) water, effective catchment management must be based on an understanding of agricultural decision making processes. This is particularly pertinent in the case of pesticides, where several widely-used active substances regularly cause water quality problems in a number of drinking water catchments (Kennedy, 2010; Kennedy et al., 2009); (Defra, 2012). These problems are especially acute for compounds that are not removed significantly by current water treatment technologies, such as metaldehyde (Autin et al., 2012) and clopyralid (Tizaoui et al., 2011).

The catchment management literature for pesticides and potable water predominantly focuses on understanding the many factors (e.g. soil type, topography, local climate, drainage, seasonal weather conditions) that influence the complex pathways along which pesticides are transported from land to water (Brown and van Beinum, 2009; Reichenberger et al., 2007; Tediosi et al., 2012). However, there is less focus in the literature on embedding understanding of behaviour at source, i.e. those contextual

factors that drive current pesticide use patterns, which will also shape future pesticide requirements; into water supplier or regulator decision making processes (Blackstock et al., 2010).

Agronomists often provide expert advice to farmers to support the management of weed, disease and pest problems. In the UK agronomists are the main decision makers for pesticide use on 80% of arable farms (Twining et al., 2009). As a group, they are, consequently, very influential in determining pesticide use patterns and how agriculture will respond to future challenges, such as changes in active substance availability or the need to reduce diffuse pollution. Agronomist expertise could, therefore, be invaluable to all European water suppliers and regulators if methods for regular consultation were developed to systematically embed knowledge of local agronomy issues into catchment management planning. Shared understanding of the challenges faced by water suppliers and the WFD competent authority would also be beneficial for agriculture (Dolan et al., 2013). Increased engagement between these stakeholders is essential if solutions to diffuse pesticide pollution problems that avoid the risk of “pollution swapping” (Stevens and Quinton, 2009a; Stevens and Quinton, 2009b) or the imposition of disproportionate cost on either water suppliers or agriculture are to be identified.

This paper presents the findings from a three-stage study of agronomist knowledge, perception and expectations. The principal aim of the study was to identify drivers of current operational pesticide use, potential agronomic impacts of restrictions or bans on active substances, potential responses (adaptation options) to such restrictions and constraints on adaptation options. The principal outputs from this study are insights

into agricultural decision making and an adaptation options framework which, when combined with knowledge of current pesticide strategies and constraints to adaptation, can be used as the basis for catchment management dialogue between key stakeholders.

The study was conducted in the Anglian region of Eastern England, which has a very high area of productive arable land and high pesticide use, occasionally resulting in DWD compliance challenges for the water industry. Although the work was focussed on the agronomy of arable crops, the general methodology and many of the principal outcomes are relevant to any situation in Europe where diffuse pesticide pollution is causing problems for DWD compliance and preventative action is required under WFD Article 7.

5.4 Methods

5.4.1 General

The study was conducted in three stages. At each stage, themes that emerged from the previous stage were developed and validated. Stage 1 was a scoping exercise, based on semi-structured interviews, during which sixteen agronomists identified the weed, pest and disease problems of greatest significance to the area in which they work and the most commonly used methods to manage these. Stage 2 used seven case study active substances to investigate the confidence with which respondents could identify the availability (or not) of alternative management options and predict how agronomists and farmers might respond if an active substance were restricted or lost. Stage 3 used an online survey to validate 43 trend statements that arose from Stages 1 and 2 against a wider population of 94 respondents. At each stage the survey was

piloted with academic colleagues and a representative from an agricultural industry body.

5.4.2 Stage 1

A semi-structured interview template (Coolican, 2009; Bryman, 2012) to examine the main crops, problems (weeds, pests and diseases) and solutions (pesticide and non-pesticide) was used for the Stage 1 interviews (Online Resource 1). When setting questions, the decision was taken to allow respondents to identify crops, weeds, pests and diseases, and not to ask directly about any pesticide active substances. The purpose was to derive maximum benefit from expert knowledge and avoid guiding the interview onto any specific active substances or issues (thereby minimising bias).

Sixteen interviews of 60–90 minutes were conducted. Interviews were performed face-to-face or by telephone by the same researcher. In all cases the semi-structured questionnaire was shared with the respondent at least one week in advance of the interview. The role of the interviewer was to allow the interview to develop based upon the semi-structured template. The interviewer used judgement to decide when to ask additional questions to prompt further detail or clarify information provided, and when to direct the interview back to the semi-structured template. Given the range of specialist knowledge amongst interviewees and a time constraint on the interview, not all topics were covered with all respondents, and some topics were covered in greater depth by individual respondents.

The interview transcripts were analysed using thematic template analysis (King, 2004) against an '*a priori*' template based on the semi-structured interview template. Grounded theory (Lansisalmi et al., 2004) was not used because the '*a priori*'

template implies preconceived expectations regarding responses. The creation of an ‘*a posteriori*’ template was used to identify themes emerging from the interview (King, 2004; Braun and Clarke, 2006). A tally of the number of times each heading in the ‘*a posteriori*’ template arose across the 16 interviews was used to assess the prevalence of a theme. Prevalence was used as a proxy for relative importance, but not to establish the validity of a theme.

To support identification of case study active substances for Stage 2, further analysis of relative use levels, future regulatory status and the extent to which the active substance is present in, or is expected to be present in raw (untreated) water was undertaken for all active substances identified during Stage 1 (Garthwaite et al., 2008; The Food and Environment Research Agency, 2009; PSD, 2009; The Voluntary Initiative, 2009; Whelan et al., 2009).

5.4.3 Stage 2

Stage 2 of the study used 7 case study active substances to investigate possible responses to plausible changes in active substance availability. The principal aims were to learn more about how agriculture might respond to the loss of specific active substances, how confidently agronomy experts could predict future adaptations and the available adaptation options (given the range of currently approved active substances) if an active substance was lost or restricted. The herbicides propyzamide, carbetamide, mesosulfuron-methyl, clopyralid, pendimethalin, chlortoluron and the molluscicide metaldehyde were selected for inclusion in Stage 2. To be selected, an active substance had to be used extensively in the Anglian region and to be subject to one or more of the following criteria that could plausibly restrict future availability:

- The pesticide is a potential challenge for water company compliance with the DWD without the adoption of enhanced treatment technologies
- The pesticide will potentially not be reapproved under EU pesticide approval Regulation 1107/2009 (EC, 2009) and there is reason to suspect that replacements might cause water quality problems.
- The efficacy of the pesticide is threatened by the emergence of resistance which means that alternatives might be needed in the future.

A standard set of questions to identify the current reasons for use, potential pesticide and non pesticide alternatives, respondent confidence in the alternatives identified and the broader impacts on crop yield and quality, if the pesticide in question were not available, was used for each active substance (Online Resource 1). The questions required respondents to consider plausible future changes to pesticide availability and to give personal judgement rather than a definitive answer. To encourage respondents to evaluate the level of confidence they placed on each answer, a confidence scale was designed into the question structure. A four-point scale (not at all, low, medium, high) using internally consistent, non-overlapping categories that covered the full range of certainties was selected (Robson, 2002; Cassell and Symon, 2004; Strauss and Corbin, 1990).

Eleven interviews were conducted using the protocol defined at Stage 1. Template analysis was used to analyse all interview transcripts (King, 2004). Because the question set was more tightly defined than at Stage 1, the '*a posteriori*' template did not differ greatly from the initial '*a priori*' template. Analysis led to the identification of a number of key findings for further validation in the Stage 3 survey. Additionally,

Stage 2 analysis led to the proposal of an ‘adaptation options preference framework’ to predict the options which agriculture would explore when faced with pressure on, restriction or loss of an active substance. This framework was originally proposed in (Dolan et al., 2013) and has subsequently been refined and tested during Stage 3 of this study (see Section 4.2).

5.4.4 Stage 3

Stage 3 used an online survey to validate findings from Stages 1 and 2 using a larger sample of agronomy experts. The Stage 3 survey included 43 Likert items, each comprising a ‘stem’ (the question), and a 5 point Likert response scale - strongly disagree, disagree, neither agree nor disagree, agree, strongly agree (Online Resource 2). Likert items can be evaluated as standalone statements (Dunlap et al., 2000); (Hovardas and Poirazidis, 2007) and response patterns across a number of Likert items can be used to test pre-defined Likert scale hypotheses. Six pre-defined Likert hypotheses were included in the Stage 3 design. The purpose of Stage 3 was to identify areas of consensus where there is widespread agreement between agronomy experts, areas where there is sufficient uncertainty that no consensus can be reached and the presence of and possible reasons for ‘outliers’ (respondents answering against consensus).

In order to avoid ambiguous or unclear Likert items, the ‘stem’ of each item contained only one attitudinal object, and no quantitative statements (John, 2012). A five point Likert response scale allowed respondents to express agreement or disagreement, without introducing ambiguity through too many response categories. Acquiescence bias, ‘the tendency to agree with statements to some extent irrespective of their

content' (John, 2012) has been identified as a potential problem in the design of surveys based upon Likert items. To avoid a unidirectional survey and reduce the risk of acquiescence bias, at least one negatively worded Likert item was included in each section. Furthermore, three pairs of similar but opposite Likert items to test for acquiescence bias and two Likert item pairs to test for internal consistency were included in the survey. Spearman's rank correlation test for ordinal data was used (Field, 2009).

Comment boxes to identify reasons for consensus and outliers were included after every section of the survey. 'Outliers' are of interest to the research because solutions to problems may diffuse from niche to mainstream as they become proven or more widely known (Taleb, 2008; Rogers, 2003).

To maximise the response rate, Stage 3 was designed to take no more than 15 minutes, and a brief justification of the purpose of the study was provided. The survey was distributed over a six month period with support of professional agronomy organisations.

All the analyses in this study treated the Likert response scale data as ordinal values and applied non-parametric statistics (Kuzon et al, 1996; Jamieson, 2004). However, some authors have argued that it is possible to apply parametric methods provided that certain conditions are met (Carifio and Perla, 2008).

The Likert response scale data from Stage 3 were analysed in three ways.

(1) Spearman's rank correlation tests ($\alpha = 0.05$) and a visual inspection of data were used to test for acquiescence bias and internal consistency (Field, 2009).

(2) A frequency distribution was created for each Likert item and chi-squared 'goodness of fit' tests ($\alpha = 0.05$), were performed to evaluate the null hypothesis (H_n) against an alternative hypothesis (H_a), where:

H_n : There is no consensus in responses to the Likert item

H_a : There is a consensus in responses to the Likert item

To conduct the chi-squared test, the 5 point Likert response scale was converted into a 2 point scale consisting of 'agreement' or 'disagreement'. All 'Agree' and 'Strongly Agree' responses were classed as agreement; all 'Disagree' and 'Strongly Disagree' responses were classed as disagreement. The response 'Neither' was excluded from the population (n). Where H_n was rejected, a direction ('Agree' or 'Disagree') was assigned to H_a based upon visual inspection of the number of agreement and disagreement responses.

(3) The results from (2) were applied to test six pre-defined Likert scale hypotheses based upon combinations of three to eight Likert items. No appropriate technique was identified for the summation of ordinal data because, whilst numerical values can be assigned to the categories to rank order, these values cannot give an indication of magnitude. Therefore, a technique based upon examination of individual Likert items was used to reach conclusions. It is acknowledged that any Type I or Type II errors at Likert item level will also impact on this examination of Likert scale hypotheses. Conclusions are, therefore, taken as indicative not definitive. The same approach was applied to test a series of pre-defined hypotheses for each case study active substance.

5.5 Results

5.5.1 Stage 1 and 2 findings

Analysis of Stage 1 and 2 interviews identified the following agronomy basics, features of the combinable crop rotation (i.e. crops harvested using a combine harvester) and impacts of pesticide and water regulation as knowledge all water companies and regulators should possess.

5.5.2 Basic agronomic features

Soil type, the availability of break crops, and the comparative economics of cropping options drive the structure of any agricultural enterprise. Different farm types (combinable, horticultural, grassland, potatoes, sugarbeet) each have associated pesticide use profiles. To understand the agronomic drivers of pesticide use, one must, therefore, understand the structure of the rotation deployed by the farm enterprise, and the nature of weed, pest and disease problems within that rotation.

Pesticides are costly inputs, so pesticide use will usually be recommended only where the cost of action is anticipated to be less than the cost of inaction.

Many control strategies involve more than one active substance applied at one or more stages throughout the growing season or across the entire rotation in which the crop is grown. Some strategies may provide incidental management of other less troublesome problems. For example, a strategy to control blackgrass (*Alopecurus agrestis* L.) (**Error! Reference source not found.**) may control other grass weed species. Additionally, the management of resistance to pesticide active substances is an important consideration when designing a control strategy.

Restricting or banning an active substance does not address the root cause of the water quality problem - the need to combat a particular, and probably widespread, weed, disease or pest issue - and is likely to trigger an increased use of one or more other active substances throughout the rotation to manage that issue (i.e. “pollution swapping” may occur (Stevens and Quinton, 2009a; Stevens and Quinton, 2009b)).

5.5.3 The combinable crop rotation

Heavy clay soils occur widely across the case study region. On these soils the dominant cropping pattern is currently an autumn sown combinable crop rotation based on two years of winter wheat (*Triticum aestivum*) followed by one year of oilseed rape (OSR: *Brassica napus* L.), or a similar variation.

Blackgrass and the risk of herbicide-resistant blackgrass need to be managed by a programme of herbicide applications every year of the rotation (**Error! Reference source not found.**). In order to maximize the level of control achieved and reduce the risk of resistance, it is often important to use several active substances with different modes of action in a control programme. Different active substances are used in the wheat and OSR phases of the rotation; the herbicide active substances used in OSR (i.e. propyzamide and carbetamide) are particularly important because, at present, there is no known resistance to these compounds. Many of the herbicides used for blackgrass control (**Error! Reference source not found.**) are residual (designed to persist in the soil) and applied to bare soil. The risk of water quality issues is often higher with these herbicides than with many others because they do not typically degrade sufficiently before the arrival of rainfall capable of mobilising them and transporting them to surface waters (Tediosi et al., 2012)

Slugs are a major pest problem every year in the combinable crop rotation. Slug pellets containing metaldehyde are considered to be the most cost-effective method of control.

Error! Reference source not found. gives an example of a rotation-wide programme of control for herbicide-resistant blackgrass. The programme is based primarily on the use of pesticides, but is increasingly receiving support from complementary non-pesticide actions such as “stale seedbeds” and delayed drilling.

Table 5.1 An example of a rotation-wide control strategy for herbicide-resistant blackgrass

Winter wheat	Winter OSR
<p>Stale seedbed</p> <p>Delay drilling to allow a stale seedbed followed by application of a non-selective herbicide, typically glyphosate, to kill any weeds which have germinated before drilling.</p>	<p>Stale seedbed</p> <p>NB: This is not widely used because OSR is drilled earlier than wheat.</p>
<p>Pre-emergence treatment</p> <p>Apply residual herbicides at the pre-emergence stage. Stack (apply) a range of actives based upon a flufenacet base (10/10). Other residual herbicides for inclusion in the stack include:</p> <ul style="list-style-type: none"> • Diflufenican (10/10) • Pendimethalin (10/10) • Triallate (5/10) • Prosulfocarb (6/10) • CTU (2/10) • Flurtamone (1/10) 	<p>Pre-emergence treatment</p> <ul style="list-style-type: none"> • Metazachlor (7/10) • Metazachlor + quinmerac (3/10) • Metazachlor + quinmerac + dimethanimid – p (2/10)
<p>Post-emergence treatment</p> <p>Atlantis (mesosulfuron-methyl +</p>	<p>Post-emergence treatment</p> <p>Propyzamide AND/OR Carbetamide</p>

<p>iodosulfuron-methyl) is the dominant product (10/10).</p>	<p>(10/10) Tepraloxym and cycloxydim can be used as support (1/10)</p>
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5.5.3.1 The impact of regulation on pesticide use patterns

Current patterns of pesticide active substance use, and any associated water quality problems, are shaped by a context of decreasing active substance availability since the introduction of EU pesticide approval Directive 91/414/EEC (EC, 1991). The new approval legislation, EU Regulation 1107/2009 (EC, 2009), will further reduce the number of active substances available (PSD, 2009), and is a significant source of uncertainty because future adaptations cannot be planned without clarity regarding which active substances will be lost and which will remain available.

Additionally, agronomists perceive the WFD to be a further source of uncertainty and potentially, a driver of decreased active substance availability. Therefore, agronomists expressed the view that any regulator or water company action for WFD Article 7 compliance must understand the causes (the reasons for use, constraints on alternative options, and impacts of losses) and not just focus on the symptoms.

5.5.4 Stage 3 results

5.5.4.1 Introduction

94 agronomists completed the Stage 3 survey. Full details of the responses to all the Likert items are provided online (Online Resource 3). The following are presented here:

- Six hypotheses based upon multiple Likert items (Section 3.2.2).

- Synopses of findings specific to the case study active substances (Section 3.2.3)
- Single Likert items that support additional themes (Section 3.2.4)

Additionally, brief details of the tests performed to assess acquiescence bias and internal consistency are given in Section 3.2.5.

5.5.4.2 Hypotheses (Likert scale) based upon multiple Likert items

The hypotheses presented in Table 5.2 were tested against multiple Likert items. Each hypothesis is relevant to the full range of approved active substances and beyond the geographical context of this study.

