

# Water Resources Management

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

--Manuscript Draft--

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| <b>Abstract:</b>                                     | <p>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.</p> |
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2  
3 **Abstract**  
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5 Water suppliers in parts of Europe currently face occasional Drinking Water Directive  
6 compliance challenges for a number of pesticide active substances including  
7  
8 metaldehyde, clopyralid and propyzamide. Water Framework Directive (WFD)  
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10 Article 7 promotes a prevention-led (catchment management) approach to such issues.  
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12 At the same time, European pesticide legislation is driving reduced active substance  
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14 availability. In this context, embedding agronomic drivers of pesticide use into  
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16 catchment management and regulatory decision making processes can help to ensure  
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18 that water quality problems are addressed at source without imposition of  
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20 disproportionate cost on either agriculture or potable water suppliers. In this study  
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22 agronomist knowledge, perception and expectations of current and possible future  
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24 pesticide use was assessed and the significance of this knowledge to other  
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26 stakeholders involved with pesticide catchment management was evaluated. This was  
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28 then used to provide insight into the possible impacts of active substance restrictions  
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30 and associated adaptation options. For many arable crops, further restrictions on the  
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32 range of pesticides available may cause increased use of alternatives (with potential  
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34 for "pollution swapping"). However, in many cases alternatives are not available, too  
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36 costly or lack a proven track record and other adaptation options may be selected  
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38 which catchment managers need to be able to anticipate.  
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49 **Keywords**  
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51 Catchment management, Water framework directive, agronomist, adaptation options,  
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53 drinking water, pesticides  
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## 1 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), which aims to increase understanding of and mitigate risks from catchment to consumer (Breach, 2011). 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; Tediosi et al., 2013). However, there

1 is less focus in the literature on embedding understanding of behaviour at source, i.e.  
2 those contextual factors that drive current pesticide use patterns, which will also shape  
3 future pesticide requirements; into water supplier or regulator decision making  
4 processes (Blackstock et al., 2010).  
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11 Agronomists often provide expert advice to farmers to support the management of  
12 weed, disease and pest problems. In the UK agronomists are the main decision makers  
13 for pesticide use on 84% of UK arable farms (Twining et al., 2009). As a group, they  
14 are, consequently, very influential in determining pesticide use patterns and how  
15 agriculture will respond to future challenges, such as changes in active substance  
16 availability or the need to reduce diffuse pollution. Agronomist expertise could,  
17 therefore, be invaluable to all European water suppliers and regulators if methods for  
18 regular consultation were developed to systematically embed knowledge of local  
19 agronomy issues into catchment management planning. Shared understanding of the  
20 challenges faced by water suppliers and the WFD competent authority would also be  
21 beneficial for agriculture (Dolan et al., 2013a). Increased engagement between these  
22 stakeholders is essential if solutions to diffuse pesticide pollution problems that avoid  
23 the risk of “pollution swapping” (Stevens and Quinton, 2009a; Stevens and Quinton,  
24 2009b) or the imposition of disproportionate cost on either water suppliers or  
25 agriculture are to be identified.  
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51 This paper presents the findings from a three-stage study of agronomist knowledge,  
52 perception and expectations. The principal aim of the study was to identify drivers of  
53 current operational pesticide use, potential agronomic impacts of restrictions or bans  
54 on active substances, potential responses (adaptation options) to such restrictions and  
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1 constraints on adaptation options. The principal outputs from this study are insights  
2 into agricultural decision making and an adaptation options framework which, when  
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4 combined with knowledge of current pesticide strategies and constraints to adaptation,  
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6 can be used as the basis for catchment management dialogue between key  
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8 stakeholders.  
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12 The study was conducted in the Anglian region of Eastern England, which has a very  
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14 high area of productive arable land and high pesticide use, occasionally resulting in  
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16 DWD compliance challenges for the water industry. Although the work was focussed  
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18 on the agronomy of arable crops, the general methodology and many of the principal  
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20 outcomes are relevant to any situation in Europe where diffuse pesticide pollution is  
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22 causing problems for DWD compliance and preventative action is required under  
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24 WFD Article 7.  
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## 31 **2. Methods**

### 32 **2.1 General**

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37 The study was conducted in three stages. At each stage, themes that emerged from the  
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39 previous stage were developed and validated. Stage 1 was a scoping exercise, based  
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41 on semi-structured interviews, during which sixteen agronomists identified the weed,  
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43 pest and disease problems of greatest significance to the area in which they work and  
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45 the most commonly used methods to manage these. Stage 2 used seven case study  
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47 active substances to investigate the confidence with which respondents could identify  
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49 the availability (or not) of alternative management options and predict how  
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51 agronomists and farmers might respond if an active substance were restricted or lost.  
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58 Stage 3 used an online survey to validate 43 trend statements that arose from Stages 1  
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1 and 2 against a wider population of 94 respondents. At each stage the survey was  
2 piloted with academic colleagues and a representative from an agricultural industry  
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## 10 **2.2 Stage 1**

11 A semi-structured interview template (Coolican, 2009; Bryman, 2012) to examine the  
12 main crops, problems (weeds, pests and diseases) and solutions (pesticide and non-  
13 pesticide) was used for the Stage 1 interviews (Online Resource 1). When setting  
14 questions, the decision was taken to allow respondents to identify crops, weeds, pests  
15 and diseases, and not to ask directly about any pesticide active substances. The  
16 purpose was to derive maximum benefit from expert knowledge and avoid guiding the  
17 interview onto any specific active substances or issues (thereby minimising bias).  
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32 Sixteen interviews of 60–90 minutes were conducted. Interviews were performed  
33 face-to-face or by telephone by the same researcher. In all cases the semi-structured  
34 questionnaire was shared with the respondent at least one week in advance of the  
35 interview. The role of the interviewer was to allow the interview to develop based  
36 upon the semi-structured template. The interviewer used judgement to decide when to  
37 ask additional questions to prompt further detail or clarify information provided, and  
38 when to direct the interview back to the semi-structured template. Given the range of  
39 specialist knowledge amongst interviewees and a time constraint on the interview, not  
40 all topics were covered with all respondents, and some topics were covered in greater  
41 depth by individual respondents.  
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1 The interview transcripts were analysed using thematic template analysis (King, 2004)  
2 against an '*a priori*' template based on the semi-structured interview template.  
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4 Grounded theory (Lansisalmi et al., 2004) was not used because the '*a priori*'  
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6 template implies preconceived expectations regarding responses .The creation of an '*a*  
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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, 2013).

