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Quick Scoping Review
The impact of pesticides used for amenity purposes on controlled waters

Final report WT1546

Produced: August 2014

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A report of research carried out by Harper Adams University, on behalf of the Department for Environment, Farming and Rural Affairs

Research contractor: Centre for Evidence Based Agriculture, Harper Adams University

Authors: Kathy James, Nicola P Randall and Anthony Millington

Review team members: Nicola Randall, Katy James, Paul Lewis, Martin Hare, Anthony Millington, Tom Hutchinson and Ruth Mann

Publishing organisation
Department for Environment, Food and Rural Affairs
Flood Risk Management Division,
Nobel House,
17 Smith Square
London SW1P 3JR

Executive Summary

Background
Amenity pesticides are those used in the urban environment, to maintain amenity and protect buildings. They cover a wide range of commercial, industrial, public, recreational and leisure uses, including sports turf management, invasive weed control and highways maintenance. Responses to a recent consultation by Defra on urban diffuse pollution, identified amenity pesticides as being a potential contributor to pollution of controlled waters in the UK

Method
A Quick Scoping Review (QSR) was used to review the evidence on the impact of pesticides used in amenity on controlled waters. The QSR involved a systematic literature search and screening process. A protocol developed *a priori* by the review team and steering group was used to lead the review process. Two secondary questions were also addressed: 1) to estimate the cost and benefits of mitigation measures tackling the impact of amenity pesticides on the water environment 2) to assess the relative importance of the impact from amenity pesticides on controlled waters within the context of other pressures driving failure to meet Water Framework Directive objectives. Although amenity pesticides were the focus, studies that investigated pesticides from domestic use were also included in the scope.

Key findings
Twenty eight studies were eligible. The majority either investigated water quality, and correlated pesticide with surrounding land use, or studied pesticide runoff from hard surfaces (eg. roads, railways) into drains or ditches. Studies most often reported on concentration of pesticide in water and whether drinking water quality standards were exceeded.

The impact of amenity pesticides on controlled waters in the UK
Of the 28 studies found, only 9 directly investigated the impact on controlled waters of pesticides currently used for amenity in the UK. All but one were concerned with herbicides (pesticides designed for plant control). Other studies looked at sorption or pesticide loss on hard surfaces.

Glyphosate was the most commonly studied pesticide. Study questions and findings varied, and this QSR did not evaluate research design, but authors indicated that: application of glyphosate to railways is unlikely to result in leaching to ground or surface waters, but that application to hard surfaces can lead to short lived high concentrations of glyphosate in drains after the first subsequent rainfall event; concentrations decline with subsequent rainfall events; glyphosate runoff from asphalt is reduced when there is a longer time lag between application and the first rainfall event; and glyphosate used for weed control on hard surfaces is unlikely to negatively impact aquatic species in ditches receiving runoff. One study found that herbicide sorption was greater on asphalt than concrete.

The costs and benefits of mitigating for impacts of amenity pesticides on controlled waters
Evidence for the costs and benefits of mitigation measures was scarce, particularly where it related to pesticides currently authorised for use in the UK. As costs and benefits were not part of the primary question, this may partially reflect the search terms used.

Two studies on pesticides no longer authorised for UK use found that controlling them at source or stopping their use led to a reduction in water contamination. Other studies (also on pesticides no longer authorised for use in the UK) found that water quality can be improved

by working with manufacturers and users of non-agricultural pesticides, and by applying other voluntary measures to reduce the amounts of herbicides reaching water sources.

One experiment of current relevance highlighted the need for correct calibration of spraying equipment to prevent overdosing. A yet to be completed study is investigating the development of 'integrated' or zero herbicide regimes to control weeds, and associated costs.

The relative importance of the impact of amenity pesticides on controlled waters within the context of other pressures
One modeling study indicated that urban runoff from glyphosate was predicted to be far less than that from agriculture, and other sources such as runoff from highways, railways, intermittent discharges and wastewater treatments were predicted to have even less of an impact. There was a lack of primary research evidence relating to this question.

Implications for policy and research
This QSR indicates that the evidence for the impact on controlled waters of amenity pesticides currently used in the UK is limited. The existing studies are almost entirely limited to herbicides, often for pesticides that are not currently authorized for use, and do not consider the ecological and toxicological impacts of amenity pesticides.

Some studies indicate that contamination of water sources is linked to surface type and rainfall events. The effect of these factors for different formulations of pesticide may be worth investigating further. An education campaign illustrating the potential impacts of applying different formulations of pesticide may also help mitigate for this.

Based on our findings, if new primary research were to be conducted in this area, we would suggest the following topics:

- Urban catchment studies that clearly demonstrate the impact of pesticides originating from amenity use on controlled waters.
- The potential of pesticides other than herbicides used in amenity to contaminate the water environment.
- Studies to quantify the contribution of pesticides from amenity to controlled waters and to determine whether concentrations of pesticide found are of consequence to the aquatic environment or human health.
- Mitigation measures detailing costs and benefits to tackle the impact of pesticides used in amenity on controlled waters.
- Studies to investigate potential pollution control benefits of mitigation measures primarily designed to manage water volume.
- Studies to identify the contribution of pesticides from different amenity sub-sectors (eg. public authorities, residential, industrial) to the pollution of controlled waters.

Background

Amenity pesticides are defined as those used in the urban environment (defined as any non-agricultural, horticultural, forestry or home or garden use), to maintain amenity and protect buildings. They cover a wide range of commercial, industrial, public, recreational and leisure uses, including sports turf management, invasive weed control and highways maintenance. Pesticides are chemicals and biological products used to kill or control living organisms such as rodents, insects, fungi and plants. Amenity pesticide use is largely to control weeds in public spaces, on transport infrastructure and industrial areas, there is little use of fungicides and insecticides (Pesticide Forum, 2011). The main use by amateurs (home and garden users) is for moss control in lawns, herbicides for lawn use, slug and snail control, and general disease and insect control on roses and brassica vegetables. Whilst amateur use of pesticides is small in comparison to that used in agriculture, the number of gardeners using pesticides in the UK is thought to be around 6-7 million (Pesticide Forum, 2011).

Responses to a recent consultation on urban diffuse pollution, identified amenity pesticides as being a potentially important contributor to the pollution of controlled waters (Anon, 2013a). Controlled waters are defined in section 104 of the Water Resources Act and include territorial, coastal, inland and ground waters (Water Resources Act 1991 section 104) (Great Britain, 1991). Defra has a policy commitment to tackle water pollution through The Water Framework Directive (WFD) (2000/60/EC) (www.eur-lex.europa.eu). This Directive aims to protect and restore the chemical and ecological status of water bodies throughout Europe, with a target date of 2015 for getting all European waters into good condition. However, in England, less than a quarter of surface waters are currently at ‘good status’ or ‘good potential’ (Anon, 2013b). The Environment Agency is currently working towards updating River Basin Management Plans to protect and improve the water environment. These plans will set objectives for every body of water in England and will detail actions required from businesses and public bodies to achieve these objectives. Government will approve the new plans which may be supported by new legislation (Anon, 2013b).

Knowledge and understanding of the key sectors and significant water management issues that are preventing WFD objectives from being achieved has improved over recent years and includes amenity users and pesticides (Anon, 2013b). However, there remains significant uncertainty around the occurrence and severity of water pollution that has arisen from the use of pesticides for amenity purposes. Consequently, amenity pesticide pollution has been identified as a potentially important contributor in a recent consultation by Defra (Anon, 2013b). The Voluntary Initiative for pesticides also identified the amenity use of pesticides as a potential contributor to water pollution from hard surface uses and aquatic weed control (Anon, 2006). The potential impact of pollution from amenity pesticides on controlled waters is varied and could include; increased costs of treating drinking water; loss of sensitive plants and animals and accumulation of pesticides in food chains.

This Quick Scoping Review (QSR) reviewed the existing evidence on the impact (spatial, frequency and severity) of amenity pesticides on controlled waters. The results will be of use to policy makers and practitioners working towards improving water standards.
A wide variety of other types of pollution (chemical/physical and or biological) also contribute to failure to meet WFD objectives including nitrates, phosphates and faecal indicator organisms. This QSR sought to assess the relative importance of the impact of amenity pesticide on controlled waters within the context of other pressures driving failure to meet WFD objectives.

Voluntary approaches and advice, for example by Amenity Forum, aim to reduce emissions of pesticides to surface and groundwaters by amenity users. Mitigation measures include changes in application technology such as nozzle design, management techniques, including alternative weed control approaches (brushing, burning, foaming and electric weeding), training in alternative approaches and the use of pesticides, best practice guidance and codes of practice for all professional pesticide users. However, there is evidence to suggest that good/best application and disposal practice is not followed in the amenity sector to the same extent as in some other sectors (Pesticide Forum, 2011). This review also examines the evidence for the cost and benefits of mitigation measures tackling the impact of amenity pesticides on the water environment.

This QSR describes the nature and volume of the evidence pertaining to the primary and secondary questions and identifies knowledge gaps. It will discuss the implications for policy, research and practice.

Objectives

The primary and secondary questions were developed in discussion with a steering group consisting of the review team, Defra and the Environment Agency, during the development of the QSR protocol.

Primary question

The primary objective of this QSR was to:

Review existing evidence on the impact of pesticides used for amenity purposes on controlled waters.

'Impact' in relation to this review means the occurrence (spatial and frequency) and severity (detriment) either in terms of observable damage to aquatic biota or a breach of the WFD's environmental standards for pesticide concentrations. In all cases it was important to be able to attribute the impact of the pesticides to non-agricultural use.
Using the Population, Intervention/Exposure, Comparator, Outcome (PICO) approach the primary question was broken down into its constituent elements as detailed in Table 1.

Table 1 PICO elements of the primary question

PICO element	**PICO element within this QSR**
Population	Controlled waters
Intervention/Exposure	Exposure: Pesticides used in amenity
Comparator	Absence of amenity pesticide, non-amenity pesticides
Outcome	Impact on: water quality, WFD environmental standards, human health, ecology, biology, ecotoxicology, invertebrates, fish and

costs.