Table 5.2 Hypotheses based on multiple Likert items (three or more)

	Hypothesis	Number of Likert items to test hypothesis	Likert items supporting hypotheses
A	There are no direct substitutes for currently used herbicides.	4	100%
B	Cultural control is a complement to not substitute for pesticide active substances	5	100%
C	Herbicide losses in wheat will lead to increased dependence on currently available pre-emergence herbicides	8	100%
D	Effective resistance management requires as many modes of action as possible	5	100%
E	The order of preference for adaptation to the loss of a pesticide active substance is: substitute pesticides, alternative pesticide in rotation, cultural control, crop architecture, rotational control	8	100%

F	The development of new active substances takes time (at least 5 years), and is not triggered in response to the potential loss of a currently approved active substance. The loss of active substances does not create an incentive for new pesticide active substances to come to market	3	100%
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5.5.4.3 Active substances specific findings

Brief synopses for each of the seven case study active substances included in Stage 3 are given below.

Propyzamide and carbetamide: Propyzamide, and to an extent carbetamide, are crucial to blackgrass management in a combinable crop rotation on heavy soil. Without these active substances it would be difficult to grow OSR or any other autumn break crop, so rotational change based upon increased spring cropping might occur. It is uncertain whether carbetamide could substitute directly for propyzamide.

Metaldehyde: Cultural control options cannot eliminate the need for slug pellets. Substitutes for metaldehyde are available. If metaldehyde were restricted for any reason, increased use of these substitutes could prevent rotational change. However, agronomist comments express concern regarding the relative cost, efficacy, availability, proven track record and environmental impact of these possible substitutes.

Mesosulfuron-methyl ('Atlantis'): Reduced efficacy of post-emergence blackgrass control in wheat will reduce wheat yields and increase the use of pre-emergence herbicides. Cultural control options are inadequate to cover for reduced efficacy; if control was too difficult, a change to the rotation might be considered.

Clopyralid: Clopyralid is the only herbicide available for the control of sow thistles. Cultural control is largely ineffective. If clopyralid were unavailable where sow thistles are a particular problem, OSR yields would decrease and reduced OSR planting might occur.

Pendimethalin and chlortoluron: Blackgrass control depends upon many active substances and different modes of action to increase total efficacy and reduce resistance risk. The loss of one active substance would have impacts on how others were used.

5.5.4.4 Likert items on general themes

Five conclusions based on a single Likert item can also be drawn from this study, these are:

- When one active substance is lost (for whatever reason) other active substance(s) will be used to manage the weed, pest or disease issue.
- In the absence of effective pesticide control, weed and pest pressures will increase over time.
- The agronomic impact of losing an active substance depends on which active substances remain available.
- No new herbicides for blackgrass are likely to be available in the next 5 years.
- A change to the rotation is the intervention of last resort.

5.5.4.5 Tests for acquiescence bias and internal consistency

In all cases, the tests for acquiescence bias and internal consistency using Spearman's rank correlation coefficient showed internally consistent responses and the absence of acquiescence bias (Online Resource 4).

5.6 Discussion

5.6.1 Agronomic adaptation options and preferences

On the basis of Likert scale Hypothesis E, Figure 5.3 is proposed as a framework to rank, in order of preference, the adaptation options agronomy can consider when any active substance is restricted or withdrawn. Typically the lower the preference for an adaptation option the higher will be the capital or operating cost of implementing it.

This framework is relevant for:

- Agronomists who need to explain the practical ramifications of the loss of any active substance
- Regulators who need to understand the ramifications of any decision to restrict active substance availability
- Water suppliers who need to anticipate which active substances to expect in 'raw' water in the future.

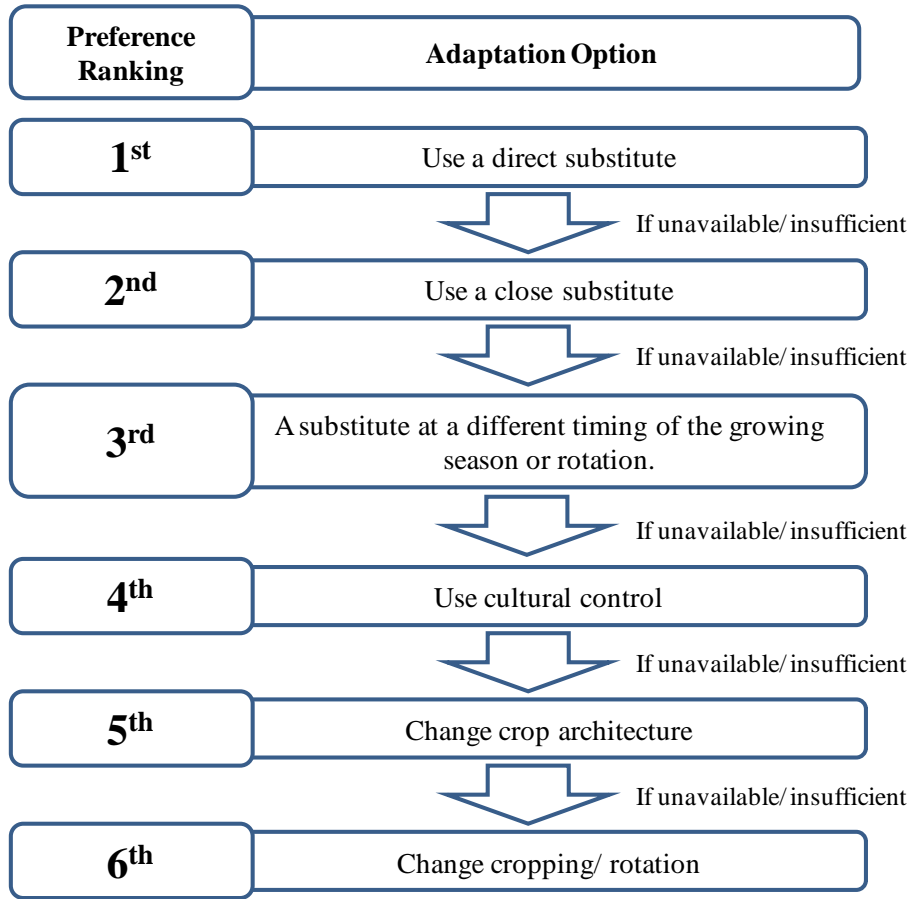


Figure 5.3 Adaptation option preference framework

Where agriculture perceives that an active substance may be restricted in the future and that voluntary action can prevent the threat of statutory restriction, actions in the framework may be initiated on a voluntary basis. For example the Voluntary Initiative in England and Wales was initiated in 2001 as a partnership between industry and government with the aim of reducing diffuse pesticide pollution through voluntary good practice (The Voluntary Initiative, 2013); the Metaldehyde Stewardship Group promotes a similar approach for metaldehyde (Metaldehyde Stewardship Group, 2013). However, the level of voluntary action available to agriculture is constrained by other practical factors (Section 4.3).

1st Preference: use a direct substitute. A direct substitute is a pesticide active substance with an equally established agronomic track record that can be applied at the same stage in the rotation with equally efficacy at an equivalent cost. Likert scale Hypothesis A indicates that direct substitutes are very rare. Metaldehyde for slug control illustrates the rarity of direct substitutes: methiocarb and ferric phosphate were identified as possible alternatives and at least one was rated as similarly efficacious. However, neither substance can be considered as a direct substitute because agronomists identify strong reservations regarding the relative cost, relative efficacy, environmental impact (methiocarb), availability of supply and lack of proven track record (ferric phosphate).

2nd Preference: use a close substitute. A close substitute is an active substance that could potentially replace a currently used active substance at similar timing but differs to some degree in terms of one or more factors from efficacy, cost, proven track record and environmental impact.

Likert scale Hypothesis D establishes the need for multiple modes of action to manage resistance, and **Error! Reference source not found.** illustrates the need for a range of active substances, to be used in some circumstances, to maximise the level of control achieved. Therefore, a distinction is needed between close substitutes and those active substances already used as part of a programme of control alongside the active substance in question. For example, flufenacet and diflufenican (**Error! Reference source not found.**) are complements rather than substitutes, because blackgrass control is most effective when these residual herbicides are used in combination (Shah

et al., 2012; Hull and Moss, 2012; Roberts and Jackson, 2012). Thus, in reality, close substitutes are also rare.

3rd Preference: A substitute at a different timing in the rotation. Similar to a close substitute but applied at a different timing. A prominent example of this is given by Likert scale Hypothesis C, where in the absence of direct or close substitutes, agronomists have begun to adapt to the decreased efficacy of the post-emergence herbicide mesosulfuron-methyl ('Atlantis') by combining more pre-emergence herbicides.

The 1st, 2nd and 3rd adaptation options all relate to replacing one active substance with another. However, the feasibility of these options is constrained by the availability of active substance chemistry. Likert scale Hypothesis F, agronomist comments and information from the literature (Shah et al., 2012) identify a shortage of new active substances coming to market, decreased availability of active substances as a result of European pesticide legislation and the perception that WFD Article 7 may potentially further-restrict active substance availability. Therefore, before restricting any active substance a regulator must consider whether sufficient (and appropriate) alternatives are available to provide equivalent control, at an equivalent cost with lower environmental and DWD compliance risks. Similar considerations must be made by any water company implementing a catchment management strategy based upon promotion of active substance substitution.

Several agronomists in the survey expected the loss of active substances to be particularly acute for horticulture, because it is dependent on specific off-label approvals (SOLAs) of active substances originally developed for other crop types, and

it is costly (relative to the returns achievable), to register an active substance for minor use.

4th Preference: use cultural control. Cultural control is the use of cultivation practices without a fundamental change to the rotation, to improve control and preventatively manage disease, weed or pest problems. Cultural control options are increasingly becoming part of an integrated control strategy (Hull and Moss, 2012; Ward et al., 2012; Neale, 2012). Examples include compaction of seed beds to reduce slug risk, the use of rotational ploughing to bury weed seeds and stale seed beds with glyphosate to reduce weed levels prior to crop drilling (**Error! Reference source not found.**). However, Likert Hypothesis B concludes that these actions should be a complement to, and not a substitute for pesticide use. This may be explained by poor efficacy and reliability in comparison to pesticides, as (Moss, 2010) observes ‘Nonchemical control methods have mean efficacy levels equivalent to a very poor [pesticide] product, but often at a premium price’.

5th Preference: change crop architecture. This intervention avoids the need for a change to the rotation by changing the approach to the management of one or more crops in the rotation. Current UK research is investigating whether precision spraying techniques can be applied to manage blackgrass using a non-selective herbicide such as glyphosate between wide rows of OSR, thereby restricting propyzamide and carbetamide use solely to the cultivated area (Ballinghall, 2013). At present the agronomist community is uncertain whether this type of intervention will reduce water quality problems caused by certain active substances. Reasons for this uncertainty are threefold: research to develop selective spraying techniques is

ongoing; work to establish the optimal row width for OSR is yet to be completed; whether only applying propyzamide and carbetamide to the cultivated area will reduce movement to water is has not been investigated. If selective spraying techniques are perfected and made commercially available, it is possible that they could be transferable to other crops.

6th Preference: change cropping/ rotation. Although this intervention was identified as a last resort it may occur if the other options fail, if the cost of a cropping change is less than adopting one of the other options (1-5), or if the expected benefit from changing the rotation outweighs the short term cost. There are three possible types of cropping change: a different crop grown in the same growing season, a spring crop introduced into the rotation in place of an autumn sown crop and the introduction of an occasional fallow into the rotation. (Moss and Hull, 2012) confirm agronomist comments that the potential for spring cropping is limited by the suitability of land, relative economics, the difficulty of establishing subsequent crops and the availability of active substances to manage weeds emerging in spring.

The adaptation options framework assumes all factors other than active substance availability will remain constant. However, exogenous factors have the potential to disrupt relative preferences for the adaptation options. Examples of such factors include global commodity prices, changes to elements of European policy (e.g. CAP reform, GMO policy, drinking water standards for pesticide active substances and incentive payments for energy crops) and technical developments making certain crops easier to produce.

5.6.2 Using the current strategy to anticipate adaptation

From responses to the Likert items it can be concluded that agronomists believe that alternative active substances will be used in increased quantities if others are lost or restricted, that few new active substances are coming to market (Likert scale Hypothesis F) and that cultural control cannot completely replace a lost active substance (Likert scale Hypotheses B). It follows that the loss of any active substance will increase pressure on other active substances in a control strategy. Consequently, pollution swapping may be an outcome of a poorly designed mitigation strategy.

Knowledge of the strategies used to control the main problems in all the major rotations (similar to **Error! Reference source not found.** for blackgrass) and the adaptation options framework (Figure 5.3) provide a foundation from which regulators and water companies can anticipate the possible impacts of action to address any water quality issue for pesticides. It is, therefore, in the shared interest of water companies, regulators and agronomists to compile this information for all rotations before discussing how to alleviate any water quality issues arising from active substance use in those rotations.

5.6.3 Constraints to adaptation

This study confirmed that current agricultural practices aim to maximize gross margins, minimize the risk of crop failure and prevent the development of resistance to any active substance. The ability to do this is constrained by soil type, topography, weather conditions, active substance availability, the availability of alternative crops and environmental impact. A number of factors constrain the level of voluntary adaptation possible:

- The availability (or not) and cost of direct substitutes, close substitutes, or substances for use elsewhere in the rotation.
- The availability, efficacy, time and cost of cultural control options.
- The need to manage the risk of resistance.
- The need to avoid short term risk in the current crop.
- Reluctance to use unproven solutions in place of proven solutions.
- The risks and cost of spring cropping.

‘Cost’ in any of the above refers not just to purchase or implementation cost relative to the current solution, but also includes the opportunity cost of yield foregone from making the adaptation. Water companies and regulators must be aware of these constraints and work with agronomists to identify feasible options in response to arising water quality problems caused by pesticides, and actions that overcome any of these constraints.

5.6.4 Messages for catchment management

A number of key messages for catchment management emerge from this study; these findings are applicable to all European Member states concerned with WFD Article 7 compliance:

- Restrictions on active substances will have knock-on effects for the use of other active substances and in many cases on agricultural productivity. How adaptation occurs and the scale of the impact will depend on the context of active substance availability at the time of any restriction and whether adaptation preferences 1, 2 and 3 (Figure 5.3) are available.

- In the majority of cases, the active substances being used are those which are most effective and the agricultural benefits of application outweigh purchase and application costs.
- Catchment management based upon product substitution is unlikely to engage pesticide users if it is voluntary, and it would impose costs on agriculture, if it were statutory.
- Cultural control options are an increasingly important element of a control programme, but are unlikely to replace active substance use (Likert scale Hypothesis B)
- The use of the adaptation option preference framework (Figure 5.3) coupled with a knowledge of the agricultural drivers for pesticide use to tackle a particular problem in a particular rotation (e.g. **Error! Reference source not found.**), can provide a foundation for regulators and water companies to anticipate the possible impacts of action to address any water quality issue for pesticides.
- Both farmers and water companies need to take a long term, whole rotation perspective on the cost of inaction, compared to the cost of action (Moss and Hull, 2012). Where costs must be incurred, evidence of a long term benefit must be available.

5.7 Conclusions

Agronomists cannot predict with confidence how agriculture would respond to active substance losses or restrictions. However, in general, the loss of one active substance will lead to the increased use of others creating a risk of pollution swapping. Therefore, water companies face considerable uncertainty when planning for pesticide

management in the potable water supply. To support the prevention-led approach to DWD compliance required by WFD Article 7, water suppliers and regulators need to work closely with agronomists to chart control strategies for the major weed, disease and pest problems in their catchments (similar to **Error! Reference source not found.**). Application of the adaptation options preference framework (Figure 5.3) to these strategies can strengthen water company and regulator knowledge of reasons for pesticide use and provide a useful basis for catchment management dialogue between key catchment stakeholders to identify appropriate management actions.

This study highlights the challenges of embedding expertise from one industry into the decision making processes of another. This challenge is relevant to both agriculture and water companies, because water company decision making on catchment management will potentially have an impact on both industries (Dolan et al., 2013). Policy makers and regulators face a similar challenge when devising policy options to address the water quality impacts of diffuse pesticide pollution (Defra, 2012).

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5.10 Online Resources

Four ‘online resources’ were submitted to support publication of the Paper, these are:

- Online Resource 1_Stage 1 and 2 Survey Templates
- Online Resource 2_Stage 3 Survey
- Online resource 3: Stage 3 results and analysis
- Online resource 4: Acquiescence bias and internal consistency tests

Online resources 1 and 2 are included as appendices 5.1 and 5.2. Online Resources 3 and 4 present results from Stage 3 of the agronomy consultation and are included as sections 5.9.1 and 5.9.2

5.10.1 Online resource 3: Stage 3 results and analysis

Table 5.3 - Table 5.9 present results from the 43 Likert items included in the Stage 3 survey for online consultation with pesticide agronomists.

Each table includes a count distribution of responses against the Likert response scale ('Strongly disagree' (SD), 'Disagree' (D), 'Neither agree nor disagree' (N), 'Agree' (A), 'Strongly agree' (SA)), a p-value from chi-squared 'goodness of fit' tests, and a conclusion at significance level (α) = 0.05 regarding whether to accept or reject H_n (i.e. that there is no consensus in response to the Likert item).