### 2.3 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

1 active substance had to be used extensively in the Anglian region and to be subject to  
2 one or more of the following criteria that could plausibly restrict future availability:  
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- 4 • The pesticide is a potential challenge for water company compliance with the  
5 DWD without the adoption of enhanced treatment technologies  
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- 7 • The pesticide will potentially not be reapproved under EU pesticide approval  
8 Regulation 1107/2009 (EC, 2009) and there is reason to suspect that replacements  
9 might cause water quality problems.  
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- 11 • The efficacy of the pesticide is threatened by the emergence of resistance which  
12 means that alternatives might be needed in the future.  
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24 A standard set of questions to identify the current reasons for use, potential pesticide  
25 and non pesticide alternatives, respondent confidence in the alternatives identified and  
26 the broader impacts on crop yield and quality, if the pesticide in question were not  
27 available, was used for each active substance (Online Resource 1). The questions  
28 required respondents to consider plausible future changes to pesticide availability and  
29 to give personal judgement rather than a definitive answer. To encourage respondents  
30 to evaluate the level of confidence they placed on each answer, a confidence scale was  
31 designed into the question structure. A four-point scale (not at all, low, medium, high)  
32 using internally consistent, non-overlapping categories that covered the full range of  
33 certainties was selected (Cassell and Symon, 2004; Strauss and Corbin, 1990).  
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51 Eleven interviews were conducted using the protocol defined at Stage 1. Template  
52 analysis was used to analyse all interview transcripts (King, 2004). Because the  
53 question set was more tightly defined than at Stage 1, the '*a posteriori*' template did  
54 not differ greatly from the initial '*a priori*' template. Analysis led to the identification  
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1 of a number of key findings for further validation in the Stage 3 survey. Additionally,  
2 Stage 2 analysis led to the proposal of an ‘adaptation options preference framework’  
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4 to predict the options which agriculture would explore when faced with pressure on,  
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6 restriction or loss of an active substance. This framework was originally proposed in  
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8 (Dolan et al., 2013a) and has subsequently been refined and tested during Stage 3 of  
9  
10 this study (see Section 4.2).  
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## 14 **2.4 Stage 3**

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16 Stage 3 used an online survey to validate findings from Stages 1 and 2 using a larger  
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18 sample of agronomy experts. The Stage 3 survey included 43 Likert items, each  
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20 comprising a ‘stem’ (the question), and a 5 point Likert response scale - strongly  
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22 disagree, disagree, neither agree nor disagree, agree, strongly agree (Online Resource  
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24 2). Likert items can be evaluated as standalone statements (Dunlap et al., 2000;  
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26 Hovardas and Poirazidis, 2007) and response patterns across a number of Likert items  
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28 can be used to test pre-defined Likert scale hypotheses. Six pre-defined Likert  
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30 hypotheses were included in the Stage 3 design. The purpose of Stage 3 was to  
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32 identify areas of consensus where there is widespread agreement between agronomy  
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34 experts, areas where there is sufficient uncertainty that no consensus can be reached  
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36 and the presence of and possible reasons for ‘outliers’ (respondents answering against  
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38 consensus).  
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50 In order to avoid ambiguous or unclear Likert items, the ‘stem’ of each item contained  
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52 only one attitudinal object, and no quantitative statements (John, 2012). A five point  
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54 Likert response scale allowed respondents to express agreement or disagreement,  
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56 without introducing ambiguity through too many response categories. Acquiescence  
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58 bias, ‘the tendency to agree with statements to some extent irrespective of their  
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1 content' (John, 2012) has been identified as a potential problem in the design of  
2 surveys based upon Likert items. To avoid a unidirectional survey and reduce the risk  
3 of acquiescence bias, at least one negatively worded Likert item was included in each  
4 section. Furthermore, three pairs of similar but opposite Likert items to test for  
5 acquiescence bias and two Likert item pairs to test for internal consistency were  
6 included in the survey. Spearman's rank correlation test for ordinal data was used  
7 (Field, 2009).

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

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

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

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

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

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(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.

### **3. Results**

#### **3.1 Stage 1 and 2 findings**

1 Analysis of Stage 1 and 2 interviews identified the following agronomy basics,  
2 features of the combinable crop rotation (i.e. crops harvested using a combine  
3 harvester) and impacts of pesticide and water regulation as knowledge all water  
4 companies and regulators should possess.  
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### 10 **3.1.1 Basic agronomic features**

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12 Soil type, the availability of break crops, and the comparative economics of cropping  
13 options drive the structure of any agricultural enterprise. Different farm types  
14 (combinable, horticultural, grassland, potatoes, sugarbeet) each have associated  
15 pesticide use profiles. To understand the agronomic drivers of pesticide use, one must,  
16 therefore, understand the structure of the rotation deployed by the farm enterprise, and  
17 the nature of weed, pest and disease problems within that rotation.  
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29 Pesticides are costly inputs, so pesticide use will usually be recommended only where  
30 the cost of action is anticipated to be less than the cost of inaction. Many control  
31 strategies involve more than one active substance applied at one or more stages  
32 throughout the growing season or across the entire rotation in which the crop is  
33 grown. Some strategies may provide incidental management of other less troublesome  
34 problems. For example, a strategy to control blackgrass (*Alopecurus agrestis* L.)  
35 (Table 1) may control other grass weed species. Additionally, the management of  
36 resistance to pesticide active substances is an important consideration when designing  
37 a control strategy.  
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54 Restricting or banning an active substance does not address the root cause of the water  
55 quality problem - the need to combat a particular, and probably widespread, weed,  
56 disease or pest issue - and is likely to trigger an increased use of one or more other  
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1 active substances throughout the rotation to manage that issue (i.e. “pollution  
2 swapping” may occur (Stevens and Quinton, 2009a; Stevens and Quinton, 2009b)).  
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### 8 **3.1.2 The combinable crop rotation** 9

10 Heavy clay soils occur widely across the case study region. On these soils the  
11 dominant cropping pattern is currently an autumn sown combinable crop rotation  
12 based on two years of winter wheat (*Triticum aestivum*) followed by one year of  
13 oilseed rape (OSR: *Brassica napus* L.), or a similar variation.  
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23 Blackgrass and the risk of herbicide-resistant blackgrass need to be managed by a  
24 programme of herbicide applications every year of the rotation (Table 1). In order to  
25 maximize the level of control achieved and reduce the risk of resistance, it is often  
26 important to use several active substances with different modes of action in a control  
27 programme. Different active substances are used in the wheat and OSR phases of the  
28 rotation; the herbicide active substances used in OSR (i.e. propyzamide and  
29 carbetamide) are particularly important because, at present, there is no known  
30 resistance to these compounds. Many of the herbicides used for blackgrass control  
31 (Table 1) are residual (designed to persist in the soil) and applied to bare soil. The  
32 risk of water quality issues is often higher with these herbicides than with many others  
33 because they do not typically degrade sufficiently before the arrival of rainfall capable  
34 of mobilising them and transporting them to surface waters (Tediosi et al., 2012)  
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48 Slugs are a major pest problem every year in the combinable crop rotation. Slug  
49 pellets containing metaldehyde are considered to be the most cost-effective method of  
50 control.  
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1 Table 1 gives an example of a rotation-wide programme of control for herbicide-  
2 resistant blackgrass. The programme is based primarily on the use of pesticides, but  
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4 is increasingly receiving support from complementary non-pesticide actions such as  
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7 “stale seedbeds” and delayed drilling.  
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### 10 11 12 **3.1.3 The impact of regulation on pesticide use patterns** 13

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15 Current patterns of pesticide active substance use, and any associated water quality  
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17 problems, are shaped by a context of decreasing active substance availability since the  
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19 introduction of EU pesticide approval Directive 91/414/EEC (EC, 1991). The new  
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21 approval legislation, EU Regulation 1107/2009 (EC, 2009), will further reduce the  
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23 number of active substances available (PSD, 2009), and is a significant source of  
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25 uncertainty because future adaptations cannot be planned without clarity regarding  
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27 which active substances will be lost and which will remain available.  
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34 Additionally, agronomists perceive the WFD to be a further source of uncertainty and  
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36 potentially, a driver of decreased active substance availability. Therefore, agronomists  
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38 expressed the view that any regulator or water company action for WFD Article 7  
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40 compliance must understand the causes (the reasons for use, constraints on alternative  
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42 options, and impacts of losses) and not just focus on the symptoms.  
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## 47 **3.2 Stage 3 Results** 48

### 49 50 51 **3.2.1 Introduction** 52

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54 94 agronomists completed the Stage 3 survey. Full details of the responses to all the  
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56 Likert items are provided online (Online Resource 3). The following are presented  
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58 here:  
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- 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 Sections 3.2.5.