Secondary question

In addition to the primary question two secondary questions were also addressed:

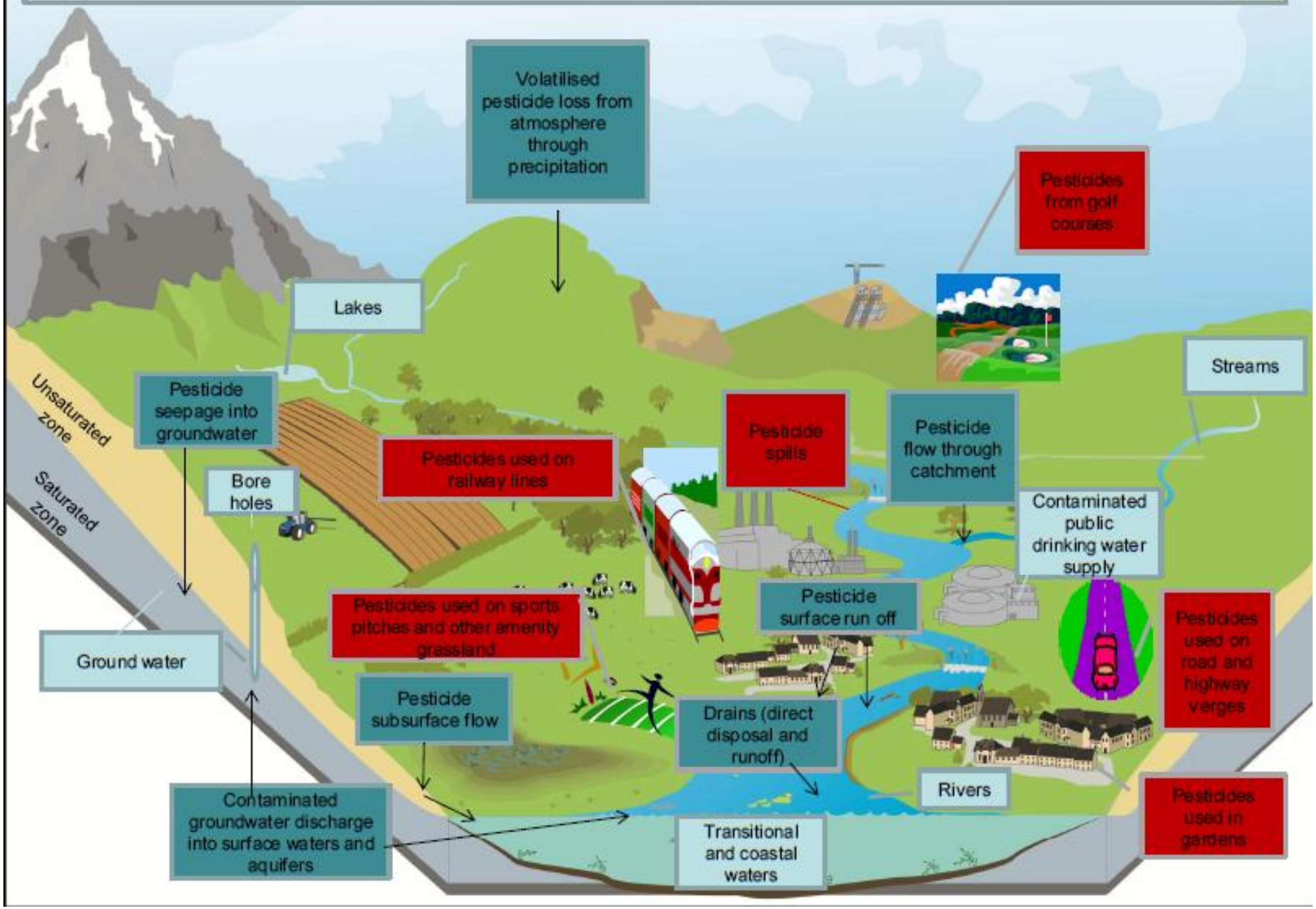
1. *Estimate the cost and benefits of mitigation measures tackling the impact of amenity pesticides on the water environment.*
2. *Assess the relative importance of the impact from amenity pesticides on controlled waters within the context of other pressures driving failure to meet Water Framework Directive objectives*

Due to time constraints, the secondary questions were assessed using evidence collated during searches for the primary question only. Documents from Defra and the Environment Agency were also provided to assist with addressing the primary and secondary questions and were essential for understanding the policy context of the work.

Conceptual Model

Figure 1 illustrates sources of amenity pesticides (as places they are used), pathways (through and over land) and receptors (as groundwater, surface waters, and water supplies)

Figure 1. Water pollution from pesticides used in amenity – sources pathways and receptors



Methods

The methods were guided by the *a priori* steps detailed in a QSR protocol (Randall and James, 2014)

Search strategy

The search strategy was developed in discussion with the steering group and members of the review team. All retrieved studies were assessed for relevance using inclusion/exclusion criteria developed in these discussions.

Inclusion criteria

Relevant studies included in this QSR were those that investigated the impact of pesticides used for amenity on water quality, human health, ecology, WFD environmental standards, biology, ecotoxicology, invertebrates, fish and costs associated with pesticide contamination and pollution.

Searches also found studies investigating the sorption and runoff of different types of pesticide used in amenity from hard surfaces. In consultation with the steering group these studies were included in the review.

Subjects for the secondary questions included studies investigating the costs and benefits of mitigation measures tackling the impact of amenity pesticides on the water environment, and the relative impact of amenity pesticides compared with other drivers of failure to meet WFD objects.

The search was limited to the English language and stakeholders agreed that the focus should be on studies from the UK.

Four specific pesticides were searched for: Glyphosate, Mecoprop, MCPA and 2,4-D as these are currently commonly used for amenity. However, all pesticides used in amenity were considered for inclusion regardless of whether or not they are now authorised for use in the UK. No date restrictions were applied. It was also agreed that due to time constraints the subjects relevant to the secondary questions should only be gathered from studies obtained during searching for the primary question.

Search terms

Search terms, formulated by the review team and stakeholders were used to gather evidence for both the primary and secondary questions. Combinations of the search terms listed in Table 2 were used to search online databases and websites. The actual combinations of search terms used are attached as an Excel file (Appendix I). Search terms were combined using the Boolean AND operator and keywords were made more restrictive by the addition of a qualifier.

Search sources

A comprehensive search was undertaken using multiple information sources to capture an un-biased sample of both published and grey literature.
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The following online sources were searched:
Electronic databases:

- *Find it @ Harper* – this search engine has access to 13 databases (Web of Knowledge, Science Direct, Wiley Online, CAB abstracts, BSI Online (not fully), Business Source Complete, Dawson E books, Emerald, Ethos (not fully), Food Science Source, Greenfile, Mintel Reports (not fully), MyiLibrary)
- *Index to Theses online*

The results of each search term were imported into a separate EndNote X2TM library file. All these databases were then incorporated into one library, recording the number of references captured. Using the automated function in the EndNote X2TM software any duplicates were removed. A record of each search was made, including date of search, database name, search term, number of hits and notes.
Organisational websites:

- *Environment Agency* – http://www.environment-agency.gov.uk
- *Defra online databases* – http:// www.gov.uk/defra
- *Water Framework Directive UK Technical Advisory Group* – http://www.wfduk.org
- *UK Water Industry Research* – http://www.ukwir.org
- *Chemicals Regulation Directorate* – http://www.pesticides.gov.uk
- *Better Thames Network* – http://www.better-thames-network.westminster.ac.uk
- *Amenity Forum* – http://www.amenityforum.co.uk
- *Glyphosate Facts* – http://glyphosate.eu

Any relevant literature was collated into the final Microsoft Access database (Additional file 1.). This was also converted into an Excel database (Additional file 2).

Table 2 Keywords and qualifiers to be used in the literature search

Amenity pesticide keywords	**Water keywords**	**Water specific alternatives (to be combined with water)**	**Other potential qualifiers**
Amenit* pesticide*	Water*	qualit*	Impact*
Urban pesticide*	River* OR stream* OR catchment*	pollut*	Human health
Garden pesticide*	Pond* OR lake*	Controlled	Ecolog*
Highway* pesticide*	Groundwater*	Territorial	Biolog*
Sport* turf pesticide*	Estuar*	Coastal	Mitigat*
Local authorit*pesticide*	Aquifer*	Drinking	Cost*
Hard surface* pesticide*		Surface	Ecotox*
Amenit* surfactant*		Transitional	Invert*
Amenit* insecticide*			Fish*
Amenit* fungicide*			Occurrence*
Amenit* herbicide*			
	WFD	environmental standard*	
Mecroprop MCPA 2,4-D Glyphosate	Used with selected 'amenity' and 'water' keywords from the lists above		

Search engines:

- Google http://www.google.co.uk
- Google Scholar http://www.scholar.google.co.uk

The first 20 hits with document or spreadsheet formats (e.g. .doc,.txt,.xls and .pdf where this could be separated) from each data source were imported into an Excel file and examined for relevant studies.

Literature reviews:

Literature reviews found in the search were scanned for any relevant primary studies which were included in the final knowledge map.

Expert opinion:

Experts and practitioners including academics, members of Defra, the Environment Agency, the Amenity Forum and from the Chemical Regulation Directorate, were contacted to identify any grey literature missed in the searches and to discuss current projects where few results were available.

Data extraction – Systematic Map Database

The EndNote X2™ library from the literature database searches was searched for suitable references first by keyword in the title, then by title and abstract and finally by full text. All retrieved studies were assessed for relevance using the inclusion/exclusion criteria. The inclusion criteria were applied by one reviewer to all potential articles, except where there was uncertainty, where a second reviewer examined the text and a consensus agreement was made. These studies were combined with relevant studies from the other searches into a searchable systematic map in the form of Microsoft Access database. The database/map is searchable by generic group including: Type of reference (eg. Journal paper, conference paper etc), Population (eg. type of water body), Intervention (eg. reduced herbicide inputs), Exposure (type of pesticide), Outcome (eg. Breach of WFD) and where in the UK a study was performed.