Table 5.3 Likert items for propyzamide and carbetamide

Item #	Likert Item	Distribution (count) (n=94)					p-value	Conclusion (Accept Null Hypothesis H ₀ or alternative hypothesis H _a)
		Disagree	Strongly Disagree	Neither	Agree	Strongly Agree		
1a	If propyzamide is not available, carbetamide can be used to manage resistant blackgrass in the OSR stage of a combinable rotation	13	26	14	34	7	0.823	Accept H ₀ : <u>No consensus</u>
1b	There are no pesticide alternatives to propyzamide and carbetamide for resistant blackgrass management in the OSR stage of a combinable rotation	2	5	8	27	51	0.000	Accept H _a : <u>Agree</u>
1c	If propyzamide and carbetamide were banned OSR would continue to be grown in areas where resistant blackgrass is a problem	22	40	12	15	3	0.000	Accept H _a : <u>Disagree</u>
1d	Without propyzamide and carbetamide, no autumn break crops can be grown where resistant blackgrass is a problem	0	19	11	40	22	0.000	Accept H _a : <u>Agree</u>
1e	Without propyzamide and carbetamide, a	0	1	4	42	43	0.000	Accept H _a :

	change to the rotation would be needed where resistant blackgrass is a problem							<u>Agree.</u>
1f	The loss of propyzamide and carbetamide will lead to increased use of spring crops to manage resistant blackgrass in the rotation	2	5	15	48	22	0.000	Accept Ha: <u>Agree</u>

Table 5.4 Likert items for metaldehyde

Item #	Likert Item	Distribution (count) (n=94)					p-value	Conclusion (Accept Null Hypothesis H ₀ or alternative hypothesis H _a)
		Strongly Disagree	Disagree	Neither	Agree	Strongly Agree		
2a	If you couldn't use metaldehyde, methiocarb could be used for slug management	1	5	6	65	15	0.000	Accept H _a : <u>Agree.</u>
2b	If you couldn't use metaldehyde, ferric phosphate could be used for slug management	1	5	11	61	14	0.000	Accept H _a : <u>Agree.</u>
2c	There are no pesticide alternatives to metaldehyde	23	54	6	6	1	0.000	Accept H _a : <u>Disagree.</u>
2d	Cultural control is not a substitute for metaldehyde slug control	0	14	18	41	15	0.000	Accept H _a : <u>Agree.</u>
2e	In the absence of metaldehyde, pesticide substitutes of equal efficacy are available	0	18	13	48	11	0.000	Accept H _a : <u>Agree.</u>
2f	The loss of metaldehyde would lead to a change to the rotation where OSR and Wheat are grown on heavy soils	5	36	28	20	3	0.024	Accept H _a : <u>Disagree.</u>

Table 5.5 Likert items for mesosulfuron-methyl (Atlantis)

Item #	Likert Item	Distribution (count) (n=94)					p-value	Conclusion (Accept Null Hypothesis H ₀ or alternative hypothesis H _a)
		Strongly Disagree	Disagree	Neither	Agree	Strongly Agree		
3a	There are no pesticide alternatives to Atlantis for blackgrass management at the post-emergence stage in wheat	4	39	9	29	12	0.827	Accept H ₀ : <u>No consensus</u>
3b	Where the efficacy of Atlantis is reduced, there will be an increase in the use of residual chemistry at pre-emergence timing in wheat	0	4	6	40	43	0.000	Accept H _a : <u>Agree.</u>
3c	Cultural control can replace the loss of Atlantis	16	49	14	12	2	0.000	Accept H _a : <u>Disagree.</u>
3d	In high pressure resistant blackgrass areas, a reduction in the efficacy of Atlantis will reduce wheat yields	1	1	9	46	36	0.000	Accept H _a : <u>Agree.</u>
3e	In high pressure resistant blackgrass areas, a reduction in the efficacy of Atlantis will prompt a change to the rotation	1	15	16	49	12	0.000	Accept H _a : <u>Agree.</u>

Table 5.6 Likert items for clopyralid

Item #	Likert Item	Distribution (count) (n=94)					p-value	Conclusion (Accept Null Hypothesis H ₀ or alternative hypothesis H _a)
		Strongly Disagree	Disagree	Neither	Agree	Strongly Agree		
4a	Clopyralid is the only available pesticide for thistle management in OSR	0	14	12	53	14	0.000	Accept H _a : <u>Agree.</u>
4b	There are available pesticide alternatives to replace clopyralid for thistle management	8	48	20	18	0	0.000	Accept H _a : <u>Disagree.</u>
4c	Cultural control interventions can substitute for clopyralid control of thistles in OSR	17	55	16	4	2	0.000	Accept H _a : <u>Disagree.</u>
4d	In the absence of clopyralid, thistles will reduce OSR yields	0	11	24	49	10	0.000	Accept H _a : <u>Agree.</u>
4e	In the absence of clopyralid, thistles can be managed without a change to the rotation	6	44	25	18	1	0.000	Accept H _a : <u>Disagree.</u>

Table 5.7 Likert items for pendimethalin

Item #	Likert Item	Distribution (count) (n=94)					p-value	Conclusion (Accept Null Hypothesis H ₀ or alternative hypothesis H _a)
		Strongly Disagree	Disagree	Neither	Agree	Strongly Agree		
5a	The loss of pendimethalin will lead to increased stacking of other pre-emergence residual herbicides to manage grassweeds in cereal crops	0	1	9	45	39	0.000	Accept H _a : <u>Agree.</u>
5b	If pendimethalin were the only active substance lost, it would be possible to maintain cereal yields using alternative herbicides	5	13	18	52	6	0.000	Accept H _a : <u>Agree.</u>
5c	Pendimethalin is one of many modes of action used as part of a resistance management strategy for Blackgrass	0	1	4	52	37	0.000	Accept H _a : <u>Agree.</u>
5d	The loss of pendimethalin would trigger a change to the combinable rotation	9	33	34	15	3	0.002	Accept H _a : <u>Disagree.</u>

Table 5.8 Likert items for chlortoluron

Item #	Likert Item	Distribution (count) (n=94)					P-value	Conclusion (Accept Null Hypothesis H ₀ or alternative hypothesis H _a)
		Strongly Disagree	Disagree	Neither	Agree	Strongly Agree		
6a	The loss of chlortoluron will lead to increased use of other herbicides at the pre-emergence stage for blackgrass control in the combinable rotation	3	7	10	60	13	0.000	Accept H _a : <u>Agree.</u>
6b	If chlortoluron were the only active substance lost, it would be possible to maintain cereal yields using alternative herbicides	3	5	17	60	8	0.000	Accept H _a : <u>Agree.</u>
6c	Chlortoluron is one of many modes of action used as part of a resistance management strategy for Blackgrass	1	1	12	56	23	0.000	Accept H _a : <u>Agree.</u>

Table 5.9 Likert items for general trends

Item #	Likert Item	Distribution (count) (n=94)					p-value	Conclusion (Accept Null Hypothesis H ₀ or alternative hypothesis H _a)
		Strongly Disagree	Disagree	Neither	Agree	Strongly Agree		
GS1a	No new herbicides for blackgrass will be available in the next 5 years	2	7	10	40	34	0.000	Accept H _a : <u>Agree.</u>
GS1b	When one active substance is lost (for whatever reason) other active substance(s) will be used to manage the weed, pest or disease issue	1	9	9	56	18	0.000	Accept H _a : <u>Agree.</u>
GS1c	In the absence of effective pesticide control, weed and pest pressures will increase over time	0	1	2	39	50	0.000	Accept H _a : <u>Agree.</u>
GS1d	The agronomic impact of losing an active substance depends upon what active substances remain available	0	1	1	52	38	0.000	Accept H _a : <u>Agree.</u>
GS1e	Cultural control is a complement to, not a direct substitute for pesticides	0	0	2	38	52	0.000	Accept H _a : <u>Agree.</u>
GS1f	Effective resistance management requires as	0	0	1	22	69	0.000	Accept H _a : <u>Agree.</u>

	many different modes of action as possible							
GS1g	When an active substance is lost, alternative active substances will be tried in preference to non pesticide interventions	0	7	14	52	18	0.000	Accept Ha: <u>Agree.</u>
GS2a	Where alternative pesticides cannot prevent severe gross margin losses, spring cropping will increase	1	5	13	64	9	0.000	Accept Ha: <u>Agree.</u>
GS2b	A change to the rotation is the intervention of last resort	3	17	8	49	15	0.000	Accept Ha: <u>Agree.</u>
GS2c	In general, direct substitutes do not exist for any active substance	1	15	14	51	10	0.000	Accept Ha: <u>Agree.</u>
GS2d	If the withdrawal of an active substance is announced 5 years in advance, alternative active substances will be available by the time of withdrawal	24	38	19	10	2	0.000	Accept Ha: <u>Disagree.</u>
GS2e	The adoption of wide OSR rows and inter row spraying will reduce current dependency on propyzamide and carbetamide	9	25	36	21	2	0.145	Accept Hn: <u>No consensus</u>
GS2f	If approved for use, RoundUp Ready OSR would reduce current	4	2	14	47	26	0.000	Accept Ha: <u>Agree.</u>

	dependency on propryamide and carbetamide							
GS2g	If the future of one active substance is uncertain, alternative active substances will come to the market	17	47	17	11	0	0.000	Accept Ha: <u>Disagree.</u>

5.10.2 Online resource 4: Acquiescence bias and internal consistency tests

Results from three acquiescence bias tests and two internal consistency tests performed to validate responses to the online consultation with pesticide agronomists (Stage 3 of the study) are presented in Table 5.10. Spearman's Rank correlation test, at 0.05 significance level was used for these tests (see section 5.4.4)

Table 5.10 Spearman's rank correlation coefficient (ρ) tests for acquiescence bias and internal consistency

Test	Test pair	ρ	Conclusion
Acquiescence bias	4a + 4b	0.548	Accept H_n^{**}
Acquiescence bias	1c + 1e	0.333	Accept H_n^{**}
Acquiescence bias	2e + 2c	0.589	Accept H_n^{**}
Internal consistency	3d + 3e	0.245	Accept H_n^*
Internal consistency	GS12d + GS2g	0.63	Accept H_n^{**}

* Accept at significance level (α) = 0.05, ** Accept at $\alpha = 0.05$ and $\alpha = 0.01$

**Chapter 6: Pesticide Active Substance Classification: A
Systematic Approach to Potable Water Investment Decision
Making**

Sections 6.2 - 6.9 of this chapter were submitted on 05/07/13 for publication by Springer in Water Resources Management.

Dolan, et al. (Cranfield University), (2013c), *Pesticide Active Substance Classification: a systematic approach to potable water investment decision making* (unpublished research paper), TBC.

6.1 Preface

6.1.1 Context

The research presented in Chapters 2 - 5, identified that WFD Article 7 promotes a prevention-led approach to DWD compliance and that some pesticides are difficult to treat with current technology. Therefore, a pesticide strategy focused predominantly on monitoring for and treating pesticides rather than understanding the factors that cause the presence of pesticides in raw water at the point of abstraction is no longer sufficient. It follows, that a systematic decision support tool to enable evidence based investment decisions for pesticide management in the potable water supply is needed.

The pesticide classification system presented in sections 6.2 – 6.9 of this Chapter provides a clear, transparent and auditable framework for the management of all pesticide active substances (not just those currently causing problems). The systematic approach proposed is designed to help water suppliers implement a rigorous evidence based approach to investment planning in order to manage pesticides in the potable water supply. One of the benefits of the system proposed is that it facilitates proactive catchment management investment decisions and will prevent the need for the type of reactive decision making that characterised UK water suppliers response to the presence of metaldehyde in the raw water. The classification system was designed for use by Anglian Water Services Ltd, but can be applied by any water supplier to improve the evidence base from which decisions for diffuse pesticide pollution management in surface water catchments are made.

6.1.2 Review of analytical techniques

The classification system was developed as a 4 step process based upon a set of simple questions, an optional assessment of treatability, allocation of an active substance into one of ten types and a unique set of recommendations for each type derived from a complete set of possible actions. To avoid ambiguity, the classification questions are simple, but must be underpinned by processes to collate evidence; this makes the system flexible to the context of the water supplier implementing the system. In order to avoid incurring unnecessary cost during the classification process, the treatability assessment is not required for all active substances. A complete set of actions has been defined because this allows both decisions to take action and decisions to not take a action to be justified through the classification process.

The pesticide classification system is designed to be used in conjunction with a pesticide fate model and temporal data on pesticide use at the catchment level. A range of pesticide fate models are available to help water suppliers understand possible pesticide concentrations at the point of abstraction (Yang and Wang, 2010; Panagopoulos et al., 2012). The classification questions are designed to be compatible with outputs from any pesticide fate model. For illustrative purposes the Paper uses the CatchIS pesticide fate model (Cranfield University, 2013). CatchIS was chosen because predictions from CatchIS have been validated, for a number of widely used active substances (Brown et al., 2002) and the model is currently used operationally by a number of water suppliers in England and Wales and by the WFD competent authority in England and Wales.

6.1.3 Significance to thesis

The pesticide classification system is the culmination of the research presented in Chapters 2 - 5 of this thesis. Analysis of the legal framework (Chapters 2 and 3) is factored into both the classification processes and the prioritisation of actions arising from the process. The structure of classification questions, makes explicit the type of evidence water companies should gather through agronomy consultation (Chapter 5) prior to planning any catchment management. Additionally, the system assumes the DWD standard for pesticides in potable water will remain fixed, but the system is sufficiently flexible to incorporate any change to the standard into the decisions recommended (Chapter 4).

6.2 Abstract

Both the European Water Framework Directive (WFD) Article 7 and the World Health Organisation (WHO) Drinking Water Safety Planning (DWSP) guidelines emphasise the importance of managing pollution at source and addressing potable water supply risks by understanding catchment processes. Pesticides provide a good example of where a systematic understanding of their use can inform assessment of diffuse pollution risk and, thus, benefit water suppliers when planning investment for potable water supply. In this paper, a pesticide classification system is proposed to facilitate the development of water supplier processes for the identification of those pesticides which are expected at problem concentrations in raw water (now and in the future), which are not sufficiently treatable with current installed treatment infrastructure, and for which further investment (in treatment or catchment management) is needed. The system enables the evaluation of every relevant active substance and allocates each to one of ten 'Classes' to enable evidence-based, catchment level, action plans to be constructed for each pesticide. These facilitate decision making, negotiation with regulators, engagement with catchment stakeholders and the prioritisation of water supplier resources to those active substances and catchments where they are most needed.

6.3 Introduction

Diffuse pollution from agricultural sources is a common problem for water quality (Novotny and D'Arcy, 2005; Orr et al., 2007; Chon et al., 2012) and its mitigation presents a significant challenge (Reichenberger et al., 2007; Wang and Yang, 2008; Yang and Wang, 2010) to stakeholders interested in compliance to the European Water Framework Directive (WFD) (Heinz, 2008) and for the suppliers of potable water which needs to meet high regulatory quality standards (Dolan et al., 2012; Dolan et al., 2013a; Keirle and Hayes, 2007).

Pesticides often present particular challenges in surface water catchments used for drinking water supply which are also used for intensive agriculture. Although only a small fraction of the pesticide applied is normally transferred to water (Tediosi et al., 2012) some pesticide active substances are difficult or expensive to remove in treatment, such that the water supplied to the consumer meets the European Drinking Water Directive (DWD) standard of $0.1\mu\text{g/l}$ for any individual pesticide active substance (EC, 1998; EC, 1980).

Over 400 pesticide active substances are approved for use in plant protection products across Europe (European Community, 2013) and any of these can, in theory, move along a range of pathways to the 'raw' water abstracted for potable water supply. Historically, water suppliers have focused on the application of treatment technologies (Croll, 1995; Evans et al., 2003) to remove pesticide active substances in order to be compliant with the DWD. As a consequence, water suppliers currently have relatively low knowledge of the agricultural drivers of pesticide use and which active substances are most likely to be present in 'raw' water at the point of abstraction and at what

concentrations (Dolan et al., 2013a). This gap in water supplier knowledge is significant because, for a number of reasons, European water suppliers now need to proactively engage with prevention at source rather than relying on treatment. These reasons include:

- WFD Article 7 (EC, 2000) encourages a prevention-led approach to DWD compliance (Dolan et al., 2013a; Dolan et al., 2013b) and may constrain the type of intervention decisions available to a water supplier (UKTAG, 2008; DWI / EA, 2012), in particular restricting investment in additional treatment.
- Some widely used active substances, e.g. the slug pellet active ingredient metaldehyde and the herbicide clopyralid, are currently very difficult to remove cost-effectively in treatment even with the best available treatment technologies installed at the point of abstraction (UKWIR, 2011; Autin et al., 2013; Tizaoui et al., 2011).
- Water suppliers are encouraged to take a Drinking Water Safety Planning (DWSP) approach (World Health Organisation, 2011) to increase understanding of, and mitigate, risks throughout the supply chain from catchment to customer (Breach, 2011).

An important issue with catchment management interventions compared to investment in treatment, however, is that their reliability is uncertain and in many cases may be variable. This is, in part, due to the following:

- Catchment management requires behavioural change on land not owned by, and beyond the direct influence of water suppliers (Keirle and Hayes, 2007; Breach, 2011).
- The efficacy of a catchment management intervention is difficult to quantify, and will vary with catchment characteristics, weather conditions and active substance properties (Reichenberger et al., 2007; Candela et al., 2009; Tediosi et al., 2012).
- Water suppliers do not understand the drivers of agricultural decision making (Dolan et al., 2013c; Blackstock et al., 2010) or the land management practices that contribute to diffuse pollution (Kay et al., 2009).
- Understanding, trust and credibility has to be built before catchment management is likely to be widely adopted (Orr et al., 2007).
- Diffuse pollution is a complex problem. Evaluating whether current actions will deliver the improvement in ‘raw’ water quality required for DWD compliance is highly uncertain (Dolan et al., 2013a).