### 3.2.2 Hypotheses (Likert scale) based upon multiple Likert items

The hypotheses presented in Table 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.

### 3.2.3 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,

1 availability, proven track record and environmental impact of these possible  
2 substitutes.  
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7 **Mesosulfuron-methyl ('Atlantis')**: Reduced efficacy of post-emergence blackgrass  
8 control in wheat will reduce wheat yields and increase the use of pre-emergence  
9 herbicides. Cultural control options are inadequate to cover for reduced efficacy; if  
10 control was too difficult, a change to the rotation might be considered.  
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19 **Clopyralid**: Clopyralid is the only herbicide available for the control of sow thistles.  
20 Cultural control is largely ineffective. If clopyralid were unavailable where sow  
21 thistles are a particular problem, OSR yields would decrease and reduced OSR  
22 planting might occur.  
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31 **Pendimethalin and chlortoluron**: Blackgrass control depends upon many active  
32 substances and different modes of action to increase total efficacy and reduce  
33 resistance risk. The loss of one active substance would have impacts on how others  
34 were used.  
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#### 42 **3.2.4 Likert items on general themes**

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45 Five conclusions based on a single Likert item can also be drawn from this study,  
46 these are:  
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- 48 • When one active substance is lost (for whatever reason) other active substance(s)  
49 will be used to manage the weed, pest or disease issue.  
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- 51 • In the absence of effective pesticide control, weed and pest pressures will increase  
52 over time.  
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- 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.

### **3.2.5 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).

## **4 Discussion**

### **4.1 Agronomic adaptation options and preferences**

On the basis of Likert scale Hypothesis E, Figure 1 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.

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

1 framework may be initiated on a voluntary basis. For example the Voluntary Initiative  
2 in England and Wales was initiated in 2001 as a partnership between industry and  
3 government with the aim of reducing diffuse pesticide pollution through voluntary  
4 good practice (Garrod et al., 2007; The Voluntary Initiative, 2013); the Metaldehyde  
5 Stewardship Group promotes a similar approach for metaldehyde (Metaldehyde  
6 Stewardship Group, 2013). However, the level of voluntary action available to  
7 agriculture is constrained by other practical factors (Section 4.3).

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19 **1<sup>st</sup> Preference: Use a direct substitute.** A direct substitute is a pesticide active  
20 substance with an equally established agronomic track record that can be applied at  
21 the same stage in the rotation with equally efficacy at an equivalent cost. Likert scale  
22 Hypothesis A indicates that direct substitutes are very rare. Metaldehyde for slug  
23 control illustrates the rarity of direct substitutes: methiocarb and ferric phosphate were  
24 identified as possible alternatives and at least one was rated as similarly efficacious.  
25 However, neither substance can be considered as a direct substitute because  
26 agronomists identify strong reservations regarding the relative cost, relative efficacy,  
27 environmental impact (methiocarb), availability of supply and lack of proven track  
28 record (ferric phosphate).

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45 **2<sup>nd</sup> Preference: Use a close substitute.** A close substitute is an active substance that  
46 could potentially replace a currently used active substance at similar timing but differs  
47 to some degree in terms of one or more factors from efficacy, cost, proven track  
48 record and environmental impact.

1 Likert scale Hypothesis D establishes the need for multiple modes of action to manage  
2 resistance, and Table 1 illustrates the need for a range of active substances, to be used  
3  
4 in some circumstances, to maximise the level of control achieved. Therefore, a  
5  
6 distinction is needed between close substitutes and those active substances already  
7  
8 used as part of a programme of control alongside the active substance in question. For  
9  
10 example, flufenacet and diflufenican (Table 1) are complements rather than  
11  
12 substitutes, because blackgrass control is most effective when these residual  
13  
14 herbicides are used in combination (Shah et al., 2012; Hull and Moss, 2012). Thus, in  
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16 reality, close substitutes are also rare.  
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24 **3<sup>rd</sup> Preference: A substitute at a different timing in the rotation.** Similar to a close  
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26 substitute but applied at a different timing. A prominent example of this is given by  
27  
28 Likert scale Hypothesis C, where in the absence of direct or close substitutes,  
29  
30 agronomists have begun to adapt to the decreased efficacy of the post-emergence  
31  
32 herbicide mesosulfuron-methyl ('Atlantis') by combining more pre-emergence  
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34 herbicides.  
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41 The 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> adaptation options all relate to replacing one active substance with  
42  
43 another. However, the feasibility of these options is constrained by the availability of  
44  
45 active substance chemistry. Likert scale Hypothesis F, agronomist comments and  
46  
47 information from the literature (Shah et al., 2012) identify a shortage of new active  
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49 substances coming to market, decreased availability of active substances as a result of  
50  
51 European pesticide legislation and the perception that WFD Article 7 may potentially  
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53 further-restrict active substance availability. Therefore, before restricting any active  
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55 substance a regulator must consider whether sufficient (and appropriate) alternatives  
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1 are available to provide equivalent control, at an equivalent cost with lower  
2 environmental and DWD compliance risks. Similar considerations must be made by  
3  
4 any water company implementing a catchment management strategy based upon  
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6 promotion of active substance substitution.  
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12 Several agronomists in the survey expected the loss of active substances to be  
13  
14 particularly acute for horticulture, because it is dependent on specific off-label  
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16 approvals (SOLAs) of active substances originally developed for other crop types, and  
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18 it is costly (relative to the returns achievable), to register an active substance for minor  
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20 use.  
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26 **4<sup>th</sup> Preference: Use cultural control.** Cultural control is the use of cultivation  
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28 practices without a fundamental change to the rotation, to improve control and  
29  
30 preventatively manage disease, weed or pest problems. Cultural control options are  
31  
32 increasingly becoming part of an integrated control strategy (Hull and Moss, 2012;  
33  
34 Neale, 2012). Examples include compaction of seed beds to reduce slug risk, the use  
35  
36 of rotational ploughing to bury weed seeds and stale seed beds with glyphosate to  
37  
38 reduce weed levels prior to crop drilling (Table 1). However, Likert Hypothesis B  
39  
40 concludes that these actions should be a complement to, and not a substitute for  
41  
42 pesticide use. This may be explained by poor efficacy and reliability in comparison to  
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44 pesticides, as (Moss, 2010) observes ‘Nonchemical control methods have mean  
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46 efficacy levels equivalent to a very poor [pesticide] product, but often at a premium  
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48 price’.  
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**5<sup>th</sup> 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.