Results

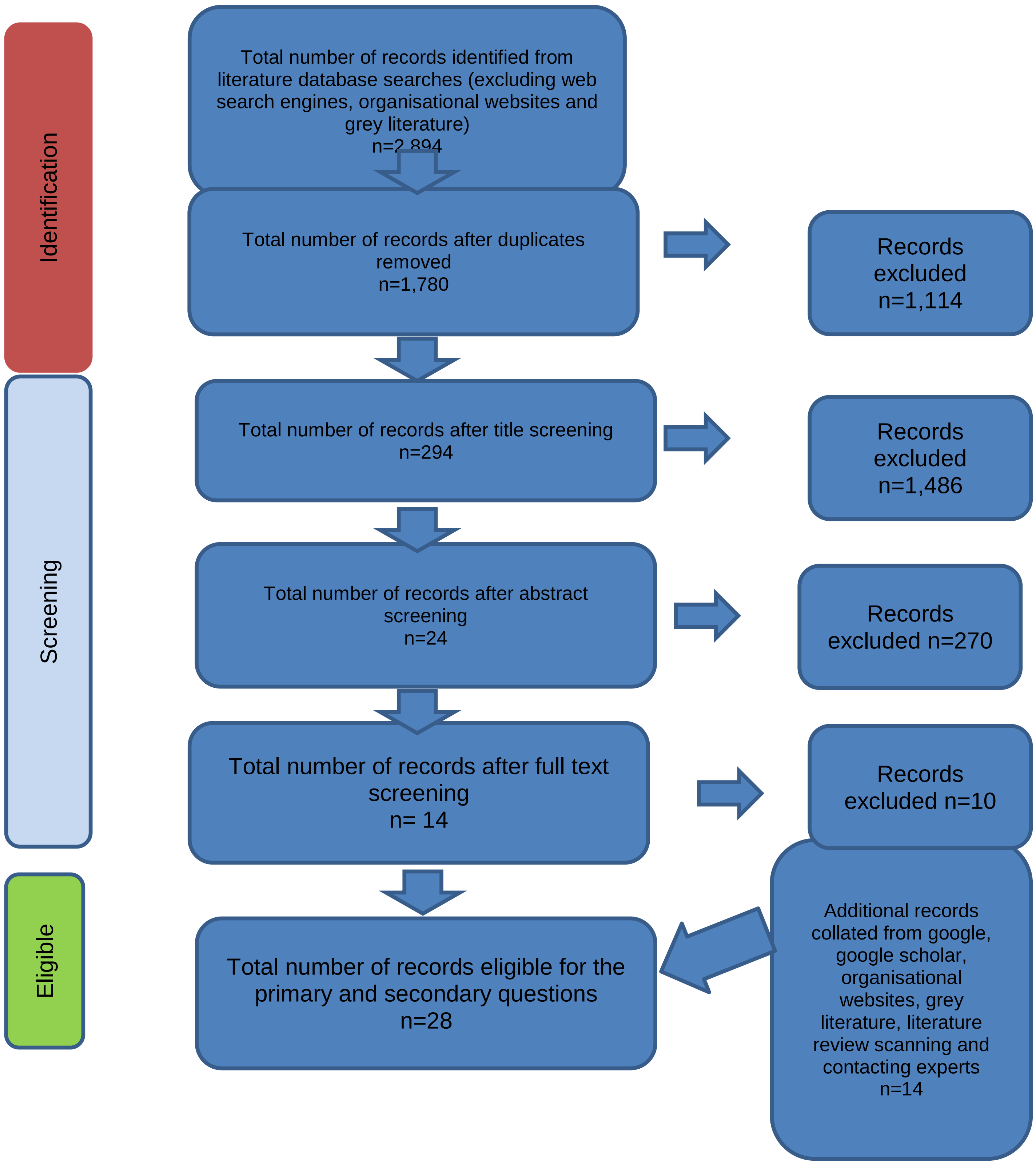
Review searching and screening

A total of 14 references were found to be eligible from the literature database searches. Figure 2 shows the literature included and excluded at each stage in the systematic mapping process. A further 14 records were found through searching organisational websites (n=3), the web search engines Google (n=4), Google Scholar (n=3), hand searching literature reviews (n=3) and from literature recommended by experts (n=1). The total number of eligible records for the QSR was therefore 28. 23 records were relevant to the primary question and 7 to the secondary question (2 studies were relevant to both the primary and secondary question). All 28 references included for mapping were found at full text and are summarised in a searchable database (Additional file 1) and in Appendix II.

During screening a number of studies (n=13) of topical relevance to the QSR but from outside of the UK were found. These were not included in the QSR database (as studies from outside the UK were not included in the scope of the review), but they are listed in an

Appendix III as useful additional information. These illustrate a wider variety of study types relevant to the topic area and are of potential interest for future research design in the UK.

Figure 2 Literature included and excluded at each stage of the systematic mapping process



Review statistics

The majority of material found in the searches was not relevant to either the primary or secondary questions in this QSR. Peer review studies (n=12) and reports (n=10) dominated the 28 articles judged to be relevant to this QSR. The remainder of the literature was from conference papers (n=3) and posters (n=2) and from a workshop presentation (Anon, 2012a).

All the literature related to herbicide use in the amenity sector, with the exception of one water quality monitoring study which found molluscicide. No literature on other pesticides was captured for studies in the UK (this was not the case from studies outside of the UK suggesting a lack of evidence for pesticides other than herbicides in the UK).

The literature found could be grouped into roughly three categories:

1) Studies investigating the impact of herbicides on water quality (n=20)
2) Laboratory or modelling studies investigating herbicide runoff or sorption from/to hard surfaces (n=3)
3) Studies to mitigate the impact of herbicides used in amenity on water resources (n=7)

Only 9 studies investigating the impact of herbicides on water quality investigated pesticides that are currently still in use in the UK. The earliest reference was from 1991 and the most recent from 2014. However, just over half of the material was over 10 years old and much of it was no longer relevant to current practice as the pesticides (eg. Diuron, Simazine and Atrazine) studied are now not authorised for use in the UK. The evidence was dominated by studies relating to ground and surface waters. One study was included that investigated surficial sediment samples from storm overflow near to salt marshes.

Half of studies (n=14) were correlative, monitoring water quality and associating the pesticides used with surrounding land use eg. urban, agriculture, railways, golf courses etc. Seven studies were manipulative experiments either in the form of field studies (n=5) or lab studies (n=2) and the majority of these were concerned with herbicide runoff from different types of hard surface (eg. roads (asphalt/concrete), ballast (railways)). Two modelling studies were included in the QSR one looking at sources of glyphosate in water bodies and one modelling pesticide runoff from hard surfaces. Studies most often recorded the level of pesticides found in water sources and whether these exceeded drinking water quality standards. Other variables measured were runoff or sorption to hard surfaces. Two studies discussed the potential impact of runoff of pesticides used in amenity on the aquatic environment using known toxicity data.

Very little literature was found in terms of mitigation measures to reduce the impact of pesticides used in amenity on water resources **(**n=6**)**. Four studies were found investigating voluntary/stewardship mitigation measures. Two studies were experimental one looking at application reducing inputs during application and another developing zero and minimal herbicide regimes for controlling weeds. The latter is an on-going experiment but some results were available.

Review synthesis primary question

Pesticides no longer authorised for use in the UK - studies investigating the impact of pesticides used in amenity on controlled waters

Of the evidence found relating the impact of pesticides used for amenity on controlled waters, twelve articles referred to pesticides that are no longer authorised for use in the UK due to their persistence in controlled waters. These water quality monitoring studies (n=9) correlated the type of pesticide found in surface or groundwaters with either surrounding land use or the main use of that product (Croll *et al* 1991; Gomme *et al*, 1992; Ellis, 1997; Defra, 2003; Knapp, 2005; Lapworth and Gooddy, 2006; Lapworth *et al.* 2006; Lapworth *et al.* 2007; Revitt *et al*. 2002). Three studies showed that controlling non-agricultural use at source or banning a pesticide led to a reduction in contamination of ground or surface waters (White and Pinkstone, 1993; Anon, 2012a and 2012b). The pesticides reported in these studies were Atrazine, Simazine and Diuron.

Pesticides currently used for amenity in the UK-- studies investigating the impact of pesticides used in amenity on controlled waters

Only 9 studies were found that investigated the impact of pesticides currently used in amenity on controlled waters. The general outcomes are described here with more detail for each study presented in Appendix II.

An EU glyphosate urban monitoring literature database was used to cross check the searches and the references found suggested that published literature for glyphosate was not missed in this QSR. Discussion with stakeholders also suggests that literature had not been missed in the searches.

Three studies correlated pesticide found with land use; 2 groundwater studies with Dicamba (Lapworth *et al*., 2006b) and metaldehyde (Manamsa *et al*., 2011) as the contaminating pesticides; 1 study of surficial sediment from storm overflow found MCPA, 2,4-D and 2,4-DP commonly used for amenity and for amateur use (Fletcher *et al*., 1994). Only metaldehyde exceeded European standards for pesticides in drinking waters (Manamsa *et al*., 2011).

Five experimental field studies were found investigating application of glyphosate and its runoff into ditches or drains. Two of these studies investigated application to a railway (Ramwell *et al*., 2000a & 2004); 2 to urban catchments (Ramwell *et al.*, 2000b & 2014) and 1 to a roadside and kerb (Ramwell *et al.*, 2002). All these studies were concerned with professional amenity use of herbicides with the exception of the study by Ramwell *et al.* (2014) which investigated domestic use of glyphosate. These studies indicated that: Application of glyphosate to railways is unlikely to leach into ground or surface waters (Ramwell *et al.*,2000a & 2004). Application to hard surfaces (ie. roads) can lead to short-lived high concentrations of glyphosate in drains after the first rainfall event following application. However, concentrations decline with successive rainfall events (Ramwell *et al*., 2000b & 2002). Predicted environmental concentrations of glyphosate when compared to toxicity test data using toxicity exposure ratios suggests that glyphosate used for weed control on hard surfaces is unlikely to result in any detriment to aquatic species in ditches receiving runoff (Ramwell *et al.*, 2002). It is unlikely that losses of Glyphosate and it’s degradate aminomethylphosphonic acid (AMPA) from residential catchments (domestic use), following proper usage would contribute significantly to the total glyphosate load in surface waters compared with other urban areas (Ramwell *et al.*, 2014).

A glyphosate source apportionment modelling study predicted that glyphosate entering the river environment of England and Wales is predominantly from direct runoff from agricultural land applications (77%). Predicted runoff of glyphosate from urban areas (16%) comprises the next most significant source. Other inputs of glyphosate from wastewater treatment works, intermittent discharges, highway runoff and rail amounted to less than 5%. This study also predicted that over 90% of AMPA entering the aquatic environment is generated via the degradation of phosphonates used in detergents and that the contribution from the degradation of glyphosate by comparison is insignificant (ATKINS, 2009).

Studies of pesticide runoff or sorption to/ from hard surfaces

A further three laboratory or modelling studies of pesticide runoff/sorption from/to hard surfaces were included as useful information for this QSR.
Two reports were found detailing laboratory studies investigating pesticide loss or sorption to different types of hard surface, namely concrete, asphalt and ballast (Shepherd and Heather, 1999 and Ramwell, 2005). The pesticides of interest to this QSR in these reports were glyphosate and Isoxaben. The general results from these studies showed that, herbicides sorption was greater on asphalt compared to concrete. On asphalt less glyphosate runoff occurs the longer the time lag between application and first rainfall event.