Nevertheless, despite these uncertainties European water suppliers must manage the transition to a prevention-led approach while remaining 100% compliant with the DWD standard for pesticides. Water supplier decision making to support this transition should be open, transparent, and proportional; based on best available evidence and engagement with relevant stakeholders (Pollard et al., 2004). Additionally, water supplier investment for DWD compliance must be allocated efficiently (Heather and Bridgeman, 2007) to prioritise interventions where action is most needed (Wang and Yang, 2008) in a way consistent with the principles of DWSP (World Health Organisation, 2011).

Water suppliers, therefore, require a system to diagnose the level of action required for each active substance in each catchment from which they abstract for potable water supply. Possible actions include: the decision to take no action, inclusion of a substance in a monitoring strategy, undertaking research into current treatability, inclusion of a substance in catchment management strategy and investment in new treatment infrastructure. In this paper, we propose a classification system that provides a clear, transparent and auditable framework to assign actions to active substances at the catchment level. The classification evaluates each active substance in terms of current and potential future use, their likelihood of being present at high concentrations at the point of abstraction (a property related to use, chemical characteristics and catchment properties) and the effectiveness of currently installed treatment to remove them from raw water. The classification system is applicable to any surface water catchment from which water is abstracted for the supply of potable water.

If implemented in collaboration with other catchment stakeholders (e.g. the WFD competent authority, the DWD competent authority, agriculture, and pesticide regulators) as part of an integrated management response at a catchment level (Orr et al., 2007), the classification system can facilitate sharing of data sources and generate collective awareness of the problems that require management to reduce DWD and WFD Article 7 non-compliance risks.

6.4 Proposal for a pesticide classification system

6.4.1 Overview

The pesticide classification system is divided into four steps (Figure 6.1). Each step is defined in sections 2.2 -2.5.

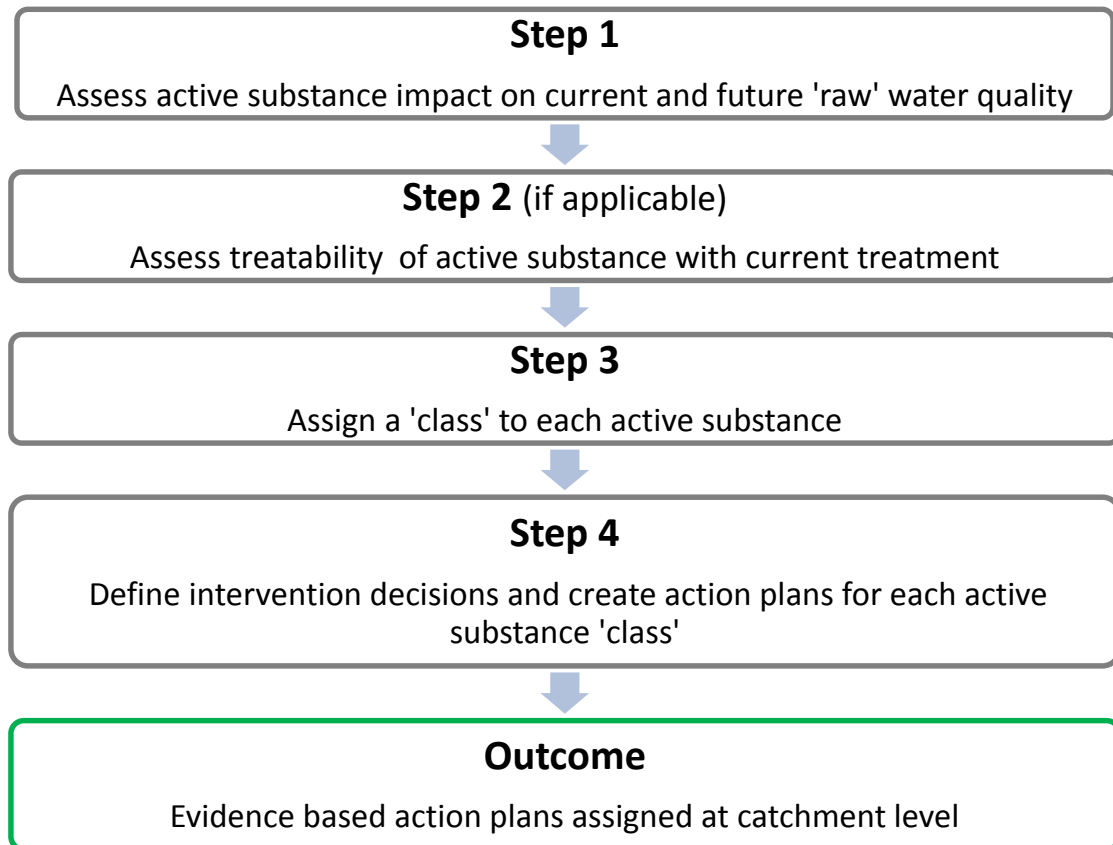


Figure 6.1 Schematic overview of the pesticide classification process.

6.4.2 Step one: Determining current and future 'raw' water quality

The aim of Step 1 is to classify all active substances as one of the four 'types' shown in Figure 6.2. To do this requires assessment of the impact of current use patterns on water quality and how this will change in the future relative to the current situation.

The five questions in Table 6.1 are proposed for this assessment.

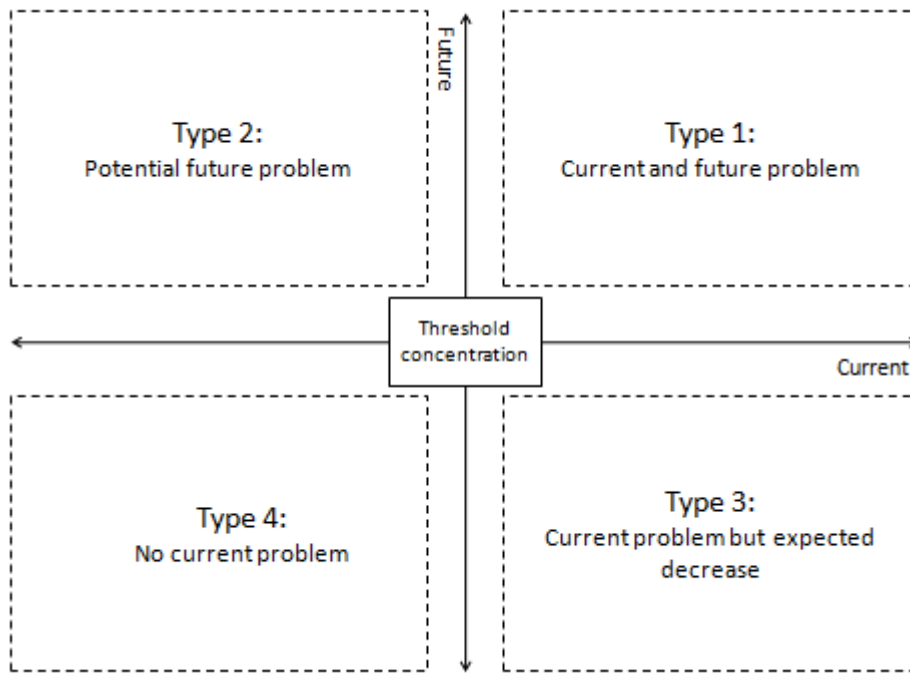


Figure 6.2 Pesticide active substance classification matrix

Table 6.1 Raw water classification questions

	Question
1	Is the pesticide active substance used in the area of interest?
2	Is the pesticide active substance already found or predicted to be found based on a validated catchment model of pesticide exposure in ‘raw’ water above a threshold concentration in the area of interest?
3	Will the active substance be withdrawn under EU pesticide approval Regulation 1107/2009 (EC, 2009b) or by a Member State approval decision?
4	Is use of the active substance expected to decrease because of the presence of resistance or decreased efficacy issues?
5	Do we have reason to expect an increase in use of the active substance, in the area of interest, in the future?

Provided the right evidence base is gathered before implementation of the pesticide classification system, a ‘yes’ or ‘no’ answer can be assigned to each of the

classification questions (Table 6.1). Completing Step 1 can help a water supplier to identify and address gaps in organisational knowledge regarding the pesticide active substances used in their catchments.

Questions one and two (Table 6.1) are concerned with current use and Questions three to five (Table 6.1) with possible future use. Possible processes to answer these questions are proposed in Sections 6.4.2.1 (current use) and 6.4.2.2 (future use)

6.4.2.1 Current use and water quality (classification questions one and two)

Before answering either Question 1 or 2 ‘the area of interest’ over which the classification system is to be applied (Question 1) and the ‘threshold concentration’ above which a water supplier will consider an active substance as a problem (Question 2) need to be defined.

The ‘area of interest’ can be an individual catchment, a WFD Article 7 safeguard zone (EC, 2000), a collection of catchments from which a water supplier abstracts, or a collection of catchments that comprise a WFD river basin district (RBD) as defined in Article 2.15 of the WFD (EC, 2000).

An active substance will only be of interest to a water supplier or water sector regulator when its concentration in ‘raw’ water causes problems for compliance with the relevant potable water standard. The ‘threshold concentration’ selected should, therefore, be linked to the drinking water standard for the active substance being classified. In the European context, setting a ‘threshold concentration’ of 0.1µg/l would identify all active substances where some form of ‘raw’ water treatment will be required to enable the supply of DWD compliant potable water. Outside of the

European context, the threshold concentration for an active substance should be set at a level derived from the WHO guideline (World Health Organisation, 2011; Dolan et al., 2013b)

Accurate pesticide usage data at catchment level and a pesticide fate model are required to answer Questions 1 and 2. Information on pesticide use is difficult to acquire (Verro et al., 2009). Nevertheless, these data are essential for any water supplier aiming to take a systematic approach to understand pesticide contamination in their catchments. Insight into pesticide use can be derived from, for example, commissioning an agricultural consultancy to monitor and predict pesticide use on an annual basis (Cranfield University, 2013); engaging directly with agronomists to identify the major weed, disease and pest problems and the active substances used to control these (Dolan et al., 2013c); Member State data on pesticide use (EC, 2009); secondary data sources on active substance approval, use and properties (European Community, 2013; FOOTPRINT, 2010).

Pesticide transfers from land to water are governed by a complex interplay of site characteristics, soil properties, weather conditions and pesticide properties (Dubus et al., 2003). A pesticide fate model is, therefore, needed to answer Question 2 (Yang and Wang, 2010). However, when using a pesticide fate model it is important to consider the sources of uncertainty from primary data and in model parameters used in such models (Dubus et al., 2003).

The classification system was initially developed as a complement to the CatchIS software (Cranfield University, 2013) to support better integration of CatchIS with water supplier decision making for pesticide and potable water management. CatchIS

uses data on land use, associated pesticide use, pesticide properties, weather and soil type to predict ‘raw’ water concentrations for all approved active substances at a catchment scale. Predictions from CatchIS have been validated, for a number of widely used active substances (Brown et al., 2002) and the model is currently used operationally (in combination with regular consultation with pesticide users) to improve understanding of which active substances should be expected at what concentrations in different catchments, by a number of UK water utilities and the WFD competent authority for England and Wales, and to support catchment sensitive farming and voluntary initiative projects in the UK. CatchIS is, therefore, recommended for answering Questions 1 and 2 (Table 6.1).

6.4.2.2 Future Use (classification questions three to five)

It is important to consider expectations of future pesticide use (Table 6.2) before a water supplier or other catchment stakeholder makes investment to address a ‘raw’ water quality problem caused by any active substance.

Table 6.2 Possible causes of changes to current pesticide use patterns

Possible causes of decreased use	Possible causes of increased use
Withdrawal under European approval process	Increased use of an active substance in response to the withdrawal, restriction or decreased use of a complementary or substitute active substance
Member State ban or restriction	
Voluntary action to reduce use	
Decreasing efficacy because of resistance	
	Approval of a new active substance
A decrease in the range of crops on which an active substance can be used	An increase in the range of crops on which an active substance can be used

Decrease in a area of a crop	Increase in area of a crop
Reduction in dose at which active substance is applied	Increase in dose at which active substance is applied
Decreased use from a change to crop management	Increased use from a change to crop management
Decrease in weed, disease or pest intensity	Increase in weed, disease or pest intensity

Question 3 considers the regulatory factors linked to active substance approval that could lead to an active substance being withdrawn from the market or restricted in use. European pesticide approval legislation requires all new active substances to be approved and all existing active substances to be reappraised when current approvals expire. Reduced availability of active substances is expected in the future (KEMI, 2008; PSD, 2009), largely because Regulation 1107/2009 (EC, 2009b) applies more stringent criteria than its predecessor (Directive 91/414/EEC) (EC, 1991). The extent of this reduction and the full impacts of Regulation 1107/2009 remain uncertain. The UK Pesticide Safety Directorate assessment (PSD, 2009) remains the most-up-to-date evaluation of which active substances may be withdrawn. This document and consultation with the relevant approval authority at Member State level can be used to answer Question 3.

Question 4 focuses on the possibility that pesticide use will decrease for agronomic reasons. Resistance management is an important driver of pesticide use patterns (Hull and Moss, 2012; Dolan et al., 2013c). To avoid a loss of efficacy due to resistance issues, a strategy to control a weed, pest or disease will often require the use of multiple active substances with different modes of action, applied at different times throughout the rotation (Shah et al., 2012). Where resistance becomes a problem, and

the efficacy of an active substance begins to decline, use of that active substance will decrease. For example, the efficacy of ‘Atlantis’ (a mix of the active substances iodosulfuron-methyl and mesosulfuron-methyl) to control blackgrass (*Alopecurus agrestis* L.) in wheat has declined in recent years (Moss, 2010). Consequently use of ‘Atlantis’ has decreased. Water suppliers, therefore, need to consider how resistance pressures may shape future pesticide use when classifying an active substance. Regular consultation with local agronomists and pesticide distributors can give water suppliers the information required to make this classification (Dolan et al., 2013c).

Question 5 considers whether use of an active substance may increase in a catchment. Increased use of an active substance could occur when alternative active substances are banned or restricted or when it is approved for use on a wider range of crops (Table 6.2). Early identification of active substances for which use is likely to increase is beneficial to a water supplier because it allows possible catchment management and treatment responses to be evaluated, and the profile of an active substance to be raised before it actually becomes a drinking water quality problem.

Communication between water suppliers, agronomists, regulators and pesticide manufacturers may help to identify the potential for increased use of any individual active substances although uncertainty is often high (Dolan et al., 2013c).

6.4.3 Step 2: Assess treatability

Those classified as Type 1, 2 or 3 at Step 1 (Figure 6.2) might be present in ‘raw’ water at concentrations above the drinking water standard. The treatability of these active substances is thus, an important consideration because it indicates whether a

water supplier needs to initiate further action (i.e. catchment management) to manage that substance.

The aim of Step 2 is to evaluate whether the current installed treatment at the water treatment works is able to remove the active substance under consideration. This evaluation should be based on currently installed treatment and apply to only those active substances classified as Types 1, 2 and 3 because:

- Collecting new data on treatability is an expensive process that often requires specific studies to be commissioned (UKWIR, 2011; Autin et al., 2013; Tizaoui et al., 2011)
- WFD Article 7 restricts a water supplier's ability to invest in new treatment which, depending on interpretation, may include blending (UKTAG, 2008; DWI / EA, 2012)

For some active substances, data on treatability will be unavailable. Where initial assessment is inconclusive an active substance should be classified as 'unknown' and prioritised for further investigation after completion of the classification process.

Identifying and validating sources of treatability data and developing a process to evaluate treatability based on these data are important outputs from Step 2.

6.4.4 Step 3: Assign a 'class' to each active substance

In Step 3, based upon Steps 1 and 2, each active substance is assigned one of ten active substances 'Classes' (Table 6.3)

Table 6.3 Step 3 assigning active substance classes

Classification			Description
Step 1	Step 2	Step 3	
Type 1			Current and future problem
	Untreatable	Class 1U	Untreatable with current WTW
	Treatable	Class 1T	Treatable with current WTW
	Unknown	Class 1?	Treatability unknown with current WTW
Type 2			Potential future problem
	Untreatable	Class 2U	Untreatable with current WTW
	Treatable	Class 2T	Treatable with current WTW
	Unknown	Class 2?	Treatability unknown with current WTW
Type 3			Current problem but expected decrease
	Untreatable	Class 3U	Untreatable with current WTW
	Treatable	Class 3T	Treatable with current WTW
	Unknown	Class 3?	Treatability unknown with current WTW
Type 4	n/a	Class 4	No current problem

6.4.5 Step 4: Define intervention options and create action plans

Step 4 requires the water supplier to identify and define all possible intervention options available to manage any active substance. A set of active substance intervention is proposed in Table 6.4.