**6<sup>th</sup> 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.

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2 The adaptation options framework assumes all factors other than active substance  
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4 availability will remain constant. However, exogenous factors have the potential to  
5  
6 disrupt relative preferences for the adaptation options. Examples of such factors  
7  
8 include global commodity prices, changes to elements of European policy (e.g. CAP  
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10 reform, GMO policy, drinking water standards for pesticide active substances and  
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12 incentive payments for energy crops) and technical developments making certain  
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14 crops easier to produce.  
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## 20 **4.2 Using the current strategy to anticipate adaptation**

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25 From responses to the Likert items it can be concluded that agronomists believe that  
26  
27 alternative active substances will be used in increased quantities if others are lost or  
28  
29 restricted, that few new active substances are coming to market (Likert scale  
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31 Hypothesis F) and that cultural control cannot completely replace a lost active  
32  
33 substance (Likert scale Hypotheses B). It follows that the loss of any active substance  
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35 will increase pressure on other active substances in a control strategy. Consequently,  
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37 pollution swapping may be an outcome of a poorly designed mitigation strategy.  
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45 Knowledge of the strategies used to control the main problems in all the major  
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47 rotations (similar to Table 1 for blackgrass) and the adaptation options framework  
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49 (Figure 1) provide a foundation from which regulators and water companies can  
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51 anticipate the possible impacts of action to address any water quality issue for  
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53 pesticides. It is, therefore, in the shared interest of water companies, regulators and  
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55 agronomists to compile this information for all rotations before discussing how to  
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57 alleviate any water quality issues arising from active substance use in those rotations.  
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### 4.3 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.

### 4.4 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:

- 1 • Restrictions on active substances will have knock-on effects for the use of other  
2 active substances and in many cases on agricultural productivity. How adaptation  
3 occurs and the scale of the impact will depend on the context of active substance  
4 availability at the time of any restriction and whether adaptation preferences 1, 2  
5 and 3 (Figure 1) are available.  
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- 11 • In the majority of cases, the active substances being used are those which are most  
12 effective and the agricultural benefits of application outweigh purchase and  
13 application costs.  
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- 19 • Catchment management based upon product substitution is unlikely to engage  
20 pesticide users if it is voluntary, and it would impose costs on agriculture, if it  
21 were statutory.  
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- 27 • Cultural control options are an increasingly important element of a control  
28 programme, but are unlikely to replace active substance use (Likert scale  
29 Hypothesis B)  
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- 33 • The use of the adaptation option preference framework (Figure 1) coupled with a  
34 knowledge of the agricultural drivers for pesticide use to tackle a particular  
35 problem in a particular rotation (e.g. Table 1), can provide a foundation for  
36 regulators and water companies to anticipate the possible impacts of action to  
37 address any water quality issue for pesticides.  
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- 46 • Both farmers and water companies need to take a long term, whole rotation  
47 perspective on the cost of inaction, compared to the cost of action (Moss and Hull,  
48 2012). Where costs must be incurred, evidence of a long term benefit must be  
49 available.  
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## 5. Conclusions

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3 Agronomists cannot predict with confidence how agriculture would respond to active  
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5 substance losses or restrictions. However, in general, the loss of one active substance  
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7 will lead to the increased use of others creating a risk of pollution swapping.  
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10 Therefore, water companies face considerable uncertainty when planning for pesticide  
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12 management in the potable water supply. To support the prevention-led approach to  
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14 DWD compliance required by WFD Article 7, water suppliers and regulators need to  
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16 work closely with agronomists to chart control strategies for the major weed, disease  
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18 and pest problems in their catchments (similar to Table 1). Application of the  
19  
20 adaptation options preference framework (Figure 1) to these strategies can strengthen  
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22 water company and regulator knowledge of reasons for pesticide use and provide a  
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24 useful basis for catchment management dialogue between key catchment stakeholders  
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26 to identify appropriate management actions.  
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34 This study highlights the challenges of embedding expertise from one industry into  
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36 the decision making processes of another. This challenge is relevant to both  
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38 agriculture and water companies, because water company decision making on  
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40 catchment management will potentially have an impact on both industries (Dolan et  
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42 al., 2013a). Policy makers and regulators face a similar challenge when devising  
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44 policy options to address the water quality impacts of diffuse pesticide pollution  
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46 (Defra, 2012).  
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## Tables

**Table 1. An example of a rotation-wide control strategy for herbicide-resistant blackgrass**

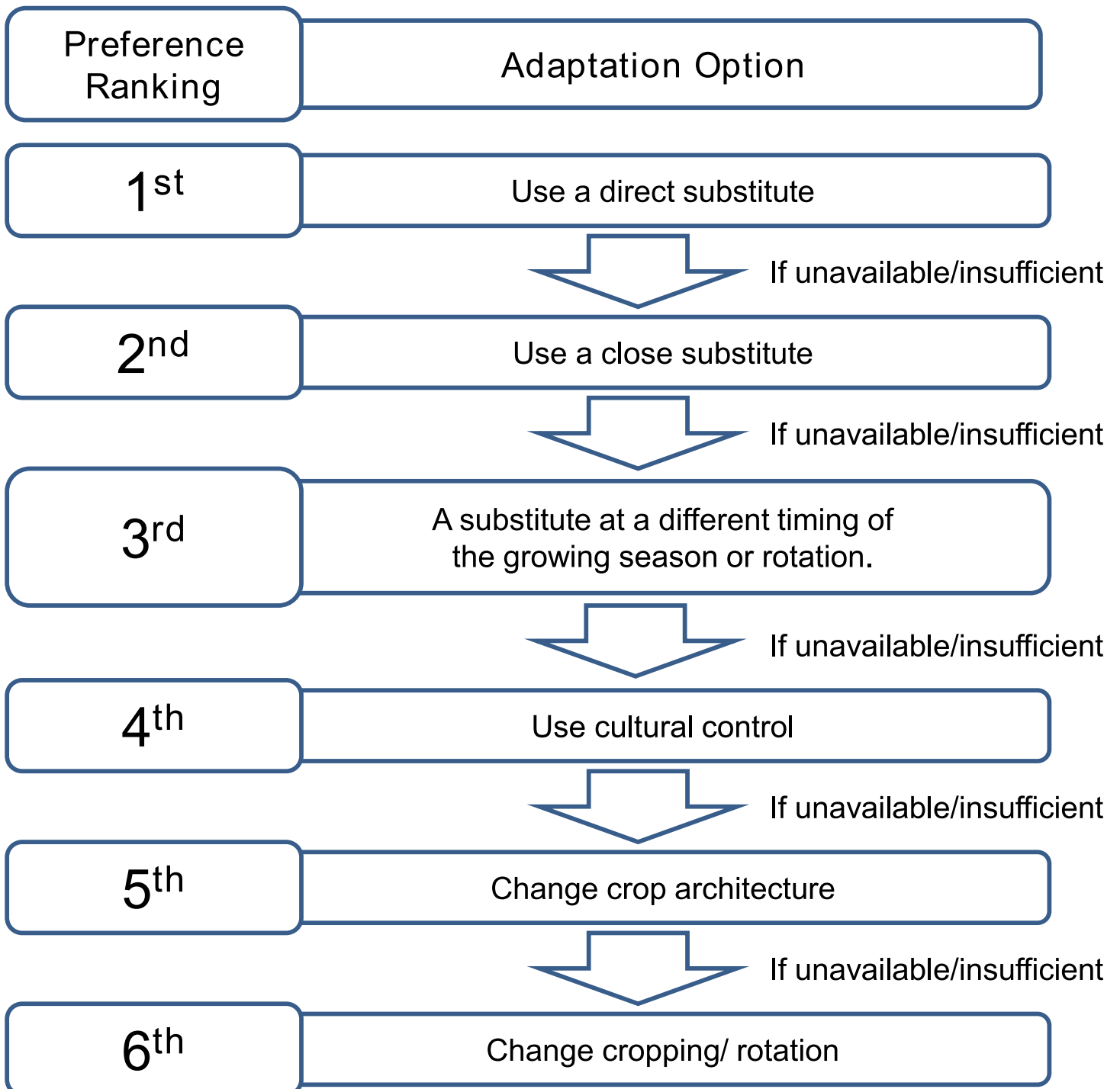
| <b>Winter wheat</b>   | <b>Winter OSR</b>   |
|---|---|
| <p><b>Stale seedbed</b></p> <p>Delay drilling to allow a stale seedbed followed by application of a non-selective herbicide, typically glyphosate, to kill any weeds which have germinated before drilling.</p>   | <p><b>Stale seedbed</b></p> <p>NB: This is not widely used because OSR is drilled earlier than wheat.</p>   |
| <p><b>Pre-emergence treatment</b></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"> <li>• Diflufenican (10/10)</li> <li>• Pendimethalin (10/10)</li> <li>• Triallate (5/10)</li> <li>• Prosulfocarb (6/10)</li> <li>• CTU (2/10)</li> <li>• Flurtamone (1/10)</li> </ul> | <p><b>Pre-emergence treatment</b></p> <ul style="list-style-type: none"> <li>• Metazachlor (7/10)</li> <li>• Metazachlor + quinmerac (3/10)</li> <li>• Metazachlor + quinmerac + dimethanimid – p (2/10)</li> </ul> |
| <p><b>Post-emergence treatment</b></p> <p>Atlantis (mesosulfuron-methyl + iodosulfuron-methyl) is the dominant product (10/10).</p>   | <p><b>Post-emergence treatment</b></p> <p>Propyzamide AND/OR Carbetamide (10/10)</p> <p>Tepraloxymid and cycloxydim can be used as support (1/10)</p>   |