One modelling study was included that used existing studies designed to explore the fate and behaviour of herbicides after application to help build a predictive model (HardSPEC) for regulatory risk assessment to assist in the approval process of compounds submitted for use in the urban environment (Hollis *et al*., 2004).

More detail about these studies is presented in Appendix II.

Review synthesis secondary questions

Estimate the cost and benefits of mitigation measures tackling the impact of pesticides used in amenity on the water environment

Very little evidence was found for this secondary question in the searches. Those found can be placed into two groups: Voluntary/Stewardship measures (n= 4) and research experiments (n= 2).

Voluntary/Stewardship mitigation

Four articles were found but these all reported on pesticides that are now banned in the UK, namely Atrazine, Diuron and Simazine. White and Pinkstone (1993), Davis *et al*. (1993 &1997) and Anon (2012a) describe how working with manufacturers, users of non-agricultural herbicides and Government departments and implementing stewardship programmes to reduce the amounts of herbicides reaching water sources can help improve water quality.

Research

In discussions with stakeholders it was noted that there is lack of 'mitigation' research in the UK, particularly concerning the use of non-chemical weed control. Only 2 research projects were found in the searches:

A Defra funded project (PS2201) highlighted the ease with which overdosing may occur if correct application procedures are not adhered to, primarily deviating from values used during calibration of equipment. It was found that the deviations from the calibrated values do not have to be large for substantial financial costs to be incurred. The study concluded that financial costs given to overdosing could be used as an incentive to adhere to guidelines which would benefit the environment (Anon, 2003). (See Appendix II for further details)

A second Defra funded project PS2802 also known as the Thanet Weed Project) due to complete in 2015 is testing three weed control measures: 1) Herbicide (glyphosate) 2) Non-chemical weed control using thermal and mechanical methods 3) Integrated weed control using reduces glyphosate input in combination with thermal and mechanical control. The type of weeds and their growth are being measured regularly and drain water is sampled on a regular basis to determine the amount of glyphosate runoff. Costs and lifecycle analysis (CO_2 and CO2e emissions and energy consumption) are also being calculated. Initial results indicate that acceptable levels of control can be achieved with all treatments. Glyphosate has been detected above drinking water standards for all treatments (Pesticide Forum, 2011) even the non-herbicide treatment areas (possibly due to domestic use). Greater costs are associated with the 'integrated' and non-herbicide treatments. An 8 fold increase in costs was found if no herbicides are used (Nigel Chadwick pers. comm.). Lifecycle analysis from 2010 indicated that there is a trade-off between reduced herbicide emissions from no herbicide control methods and increased CO_2 emissions compared to herbicide use (Anon, 2011).

Assess the relative importance of the impact from amenity pesticides on controlled waters within the context of other pressures driving failure to meet WFD objectives

Due to the lack of evidence of the impact from pesticides used in amenity on controlled waters it is difficult to assess the relative importance in the context of other pressures.

Evidence from reports of national UK pesticide usage data and surface water quality monitoring (eg. Pesticide Forum 2012; Tuffnell and Britt, 2008), combined with a modelling source apportionment study (Atkins, 2009), suggests that agriculture is the main source of pesticides contaminating the water environment. However, further research is needed to fully quantify the contribution by amenity.

Conclusions

Primary question – review the existing evidence on the impact of pesticides used for amenity on controlled waters

This QSR indicates that evidence regarding the impact of pesticides currently used in amenity in the UK on controlled waters is limited. This is particularly important when considering the actual contribution of pesticides used by the amenity sector to contamination of the water environment. Evidence from reports of national UK pesticide usage data and surface water quality monitoring (eg. Anon, 2012; Tuffnell, 2008), combined with a modelling source apportionment study (Atkins, 2009), suggests that agriculture is the main source of pesticides contaminating the water environment. However, it would be useful to further investigate the approximate contribution from amenity in order to help mitigate risks by targeting measures appropriately.

Pesticides used in amenity that are identified as causing a compliance risk with WFD standards are not exclusively used by this sector. The majority of the studies found in this QSR only correlated pesticide concentrations found in ground/surface water with surrounding land use or the common use of that particular pesticide. Modelling and laboratory studies found in this QSR although useful are based on applications made in strict accordance to manufacturers guidelines and may not always reflect actual practice. Whilst there are many good examples of best practice amongst amenity and amateur users, there is some evidence that these sectors are not operating to the same high standards as found in agriculture (National Association of Agricultural Contractors 2004, 2005, 2009; Defra, 2013; French, 2013).

An evidence gap exists for urban catchment studies that can clearly demonstrate the impact of pesticides originating from UK amenity use on controlled waters. The Thanet Weed Project due to complete in 2015 is an exception. The Thanet catchment was selected for this project partly because it is an enclosed area with easily identified drain flow and therefore glyphosate applied in the experiment by contractors can more easily be attributed to that found in the sampled drain water (Nigel Chadwick pers. comm.).

Of particular importance is the need for evidence pertaining to glyphosate, the most commonly used pesticide in the amenity sector (Goulds, 2012**)**. This extremely useful herbicide is being found in surface waters and as a result has been identified as a UK Specific Pollutant (Nigel Chadwick pers. comm.). The quantification of the contribution of glyphosate by the amenity sector to contamination of water resources is important so that appropriate mitigation measures can be applied.

It is unsurprising that herbicide contamination of the water environment dominated the literature, as herbicides account for 96% (by weight) of active substances applied by the amenity sector (Goulds, 2012). There is little evidence for the potential of other pesticides (eg. biocides) used in amenity to contaminate the water environment. This is a potential area of importance for future research. In studies from Switzerland, biocides used in urban construction were found in urban stormwater and receiving waters exceeded Swiss water quality standards of 0.1 $\mu g/L^{-1}$ (Burkhardt *et al.*, 2007 & 2011 – see Appendix III).

Furthermore, the evidence found in this QSR related almost exclusively to ground and surface waters, reflecting the UKs obligation to conform to European Drinking Water Standards.

Depending upon the overall contribution from amenity to pollution by pesticides of controlled waters, further research may be required to identify the contribution from different amenity sub-sectors (eg. public authorities, residential, industrial).

Little evidence was found about the impact of pesticides used in amenity on aquatic ecosystems. An evidence gap exists to quantify the contribution of pesticides from amenity to controlled waters and determine whether concentrations of pesticide found are of consequence to the aquatic environment or human health.

Secondary questions

Estimate the cost and benefits of mitigation measures tackling the impact of pesticides used in amenity on the water environment

This QSR indicates an evidence gap for mitigation measures detailing costs and benefits to tackle the impact of pesticides used in amenity on controlled waters.

Only one study was found that provided a cost incentive to the user and a reduction in inputs to the environment of calibrating equipment carefully to prevent overdosing (Anon, 2003).

The Thanet Weed Project indicates that non-herbicide (mechanical or thermal control) or 'integrated' (reduced herbicide with mechanical and thermal control) weed control is initially more expensive than the use of herbicide alone (Nigel Chadwick pers.comm.). However, there is an incentive for amenity users to look to ways of reducing herbicide inputs as part of a sustainable weed control programme.

During the searches a Susdrains Case study- Nottingham Green Streets - Retrofit Rain Garden Project (www.susdrain.org) was noted of interest. The primary objective of this study was to manage surface water runoff in heavy rainfall events. However, the project also stated that the gardens would always intercept and treat the often polluted first flush of highway runoff. This study did not provide any water quality results but highlights that mitigation measures primarily designed to manage water volume may also be of benefit to pollution control and deserve further research.

A number of regulatory measures and non-regulatory initiatives are in place in the UK that will help mitigate the impact of pesticides used in amenity on controlled waters. Many of these are outlined in the UK's National Action Plan for the sustainable use of pesticides (plant protection products). One of the aims of this plan is to ensure that pesticide pollution of water does not result in the UK failing to meet its objectives under the WFD. The plan will be delivered through Government working in partnership with a wide range of stakeholders. The plan aims for non-regulatory approaches to be adopted as much as possible and looks towards the Amenity Forum to help deliver the plan to the amenity sector. Details of specific mitigation measures for the amenity sector are detailed in the plan. Regular surveys of use and practice in the amenity sector have been incorporated into the government's pesticide usage survey programme (Defra, 2013).

Assess the relative importance of the impact from amenity pesticides on controlled waters within the context of other pressures driving failure to meet WFD objectives

A number of factors other than pesticides contribute towards pressures driving failure to meet WFD objectives, for example nitrates. However, until there is further evidence for the contribution of pesticides used in amenity to the water environment it is difficult to assess the relative importance compared to other pressures driving failure to meet WFD objectives.

Implications

Implications for policy and practice

Evidence for the impact on controlled waters of amenity pesticides currently used in the UK is limited. The existing studies are almost entirely herbicide studies, often refer to pesticides that are not currently authorized for use, and do not consider the ecological and toxicological impacts of amenity pesticides.

Some studies indicate that contamination of water sources is linked to surface type and to rainfall events (particularly for glyphosate). The effect of these factors for different formulations of pesticide would be worth investigating further. An education campaign outlining the potential variation in characteristics of different formulations of pesticide may also worth considering. Characteristics of products can vary according to their formulation, and can affect factors such as their drying time, and take up time by plant, which may impact on water pollution from different surfaces and under variable weather conditions.

In order to inform objective evidence based decisions, to help quantify the actual contribution of pesticides from amenity on controlled waters, and to determine the consequences to the aquatic environment or human health, further primary research would be useful. Suggestions for research topics are listed below.

Implications for research

This QSR indicates that there is a lack of robust evidence to answer both the primary and secondary questions. A number of potential future research topics have been highlighted by this study:

- Urban catchment studies that can clearly demonstrate the impact of pesticides originating from amenity use on controlled waters.
- The potential of pesticides other than herbicides used in amenity to contaminate the water environment.
- Studies to quantify the contribution of pesticides from amenity to controlled waters and to determine whether concentrations of pesticide found are of consequence to the aquatic environment or human health.
- Mitigation measures detailing costs and benefits to tackle the impact of pesticides used in amenity on controlled waters.
- Studies to investigate potential pollution control benefits of mitigation measures primarily designed to manage water volume.
- Studies to identify the contribution of pesticides from different amenity sub-sectors (eg. public authorities, residential, industrial) to the pollution of controlled waters.