Table 6.4 Possible intervention options for active substance management

	Intervention	Description
1	No action	Take no additional action for the active substance
2	Basic profile	Collate basic information on the active substance as a point of reference for any future decisions regarding the

		active substance
3	Monitor	Include the active substance in the monitoring strategy for the catchment and abstraction point
4	Assess current treatability	Undertake additional investigation of whether the currently installed treatment infrastructure can adequately remove the active substance from 'raw' water, and to identify the maximum 'raw' water active substance concentration that can be managed for DWD compliance
5	Include in risk assessment	Include the active substance in water supplier risk assessment (statutory or non-statutory)
6	Include in catchment management strategy	
6a	Engage to raise awareness	Engage with the WFD competent authority, DWD competent authority and catchment stakeholders to raise awareness of the active substances
6b	Engage with WFD Article 7 safeguard zone	Request the inclusion of the active substance in a WFD safeguard zone action plan*
6c	Engage to understand	Consult with agronomists (advisors on pesticide use) to develop a full understanding of the reasons for use of the active substance (Dolan et al., 2013c)
6d	Engage to identify adaptation options and barriers	Work with agronomists to identify possible adaptations to current use patterns and any barriers to the adoption of these adaptations (Dolan et al., 2013c)
6e	Evaluate need for additional action	Evaluate whether current actions can deliver the required improvement in raw water quality (Dolan et al., 2013a)
6f	Fund targeted catchment management	Where barriers to adaptation exist (6d), but action is needed (6e), a water supplier may consider funding appropriate interventions targeted to the active substance of concern, the options funded need to be decided on a case by case basis**
7	Research or invest in additional treatment	Investigate whether the installation of additional treatment can resolve a problem with an active substance

* Safeguard zone action plans are possible under WFD Article 7.3. In the UK these are currently being developed by the WFD competent authority and water suppliers.

** The 'Scottish Water (2013) is an example of water supplier funded catchment management

Based upon the intervention options (Table 6.4) an action plan can be defined for each 'Class' of active substance (Table 6.3). These action plans are designed to be indicative of the intervention measures required for an active substance and to justify which actions are taken for what active substances in which catchments. The catchment management element of these action plans is not intended to be prescriptive because the precise action needed will vary with the context of the active substance and the catchment.

When defining intervention options and creating action plans for the active substance 'Classes', the water supplier must consult all business areas involved in potable water supply and pesticide management. Intervention options should include a designation of ownership and establish a clear rationale to assign interventions to active substance 'Classes'.

6.5 Application of classification tool –case study

As an illustration of how the classification system could work, it was applied to classify active substances in a case study catchment in the Anglian River Basin District of the UK. The catchment was assumed to be approximately 40% cereals (predominantly winter wheat and oilseed rape (OSR) grown in rotation.), 30% improved grassland, 10% horticulture, and 10% woodland to represent land use typical of that found in the region.

The assessment employed pesticide use and water quality predictions from CatchIS (Cranfield University, 2013), a threshold concentration of 0.1µg/l and water sector treatability data. Over 130 different active substances are used in the catchment. Figure 6.3 and Table 6.5 present CatchIS worst case predictions (Figure 6.3) and classification system results (Table 6.5) for a small number of these. Worst case predictions represent peak concentrations at the catchment outlet (the river abstraction point) generated by employing the lowest reported value of the organic carbon to water partition coefficient (K_{OC}) and the highest reported value of the median dissipation time (DT_{50}) for each substance (Whelan et al., 2007).

Metaldehyde and methiocarb are active substances used as slug pellets; propyzamide, carbetamide, flufenacet and diflufenican are amongst the most widely used residual chemicals for blackgrass control in a combinable wheat and OSR rotation; clopyralid is used for sow thistle control; and glyphosate and pendimethalin are active substances used on a range of crop types.

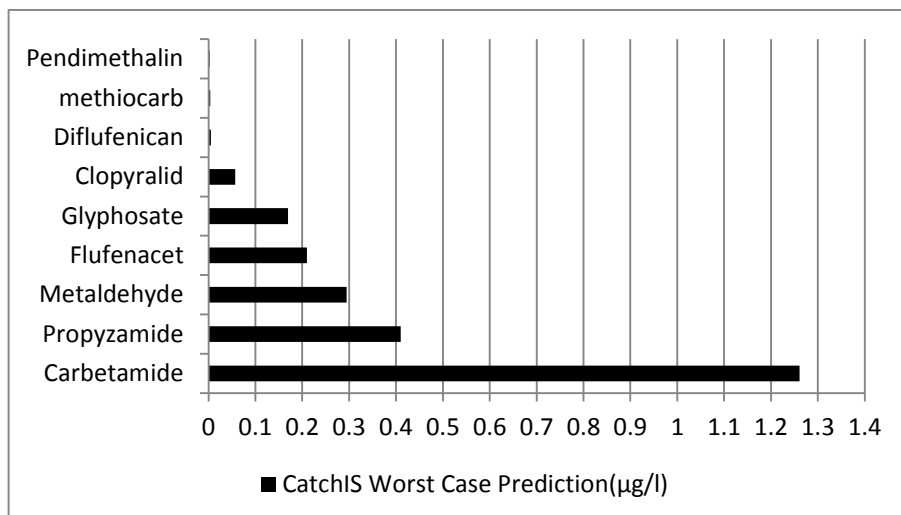


Figure 6.3 CatchIS predictions for selected active substances in the case study catchment

Table 6.5 Classification of selected active substances in the case study catchment

Active substance	Step 1 (Question 1-5)					Step 1 'type'	Step 2	Overall 'class'*
	1	2	3	4	5			
Metaldehyde	✓	✓	✗	✗	n/a	1	Untreatable	1U
Propyzamide	✓	✓	✗	✗	n/a	1	Unknown	1?
Flufenacet	✓	✓	✗	✗	n/a	1	Unknown	1?
Diflufenican	✓	✗	✗	✗	✓	2	Unknown	2?
Carbetamide	✓	✓	✓	✗	✗	3	Unknown	3?
Glyphosate	✓	✓	✗	✗	n/a	1	Treatable	1T
Methiocarb	✓	✗	✗	✗	✗	4	n/a	4
Clopyralid	✓	✗	✗	✗	✗	4	n/a	4
Pendimethalin	✓	✗	✓	✗	✗	4	n/a	4

* Where, ? = treatability of the active substance is unknown with current data; see Table 6.3 for explanation of the classification classes.

The results in Table 6.5 have been ranked by 'Class' to give an indication of the relative priorities for active substance management in the catchment. Metaldehyde is classified as 'Class 1U' and is the highest priority for action. Those classified as 'Class 1?' (propryzamide and flufenacet) are the next highest priority for action because they are present in raw water above the threshold concentration and the extent to which current treatment can remove these is unknown. Glyphosate is Class 1T and a low priority for action because, although it is predicted to be present in raw water at high concentrations, it can be removed extensively with current treatment. Diflufenican is 'Class 2?' because increased use is expected in the future and current treatability is unknown. Carbetamide is 'Class 3?' because it is currently a water quality problem but decreased use is expected in the future. Those classified as 'Class 4' are not expected in raw water above the threshold concentration and are the lowest priority for action.

Detailed examination of the classification for metaldehyde demonstrates the classification process. Metaldehyde was classified as 'Class 1U' because it is widely used (Q1), CatchIS predicts a worst case peak concentration of 0.3 µg/l (Q2), there is no evidence that the active substance will be withdrawn under European pesticide approval Regulation 1107/2009 (Q3), or that resistance issues will decrease use (Q4) and available data indicate that it is currently untreatable with installed treatment (Step 2).

6.6 Discussion

6.6.1 The significance of WFD Article 7 to European water supplier

WFD Article 7 encourages a prevention-led approach to DWD compliance (Dolan et al., 2013a) and, therefore, is significant to the classification system and water supplier active substance management in a number of ways. Firstly, the requirement to avoid deterioration of water quality at the point of abstraction for potable water supply means ‘Class 2’ active substances should not occur, and the intensity of a water quality problem caused by a ‘Class 1’ active substance should not increase. However, in practice, the requirement to avoid deterioration is ambiguous for active substances not widely monitored in the protected area and for new active substances not yet approved for use (Dolan et al., 2013a). Therefore, water suppliers, as the body legally responsible for the supply of DWD compliant potable water, must assume that ‘Class 2’ active substances can exist (i.e. that new problem active substances will not be prevented by WFD Article 7) and that problems caused by ‘Class 1’ active substances (such as metaldehyde) will not be resolved without action by the water supplier.

WFD Article 7 also influences the type of intervention options available to a water supplier and how they should prioritise these (UKTAG, 2008; DWI / EA, 2012). Interventions should be prioritised in the following order: (1) those which improve knowledge; (2) those which engage catchment stakeholders to raise the profile of a problem and promote catchment wide prevention actions; (3) the provision of extra funding for water-supplier-led catchment management actions. Investment in additional treatment should only be considered where a water supplier is not confident that catchment management can support DWD compliance. All water suppliers must,

therefore, fully engage with interventions 2-5 and, where needed, include active substances in their catchment management strategies (interventions 6a-f) to demonstrate that action is being taken to achieve DWD compliance without the need for additional treatment.

6.6.2 The classification system and catchment management strategy

The classification system presented is designed to be a pre-cursor to catchment management strategy development. The high level action plans produced, through the classification system, provide an evidence base to prioritise active substances for inclusion in a catchment management strategy but, importantly, do not specify precisely what that strategy should involve. This is because catchment management requires a bespoke programme of measures to account for the physical characteristics of the catchment (e.g. soil, climate, topography), prevailing farming practises and those active substances known to be problematic.

6.6.3 Voluntary action to reduce diffuse pesticide pollution

In the UK, established programmes of voluntary action such as the Metaldehyde Stewardship Group (MSG); and the Voluntary Initiative (VI) (MSG, 2013; VI, 2013) demonstrate a willingness to reduce pesticide use, where it is perceived that a substance is causing water quality problems. All water suppliers should be aware of and promote these types of action in their catchments. However, the classification system does not include a question on the impacts of voluntary action on active substance use because these impacts are harder to anticipate than changes to approval regulation. In catchments where voluntary action to reduce use and diffuse pollution is

well established, a water supplier classifying active substances may choose to consider the impacts of voluntary action in their classification process.

6.6.4 Active substance treatability

Treatability at the water treatment works (WTW) is not a criterion which is currently included in European pesticide approval legislation (EC, 1991; EC, 2009b). The assessment of treatability is, thus, the sole responsibility of the water supplier. The extent to which an active substance can be removed at a WTW depends on a number of factors: The type of treatment technology installed and how this is managed, average and peak concentrations of active substance at the point of abstraction, and the physico-chemical properties of the active substances under consideration.

The range of active substances potentially causing problems and the types of treatment installed may be very similar between water suppliers for similar catchment characteristics. Assessment of treatability can, therefore, be identified at a European level and opportunities exist for cooperation and co-funding of research. Additionally, pesticide manufacturers and WFD competent authorities may have a role to play in supporting these investigations because both benefit from knowledge of treatability in that treatable active substances are less likely to be banned or restricted as a consequence of drinking water pollution, compared with untreatable ones - which should be targeted for more intensive catchment management.

6.6.5 The role of pesticide fate modelling

A validated pesticide fate model, based upon high quality input data, is a central component of any water supplier risk assessment of the threat to the potable water supply posed by diffuse pesticide pollution. However, model outputs cannot be

viewed in isolation of the underlying legislative context and agronomic factors that drive pesticide use, the need for water suppliers to engage with agricultural and sector regulators at catchment level and water supplier knowledge of the relative treatability of different active substances. The pesticide classification system brings these factors together in a systematic way to create an action plan for all active substances and to provide an evidence base for water supplier investment decisions in surface water catchments.

6.7 Conclusion

The classification system presented here is a pre-cursor to development of catchment management strategies. It is designed to support potable water supply decision making by identifying which active substances require what level of intervention, in which catchments. The system is flexible and can be applied regardless of the regulatory regime in place. The systematic classification of active substances is particularly pertinent in a European context because WFD Article 7 requires a prevention-led approach to compliance with the DWD standard for pesticides.

Implementing the classification system challenges a water supplier to develop processes: to assess current pesticide use and water quality problems; to assess future expectations of pesticide use; to evaluate active substance treatability and to define and implement intervention options. The benefits which such processes can deliver include:

- Increased awareness of which active substances are being used in particular catchments

- An evidence base from which to produce clearly defined, evidence based, catchment level action plans for all active substances.
- A clear, transparent and auditable framework to justify investment decisions and support negotiation with regulators
- Greater insight into the regulatory and agronomic factors which shape current and possible future pesticide use patterns
- The opportunity to engage with stakeholders involved in pesticide use in affected catchments

Implementation of the classification system, can also deliver similar benefits to other stakeholders involved with pesticide use and the contamination of water including the competent authorities responsible for WFD and DWD compliance in European Member States. Such benefits include improved dialogue and engagement, shared understanding of pesticide use and water quality problems and an evidence base from which to target catchment management interventions.

6.8 Acknowledgements

The authors would like to acknowledge the support of Anglian Water Services Ltd and the EPSRC for funding the EngD research on which this article is based.

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**Chapter 7: Improving Knowledge and Processes:
Commercial Significance of Research Outputs for
Anglian Water Services Ltd**

7.1 Introduction

An EngD research project is, by definition, one that is of direct interest to industry. An EngD thesis is, therefore, required to address both the technical aspects of a research project and the business and commercial context in which these aspects are relevant. With this in mind, in addition to the Papers presented in Chapters 2-6, outputs to improve organisational knowledge and deliver process improvements have been produced on behalf of the sponsoring organisation Anglian Water Services Ltd (AWS). This Chapter provides an overview of the business need that underpins the research and outlines the commercial outputs produced through this research project.

Commercial outputs produced during this research include a series of legislative, agronomic and catchment management briefing notes to address gaps in organisational knowledge and a proposal for a pesticide classification tool which AWS plan to implement during the next asset management planning cycle (AMP6 2015-20). Full copies of the briefing notes are included in appendices 7.1 – 7.6 and the pesticide classification tool proposal document in appendix 7.7.

7.2 Context

7.2.1 Potable water supply as a transformation process

The supply of potable water is based on management of a transformation process (Slack et al., 2010; The Open University, 2013) to convert ‘raw’ water abstracted from the environment into a ‘product’ (potable water) compliant with standards defined in the Drinking Water Directive (DWD) (EC, 1998) (Figure 7.1).

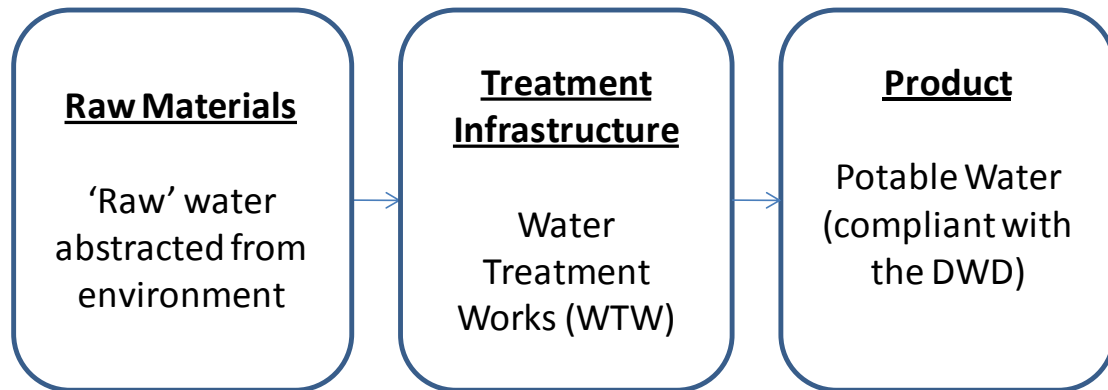


Figure 7.1 Potable water supply as a transformation process

Water suppliers in England and Wales make investment plans in five year cycles, known as asset management plans (AMP); one objective of the AMP is to plan investment to ensure a cost-effective management of the transformation process (Figure 7.1) and reduce the risk of DWD non compliance.

7.2.2 The Drinking Water Directive (DWD) standard for pesticides

Compliance with the pesticide standard defined in Annex I (Part B) of the European Drinking Water Directive (DWD) is a legal responsibility for all European water suppliers. The standard defined is a maximum allowable concentration (MAC) of 0.1µg/l for individual pesticide active substances (a lower value of 0.03 µg/l is applied for four active substances aldrin, dieldrin, heptachlor and heptachlor epoxide) and 0.5µg/l for total pesticide active substances; compliance is required 100% of the time (Jordan, 1999; Hey, 2006). In England and Wales, the standards defined in the DWD were transcribed into national law through The Water Supply (Water Quality) Regulations 2000 (HMSO, 2000b).

Failure to comply with the DWD will have legal, financial and reputational ramifications for any water supplier in England and Wales (Table 7.1). Dependent on

the regulatory regime in place in the Member State where they operate, failure to comply with the DWD may have similar implications for other European water suppliers.