**Table 2. Hypotheses based on multiple Likert Items (three or more)**

|   | <b>Hypothesis</b>   | <b>Number of Likert items to test hypothesis</b> | <b>Likert items supporting hypotheses</b> |
|---|---|--|---|
| 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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3 **Figure captions**  
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5 Fig. 1 Adaptation Option Preference Framework  
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# **Identifying Adaptation Options and Constraints: The role of agronomist knowledge in catchment management strategy**

Water Resources Management

Tom Dolan<sup>a</sup>, Peter Howsam<sup>a</sup>, David J. Parsons<sup>a,\*</sup>, Mick J. Whelan<sup>b</sup>, Liz Varga<sup>c</sup>

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## **Captions for Online Resources**

Online Resource 1. Interview templates from Stages 1 and 2 of the study

Online Resource 2. Hard copy of Stage 3 online survey

Online Resource 3. Results and analysis from Stage 3 of the study

Online Resource 4. Results from acquiescence and internal consistency tests (Stage 3 validation)



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Caption: Interview templates from Stages 1 and 2 of the study

## **Online Resource 1 – Stage 1 and 2 Survey Templates**

This document presents the survey templates used to conduct semi-structured interviews during Stages 1 and 2 of the study

|  |   |
|--|---|
| <b>Stage I – Semi-structured interview template</b> .....                            | 2 |
| Part 1 - General Questions: .....  | 2 |
| Part 2 - Regulatory Questions: .....   | 3 |
| Part 3 - Follow Up Questions: .....  | 3 |
| <b>Stage 2 – Semi-structured interview template and supporting information</b> ..... | 4 |
| Introduction.....  | 4 |
| Confidence Scale.....  | 5 |
| Semi-structured Interview Template.....  | 6 |

## **Stage I – Semi-structured interview template**

### **Part 1 - General Questions:**

1. In what region do you operate, and what is the total land area you cover?
2. What are the most significant crops, in terms of land area, in the region that you cover?
3. What are the most significant crops, in terms of revenue generation, in the region that you cover?
4. What crops do you provide advice for the management of, and for these what are the most widespread and/or economically significant
  - Pest problems
  - Diseases
  - Weeds
5. What recommendations do you make for the management of the above problems, in terms of?
  - Chemicals
  - Cultural management (field selection, drilling date, cultivation, variety, nitrogen, biological control)
  - Integrated crop management (ICM)
6. Do you make the same recommendation for all crops affected by the problem?

**Part 2 - Regulatory Questions:**

7. From what source(s) do you hear about developments in EU Directives and Regulation?
8. Have you thought about what impact the new EC approval mechanism for plant protection products (Regulation 1107/2009) is likely to have on:
  - a. The availability of pesticide active substances?
  - b. The recommendations that you make?
  - c. What do you consider will be the impact of endocrine disruptor criteria under Reg. 1107/2009?
  - d. What do you consider will be the impact of Candidates for Substitution (CfS) under Reg. 1107/2009?
9. Does anybody in your organisation specialise in considering the long term impacts of changes to pesticide and water legislation, such as the introduction of Reg. 1107/2009, on your business?
10. To what extent do you consider schemes like the Voluntary Initiative (VI)/ Catchment sensitive farming (ECSFDI)/ Environmental stewardship (ELS) when making recommendations for pesticide use?
11. To what extent do you consider the Water Framework Directive (WFD) and water quality when making recommendations for pesticide use?
12. To what extent do you consider the Sustainable Use of Pesticides Directive (SUPD) and water quality when making recommendations for pesticide use?

**Part 3 - Follow Up Questions:**

13. Can you recommend additional agronomy or chemical company experts that would be interested in participating in this study?
14. Can I contact you in the future for a follow up interview?

## **Stage 2 – Semi-structured interview template and supporting information**

### **Introduction**

This questionnaire will focus upon 7 pesticide active substances identified as of agronomic significance to the Anglian region during the first round of expert interviews. The pesticides included in this round have been selected for one of three reasons, all reasons relate to the possibility of reduced future availability of the pesticide. These reasons are:

- The pesticide is a potential problem for WFD Article 7, and so may be targeted for enhanced voluntary action in a safeguard zone.
- The pesticide will potentially not be reapproved under Regulation 1107/2009, 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, and alternatives might be needed in the future.

The focus of these questions is on the impact that reduced availability could have on the use of other pesticides, agriculture and the water environment. The pesticides selected for inclusion are:

- Metaldehyde
- Clopyralid
- Propyzamide
- Carbetamide
- Pendimethalin
- Chlorotoluron
- Mesosulfuron-methyl

In the interview you will be asked about the above, using a standard question set for each pesticide to identify:

- current reasons for use
- potential pesticide and non pesticide alternatives
- your confidence in the alternatives you identify
- the broader impacts on crop yield and quality if the pesticides in question were not availability

Before each question set, a brief justification will be given for the inclusion of the pesticide in these questions. It is anticipated that the question set for a pesticide will take 10 minutes.

The confidence scale to answer questions 2b, 2c, 3b and 3c is provided below.