Acknowledgements

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Appendix I -Search strings used for database and web searches

Find it @Harper

Ref	Search String	Hits
2	amenit* pesticide* AND water*	176
11	amenit* pesticide* AND river* OR stream* OR catchment*	38
15	amenit* pesticide* AND pond* OR lake*	29
18	amenit* pesticide* AND groundwater*	34
19	amenit* pesticide* AND estuar*	6
A19	amenit* pesticide* AND aquifer*	11
21	urban pesticide* AND water*	25
30	urban pesticide* AND river* OR stream* OR catchment*	14
34	urban pesticide* AND pond* OR lake*	5
37	urban pesticide* AND groundwater*	4
38	urban pesticide* AND estuar*	2
A38	urban pesticide* AND aquifer*	112
40	garden pesticide* AND water*	15
49	garden pesticide* AND river* OR stream* OR catchment*	2
53	garden pesticide* AND pond* OR lake*	3
56	garden pesticide* AND groundwater*	2
57	garden pesticide* AND estuar*	4
A57	garden pesticide* AND aquifer*	1
59	highway* pesticide* AND water*	378
68	highway* pesticide* AND river* OR stream* OR catchment*	129
72	highway* pesticide* AND pond* OR lake*	98
75	highway* pesticide* AND groundwater*	43
76	highway* pesticide* AND estuar*	33
A76	highway* pesticide* AND aquifer*	21
78	sport* turf pesticide* AND water*	356
87	sport* turf pesticide* AND river* OR stream* OR catchment*	61
91	sport* turf pesticide* AND pond* OR lake*	59
94	sport* turf pesticide* AND groundwater*	31
95	sport* turf pesticide* AND estuar*	1
A95	sport* turf pesticide* AND aquifer*	2
96	Local authorit*pesticide*	0
98	amenit* horticulture pesticide* AND water*	26
107	amenit* horticulture pesticide* AND river* OR stream* OR catchment*	3
111	amenit* horticulture pesticide* AND pond* OR lake*	1
114	amenit* horticulture pesticide* AND groundwater*	3
116	amenit* horticulture pesticide* AND aquifer*	1
118	hard surface* pesticide* AND water*	195
127	hard surface* pesticide* AND river* OR stream* OR catchment*	57
131	hard surface* pesticide* AND pond* OR lake*	32
134	hard surface* pesticide* AND groundwater*	33
135	hard surface* pesticide* AND estuar*	9
136	hard surface* pesticide* AND aquifer*	11

138	amenit* herbicide* AND water*	95
147	amenit* herbicide* AND river* OR stream* OR catchment*	14
151	amenit* herbicide* AND pond* OR lake*	16
154	amenit* herbicide* AND groundwater*	9
155	amenit* herbicide* AND estuar*	5
156	amenit* herbicide* AND aquifer*	3
158	amenit* surfactant* AND water*	31
167	amenit* surfactant* AND river* OR stream* OR catchment*	1
171	amenit* surfactant* AND pond* OR lake*	1
174	amenit* surfactant* AND groundwater*	2
175	amenit* surfactant* AND estuar*	1
176	amenit* surfactant* AND aquifer*	2
178	amenit* insecticide* AND water*	40
187	amenit* insecticide* AND river* OR stream* OR catchment*	5
191	amenit* insecticide* AND pond* OR lake*	10
194	amenit* insecticide* AND groundwater*	3
195	amenit* insecticide* AND estuar*	1
198	amenit* fungicide* AND water*	23
211	amenit* fungicide* AND pond* OR lake*	5
217	amenit* AND WFD AND "environmental standard*"	0
220	Mecoprop AND urban AND water*	31
221	Mecoprop AND garden AND water*	1
223	Mecoprop AND sport* turf AND water*	17
224	Mecoprop AND local authorit* AND water*	3
225	Mecoprop AND hard surface* AND water*	2
227	MCPA AND amenit* AND water*	1
228	MCPA AND urban AND water*	25
229	MCPA AND garden AND water*	3
230	MCPA AND highway* AND water*	1
231	MCPA AND sport* turf AND water*	1
232	MCPA AND local authorit* AND water*	3
233	MCPA AND hard surface* AND water*	1
235	2,4-D AND amenit* AND water*	5
236	2,4-D AND urban AND water*	110
237	2,4-D AND garden AND water*	46
238	2,4-D AND highway* AND water*	8
239	2,4-D AND sport* turf AND water*	27
240	2,4-D AND local authorit* AND water*	2
241	2,4-D AND hard surface* AND water*	1
243	glyphosate AND amenit* AND water*	15
244	glyphosate AND urban AND water*	123
245	glyphosate AND garden AND water*	68
246	glyphosate AND highway* AND water*	30
247	glyphosate AND sport* turf AND water*	21
248	glyphosate AND local authorit* AND water*	4
249	glyphosate AND hard surface* AND water*	16
	Total	2898

Google Scholar

Ref	Search String	Hits
2	amenit* pesticide* AND water*	8
11	amenit* pesticide* AND river* OR stream* OR catchment*	2
15	amenit* pesticide* AND pond* OR lake*	1
18	amenit* pesticide* AND groundwater*	6
19	amenit* pesticide* AND estuar*	3
A19	amenit* pesticide* AND aquifer*	4
21	urban pesticide* AND water*	20+
30	urban pesticide* AND river* OR stream* OR catchment*	20+
34	urban pesticide* AND pond* OR lake*	20+
37	urban pesticide* AND groundwater*	20+
38	urban pesticide* AND estuar*	20+
A38	urban pesticide* AND aquifer*	20+
40	garden pesticide* AND water*	20+
49	garden pesticide* AND river* OR stream* OR catchment*	20+
53	garden pesticide* AND pond* OR lake*	20+
56	garden pesticide* AND groundwater*	20+
57	garden pesticide* AND estuar*	16
A57	garden pesticide* AND aquifer*	20+
59	highway* pesticide* AND water*	3
68	highway* pesticide* AND river* OR stream* OR catchment*	0
72	highway* pesticide* AND pond* OR lake*	0
75	highway* pesticide* AND groundwater*	1
76	highway* pesticide* AND estuar*	0
A76	highway* pesticide* AND aquifer*	0
78	sport* turf pesticide* AND water*	0
87	sport* turf pesticide* AND river* OR stream* OR catchment*	0
91	sport* turf pesticide* AND pond* OR lake*	0
94	sport* turf pesticide* AND groundwater*	0
95	sport* turf pesticide* AND estuar*	0
A95	sport* turf pesticide* AND aquifer*	0
96	Local authorit*pesticide* AND	0
98	amenit* horticulture pesticide* AND water*	0
107	amenit* horticulture pesticide* AND river* OR stream* OR catchment*	0
111	amenit* horticulture pesticide* AND pond* OR lake*	0
114	amenit* horticulture pesticide* AND groundwater*	0
115	amenit* horticulture pesticide* AND estuar*	0
116	amenit* horticulture pesticide* AND aquifer*	0
118	hard surface* pesticide* AND water*	0
127	hard surface* pesticide* AND river* OR stream* OR catchment*	0
131	hard surface* pesticide* AND pond* OR lake*	0
134	hard surface* pesticide* AND groundwater*	0
135	hard surface* pesticide* AND estuar*	0
136	hard surface* pesticide* AND aquifer*	0

138	amenit* herbicide* AND water*	1
147	amenit* herbicide* AND river* OR stream* OR catchment*	1
151	amenit* herbicide* AND pond* OR lake*	1
154	amenit* herbicide* AND groundwater*	1
155	amenit* herbicide* AND estuar*	0
156	amenit* herbicide* AND aquifer*	1
158	amenit* surfactant* AND water*	0
167	amenit* surfactant* AND river* OR stream* OR catchment*	0
171	amenit* surfactant* AND pond* OR lake*	0
174	amenit* surfactant* AND groundwater*	0
175	amenit* surfactant* AND estuar*	0
176	amenit* surfactant* AND aquifer*	0
178	amenit* insecticide* AND water*	0
187	amenit* insecticide* AND river* OR stream* OR catchment*	0
191	amenit* insecticide* AND pond* OR lake*	0
194	amenit* insecticide* AND groundwater*	0
195	amenit* insecticide* AND estuar*	0
196	amenit* insecticide* AND aquifer*	0
198	amenit* fungicide* AND water*	0
211	amenit* fungicide* AND pond* OR lake*	0
217	amenit* AND WFD AND environmental standard*	20+
219	Mecoprop AND amenit* AND water*	20+
220	Mecoprop AND urban AND water*	20+
221	Mecoprop AND garden AND water*	20+
222	Mecoprop AND highway* AND water*	20+
223	Mecoprop AND sport* turf AND water*	0
224	Mecoprop AND local authorit* AND water*	20+
225	Mecoprop AND hard surface* AND water*	19
227	MCPA AND amenit* AND water*	20+
228	MCPA AND urban AND water*	20+
229	MCPA AND garden AND water*	20+
230	MCPA AND highway* AND water*	20+
231	MCPA AND sport* turf AND water*	0
232	MCPA AND local authorit* AND water*	20+
233	MCPA AND hard surface* AND water*	20+
235	2,4-D AND amenit* AND water*	20+
236	2,4-D AND urban AND water*	20+
237	2,4-D AND garden AND water*	20+
238	2,4-D AND highway* AND water*	20+
239	2,4-D AND sport* turf AND water*	3
240	2,4-D AND local authorit* AND water*	20+
241	2,4-D AND hard surface* AND water*	20+
	Total	651+

Google

Ref	Search String	Hits
2	amenit* pesticide* AND water*	8
11	amenit* pesticide* AND river* OR stream* OR catchment*	1
15	amenit* pesticide* AND pond* OR lake*	1
18	amenit* pesticide* AND groundwater*	3
19	amenit* pesticide* AND estuar*	1
A19	amenit* pesticide* AND aquifer*	1
21	urban pesticide* AND water*	20+
30	urban pesticide* AND river* OR stream* OR catchment*	20+
34	urban pesticide* AND pond* OR lake*	20+
37	urban pesticide* AND groundwater*	20+
38	urban pesticide* AND estuar*	20+
A38	urban pesticide* AND aquifer*	8
40	garden pesticide* AND water*	20+
49	garden pesticide* AND river* OR stream* OR catchment*	20+
53	garden pesticide* AND pond* OR lake*	20+
56	garden pesticide* AND groundwater*	20+
57	garden pesticide* AND estuar*	8
A57	garden pesticide* AND aquifer*	4
59	highway* pesticide* AND water*	1
68	highway* pesticide* AND river* OR stream* OR catchment*	20+
72	highway* pesticide* AND pond* OR lake*	20+
75	highway* pesticide* AND groundwater*	1
76	highway* pesticide* AND estuar*	20+
A76	highway* pesticide* AND aquifer*	20+
78	sport* turf pesticide* AND water*	20+
87	sport* turf pesticide* AND river* OR stream* OR catchment*	20+
91	sport* turf pesticide* AND pond* OR lake*	20+
94	sport* turf pesticide* AND groundwater*	20+
95	sport* turf pesticide* AND estuar*	20+
A95	sport* turf pesticide* AND aquifer*	20+
96	Local authorit*pesticide*	0
98	amenit* horticulture pesticide* AND water*	0
107	amenit* horticulture pesticide* AND river* OR stream* OR catchment*	0
111	amenit* horticulture pesticide* AND pond* OR lake*	0
114	amenit* horticulture pesticide* AND groundwater*	0
116	amenit* horticulture pesticide* AND aquifer*	0
118	hard surface* pesticide* AND water*	20+
127	hard surface* pesticide* AND river* OR stream* OR catchment*	20+
131	hard surface* pesticide* AND pond* OR lake*	20+
134	hard surface* pesticide* AND groundwater*	20+
135	hard surface* pesticide* AND estuar*	20+
136	hard surface* pesticide* AND aquifer*	20+