Table 7.1 Legal, financial and reputation impacts of DWD non compliance

Impact	Details
Legal	In England and Wales, failure to comply with the DWD standard for pesticides, will prompt a ‘legal undertaking’ to be issued under the Water Industry Act (1991) (The Director General of Water Services, 1991). Undertakings for pesticides require inclusion of the pesticide in formal risk assessment procedure (Regulation 27 (HMSO, 2000b)) and development of short, medium, long action plans to resolve the problem. Failure to resolve an issue subject to an undertaking may lead to further enforcement action against the water supplier concerned.
Financial	Legal undertaking could result in fines being issued to the non compliant water supplier
Reputation	Mean zonal compliance (MZC) is a metric, based on compliance with 39 drinking water parameters, to compare the performance of water suppliers. Failure for even one parameter will reduce the MZC score. For example, in 2009, the presence of metaldehyde in the potable water supply reduced MZC for AWS from 99.97% (above the national average) to 99.93% (below the national average) (Chief Inspector of Drinking Water, 2009). A low MZC relative to other English and Welsh water suppliers will influence the final determination issued by Ofwat (the level of investment and return on investment Ofwat are prepared to allow during an AMP cycle) (Ofwat, 2009). This will influence the future cost of raising capital from investors. Additionally, poor performance against any metric

	may have ramifications for a water suppliers franchise as competition is introduced into the sector following the Cave Review on competition and innovation in water markets (Cave, 2009).
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7.2.3 A treatment-led approach to potable water supply

For a number of reasons, treatment has historically, been viewed as providing greater certainty of DWD compliance than pollution prevention at source:

- Diffuse pollution often originates from land not owned by the water supplier (Breach, 2011b; Keirle and Hayes, 2007),
- Water suppliers do not understand the drivers of agricultural decision making (Blackstock et al., 2010; Kay et al., 2009)
- Water suppliers lack established working relationships in catchments (Orr et al., 2007)
- The efficacy of a catchment management intervention is difficult to quantify. (Reichenberger et al., 2007; Candela et al., 2009; Tediosi et al., 2012)

Water suppliers in England and Wales have, therefore, traditionally focused predominantly on investments in the provision of treatment infrastructure to remove pesticide pollutants from the ‘raw’ water at the point of abstraction (Croll, 1995; Evans et al., 2003).

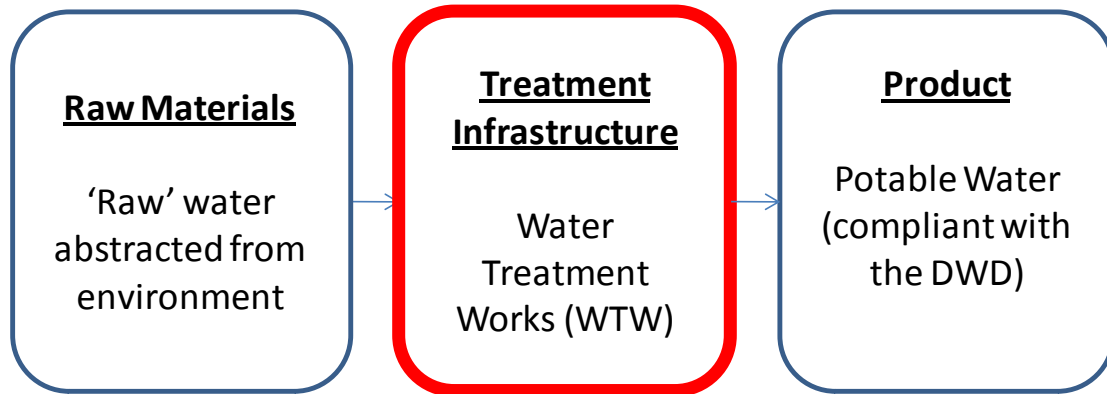


Figure 7.2 Potable water supply a treatment-led transformation

AWS, at all surface water treatment works, manage a treatment-led transformation process (Figure 7.2) comprising screens, primary ozone treatment, ASG filters, granular activated carbon (GAC) and secondary ozone treatment.

7.2.3.1 A prevention-led approach to potable water supply

Four factors coincide to encourage water suppliers to make a transition from a treatment-led transformation process (Figure 7.2) to a prevention-led transformation process (Figure 7.3), these are:

- Water Framework Directive (WFD) Article 7 (EC, 2000)
- The presence of metaldehyde and clopyralid in ‘raw’ water at concentrations that cannot be treated with current treatment technologies
- Widespread adoption of the World Health Organisation (WHO) drinking water safety planning (DWSP) approach (World Health Organisation, 2008) which encourages water suppliers to increase understanding of and mitigate risks throughout the supply chain from catchment to customer (Breach, 2011a).
- Water supplier targets to reduce the carbon footprint (CO₂ eq) of the operations and assets they manage

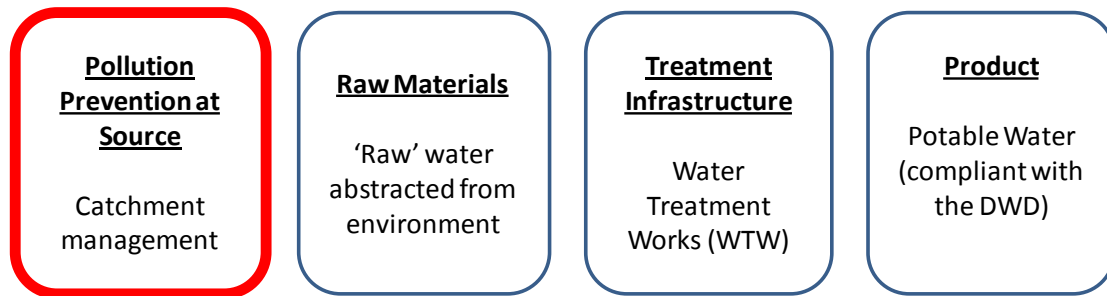


Figure 7.3 Potable water supply: a prevention-led model

The most significant of these, the Water Framework Directive (WFD) was published in 2000. Through Article 7 it requires that protected areas are defined for all water bodies from which water is abstracted for potable water supply. For each protected area an objective of ‘no deterioration’ in water quality is set and water quality must be improved such that DWD compliance can be achieved without the need for additional treatment. These objectives possibly prohibit additional investment in treatment infrastructure (although this remains unclear) and, therefore, favour investment in a prevention-led transformation process for potable water supply (Figure 7.3).

WFD Article 7 implies that pollution prevention at source will take place to control and improve ‘raw’ water quality such that water suppliers can achieve DWD compliance without the need to:

- Abandon a current (or planned) abstraction
- Blend abstracted water with water abstracted from another source;
- Apply additional purification treatment;
- Significantly increase the operating demand on existing purification treatment.

(UKTAG, 2008)

Who is responsible for delivering actions to improve ‘raw’ water quality and the timescale over which improvement is required are not specified. Furthermore, the WFD and DWD are legally distinct; regardless of targets set by WFD Article 7 the water supplier remains responsible for DWD compliance. By necessity, water suppliers should, therefore, take a central role in promoting and implementing improvements to ‘raw’ water quality at the point of abstraction as part of a strategy to manage the transformational process and reduce DWD non-compliance risk.

7.3 Overview of research outputs

7.3.1 Introduction

In order to play a central role in improving ‘raw’ water quality at the point of abstraction and reduce DWD non compliance risk, water suppliers need to:

- Fully understand the legal framework linked to pesticides, water quality and diffuse pollution
- Improve knowledge of the reasons for pesticide use in water supply catchments
- Develop a system to identify in which catchments and for which active substances pollution prevention at source is required

7.3.2 Briefing notes

The Papers presented in Chapters 2 - 6 address the above challenges. The analysis underpinning Papers 1, 2 and 4 (Chapters 2, 3 and 5) has also been presented as a series of legislative, agronomy and catchment management briefing notes, of general relevance to European water suppliers, and of specific relevance to AWS. An

overview of these briefing notes is given in Table 7.2, Table 7.3 and Table 7.4, full copies are provided in appendices 7.1 - 7.6.

Table 7.2 Overview of legislative briefing notes

<u>Legislative briefing notes</u>
Legislative note 1: Impacts of pesticide approval Regulation 1107/2009
<ul style="list-style-type: none">• Explains the significance of European pesticide approval legislation• Links expected impacts to those pesticide active substances already monitored by or of concern to Anglian Water Services• Details ongoing uncertainty on how Regulation 1107/2009 will effect pesticide active substance availability across Europe
Legislative note 2: The Water Framework Directive (WFD)
<ul style="list-style-type: none">• Explains the relative significance of WFD Article 7 and Chemical and Ecological status for potable water supply.• Reviews the challenges for water companies, the Environment Agency (EA), the DWI, and agriculture arising from WFD Article 7.• Lists the actions available to the EA for WFD Article 7 compliance• Presents five criteria that prevention actions need to satisfy to support DWD and WFD Article 7 compliance
Legislative note 3: The Sustainable Use of Pesticides Directive (Dir. 09/128/EC)
<ul style="list-style-type: none">• Outlines the significance of this Directive to potable water supply• Details the consultations completed to transcribe the Directive in UK Law• Details consultations to develop a National Action Plan for England and Wales

Table 7.3 Overview of agronomy briefing notes

<u>Agronomy briefing notes</u>
Agronomy note 1: Agronomic drivers of pesticide use in the region
<ul style="list-style-type: none">• Outlines the agronomic reasons for pesticide use patterns in the Anglian region, and how these link to land type and cropping decisions• Details the herbicides used in the combinable rotation for blackgrass (<i>Alopecurus agrestis</i> L.) control• Identifies the main fungicides used in the combinable crop rotation (wheat and oilseed rape)

- Examines the relative merits of different pesticide options for slug control

Agronomy note 2: Active substance, plant protection product (PPP) and agronomy information sources

An overview of publically available resources on specific active substances and reasons for pesticide use.

Table 7.4 Overview of catchment management briefing note

Briefing note on catchment management for pesticides

Pesticide active substances - eight steps before catchment management

- WFD Article 7 emphasises prevention over treatment, creating a need for water companies to develop and implement catchment management strategies.
- Proposes eight steps that a water company should take to gain knowledge of, and prioritise, pesticide active substances before implementing a catchment management strategy for diffuse pesticide pollution.
- Details how outputs from the EngD can be used to complete these eight steps
- Presents a case study for metaldehyde

7.3.3 Pesticide classification system

The pesticide classification system presented in Paper 5 (Chapter 6) was developed to support the management of pesticide active substances as part of the potable water supply transformation process at AWS. It provides a systematic, transparent and auditable framework to prioritise active substances for inclusion in catchment management strategy and justify the allocation of different levels of pollution prevention actions to different pesticide active substances.

The classification system was originally produced as a proposal document for AWS (appendix 7.7) and is currently being implemented by AWS and will be a central component of pesticide strategy in AMP6 (2015-20). The rationale underpinning development of the proposal, challenges during development and implementation and potential future developments are included in Section 7.4

7.4 Pesticide classification system

7.4.1 Rationale for proposal

On attending quarterly Pesticide Strategy Group (PSG) meetings to research existing processes for the management of pesticides, it was observed that the PSG were required to make decisions based on limited information and without clearly established processes to gather further evidence. As a consequence, it can be argued that some elements of AWS decision making for pesticide management were inconsistent, reactive and based on insufficient evidence. For example, when a problem pesticide is identified it is included in the internal monitoring strategy, but no formal process exists to initiate additional management or research actions.

An overview of current pesticide strategy at Anglian Water is given in Figure 7.4, and explained below.

The Water Resources team (WR) receive CatchIS reports for all AWS catchments. The CatchIS reports (produced by Cranfield University) predict pesticide active substance concentrations ($\mu\text{g/l}$) at the point of 'raw' water abstraction (predictions are based on land use, pesticide use, climate, soil and pesticide properties.) If the CatchIS worst case prediction exceeds a threshold value of $0.05 \mu\text{g/l}$ and the Pesticide Strategy Group (PSG) decide monitoring is required or if the regional quality team (RQT) identify it as an important element of a water quality action plan (WQAP) then an active substance will be included in the internal monitoring (IM) strategy.

The Drinking Water Standards Team (DWST) manages and reviews the IM strategy. Results are reviewed regularly to decide whether to remove an active substance from

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the IM programme or increase monitoring and include the active substance in the regulatory monitoring strategy (MT). The collection of MT data for pesticides where a risk has been identified is a regulatory requirement, and is shared with the Environment Agency (EA), whereas IM data is collected for internal purposes only.

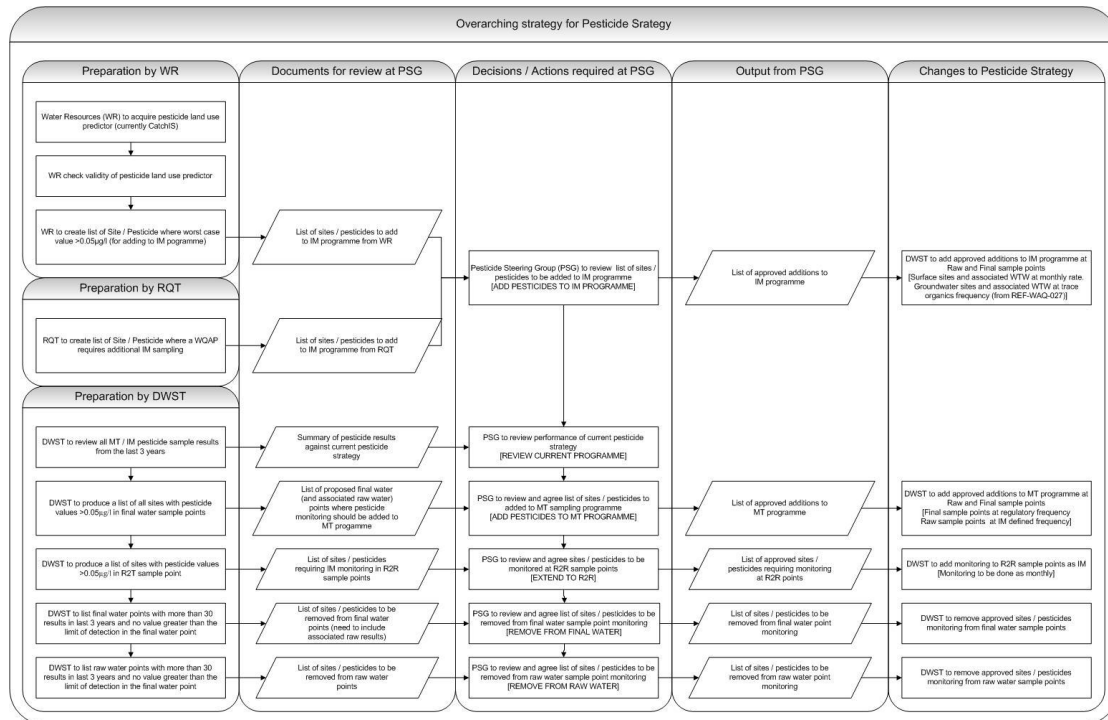


Figure 7.4 Overarching pesticide strategy (Reproduced from Anglian Water Pesticide Strategy)

The pesticide strategy (Figure 7.4) is a structured way of developing a monitoring programme; however, its sole purpose is to determine which pesticides to monitor. The strategy, therefore, increases the number of active substances being monitored, and the associated cost, without necessarily increasing knowledge of the reasons for pesticide use. A strategy based solely on monitoring focuses on understanding the symptom (i.e. concentrations at the point of abstraction) without seeking to understand the cause (i.e. the reasons for pesticide use). As a consequence AWS lack

an evidence base to understand the cause of water quality problems, feed meaningful information into other areas of the business, communicate with catchment stakeholders or develop catchment management strategy.

Ideally, where CatchIS identifies a potential problem (i.e. predicts an active substance at a concentration above the 0.05µg/l threshold) this would initiate a number of closely linked processes not just inclusion in the monitoring strategy. These actions could include:

- Assessment to understand the reasons for use of the active substance (i.e. for what weeds/pests/diseases in which crops), and the relative prevalence of use in the catchment (i.e. percentage of crop or percentage of catchment land area treated.)
- Investigation into the regulatory status of the active substance in question, and whether current regulation, in particular European approval legislation is expected to increase or decrease the extent to which an active substance is used.
- Evaluation of available treatability data to assess the potential to manage the problem with currently installed treatment technologies.
- A process to automatically add an active substance to the Regulation 27 risk assessment (required in England and Wales under the Water Supply (Water Quality) Regulations.)
- Inclusion of the active substance in catchment management strategy

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- A process to contact the Environment Agency (the WFD competent authority) with an up to date list of water company priorities for DWD and WFD Article 7 compliance.
- As above but with the Drinking Water Inspectorate (the DWD competent authority), the Voluntary Initiative (an industry body focused on reducing diffuse pesticide pollution), the Catchment Sensitive Farming initiative (a scheme, in some catchments, to tackle all forms of diffuse pollution), BASIS (the body responsible for agronomist professional training), Natural England (the body responsible for Environmental Stewardship - a programme of fiscal incentives to change farming behaviour and improve environmental outcomes.)

However, none of these processes are formally defined or automatically initiated as part of the current strategy (Figure 7.4). Consequently, in some circumstances AWS do not respond to a potential problem active substance until it is causing DWD compliance problems. Hence, processes for pesticide management are reactive rather than proactive and fail to recognise the value of agricultural knowledge to catchment management planning. The classification system was developed with the aim of implementing a transparent, systematic and auditable framework to address these challenges and establish additional procedures for pesticide management. The classification system extends the strategy in Figure 7.4 by broadening the level of up front assessment and the range of actions initiated (Figure 7.5.)