## Confidence Scale

In questions 2b, 2c, 3b and 3c of the question set, a four point confidence scale will be used to evaluate confidence in the pesticide and non pesticide alternatives identified. This scale is defined in the text box below:

| <b>Confidence Scale</b><br>(for use with questions 2b, 2c, 3b and 3c) |  |
|---|--|
| <b>Not at all</b>   | It isn't clear what will happen                  |
| <b>Low</b>  | This option might happen but others are possible |
| <b>Medium</b>   | This option is the most likely                   |
| <b>High</b>   | This option is certain to happen                 |

## Semi-structured Interview Template

This question set will be repeated for each of the pesticides listed in the introduction. It is anticipated that the question set will take 10 minutes for each pesticide.

The name of the pesticide active substance being asked about will be included in place of pesticide X in each question.

### Q1 – Current use of pesticide X

- a) On which crops is pesticide X used?
- b) Why do you recommend the use of pesticide X?
  - i. It is the only product available
  - ii. It is the most cost effective option
  - iii. It is the main product in a resistance management strategy
  - iv. It is one of many products used in a management strategy
  - v. It is an optional extra in a management strategy
  - vi. Other reason (please specify)

### Q2 - Identifying alternative pesticide options

- a) What alternative pesticide(s) would be available if pesticide X were not available?

Please name specific active ingredients that would be used in its place.
- b) How confident are you (**not at all, low, medium, high**) that the pesticide alternatives(s) you identify would be used if pesticide X were not available?

Please give a brief explanation of your answer
- c) How confident are you (**not at all, low, medium, high**) that the pesticide alternatives(s) you identify would be used if pesticide X were not available 5 years from now?

Please give a brief explanation of your answer

### Q3 - Identifying non pesticide alternatives

## Online Resource 1\_Stage 1 and 2 Survey Templates

- a) What non pesticide alternatives would be available if pesticide X were not available?
- b) How confident are you (**not at all, low, medium, high**) that the non pesticide alternative(s) you identify would be used if pesticide X were not available?  
Please give a brief explanation of your answer
- c) How confident are you (**not at all, low, medium, high**) that the non pesticide alternative(s) you identify would be used if pesticide X were not available 5 years from now?  
Please give a brief explanation of your answer

### **Q4 – Pesticide or non pesticide**

If pesticide X were not available, do you believe that the use of pesticide alternatives or non pesticide alternatives is more likely?

Please answer Y or N and give reasons

### **Q5 – Impacts of non availability on Yields, Quality and Gross Margins**

- a) Would the non availability of pesticide X reduce crop yields?  
Please answer Y or N and give reasons
- b) Would the non availability of pesticide X reduce crop quality?  
Please answer Y or N and give reasons
- c) Would the non availability of pesticide X reduce crop gross margins?  
Please answer Y or N and give reasons

### **Q6 - General Comments**

Do you have any general comments on pesticide X?

| General Statements (continued)  | Please Select One |       |         |          |                   |
|---|-------------------|-------|---------|----------|-------------------|
|   | Strongly Agree    | Agree | Neither | Disagree | Strongly Disagree |
| a. Where alternative pesticides cannot prevent severe gross margin losses, spring cropping will increase  |                   |       |         |          |                   |
| b. A change to the rotation is the intervention of last resort  |                   |       |         |          |                   |
| c. In general, direct substitutes do not exist for any active substance   |                   |       |         |          |                   |
| d. If the withdrawal of an active substance is announced 5 years in advance, alternative active substances will be available by the time of withdrawal    |                   |       |         |          |                   |
| e. The adoption of wide OSR rows and inter row spraying will reduce current dependency on propryamide and carbetamide                                     |                   |       |         |          |                   |
| f. If approved for use, RoundUp Ready OSR would reduce current dependency on propryamide and carbetamide  |                   |       |         |          |                   |
| g. If the future of one active substance is uncertain, alternative active substances will come to the market  |                   |       |         |          |                   |
| Please comment on any of the above statements (a-g). Comments on any statements that evoked a strong opinion from you are particularly valued. (Optional) |                   |       |         |          |                   |

## Identifying Adaptation Options and Constraints: The role of agronomist knowledge in catchment management strategy

Water Resources Management

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### Request for Support with Online Survey

**Research Aim:** to help the water sector better understand pesticide use patterns in water supply catchments, the agronomic reasons for pesticide use and limitations to the range of active substances available for key weed, pest and disease problems.

**Request for Support:** In light of your expert knowledge in this area, I would be very grateful if you could take 15 minutes of your time to support this research by completing the survey included in this booklet.

The survey is also available at:

<https://www.survey.cranfield.ac.uk/pesticideconsultation>

**Research Outputs:** Findings generated through this research will be used to help water company planning processes for potable water supply. Additionally, research findings will be shared with all respondents and the broader community of pesticide users.

All data will be treated in strict confidence and you may respond anonymously if you prefer. Further details are given on the web site.

**Further Information:** The research is part of an EngD student research project at Cranfield University. Please contact Tom Dolan [t.e.dolan@cranfield.ac.uk](mailto:t.e.dolan@cranfield.ac.uk) for further information.

Many thanks for your support



This survey is the third stage of an expert consultation process designed to help Anglian Water gain a greater understanding of the agronomic and the legislative drivers that influence pesticide use in the Anglian region. The statements included in this survey are based upon two rounds of in depth interviews performed with expert agronomists from a range of agronomy organisations.

The survey is divided into seven sections:

- Propyzamide + Carbetamide
- Metaldehyde
- Clopyralid
- Pendimethalin
- Chlortoluron
- Mesosulfuron-methyl
- General pesticide trends

Each section presents a series of statements, for each statement please select one answer from the five point scale 'Strongly Agree' to 'Strongly Disagree'. An optional comments box is included at the end of each section.

| <b>Introductory Questions</b>  |   |   |  |
|--|---|---|--|
| 1. Name <i>(optional)</i>  |   |   |  |
| 2. Organisation <i>(optional)</i>  |   |   |  |
| 3. Email address <i>(optional)</i>   |   |   |  |
| 4. Do you hold a Basis Certificate in Crop Protection?   | Y | N |  |
| 5. Which of the following would you use to describe your profession? <i>(please select all that apply)</i> |   |   |  |
| Agronomist (self employed)   |   |   |  |
| Agronomist (employed by pesticide distributor)   |   |   |  |
| Agronomist (employed by pesticide manufacturer)  |   |   |  |
| Agronomist (employed by research organisation)   |   |   |  |
| Agronomist (employed by agricultural consultant)   |   |   |  |
| Agronomist (employed by farming group)   |   |   |  |
| Other (please specify)   |   |   |  |

| <b>General Statements</b>  | <b>Please Select One</b> |       |         |          |                   |
|--|--------------------------|-------|---------|----------|-------------------|
|  | Strongly Agree           | Agree | Neither | Disagree | Strongly Disagree |
| a. No new herbicides for blackgrass will be available in the next 5 years  |                          |       |         |          |                   |
| b. When one active substance is lost (for whatever reason) other active substance(s) will be used to manage the weed, pest or disease issue                      |                          |       |         |          |                   |
| c. In the absence of effective pesticide control, weed and pest pressures will increase over time  |                          |       |         |          |                   |
| d. The agronomic impact of losing an active substance depends upon what active substances remain available   |                          |       |         |          |                   |
| e. Cultural control is a complement to, not a direct substitute for pesticides   |                          |       |         |          |                   |
| f. Effective resistance management requires as many different modes of action as possible  |                          |       |         |          |                   |
| g. When an active substance is lost, alternative active substances will be tried in preference to non pesticide interventions                                    |                          |       |         |          |                   |
| Please comment on any of the above statements (a-g). Comments on any statements that evoked a strong opinion from you are particularly valued. <i>(Optional)</i> |                          |       |         |          |                   |