138	amenit* herbicide* AND water*	12
147	amenit* herbicide* AND river* OR stream* OR catchment*	3
151	amenit* herbicide* AND pond* OR lake*	1
154	amenit* herbicide* AND groundwater*	3
155	amenit* herbicide* AND estuar*	0
156	amenit* herbicide* AND aquifer*	0
158	amenit* surfactant* AND water*	20+
167	amenit* surfactant* AND river* OR stream* OR catchment*	20+
171	amenit* surfactant* AND pond* OR lake*	20+
174	amenit* surfactant* AND groundwater*	20+
175	amenit* surfactant* AND estuar*	0
176	amenit* surfactant* AND aquifer*	20+
178	amenit* insecticide* AND water*	20+
187	amenit* insecticide* AND river* OR stream* OR catchment*	20+
191	amenit* insecticide* AND pond* OR lake*	20+
194	amenit* insecticide* AND groundwater*	20+
195	amenit* insecticide* AND estuar*	20+
196	amenit* insecticide* AND aquifer*	20+
198	amenit* fungicide* AND water*	20+
207	amenit* fungicide* AND river* OR stream* OR catchment*	20+
211	amenit* fungicide* AND pond* OR lake*	20+
214	amenit* fungicide* AND groundwater*	20+
215	amenit* fungicide* AND estuar*	20+
216	amenit* fungicide* AND aquifer*	20+
217	amenit* AND WFD AND "environmental standard*"	20+
219	Mecoprop AND amenit* AND water*	20+
220	Mecoprop AND urban AND water*	20+
221	Mecoprop AND garden AND water*	20+
222	Mecoprop AND highway* AND water*	20+
223	Mecoprop AND sport* turf AND water*	1
224	Mecoprop AND local authorit* AND water*	4
225	Mecoprop AND hard surface* AND water*	20+
227	MCPA AND amenit* AND water*	20+
228	MCPA AND urban AND water*	20+
229	MCPA AND garden AND water*	20+
230	MCPA AND highway* AND water*	20+
231	MCPA AND sport* turf AND water*	2
232	MCPA AND local authorit* AND water*	4
233	MCPA AND hard surface* AND water*	20+
235	2,4-D AND amenit* AND water*	20+
236	2,4-D AND urban AND water*	20+
237	2,4-D AND garden AND water*	20+
238	2,4-D AND highway* AND water*	20+
239	2,4-D AND sport* turf AND water*	13

240	2,4-D AND local authorit* AND water*	20+
241	2,4-D AND hard surface* AND water*	20+
243	glyphosate AND amenit* AND water*	11
244	glyphosate AND urban AND water*	20+
245	glyphosate AND garden AND water*	20+
246	glyphosate AND highway* AND water*	20+
247	glyphosate AND sport* turf AND water*	2
248	glyphosate AND local authorit* AND water*	20+
249	glyphosate AND hard surface* AND water*	20+
	Total	1373+

Index to Theses

Ref	Search String	Hits
1	Amenit* pesticide*	1
2	Urban pesticide*	8
3	Garden pesticide*	2
4	Highway* pesticide*	0
5	turf AND pesticide*	1
6	Glyphosate AND water	14
7	Local authorit*pesticide*	1
8	horticulture AND pesticide*	4
9	Hard surface* pesticide*	1
10	Amenit* herbicide*	4
11	Amenit* surfactant*	0
	Total	36

Appendix II Studies included in the QSR

Studies relating to pesticides currently authorised for use in the UK	Summary
Fletcher, C. A Meakin, N.C., Bubb, J.M., Lester, J.N. (1994). Magnitude and distribution of contaminants in salt marsh sediments of the Essex coast, UK. III. Chlorophenoxy acid and s-triazine herbicides. Science of the Total Environment 155(1): 61-7	Study of surficial sediment samples from the Leigh-on-Sea storm overflow situated near a salt marsh in Essex to evaluate the role of urban run-off as a herbicide source to the Thames Estuary. Three herbicides commonly used in non-agricultural applications were found to contaminate the sediments MCPA, 2,4-D and 2,4-DP (found at mean concentrations of 4.9 ng g^{-1}, 2.0 ng g^{-1} and 2.7 ng g^{-1} respectively). The results of this study were discussed in terms of the potential effects on the aquatic ecosystem in relation to known toxicity levels. However, further work is needed to fully understand the impact of the persistence and residence of herbicides contaminating the salt marshes and the possible combined effects of herbicides on salt marsh flora to draw any firm conclusions.
Lapworth, D. ,Gooddy, D.C., Stuart, M.E., Chilton, P.J., Cachandt, G., Knapp, M., Bishop, S. (2006). Pesticides in groundwater: some observations on temporal and spatial trends. Water and Environment Journal 20(2): 55-64.	Pesticides in 14 shallow boreholes in the Triassic Sherwood Sandstone aquifer of South Yorkshire were investigated. Dicamba was found on more than one occasion at a mean concentration of 0.041 μgL^{-1} below the drinking water standard for any pesticide of 0.1 μgL^{-1}. Dicamba occurrence was related to land use from a golf course.
Manamsa, K., Lapworth, D., Stuart, M. (2011) Investigating organic micropollutants in a peri-urban flood plain aquifer. Priority substances monitoring and occurrence in the environment: Future challenges for PBTs in surface and groundwaters, Dublin 20 Sep	In an investigation of organic micropollutants in a peri-urban flood plain aquifer detected metaldehyde at concentrations exceeding 1 μgL^{-1} in groundwater from the leachate plume of a closed landfill site. Part of the area of made ground was used as allotments.
Ramwell C.T., Boxall, A.B.A.,Hollis, J.M. (2000a) Potential Contamination of Surface and Groundwaters Following Herbicide Application to a Railway. Draft Report Nov 2000. & Ramwell, .T., Heather, A.I.J., Shepherd, A.J. (2004). Herbicide loss following application to a railway. Pest Management Science 60(6): 556-564.	Investigated herbicide application to a railway which included glyphosate and herbicides now banned in the UK. The results indicated that during an ‘average’ rainfall year and when applied to an embankment, herbicides are unlikely to leach into ground or surface waters (atrazine and diuron now banned in UK had the potential to contaminate surface waters under extreme rainfall) and that glyphosate is unlikely to be detrimental to the environment when applied to railways.
Ramwell, C.T., Hollis, J.M., Shepherd, A. (2000b) Herbicide losses from a small urban	A study of herbicide losses from a small urban catchment (car park) found that herbicides differ in their susceptibility to runoff from hard surfaces. Retention by organic matter may influence loss

catchment. Soil Survey and Land Research Centre Report JF4085-2 for the Hard Surfaces Project Consortium 23pp.	of glyphosate and receiving ditch water significantly diluted herbicides that had runoff from the car park. During a short intense rain event concentrations of glyphosate were found above 2μgL^{-1} in receiving ditch water but after 58mm of rain had fallen these concentrations fell to 0.1 μgL^{-1}. It was suggested that these results were because glyphosate is either easily degraded or removed from solution due to retention by sediment in the ditch.
Ramwell, C. T., Heather A.I.J., Shepherd, A.J. (2002). Herbicide loss following application to a roadside. Pest Management Science 58(7): 695-701.	Six herbicides including glyphosate were applied to a 16 meter length of road and kerb edge. Run off was collected in gulley pots until 25mm of rain had fallen. Glyphosate run off was lower than that for atrazine and diuron possibly due to its ability to bind to organic carbon in asphalt. The authors stated that lack of a soil buffer between herbicide application area and drain outfall results in rapid removal of herbicide with the onset of rainfall which can produce short-lived high concentrations of herbicides in drains. In this study a short rain shower fell 6hrs after application (2mm rain in 2hrs) resulting in a peak concentration of glyphosate run off of 650 μgL^{-1}. However, glyphosate run off decreased to 48 μgL^{-1} when rain fell the next day and continued to decline with each successive rain event until after 25mm had fallen glyphosate was detected at c 3 μgL^{-1}. Predicted environmental concentrations were compared to toxicity test data using toxicity exposure ratios. The authors concluded that glyphosate used for weed control on hard surfaces is unlikely to result in any detriment to aquatic species in ditches draining the treated area arising from residual concentrations contained in run off.
Ramwell, C.T., Kah, M., Johnson, P.D. (2014) Contribution of household herbicide usage to glyphosate and its degradate aminomethylphosphonic acid in surface water drains. Pest management science (Early view online version 20 March 2014)	Investigated the contribution of household herbicide usage to glyphosate and its degradate aminomethylphosphonic acid (AMPA) in surface water drains. Whilst maximum glyphosate and AMPA concentrations in surface water drains were high (8.99 μgL^{-1} and 1.15 μgL^{-1} respectively) after the first rain event following the main application period, concentrations rapidly declined thereafter (less than 1.5 μgL^{-1} and 0.5 μgL^{-1}respectively). Less than 1% of the applied glyphosate was recovered in drain water. This study concluded that it is unlikely that losses from residential catchments, following proper usage would contribute significantly to the total glyphosate load in surface waters compared with other urban areas.
ATKINS (2009) Glyphosate source apportionment. Final report for the Environment Agency.	Quantitative assessment of the most significant fluxes of glyphosate and its degradation product AMPA to the aquatic environment of England and Wales based on mass balance calculations. Runoff of glyphosate from urban areas (16%) was predicted to be less than that from agriculture (77%). Other inputs of glyphosate from wastewater treatment works, intermittent discharges, highway runoff and rail amounted to less than 5%. AMPA is also generated via the degradation of phosphonates used in detergents which are degraded during wastewater treatment. It was predicted that over 90% of AMPA entered the aquatic environment via this route and that the contribution from the degradation of glyphosate by comparison was insignificant. Groundwater monitoring reporting less than 0.1 μgL^{-1} AMPA supports the hypothesis that AMPA is a relatively short-lived