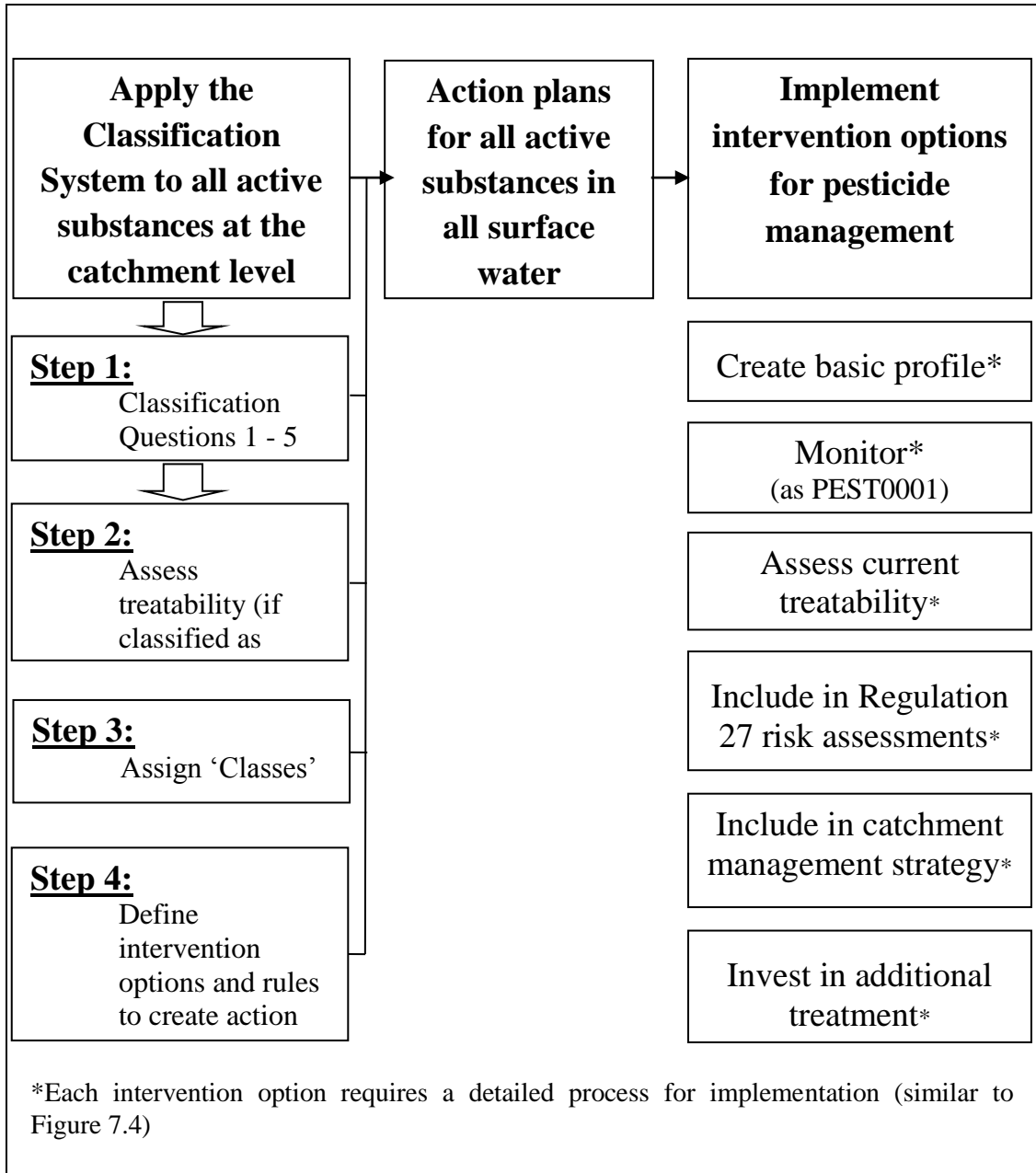


Figure 7.5 Classification system as an extension to current strategy

7.4.2 Development and implementation challenges

A number of challenges arose during development and implementation. These challenges, how they were addressed and how they will be addressed in the future are briefly outlined below

7.4.2.1 Gaining management support for the proposal

This challenge was addressed through a number of development and proposal meetings at various levels within the organisation. The process began with a proposal to the Project Steering Group and the Pesticide Strategy Group. A development meeting with interested representatives from the two groups was then arranged; this meeting tightened the business case and raised awareness of the pesticide classification tool. A formal proposal document was prepared for, and presented to, the Pesticide Strategy Group; this in turn led to an invitation to present to a group of senior managers, the Strategy and Risk team and Water Quality and Environmental Performance teams. A further development meeting was held and a job description for a twelve month post to fully implement the system at AWS was commissioned.

The proposal has gained the support of managers in the Innovation team, the Pesticide Strategy Group, the Source Protection Manager, Catchment and Coastal Strategy Manager and Head of Water Resources, and was presented to the Catchment Management Strategic Steering Group in September 2013. It is envisaged that funding for a twelve month post and inclusion of the pesticide classification system in the periodic review business plan (PR14) for investment over the Asset Management Plan period 2015-20 (AMP6) may occur.

Management support will continue to be required during implementation, in particular to ensure that the action plans created through the classification system assign actions to the relevant teams and that these actions are completed over the relevant timescales.

7.4.2.2 Processes to collate data (classification Steps 1 and 2)

AWS manage 23 surface water catchments and over 400 active substances are approved for use in Europe. Each active substance needs to be classified separately at the catchment level; therefore, to classify all active substances in all catchments AWS must apply the classification system on 9200 separate occasions. The classification system at Step 1 and 2 comprises a total of 6 questions; therefore, in theory 55,200 questions need to be answered. However, classification Questions 3, 4 and 5 only need be answered once for each active substance as does the treatability assessment for Step 2, thus reducing the informational demand to 19,600 questions. This can be further reduced to 10,800 if Question 1 is answered once at the regional level.

Nevertheless, this remains a large undertaking; it follows that for this to be a manageable proposition, processes to answer the five classification questions at Step 1 and to assess treatability at Step 2 need to be clearly defined such that the questions are simple to answer using readily available data. Additionally, a spreadsheet is required to record answers to all questions and automatically assign 'Classes' to over 400 active substances in each of the 23 catchments. All the above challenges have been addressed in section 4.2 of the proposal document produced for AWS (Appendix 7.7).

Defining these processes allows AWS to implement a comprehensive assessment to evaluate the relative significance of active substances in a clearly defined, well recorded, transparent and auditable manner. By introducing robust processes for Steps 1 and 2, the actions assigned at Step 4 can be justified with confidence.

7.4.2.3 Intervention options and Action Plans (classification Step 4)

As discussed, the classification system was developed because processes were not in place to assign actions for active substance management at the catchment level. The classification system addresses this and produces an action plan for each active substance at the catchment level and in so doing assigns actions for the management of each active substance.

For the classification system to be effective these actions need to be agreed by the business and automatically assigned to the relevant team when the classification system is implemented. This challenge has been addressed in section 4.2 of the proposal document produced for AWS (Appendix 7.7).

7.4.3 Future developments

The classification has been developed for use in all AWS surface water catchments, once successfully implemented the classification system can be expanded to a number of additional areas, these include:

- Non agricultural diffuse pollution – agriculture is the dominant, but not the only, source of diffuse pesticide pollution. If AWS obtain appropriate data on non agricultural use as an input for the CatchIS model, the classification system could be extended.

- Pesticide management for groundwater abstractions – AWS receive CatchIS reports for all groundwater abstractions, with some adaptations the classification system can be applied to classify pesticides in these areas.
- Asset condition of treatment infrastructure – The efficacy of treatment varies depending upon asset age and condition. This variation could be factored into the classification system by modifying the Step 2 treatment assessment.

Additionally, the classification system is applicable to all UK water suppliers and possibly other European water suppliers.

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Chapter 8: Integrated Discussion

8.1 Introduction

The five interconnected Papers presented in Chapters 2 - 6 of this thesis are grounded by reference to European legislation (including the guiding principles for European Environmental policy); government policy enacted, in England and Wales, in response to European legislation and guidance; consultation and impact assessment documents produced by a range of government bodies in England and Wales on how elements of European legislation will fit into national law and the possible impacts this will have. In addition, each Paper makes use of further specialist literature (Table 8.1) and builds upon the analysis undertaken in the previous Paper(s).

The thesis makes a number of contributions to the body of knowledge (section 8.2), and identifies factors at European, national and catchment level that shape the challenges those stakeholders involved with DWD and WFD Article 7 compliance face as a consequence of WFD Article 7 promoting a prevention-led approach to DWD compliance (section 8.3). As a whole, this thesis addresses the research question: What are the implications of the Water Framework Directive and other relevant European legislation for the management of potable water quality with respect to pesticides? Conclusions are presented in section 8.4.

Table 8.1 Overview of specialist literature types

Chapter	Specialist Literature Types
Chapter 2 (Paper 1)	<ul style="list-style-type: none"> • Academic and technical evaluations of current initiatives to manage diffuse pollution • Literature on agri-environment schemes in the UK (with a particular emphasis on England) • Literature on the possible impacts of changes to European pesticide approval legislation

	<ul style="list-style-type: none"> • Literature on conceptual frameworks for managing environmental risk
Chapter 3 (Paper 2)	<ul style="list-style-type: none"> • Water sector research into pesticide treatment technologies • Literature evaluating the efficacy of currently available catchment management options • Literature on modelling pesticide movement through catchments • Literature on agricultural perspectives on the WFD and European pesticide approval regulation
Chapter 4 (Paper 3)	<ul style="list-style-type: none"> • Contextual literature on the origin of European environmental policy (including the origin of the DWD) • Academic literature and European Commission guidance on the use of the precautionary principle • Technical guidance on WHO, Australian and USA methodologies for regulating pesticides in potable water • Academic literature on toxicology
Chapter 5 (Paper 4)	<ul style="list-style-type: none"> • Technical and academic literature on the use of pesticides and other techniques for weed, pest and disease control • Literature on catchment management for diffuse pollution mitigation, catchment modelling literature • Social science literature on research methodologies and stakeholder engagement
Chapter 6 (Paper 5)	<ul style="list-style-type: none"> • Academic literature on pesticide fate modelling at the catchment level, • Water sector research into potable water treatment technologies • Risk management literature

8.2 Contributions to Knowledge

The thesis builds upon prevailing literature to make a number of contributions to the body of knowledge; these contributions and the context in which they sit are discussed in the following paragraphs.

The thesis provides the first examination of the combined significance of the Water Framework Directive, the European thematic strategy on pesticides, voluntary action for diffuse pollution prevention and agri-environment schemes, on pesticides in the potable water supply. A body of previous research (Garratt and Kennedy, 2006; Garrod et al., 2007; Glass et al., 2008; PSD, 2009; Humphrey, 2007; Hodge and Reader, 2010; Posthumus and Morris, 2010) considers many of these issues in isolation but not as a whole framework.

The WFD sets a number of targets for improvements to raw water quality. Analysis in this thesis provides an overview of the significance of each element of the WFD and quantifies the extent to which WFD Article 7 is more significant than Chemical and Ecological status targets for potable water suppliers concerned with diffuse pesticide pollution. Previous technical reports (UKTAG, 2012; UKTAG, 2008; EC, 2012; EC, 2008; EC, 2001) focused solely on identification and evaluation of specific active substances.

Compliance with WFD Article 7 targets and the DWD standard for pesticides in potable water is inextricably linked to pesticide availability as driven by European pesticide approval processes, in particular Regulation 1107/2009. Previous technical reports and academic papers (PSD, 2009; KEMI, 2008; PSD, 2008a; PSD, 2008b; Rickard, 2009; Richardson, 2009a; Richardson, 2009b; Kortenkamp et al., 2011;

EFSA Scientific Committee, 2013) have examined the criteria on which approval decisions will be made and the associated uncertainty regarding whether individual active substances will be available in the future. This thesis is the first to identify uncertain future pesticide availability as a key determinant of the decision making process for those addressing the linked challenges of WFD Article 7 and DWD compliance.

Assessing whether a programme of prevention interventions at catchment level will satisfy DWD and WFD Article 7 requirements is very difficult due to the inherent uncertainty involved in catchment management and predicting pesticide movements (Reichenberger et al., 2007; Brown and van Beinum, 2009; Tediosi et al., 2012; Tediosi et al., 2013). Additionally, with the exception Kennedy *et al.* (2009), little guidance is available in the literature on how to tailor a programme of interventions to a specific catchment, how to evaluate whether the proposed programme will deliver the required improvement, and the timescale by which WFD Article7 compliance is required. A framework, comprising five criteria (scale, stability, consistency, level of engagement and timeliness), is proposed in this thesis to give those planning or evaluating catchment management programmes a strategic overview of the elements of this challenge. Furthermore, an iterative toolbox of actions that any WFD competent authority can take to manage reduction or mitigation of diffuse pesticide pollution in DrWPAs is proposed.

This thesis identified that if WFD Article 7 promotes pollution prevention in favour of treatment, then the DWD standard for pesticides in potable water is the central determinant of the level of diffuse pollution prevention required for pesticides in a

catchment. Previous literature details the absolute nature of the DWD standard for pesticides in potable water (Jordan, 1999; Hey, 2006), and demonstrates that catchment management interventions are characterised by epistemic and aleatory uncertainty (Reichenberger et al., 2007; Brown and van Beinum, 2009; Tediosi et al., 2012; Tediosi et al., 2013). However, the inconsistency of WFD Article 7 requiring the use of catchment management to meet an absolute DWD standard for pesticides in potable water is not covered elsewhere in the literature.

In theory, all European environmental policy must be consistent with the precautionary principle (EC, 2002). Analysis of whether the European Drinking Water Directive standard for pesticide active substances in potable water remains consistent with the precautionary principle as defined in academic literature (Aven, 2011; Klinke and Renn, 2001; Stirling and Gee, 2002) and through European Commission guidance (European Commission, 2000) was undertaken for this thesis. Previous work analysed the DWD standard for pesticides (Jordan, 1999; Hey, 2006) and examined European use of the precautionary principle (Sandin et al., 2002; Sand, 2000; De Sadeleer, 2009), but no analysis of whether the standard is consistent with the precautionary principle has been performed. This thesis is the first to perform such analysis for the DWD standard and other approaches to regulating pesticides in potable water. This analysis is significant because if the DWD is inconsistent with the precautionary principle, it is inconsistent with the guiding principles of European environmental policy, and by association WFD Article 7 is also inconsistent with these guiding principles.

The requirements of WFD Article 7 increase the need for knowledge of pesticide use in catchments and the implementation of catchment management to tackle diffuse pesticide pollution. The majority of literature on the subject examines options for catchment management (Reichenberger et al., 2007), however less attention is given pesticide user behaviours that create a need for catchment management (Orr et al., 2007; Blackstock et al., 2010) and specialist agricultural literature (Moss and Hull, 2012; Hull and Moss, 2012; Shah et al., 2012; Roberts and Jackson, 2012; Ward et al., 2012), is not yet widely consulted by water suppliers involved in catchment management. For this reason an adaptable consultation methodology to promote engagement between water suppliers and pesticide users; an adaptation options hierarchy to examine possible outcomes when a single active substance is lost or restricted; a list of factors that may constrain behavioural change amongst agricultural pesticide users; a set of key insights for catchment managers, were all developed as a suite of outputs from the agronomist consultation exercise undertaken as part of this research. This suite of outputs, particularly the consultation methodology and the adaptation options hierarchy, although developed in the context of combinable crop rotations in the Anglian region of the UK, can be applied in other European contexts for strategic engagement between water suppliers and pesticide users in their catchments.

A system to classify all pesticides at the catchment level in order to prioritise water supplier investment decisions for catchment management and treatment infrastructure was developed as part of this thesis. In response to a number of literature themes previously flagged throughout the thesis, the system is designed to be an evidence-led pre-cursor to catchment management strategy. In particular, the system addresses a

lack of water supplier knowledge of pesticide use (and the reasons for pesticide use) in their catchments (Orr et al., 2007; Blackstock et al., 2010; Kay et al., 2009; Keirle and Hayes, 2007), the need for water suppliers to be able to justify all investment decisions and prioritise scarce resources. Importantly, the classification system also draws on a number of the other contributions to knowledge made by this thesis, and could not have been developed without the research actions reported in Chapters 2 - 5.

8.3 Integration of Findings

Integration of the contributions to knowledge made by each of the papers supports creation of an overview of the connections between the factors at European, national and catchment level that shape the challenges those stakeholders involved with DWD and WFD Article 7 compliance face as a consequence of WFD Article 7 promoting a prevention-led approach to DWD compliance (Figure 8.1).