|  | Please Select One |       |         |          |                   |
|--|-------------------|-------|---------|----------|-------------------|
|  | Strongly Agree    | Agree | Neither | Disagree | Strongly Disagree |
| <b>Pendimethalin and Chlortoluron</b>  |                   |       |         |          |                   |
| <b>Pendimethalin</b>   |                   |       |         |          |                   |
| a. The loss of pendimethalin will lead to increased stacking of other pre-emergence residual herbicides to manage grassweeds in cereal crops                     |                   |       |         |          |                   |
| b. If pendimethalin were the only active substance lost, it would be possible to maintain cereal yields using alternative herbicides                             |                   |       |         |          |                   |
| c. Pendimethalin is one of many modes of action used as part of a resistance management strategy for Blackgrass  |                   |       |         |          |                   |
| d. The loss of pendimethalin would trigger a change to the combinable rotation   |                   |       |         |          |                   |
| Please comment on any of the above statements (a-d). Comments on any statements that evoked a strong opinion from you are particularly valued. <i>(Optional)</i> |                   |       |         |          |                   |
| <b>Chlortoluron</b>  |                   |       |         |          |                   |
| a. The loss of chlortoluron will lead to increased use of other herbicides at the pre-emergence stage for blackgrass control in the combinable rotation          |                   |       |         |          |                   |
| b. If chlortoluron were the only active substance lost, it would be possible to maintain cereal yields using alternative herbicides                              |                   |       |         |          |                   |
| c. Chlortoluron is one of many modes of action used as part of a resistance management strategy for Blackgrass   |                   |       |         |          |                   |
| Please comment on any of the above statements (a-c). Comments on any statements that evoked a strong opinion from you are particularly valued. <i>(Optional)</i> |                   |       |         |          |                   |

|  | Please Select One |       |         |          |                   |
|--|-------------------|-------|---------|----------|-------------------|
|  | Strongly Agree    | Agree | Neither | Disagree | Strongly Disagree |
| <b>Propyzamide and Carbetamide</b>   |                   |       |         |          |                   |
| a. If propyzamide is not available, carbetamide can be used to manage resistant blackgrass in the OSR stage of a combinable rotation                             |                   |       |         |          |                   |
| b. There are no pesticide alternatives to propyzamide and carbetamide for resistant blackgrass management in the OSR stage of a combinable rotation              |                   |       |         |          |                   |
| c. If propyzamide and carbetamide were banned OSR would continue to be grown in areas where resistant blackgrass is a problem                                    |                   |       |         |          |                   |
| d. Without propyzamide and carbetamide, no autumn break crops can be grown where resistant blackgrass is a problem   |                   |       |         |          |                   |
| e. Without propyzamide and carbetamide, a change to the rotation would be needed where resistant blackgrass is a problem   |                   |       |         |          |                   |
| f. The loss of propyzamide and carbetamide will lead to increased use of spring crops to manage resistant blackgrass in the rotation                             |                   |       |         |          |                   |
| Please comment on any of the above statements (a-f). Comments on any statements that evoked a strong opinion from you are particularly valued. <i>(Optional)</i> |                   |       |         |          |                   |

|  | Please Select One |       |         |          |                   |
|--|-------------------|-------|---------|----------|-------------------|
|  | Strongly Agree    | Agree | Neither | Disagree | Strongly Disagree |
| <b>Metaldehyde</b>   |                   |       |         |          |                   |
| a. If you couldn't use metaldehyde, methiocarb could be used for slug management   |                   |       |         |          |                   |
| b. If you couldn't use metaldehyde, ferric phosphate could be used for slug management   |                   |       |         |          |                   |
| c. There are no pesticide alternatives to metaldehyde  |                   |       |         |          |                   |
| d. Cultural control is not a substitute for metaldehyde slug control   |                   |       |         |          |                   |
| e. In the absence of metaldehyde, pesticide substitutes of equal efficacy are available  |                   |       |         |          |                   |
| f. The loss of metaldehyde would lead to a change to the rotation where OSR and Wheat are grown on heavy soils   |                   |       |         |          |                   |
| Please comment on any of the above statements (a-f). Comments on any statements that evoked a strong opinion from you are particularly valued. <i>(Optional)</i> |                   |       |         |          |                   |

|   | Please Select One |       |         |          |                   |
|---|-------------------|-------|---------|----------|-------------------|
|   | Strongly Agree    | Agree | Neither | Disagree | Strongly Disagree |
| <b>Mesosulfuron-methyl (Atlantis)</b>   |                   |       |         |          |                   |
| a. There are no pesticide alternatives to Atlantis for blackgrass management at the post-emergence stage in wheat                         |                   |       |         |          |                   |
| b. Where the efficacy of Atlantis is reduced, there will be an increase in the use of residual chemistry at pre-emergence timing in wheat |                   |       |         |          |                   |

|  |  |  |  |  |  |
|--|--|--|--|--|--|
| c. Cultural control can replace the loss of Atlantis   |  |  |  |  |  |
| d. In high pressure resistant blackgrass areas, a reduction in the efficacy of Atlantis will reduce wheat yields   |  |  |  |  |  |
| e. In high pressure resistant blackgrass areas, a reduction in the efficacy of Atlantis will prompt a change to the rotation                                     |  |  |  |  |  |
| Please comment on any of the above statements (a-e). Comments on any statements that evoked a strong opinion from you are particularly valued. <i>(Optional)</i> |  |  |  |  |  |

|  | Please Select One |       |         |          |                   |
|--|-------------------|-------|---------|----------|-------------------|
|  | Strongly Agree    | Agree | Neither | Disagree | Strongly Disagree |
| <b>Clopyralid</b>  |                   |       |         |          |                   |
| a. Clopyralid is the only available pesticide for thistle management in OSR  |                   |       |         |          |                   |
| b. There are available pesticide alternatives to replace clopyralid for thistle management   |                   |       |         |          |                   |
| c. Cultural control interventions can substitute for clopyralid control of thistles in OSR   |                   |       |         |          |                   |
| d. In the absence of clopyralid, thistles will reduce OSR yields   |                   |       |         |          |                   |
| e. In the absence of clopyralid, thistles can be managed without a change to the rotation  |                   |       |         |          |                   |
| Please comment on any of the above statements (a-e). Comments on any statements that evoked a strong opinion from you are particularly valued. <i>(Optional)</i> |                   |       |         |          |                   |

# **Identifying Adaptation Options and Constraints: The role of agronomist knowledge in catchment management strategy**

Water Resources Management

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Caption: Results and analysis from Stage 3 of the study

## **Online Resource 3 – Results from Stage 3 Online Survey**

This document (Tables 1 - 7) presents 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 ( $\alpha$ ) = 0.05 regarding whether to accept or reject  $H_n$  (i.e. that there is no consensus in response to the Likert item).