	intermediate in the glyphosate degradation pathway and that AMPA is not accumulated in groundwater.
Shepherd, A.J. and Heather, A.I. (1999) Factors affecting the loss of six herbicides from hard surfaces. Report for the Department of Environment Transport and Regions.	Quantified percentage loss relationships with rainfall and physio-chemical properties for three different surface types. Glyphosate and five other herbicides (isoxaben, oryzalin, oxadiazon, diuron and atrazine) were applied to asphalt, concrete and ballast in accordance to amenity label advice. The surfaces were exposed 'natural climate' and different amounts of simulated rainfall applied conditions and run off collected. The interval between herbicide application and initiation of rainfall affected glyphosate loss on asphalt. Losses were greater for a short time lag (6hrs) compared to longer time lags (12, 24 or 168 hrs). Overall, concentrations and subsequent loss of herbicides were highest for concrete followed by asphalt then ballast, with the exception of glyphosate where peak concentrations and losses were greatest for asphalt.
Hollis, J.M., Ramwell, C.T., Holman, I.P. (2004). HardSPEC A first-tier for estimating surface-and ground-water exposure resulting from herbicides applied to hard surfaces. NSRI research report No SR3766E for Defra PL0531 79pp. Plus 3 Appendicies.	This study used experiments designed to explore the fate and behaviour of herbicides after application to build a predictive model for regulatory risk assessment to assist in the approval process of compounds submitted for use in the urban environment.
Ramwell, C. T. (2005). Herbicide sorption to concrete and asphalt. Pest Management Science 61(2): 144-150.	Herbicides sorption was greater to asphalt compared to concrete but there was limited sorption compared to soil. The study showed that the results can be used to predict the behaviour of compounds after application.
Anon (2003) Defra funded project: Quantification of total herbicide losses in urban areas PS220.	Defra funded project: Quantification of total herbicide losses in urban areas PS220. This project was developed to provide educational material relating to weed control in urban areas to improve practice and prevent water pollution. Factors influencing the quantity of herbicides entering the environment during application were identified. Theoretical, but realistic values were given to influential parameters to quantify the extent to which overdosing may occur. The study highlighted the ease with which overdosing may occur if the correct procedures are not adhered to, primarily deviating from values used during calibration of the equipment. Costs were based on a theoretical price of £50 per hectare comparable to prices of Roundup Pro Biactive (£45/ha) and Freeway (£75/ha) both used in the urban environment. It was found that the deviations from the calibrated values do not have to be large for substantial costs to be incurred. For example, if the lance is dropped by only 10 cm and the speed reduced by 15 s per 100m than the extra cost incurred to the operator is over £20 per hectare. To assess the environmental impact a model was used which indicated that for glyphosate, the output rate would have to increase by *c.* 5.5 fold for there to be cause for concern, whilst for isoxaben an increase of 70 times the normal application rate should not detrimental to aquatic organisms. The authors concluded that it is unlikely that deviating from spray procedures detailed in this

	report would result in such a dramatic increase in output. However, for compounds where the predicted environmental concentrations exceeds the threshold in the (Tier 1) model, the correct application rate will be more important to the compound's impact on the environment. The study concluded that financial costs given to overdosing could be used as an incentive to adhere to guidelines which would benefit the environment.
Defra funded project Development of zero and minimal herbicide regimes for controlling weeds on hard surfaces and determining their emissions (PS2802) also known as the Thanet Weed Project)	Testing three weed control measures: 1) Herbicide (glyphosate) 2) Non-chemical weed control using thermal and mechanical methods 3) Integrated weed control using reduces glyphosate input in combination with thermal and mechanical control. The type of weeds and their growth are being measured regularly and drain water is sampled on a regular basis to determine the amount of glyphosate runoff. Costs and lifecycle analysis (CO_2 and CO2e emissions and energy consumption) are also being calculated.
Pesticide Forum (2011) Pesticides in the UK. The 2011 report on the impacts and sustainable use of pesticides. A report of the Pesticide Forum.	Glyphosate has been detected above drinking water standards for all treatments even the non-herbicide treatment areas (possibly due to domestic use) Greater costs are associated with the 'integrated' and non-herbicide treatments. Lifecycle analysis from 2010 indicated that there is a trade-off between reduced herbicide emissions from no herbicide control methods and increased CO_2 emissions compared to herbicide use
Studies relating to pesticides not authorised for use in the UK.	**Author abstracts where available**
Anon (2012). Case study 4. Decreasing impacts of pesticides on groundwater and surface water. Better Thames Network Groundwater Workshop, April 18, 2012 Reading.	No abstract available.
Defra (2012). Observatory monitoring framework - indicator data sheet. Environmental Impact: Water; Indicator DA4: Pesticides in water	When Diuron which is only used in amenity sector was withdrawn from market, there was a reduction in the detection of this pesticide (exceeding WFD standards) in surface waters in England and Wales.
Croll, B. T. (1991) Pesticides in surface waters and groundwaters. Journal of the Institute of water and environmental management 5 (4), 389-395	Diffuse pollution by pesticides, particularly herbicides, has been recognised in the UK for several years. Atrazine, Simazine, Mecoprop, Dimethoate and, more recently Isoproturon and Chlortoluron have been found frequently in surface waters at concentrations up to 0.5 μgL^{-1}, with a maximum of 11.5 μgL^{-1}. Pesticides are detected less frequently in groundwaters, at concentrations generally lower than 0.1 μgL^{-1}. Atrazine is found most frequently. Concentrations in untreated surface and groundwaters have generally been below the maximum recommended for drinking water by the DoE. Concentrations in treated drinking water have not exceeded DoE recommended concentrations, but measures are being taken to reduce concentrations below 0.1 μgL^{-1}.
Davis, A.B., Noble, J., Joice,	A product stewardship programme has been undertaken, involving

R., Banks, J.A., Jones, R.L (1993) A strategy for protecting UK water quality through a concerted diuron stewardship programme. Brighton, Crop Protection Conference - Weeds pp. 375-380.	modifying product use recommendations, education and training for users, improved lines of communication and research on diuron transport mechanisms.
Davis, A.B., Hill, J.C., Higginbotham, S., Jones, R. (1997). Stewarding Diuron within UK amenity areas. The Brighton Crop Protection Conference Weeds 1997 pp. 1099-1105.	An industry-wide stewardship campaign, with an education programme was launched using the theme of 'product placement' and slogan 'the right product, right place, right time'. Bore hole protection schemes and water catchment studies were initiated along with voluntary revision of all labels for diuron containing products.. Levels of diuron in water, as published by the Drinking Water Inspectorate have fallen during the mid 1990s.
Ellis, J.., Revitt, D.M., Llewellyn, N. (1997). Transport and the environment: Effects of organic pollutants on water quality. Journal of The Chartered Institution of Water and Environmental Management 11(3): 170-177.	The eighteenth report of the Royal Commission on Environmental Pollution made no reference to any potential environmental impacts resulting from runoff pollution associated with transport activities. This paper identifies the magnitude and extent of pollution associated with discharges from various transport sources and identifies solids, metals, hydrocarbons, herbicides and de-icing agents as the principal contaminants of environmental concern, The impacts of these pollutants on the receiving mater are reviewed, They are primarily associated with highways which have a high traffic density and herbicides are considered to be the only potential and widespread hazard to groundwaters. Highway and airport runoff are shown to have both acute and chronic effects on biotic diversity and organism mortality rates, although these effects appear to be largely confined to reaches Immediately downstream from the discharge outfalls.
Gomme, J., Shurrell, S., Hennings, S.M., Clarke, L. (1992) Hydrology of pesticides in a chalk catchment: Ground water. Journal of the Institute of water and environmental management 6 pp. 172-17	The paper reports the findings of a two-year programme of groundwater sampling in which supply and observation borehole waters from an English Chalk catchment were analysed for 20 pesticides. A majority of samples contained pesticides. Triazine compounds were widespread at low levels and 2 boreholes with probable connection to steams showed contamination by uron herbicides.
Knapp, M. F. (2005). Diffuse pollution threats to groundwater: a UK water company perspective. The Quarterly Journal of Engineering Geology and Hydrogeology 38(1): 39	UK Water services companies have a statutory duty to supply water compliant with drinking water quality regulations. Twenty percent of Yorkshire Water's supply is from groundwater. Deteriorating groundwater quality has resulted in closure, blending or treatment of sources. Diffuse pollutants of prime concern are Cryptosporidium, nitrate and pesticides. Risk assessments for Cryptosporidium lead to closure of spring sources and installation of membrane treatment for groundwater abstracted from a major chalk aquifer. Upward nitrate trends are observed in many aquifers; the concentration of abstracted nitrate is influenced by water-table level and pumping regimes. Government sponsored schemes to control fertilizer applications have reduced nitrate leaching from soil but not yet affected concentrations in deep well abstractions. Potential pesticide contamination from upland bracken removal has been managed by co-operative agreements with land agents. A major sandstone aquifer has been contaminated by amenity and agricultural pesticides. The implications for the