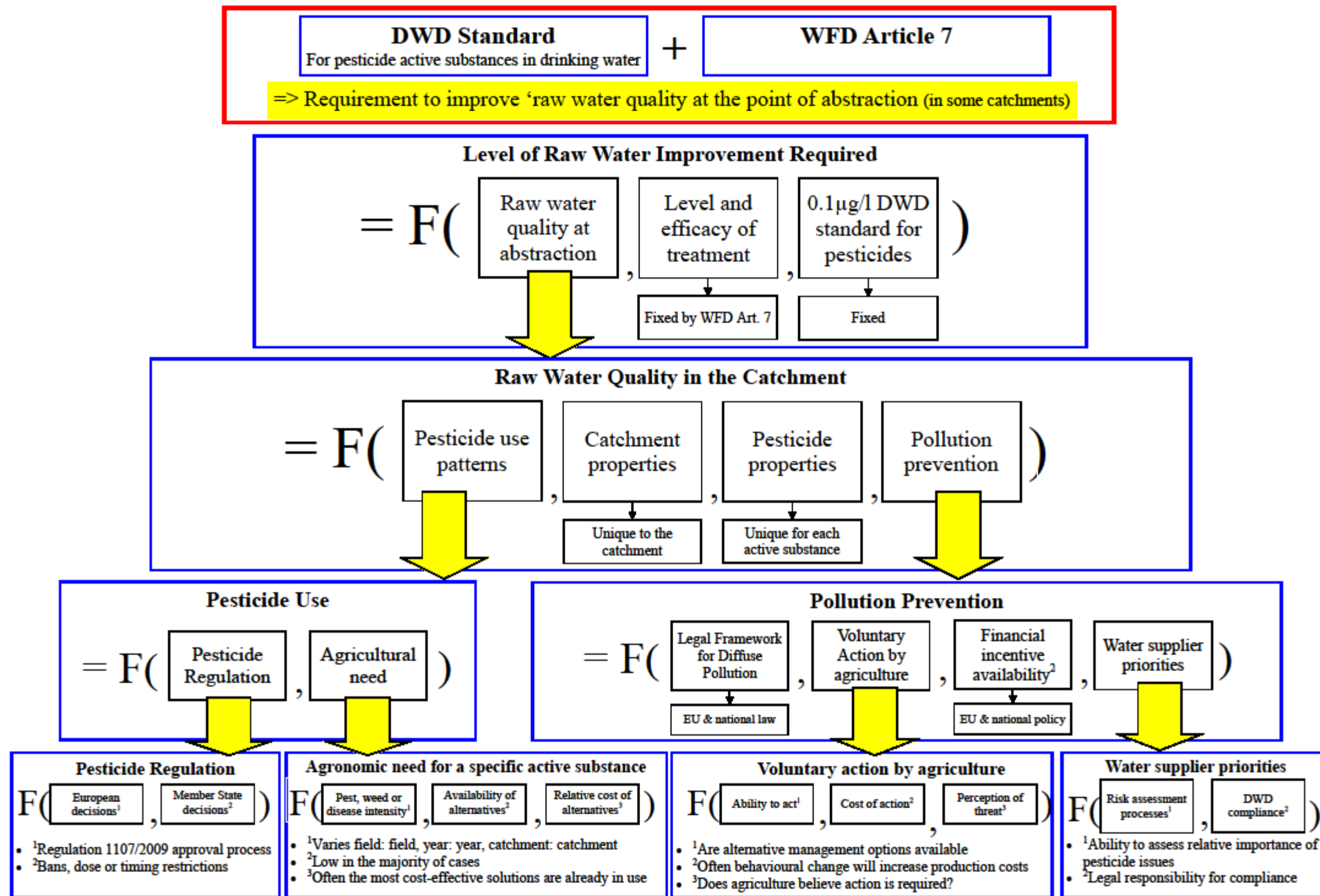
Row 1 of Figure 8.1 highlights how the interaction between WFD Article 7 and the DWD standard leads to a prevention-led approach to DWD compliance and creates the need to improve raw water quality in some catchments (Chapter 3).

Row 2 of Figure 8.1 reproduces the conceptual model of potable water supply (Chapter 2 Figure 2.1) to identify three factors that influence the level of raw water quality improvement needed at the point of abstraction in any WFD Article 7 protected catchment. Two elements of Row 2, the level of treatment available and the 0.1µg/l standard for individual pesticides in drinking water are fixed by WFD Article 7 (Chapter 3) and the DWD (Chapter 4) respectively. It follows that improving raw water quality is the only option for those stakeholder groups interested in achieving both WFD Article 7 and DWD compliance for pesticides.

Row 3 of Figure 8.1 presents those factors that influence current and future raw water quality in a catchment. Two of those factors, catchment properties and pesticide properties are beyond the control of stakeholders affected by WFD Article 7 and the DWD. However, two other closely related factors, current pesticide use patterns and the level of pollution prevention actions in place can be influenced, manipulated or controlled by affected stakeholders.

Rows 4 and 5 of Figure 8.1 consider the constituents of these factors in more detail. Pesticide regulation (Chapter 2) and the agricultural need for cost-effective weed, disease and pest control (Chapter 5) each shape levels of pesticide use. The level of pollution prevention in place is a function of four factors: the legal framework for the prevention of diffuse pesticide pollution (Chapter 2); the willingness of governments and the WFD competent authority to provide fiscal incentives for behavioural change (Chapters 2 and 3); the level of voluntary action that agriculture can realistically take given the existence of constraints to adaptation such as the availability and relative cost of alternative solutions (Chapter 5); water supplier priorities for catchment management strategy to mitigate these risks (Chapter 6).

Chapter 8: Integrated Discussion



Where, = F (... , ...) indicates that a variable is a function of other variables

Figure 8.1 Overview of the factors that shape the challenges faced by stakeholders involved with DWD and WFD Article 7 compliance

8.4 Conclusions

Based upon the collection of Papers presented, a number of conclusions can be drawn under each of the headings in Figure 8.1

8.4.1 DWD and WFD Article 7

Before WFD Article 7, the DWD standard for pesticides (Annex 1b) determined the level of treatment required for potable water supply. As a consequence of WFD Article 7 emphasising pollution prevention at source, the DWD now determines the level of resources allocated to catchment management.

The need for absolute compliance with a surrogate zero for pesticides in drinking water (the DWD) and the uncertainties associated with the efficacy of prevention interventions make WFD Article 7 targets a significant challenge.

Government, the WFD competent authority, the DWD competent authority, water companies and agriculture all have a different perspective on WFD Article 7. These groups need to work together to achieve the shared goals of WFD Article 7 compliance and DWD compliance while minimising any impact on agricultural productivity.

A number of factors central to WFD Article 7 need to be defined more clearly:

- How the baseline concentrations of pesticide active substances in ‘raw’ water, are measured
- The timescale for WFD Article 7 compliance
- Whether water suppliers can legitimately invest in additional treatment infrastructure

- WFD competent authority expectations of each stakeholder group

8.4.2 Level of raw water improvement required

8.4.2.1 DWD Regulation of pesticides in drinking water

Given scientific and legislative developments since the standard was last reviewed, objective debate about whether the current standard for pesticides in drinking water remains consistent with the principles of European Environmental Policy (as defined in Maastricht Treaty Article 174) and the precautionary principle is required.

In the absence of available scientific understanding and technical data, a surrogate zero for pesticides in drinking water can be justified under the precautionary principle and is in keeping with both EU Treaty Article 174 and DWD Article 1.2. However, where a no observed adverse effect level (NOAEL) or lowest observed adverse effect level (LOAEL) can safely be established through toxicological studies, a regulatory approach based on the WHO GV method would utilize scientifically robust toxicological understanding more effectively and still be consistent with the precautionary principle.

DWD standards for individual active substances based upon toxicological data collected during the European pesticide approval process would allow catchment management resources to be allocated to pesticide active substances where the health or ecological need is greatest.

8.4.2.2 Treatment

Treatability at the water treatment works (WTW) is not a criterion currently included in European pesticide approval legislation. Water suppliers are unaware of whether or

not the majority of active substances can be removed with current installed technology. The extent to which an active substance can currently be removed at a WTW is a significant factor when identifying which active substances require catchment management because WFD Article 7 possibly places restrictions on the installation of additional treatment.

Opportunities exist for European water suppliers to collaborate on collective research to assess the treatability of those active substances most commonly occurring at the point of abstraction in Europe. Additionally, pesticide manufacturers and WFD competent authorities should both contribute to these investigations because they will benefit from knowledge of treatability because treatable active substances are less likely to be banned or restricted compared with untreatable ones which should be targeted for catchment management.

8.4.3 Raw water quality in the catchment – catchment and pesticide properties

Improved understanding of catchment and pesticide properties can help to target pollution prevention actions to the areas of a catchment where they are most needed. Integration between pesticide fate models and reliable data on the efficacy of catchment management interventions is needed to allow these properties to guide catchment management planning.

8.4.4 Raw water quality in the catchment - pesticide use

Future pesticide use patterns are governed by a number of factors including pesticide availability, resistance pressures, regulatory decisions on allowable timing and dose rates, farming practice, cropping decisions and the intensity of a weed, pest or disease.

8.4.4.1 Regulation

European pesticide approval legislation is a rolling baseline influencing pesticide use patterns and diffuse pollution issues. Uncertainty regarding the full impact of European pesticide approval legislation Regulation 1107/2009 makes it difficult to predict which active substances will be most widely used in the future, and what diffuse pesticide pollution issues will need resolving.

8.4.4.2 Agricultural need

Increasing gross margins, reducing the risk of crop failure and preventing the development of resistance to any active substance are important drivers of pesticide use. A pesticide will only be used where the cost of use is less than the value of the expected benefit.

Agronomists cannot predict with confidence how agriculture would respond to active substance losses or restrictions. However, adaptation options to manage a weed, pest or disease when one active substance is lost can be ranked in order of agronomist preference. This ranking reads direct substitute, close substitute, substitute at different growth or rotation stage, cultural control (non-pesticide), change to crop architecture, a switch to spring cropping. However, direct substitutes for those active substances currently in use are rare.

8.4.5 Raw water quality in the catchment - pollution prevention

8.4.5.1 Legal framework for diffuse pollution prevention

Current legislation does not provide a coordinated legal and regulatory framework to mitigate diffuse pesticide pollution of the potable water supply. Better coordination is

needed between legislation dealing with pesticides and pesticide use, environmental water quality, and drinking water quality.

An iterative approach, based upon repeated phases of communication, implementation and assessment, may be needed to ensure sufficient pollution prevention actions are initiated to achieve WFD Article 7 compliance without over regulation.

8.4.5.2 Voluntary action by agriculture

The availability (or not) and cost of substitutes; the availability, efficacy, time and cost of cultural control options; the need to manage the risk of resistance; the need to avoid short term risk in the current crop; a reluctance to use unproven solutions in place of proven solutions; the risks and cost of spring cropping, can all act as constraints' to the level of behavioural change agriculture can voluntarily undertake.

8.4.5.3 Financial incentives

The provision of financial incentives must be careful not to fund adaptation that agriculture would have willingly undertaken on a voluntary basis. Fiscal incentives are appropriate where voluntary action is constrained.

8.4.5.4 Water supplier priorities

For a number of reasons, water suppliers now need to proactively engage with prevention of diffuse pollution at source rather than relying on treatment. These reasons include:

- WFD Article 7 encourages a prevention-led approach to DWD compliance and may constrain the type of intervention decisions available to a water supplier, in particular restricting investment in additional treatment.

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- Some widely used active substances (particularly metaldehyde and clopyralid) are currently very difficult to treat cost-effectively even with the best available treatment technologies installed at the point of abstraction.
- The need to take a drinking water safety planning (DWSP) approach to understanding and mitigation of risks throughout the supply chain from catchment to customer.

However, catchment management interventions typically provide water suppliers with less certainty than investment in treatment:

- Efficacy varies with catchments characteristics, weather conditions and active substance properties and is often uncertain
- Behavioural change on land not owned by, and beyond the direct influence of water suppliers is required
- Agricultural decision making and the land management processes that contribute to diffuse pollution are not understood by water suppliers
- Understanding, trust and credibility are needed before catchment management is likely to be widely adopted.

As part of catchment management strategy, water suppliers and regulators should work closely with agronomists to chart control strategies for major weed, disease and pest problems, identify the available adaptation options available to replace key components of these strategies. Such information can provide a useful basis for dialogue between key catchment stakeholders to identify appropriate management actions.

WFD Article 7 influences the type of intervention options available to a water supplier when managing pesticides. Interventions should be prioritised in the following order: (1) those which improve knowledge; (2) those which engage catchment stakeholders to raise the profile of a problem and promote catchment wide prevention actions; (3) the provision of extra funding for water-supplier-led catchment management actions. Investment in additional treatment should only be considered where a water supplier is not confident that catchment management can support DWD compliance.

Catchment management strategy should primarily be based on engagement to raise the profile of problems and identify mutually beneficial solutions. Additional action should only be funded by water suppliers when behavioural adaptations to mitigate diffuse pollution would not otherwise take place.

Water supplier decision making for catchment management strategy will potentially impact both agriculture and the potable water supply business. Embedding expertise from one industry into the decision making processes of another is, therefore, in the collective interest of both industries.

All active substances can be classified by current use, expected future use, and treatability in order to prioritise which active substances in which catchments require some form of action. Such a classification should form a pre-cursor to water supplier catchment management strategy for pesticides. Systematically classifying active substances:

- Increases awareness of which active substances are being used in particular catchments

- Creates an evidence base for catchment level action plans for active substance management.
- Provides a clear, transparent and auditable framework to justify investment decisions and support negotiation with regulators
- Offers insight into the regulatory and agronomic factors which shape current and possible future pesticide use patterns
- Facilitates engagement with stakeholders involved in pesticide use in catchments affected by diffuse pesticide pollution

A decision to take no action for an active substance can be justified for the majority of active substances provided an evidence base is gathered to underpin the decision.

8.5 Future research

Further work and research is required to develop, implement and extend the research presented in this thesis

- Further development of the adaptation options framework (Chapter 5) to enable use by water suppliers, regulators and agronomy experts as a tool to evaluate and make explicit the likely impacts, in terms of alternative pesticide use and agricultural productivity, of restrictions on any active substance.
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- The classification system (Chapter 6) should be adapted for use by all European water suppliers. As part of this further development of a framework (based upon Chapter 3 and Chapter 5) for regular engagement between water suppliers, regulators and agronomists to facilitate increased mutual understanding of water supplier priorities, agricultural drivers of use, the

extent to which agriculture can adapt voluntary and the impacts of regulation on pesticide use is required.

- The European Commission should consider using the WHO guideline value methodology to review the regulation of pesticides in drinking water and ensure this is consistent with the guiding principles of European environmental policy as defined in Treaty Article 174.
- The European Commission should investigate the feasibility of including treatability as a criterion in the pesticide approval process.
- European water suppliers, pesticide manufacturers and regulators should collaborate to create a database of treatability data.
- Further research into methods to target catchment management for problem active substances is needed.
- Given the inconsistency between the DWD standard for pesticides in drinking water and the guiding principles of environmental policy it is intended to embody, investigation is needed to evaluate the consistency of other elements of European environmental policy.
- Research is needed to evaluate European public perceptions of evidence based policy, and whether in any circumstances policy can overrule evidence and be based solely on political considerations.

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References

Appendices

List of Appendices

The table below provides an overview of the thesis appendices included on the supporting CD-Rom.

List of appendices

Section	Document Name	Description
1.0	Appendices to Chapter 1	
	None	
2.0	Appendices to Chapter 2	
2.1	Pesticide Problems the Case for a Treatability Criterion at the Approval Stage	A briefing note for Defra to highlight the possible need for inclusion of a treatability criterion in the pesticide approval process
3.0	Appendices to Chapter 3	
3.1	Environment Agency Consultation	Details of Environment Agency consultation
4.0	Appendices to Chapter 4	
	None	
5.0	Appendices to Chapter 5	
5.1	Online Resource 1_Stage 1 and 2 Survey Templates	Semi-structured survey templates for Stages 1 and 2 of the agronomy consultation
5.2	Online Resource 2_Stage 3 Survey	Paper copy of the Stage 3 online agronomy consultation
5.3	Analytical Techniques for Agronomist Consultation	Additional information on the analytical techniques used to support the agronomist consultation
5.3b	Phase 2 Methodology	Overview of the methods used for the agronomist consultation

5.4	Stage 1 Interview Transcripts	Full transcripts for all Stage 1 interviews
5.5	Stage 1 Prevalence Charts	Stage 1 prevalence charts
5.6	Stage 1 Part 1 Template Analysis	Overview of template analysis performed on Stage 1 data
5.7	Agronomic Significance, Shortlists and Profiles	Analysis of all active substances identified during Stage 1 interviews
5.8	Stage 2 Interview Transcripts	Full transcripts for all Stage 2 interviews
5.9	Stage 2 Prevalence Charts	Stage 2 prevalence charts
5.10	Stage 2 Analysis	Overview of all analysis of Stage 2 data
5.11	Selection of Stage 3 Statements	Rationale for the selection of Stage 3 statements and survey design
5.12	Stage 3 Survey_Raw Data	All Stage 3 survey data before any analysis
5.13	Stage 3 Respondent Comments	SPSS files containing respondents comments for each section of the Stage 3 survey
5.14	Analysis of Stage 3 Comments	Details of coding for analysis of Stage 3 respondent comments
6.0	Appendices to Chapter 6	
6.1	Online Resource 1_Example Action Plans	Example action plans for metaldehyde and methiocarb
7.0	Appendices to Chapter 7	
7.1	Impacts of European Pesticide Approval Regulation 1107/2009	Legislative briefing note 1
7.2	The Water Framework Directive	Legislative briefing note 2
7.3	The Sustainable use of Pesticides Directive	Legislative briefing note 3

List of Appendices

7.4	Agronomic Drivers of Pesticide Use in the Region	Agronomic briefing note 1
7.5	Active Substance, PPP and Agronomy Information Sources	Agronomic briefing note 2
7.6	Pesticide Active Substances - Eight Steps Before Catchment Management	Catchment management briefing note 1
7.7	Revised Proposal for Pesticide Classification System_July2013	Proposal to AWS for a pesticide classification system
7.8a	Implementation of Pesticide Classification System_Role Description	15 step guide to implementation of the classification information
7.8b	Supporting Information	Implementation notes to support 7.8a
8.0	Additional Appendices	
8.1	EngD Transcript for MBA-Core-Specialist Modules	Results from EngD modules
8.2	EngD Research Presentations	List of presentations to research sponsor and Cranfield University