|   |   |
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**Table 1. Likert items for propyzamide and carbetamide**

| Item #    | Likert Item  | Distribution (count) (n=94) |                   |         |       |                | p-value | Conclusion<br>(Accept Null Hypothesis H <sub>0</sub> or alternative hypothesis H <sub>a</sub> ) |
|-----------|--|-----------------------------|-------------------|---------|-------|----------------|---------|---|
|           |  | Disagree                    | Strongly Disagree | Neither | Agree | Strongly Agree |         |   |
| <b>1a</b> | 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 <sub>0</sub> :<br><u>No consensus</u>  |
| <b>1b</b> | 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 <sub>a</sub> :<br><u>Agree</u>   |
| <b>1c</b> | 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 <sub>a</sub> :<br><u>Disagree</u>  |
| <b>1d</b> | 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 <sub>a</sub> :<br><u>Agree</u>   |
| <b>1e</b> | Without propyzamide and carbetamide, a change to the rotation would be needed where resistant blackgrass is a problem                            | 0                           | 1                 | 4       | 42    | 43             | 0.000   | Accept H <sub>a</sub> :<br><u>Agree.</u>  |
| <b>1f</b> | 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 H <sub>a</sub> :<br><u>Agree</u>   |

**Table 2. Likert items for metaldehyde**

| Item # | Likert Item   | Distribution (count) (n=94) |                   |         |       |                | p-value | Conclusion<br>(Accept Null Hypothesis H <sub>0</sub> or alternative hypothesis H <sub>a</sub> ) |
|--------|---|-----------------------------|-------------------|---------|-------|----------------|---------|---|
|        |   | Disagree                    | Strongly 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 <sub>a</sub> :<br><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 <sub>a</sub> :<br><u>Agree.</u>  |
| 2c     | There are no pesticide alternatives to metaldehyde  | 23                          | 54                | 6       | 6     | 1              | 0.000   | Accept H <sub>a</sub> :<br><u>Disagree.</u>   |
| 2d     | Cultural control is not a substitute for metaldehyde slug control   | 0                           | 14                | 18      | 41    | 15             | 0.000   | Accept H <sub>a</sub> :<br><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 <sub>a</sub> :<br><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 <sub>a</sub> :<br><u>Disagree.</u>   |

**Table 3. Likert items for mesosulfuron-methyl (Atlantis)**

| Item # | Likert Item  | Distribution (count) (n=94) |                   |         |       |                | p-value | Conclusion<br>(Accept Null Hypothesis H <sub>0</sub> or alternative hypothesis H <sub>a</sub> ) |
|--------|--|-----------------------------|-------------------|---------|-------|----------------|---------|---|
|        |  | Disagree                    | Strongly 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 <sub>0</sub> :<br><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 <sub>a</sub> :<br><u>Agree.</u>  |
| 3c     | Cultural control can replace the loss of Atlantis  | 16                          | 49                | 14      | 12    | 2              | 0.000   | Accept H <sub>a</sub> :<br><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 <sub>a</sub> :<br><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 <sub>a</sub> :<br><u>Agree.</u>  |

**Table 4. Likert items for clopyralid**

| Item # | Likert Item   | Distribution (count) (n=94) |                   |         |       |                | p-value | Conclusion<br>(Accept Null Hypothesis H <sub>0</sub> or alternative hypothesis H <sub>a</sub> ) |
|--------|---|-----------------------------|-------------------|---------|-------|----------------|---------|---|
|        |   | Disagree                    | Strongly 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 <sub>a</sub> :<br><u>Agree.</u>  |
| 4b     | There are available pesticide alternatives to replace clopyralid for thistle management | 8                           | 48                | 20      | 18    | 0              | 0.000   | Accept H <sub>a</sub> :<br><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 <sub>a</sub> :<br><u>Disagree.</u>   |
| 4d     | In the absence of clopyralid, thistles will reduce OSR yields                           | 0                           | 11                | 24      | 49    | 10             | 0.000   | Accept H <sub>a</sub> :<br><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 <sub>a</sub> :<br><u>Disagree.</u>   |



**Table 5. Likert items for pendimethalin**

| Item # | Likert Item   | Distribution (count) (n=94) |                   |         |       |                | p-value | Conclusion<br>(Accept Null Hypothesis H <sub>0</sub> or alternative hypothesis H <sub>a</sub> ) |
|--------|---|-----------------------------|-------------------|---------|-------|----------------|---------|---|
|        |   | Disagree                    | Strongly 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 <sub>a</sub> : <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 <sub>a</sub> : <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 <sub>a</sub> : <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 <sub>a</sub> : <u>Disagree.</u>  |

**Table 6. Likert items for chlortoluron**

| Item # | Likert Item  | Distribution (count) (n=94) |                   |         |       |                | p-value | Conclusion<br>(Accept Null Hypothesis H <sub>0</sub> or alternative hypothesis H <sub>a</sub> ) |
|--------|--|-----------------------------|-------------------|---------|-------|----------------|---------|---|
|        |  | Disagree                    | Strongly 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 <sub>a</sub> :<br><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 <sub>a</sub> :<br><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 <sub>a</sub> :<br><u>Agree.</u>  |

Table 7. Likert items for general trends

| Item # | Likert Item  | Distribution (count) (n=94) |                   |         |       |                | p-value | Conclusion<br>(Accept Null Hypothesis H <sub>0</sub> or alternative hypothesis H <sub>a</sub> ) |
|--------|--|-----------------------------|-------------------|---------|-------|----------------|---------|---|
|        |  | Disagree                    | Strongly 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 Ha:<br><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 Ha:<br><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 Ha:<br><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 Ha:<br><u>Agree.</u>   |
| GS1e   | Cultural control is a complement to, not a direct substitute for pesticides  | 0                           | 0                 | 2       | 38    | 52             | 0.000   | Accept Ha:<br><u>Agree.</u>   |
| GS1f   | Effective resistance management requires as many different modes of action as possible   | 0                           | 0                 | 1       | 22    | 69             | 0.000   | Accept Ha:<br><u>Agree.</u>   |
| 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:<br><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:<br><u>Agree.</u>   |
| GS2b   | A change to the rotation is the intervention of last resort  | 3                           | 17                | 8       | 49    | 15             | 0.000   | Accept Ha:<br><u>Agree.</u>   |
| GS2c   | In general, direct substitutes do not exist for any active substance   | 1                           | 15                | 14      | 51    | 10             | 0.000   | Accept Ha:<br><u>Agree.</u>   |

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|             |   |    |    |    |    |    |       |   |
|-------------|---|----|----|----|----|----|-------|---|
| <b>GS2d</b> | 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:<br><u>Disagree.</u>              |
| <b>GS2e</b> | 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:<br><u>No</u><br><u>consensus</u> |
| <b>GS2f</b> | If approved for use, RoundUp Ready OSR would reduce current dependency on propyzamide and carbetamide   | 4  | 2  | 14 | 47 | 26 | 0.000 | Accept Ha:<br><u>Agree.</u>                 |
| <b>GS2g</b> | 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:<br><u>Disagree.</u>              |

## Identifying Adaptation Options and Constraints: The role of agronomist knowledge in catchment management strategy

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Caption: Results from acquiescence and internal consistency tests (Stage 3 validation)

### Online Resource 4 – Acquiescence and Internal Consistency Data from Stage 3 Online Survey

This document presents 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). As described in Section 2.4, Spearman's Rank correlation test, at 0.05 significance level was used for these tests.

**Table 1. Spearman's rank correlation coefficient ( $\rho$ ) tests for acquiescence bias and internal consistency**

| Test                 | Test pair    | $\rho$ | 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 ( $\alpha$ ) = 0.05, \*\* Accept at  $\alpha = 0.05$  and  $\alpha = 0.01$