	water company of diffuse pollution of groundwater are long term resource reduction, less operational flexibility and increased costs. Groundwater monitoring, trend analysis and UK and international experience of cooperative agreements is discussed with reference to the requirement of the Water Framework Directive and associated Groundwater Directive for measures to protect the water environment.
Lapworth, D. J. and D Gooddy, D.C. (2006). Source and persistence of pesticides in a semi-confined chalk aquifer of southeast England. Environmental Pollution 144(3): 1031-1044.	Pesticide contamination in groundwater is an increasing problem that poses a significant long-term threat to water quality. Following the detection of elevated concentrations of diuron in boreholes in a semi-confined chalk aquifer from southeast England, a sampling programme was undertaken. Between 2003 and 2004 diuron was observed in 90% of groundwaters analysed. In 60% of groundwater samples metabolites of diuron were more prevalent than the parent compound. Longer-term (1989-2005) monitoring shows that pollution of the aquifer by atrazine, simazine, and more recently diuron, shows a positive correlation with periods of high groundwater levels. Results from groundwater residence time indicators suggest that the highest diuron concentrations are associated with waters containing the greatest proportion of recent recharge. There is some evidence to indicate that diuron occurrence can be spatially related to areas of urban and industrial development and is probably correlated with amenity usage.
Lapworth, D., Gooddy, D.,Stuart, M.E., Harrison, I., Chilton, P. (2007) Pesticides and metabolites in groundwater: examples fm 2 UK aquifers International Conference on water status monitoring of aquatic ecosystems in the context of the WFD. Lille, France.	Reducing the impact of anthropogenic pollution on groundwater bodies and ameliorating any deterioration of water quality is central to key legislative drivers such as the EU Water Framework Directive and the proposed daughter Directive relating to the protection of groundwater. Pesticide pollution has a direct impact on groundwater quality and an indirect impact on the associated aquatic ecosystems supported by groundwater. There is currently no legislative requirement to monitor pesticide metabolite concentrations in groundwater. Pesticide and metabolite results from two nationally important aquifers are presented, the Trassic Sandstone and the Chalk of Southern England. At nine sites in Kent, Southern England, (60%) metabolites were more prevalent than diuron. Both aquifers are an important source of water, locally supplying up to 80% of public drinking water. The sandstone site has a predominantly arable land use with a potential diffuse source of pesticides although soakaways are possible point sources. The chalk site has a mixture of arable and industrial/urban land use. A significant source has been from excessive applications of diuron ("over-spray") on a number of public amenities. Pesticides from amenity use and diffuse agricultural sources both pose a threat to groundwater quality. Pesticide metabolites are present in significant concentrations in groundwaters. Systematic, long-term monitoring (5-10 years) is required to understand trends in groundwater quality
Revitt, D.M., Ellis, J.B., Llewellyn, N.R. (2002) Seasonal removal of herbicides	The occurrence of two herbicides (diuron and simazine) in receiving surface waters is related to their seasonal applications within an urban catchment. Comparisons of herbicide

in urban runoff. Urban Water 4: 13-19	concentrations within baseflow and during rainfall conditions provide an insight into pollutant transport processes following application to urban surfaces. Two storm events, with different hydrological characteristics, are described. The maximum recorded herbicide concentrations reached 238.4 and 2:23 lg/l for diuron and simazine, respectively, with the former corresponding to an application loss of 45.1% with respect to the diuron recently applied to the urban catchment. The factors influencing the extent of application losses to receiving waters of herbicides applied to urban substrates are discussed.
Tuffnell, N and Britt, C. (2011) Determining the usage and usage patterns of amenity pesticides across the UK. Final report for Chemical Regulation Directorate. PS2806	No abstract available
White, S. L. and Pinkstone, D.C. (1993). Amenity and industrial use of herbicides: the impact on drinking water quality. Brighton Crop Protection Conference, Weeds 363-36	Pesticides, and in particular herbicides, account for the majority of failures to meet the standards for drinking water quality in the UK. Most of these herbicides are used in the non-agricultural sector, including amenity and recreation areas, and industrial sites. In addition to installing new treatment processes, Thames Water has been working with manufacturers, users of non-agricultural herbicides and Government departments to reduce the amounts of herbicides reaching water sources. The aim was to increase awareness of water quality and encourage improved practices in the use and disposal of herbicides. Controlling herbicides at the source resulted in a significant decline in the concn of atrazine and simazine in water sources. However, in several sources there were small but significant increases in diuron concn. The need for further research on the movement of non-agricultural herbicides in the environment is discussed.

Appendix III Selected article summaries from outside the UK

Reference	**Summary**
Botta, F.,Lavison, G., Couturier, G., Alliot, F., Moreau-Guigon, E., Fauchon, N., Guery, B., Chevrevil, M., Blanchoud, H. (2009). Transfer of glyphosate and its degradate AMPA to surface waters through urban sewerage systems. Chemosphere 77(1): 133-139.	Found glyphosate was commonly found at concentrations exceeding European drinking water quality standards in the river sampled. Annual glyphosate load was estimated to be significantly lower in the agricultural zone compared to the urban zone suggesting that contamination of the basin was essentially from urban origin. Glyphosate reached surface waters through the sewer system during rain fall events with maximum concentrations just after rainfall of 75-90 μgL^{-1} detected. The authors suggested

	high concentrations in surface waters during rain fall events reflected urban runoff impact.
K. Lamprea and Ruban, V. (2011) Pollutant concentrations and fluxes in both stormwater and wastewater at the outlet of two urban watersheds in Nantes (France). Urban Water Journal 8(4):219-231	Found that despite a reduction in the use of pesticides in the Nantes, Metropolitan area glyphosate was still detected in stormwater and may reflect its use by homeowners.
Hanke, I., Wittmer, I., Bischofberger, S., Stamm, C., Singer, H. (2010) Relevance of urban glyphosate use for surface water quality. Chemosphere 81(3): 422-429.	Studied glyphosate contamination of surface waters in a small catchment in Switzerland. Water samples from the river system and urban drainage system were investigated. Concentrations at peak discharge during storm events were elevated throughout the year (maximum concentrations of 4.15 μgL^{-1}). Fast runoff from hard surfaces led to a fast increase in concentrations shortly after the beginning of rainfall not coinciding with the concentration peak normally observed from agricultural use. Comparison with agricultural application and seasonal concentrations showed that the occurrence of glyphosate cannot be explained by agricultural use only. Extrapolations from agricultural loss rates and from concentrations found in the urban drainage system showed that 60% of the load during selected rain events originated from urban areas.
Burkhardt, M., Kupper, T., Hean, S., Haaq, R., Schmid, P., Kohler, M., Boller, M. (2007) Biocides used in building materials and their leaching behaviour to sewer systems. Water Science and Technology. London; UK, IWA Publishing. 56: 63-67.	Investigated diffuse pollution of aquatic systems by biocides which main source appeared to be from building envelopes, facades (paints, plasters) and roof sealing membranes. Results from a defined urban catchment drained by a separated sewer system without any agricultural activities revealed that even after the first flush, concentrations of terbutryn, carbendazim, mecoprop as well as Irgarol 1051® and its metabolite exceeded the Swiss water quality standard of 0.1 μgL^{-1}.
Burkhardt, M., Zuleeg, S., Vonbank, R., Schmid, P., Hean, S., Lamani, X., Bester, K., Boller, M. (2011). Leaching of additives from construction materials to urban storm water runoff. Water Science and Technology 63(9): 1974-1982.	Showed that under wet weather conditions biocides used in urban construction found in urban stormwater and receiving waters exceeded Swiss water quality standards of 0.1 $\mu g/L^{-1}$. Using laboratory experiments the authors showed that despite the amount of biocide used, the impact of construction materials containing biocide on water quality is related to age of the building and the separated sewerage network.
Angoujard, G., Godec, N. le., Lefevre, L., Blanchet, P. (2001). Herbicide flow from two types of hard surfaces in urban areas: first results for glyphosate and diuron. Pesticide behaviour in soils and water. Proceedings of a Symposium	Studies of runoff from hard surfaces indicated that low amounts of rainfall (3-5mm) are enough for the leaching of 50% of the total loss of glyphosate from concrete surfaces.

organized by the British Crop Protection Council, Brighton, UK, 13-15 November 2001. Farnham; UK, British Crop Protection Council.	
Beltman, W. H. J., Kempenaar, C., Horst, K. van der. Withagen, A. (2006). How pesticides used on hard surfaces end up in drinking water. DIAS Report, Plant Production (126): 41-46.	Glyphosate runoff is affected by the time taken between application and the first rain event and its use on hard surfaces can contribute to concentrations measured in surface water extracted for drinking
Botta, F.,Fauchon, N., Blanchoud, H., Chevrevil, M., Guery, B. (2012). Phyt'Eaux Cites: Application and validation of a programme to reduce surface water contamination with urban pesticides. Chemosphere 86(2): 166-176.	Presented the results from a programme put in place with the local water supply agency in collaboration with local authorities and the private sector to control urban pesticide applications and reduce surface water contamination. After three years the programme reduced the use of pesticides and an improvement in surface water contamination was seen.
Kempenaar, C., L. A. P. Lotz, et al. (2007). Trade off between costs and environmental effects of weed control on pavements. Crop Protection 26(3): 430-435.	A project was performed in 2002 and 2003 in nine Dutch municipalities on defined urban areas of 5-25 ha. Use of herbicides (mainly glyphosate) was reduced by 11-66% compared to standard practice. Levels of weed control remained good and ecological threshold concentrations in surface waters were not exceeded. Monitoring showed a glyphosate emission factor via the sewage water system of 2% on average. Costs of weed control with the new concept were higher (10-25 %) compared to the standard practice control of weeds (using herbicides) on pavements, but much lower compared to alternative (non-herbicide) weed control systems. The project concluded that this experiment provides a useful framework for finding a good trade off between economical and ecological aspects of weed control on pavements.
Kempenaar, C. and J. H. Spijker (2004). Weed control on hard surfaces in The Netherlands. Pest Management Science 60 (6): 595-599.	Non-agricultural use of pesticides in The Netherlands declined in the period 1986-2001 from 127 000 to 40 000 kg AI per annum. However use on pavements rose from 23% to 50% of the total non-agricultural use. To mitigate this both preventive and curative non-chemical weed control methods were examined. On flat pavements mechanical methods are preferred because they are more effective. Two methods used by municipalities to lower the environmental impact of the use of herbicides on pavements were 1) phase out the use of chemicals on hard surfaces 2) integrated approach in which herbicides are not prohibited, but used only on places and at times when the risk of run-off is below a mutually accepted level. Both approaches can be effective.
Kempenaar, C. and Lotz, L.A.P. (2004).	Research presented includes developing and

Reduction of herbicide use and emission by new weed control methods and strategies. Water Science and Technology 49(3): 135-138.	implementing sustainable weed control strategies for non-agricultural use, developing and improving weed preventive and non-chemical methods and rational weed control on hard surfaces.
Luijendijk, C.D., Beltman, W.H.J., Wolters, M.F. (2003) Measures to reduce glyphosate runoff from hard surfaces; 1 effect of a bufferzone around the drain, Plant Research International.	Field experiments under controlled conditions found that applying a buffer zone around the drain of a sewerage system can reduce the runoff of glyphosate into sewerage system.
Luijendijk, C.D., Beltman, W.H.J., Smidt, R.A., Pas, L.J.T. van der., Kempenaar, C. (2005) Measures to reduce glyphosate runoff from hard surfaces, 2: effect of time interval between application and first precipitation event, PLANT Research International.	Plot experiments under controlled conditions used to determine glyphosate runoff from dry and wet brick pavement. Results found a wet pavement did not result in increased runoff. However, infiltration capacity of the soil under the wet and dry pavements may have been a confounding factor.