VINESCAPES
VINEYARD & WINERY CONSULTANTS

Mitigating Pesticide Use and Preventing Contamination of Water Resources in Viticulture within the Kent Downs AONB

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Background

Viticulture in the UK and Kent

Kent is one of the largest English counties and its varied landscape covers nearly 400,000 hectares. It is considered to have significant importance as a habitat and contains 24 UK Biodiversity Action Plan habitats as of 2012, with categories ranging from grassland to coastland, ancient woods to orchards. Within this, the Kent Downs AONB covers almost 90,000 hectares, contains all of the broad habitats present in Kent and accounts for 22.7% of the county (Kent County, 2012). Geologically, it is mostly comprised of the chalk ridge of the ridge North Downs, part of the Greensand Ridge and the Low Weald and contains 80% of the calcareous grassland that is synonymous with the area (Brennan, 2012). Nevertheless, within the Kent Downs AONB itself, most of the land is intensively farmed or managed with 35% being utilised for arable and horticulture and 31% managed as improved grassland which offers little opportunity for habitat. Kent has a long history of heavy industry including paper mills, chalk quarrying, cement, pharmaceutical, gas works, oil refineries and pesticide manufacturing plants. Although now in decline, these have left a legacy of contaminated and derelict land (Smedley et al, 2004). Subsequently, in these areas the high level of nutrients and contaminants prevent colonisation of native plant species which are sensitive to pesticides and variable fertility (Kent County, 2012).

In the UK from 2014-2018 over 1,980 hectares of land have been established for commercial viticulture purposes, with a further 53 hectares established by hobbyists (English Wine, 2018). The rising temperatures associated with climate change means it is safe to assume that this number is going to increase nationwide and within the Kent Downs AONB. Indeed, the landscape character report carried out by Vinescapes in 2020 identified an additional ~7,160 hectares of land suitable for future viticulture. Vineyards are being established on previous arable and fruit growing farms that would have historically utilised a catalogue of pesticides and chemical fertilisers, some of which are now banned in the UK due to their toxic environmental and human health impacts including those containing arsenic, and lead. This is concerning considering the stability of heavy metals in the soil as they are not degradable.

Viticulture in the UK can be classified under the 'cool climate' umbrella, meaning that growing seasons are characterised by high rainfall, growing season average temperatures between 13-15°C and 850-1389 growing degree days (GDD) on the Winkler Index scale. Due to these factors, viticulturists in the UK rely heavily on both organic and inorganic chemicals to control fungal diseases, reduce weed growth, and increase yields. Vinescapes identified that growers will make between 6-20 applications of pesticide alone throughout the season utilising a range of spraying equipment and rates of application over varying environmental and soil conditions.

Ground and Surface Water

Groundwater is the water found underground in the cracks and spaces in soil, sand and rock. It is stored and moves slowly through geologic formations called aquifers. The rate at which it moves through an aquifer depends on its properties including the size and space within the rock and how well the spaces are connected (UK Groundwater, 2019). Examples of common aquifer materials are gravel, sand, sandstone, or fractured rock, like limestone. Groundwater is typically replenished naturally by rain and discharged into waterways including ditches, streams, rivers and the sea or can be extracted for drinking water or industrial use via wells.

Groundwater is of particular importance within the South East of the UK and areas of Kent as the chalk aquifers are considered highly productive and supply between 75-100% of groundwater designated for public use as seen in Figure 1 (British Geological Survey, 2015). These aquifers are particularly susceptible to leaching nitrates and pesticides introduced by agriculture.

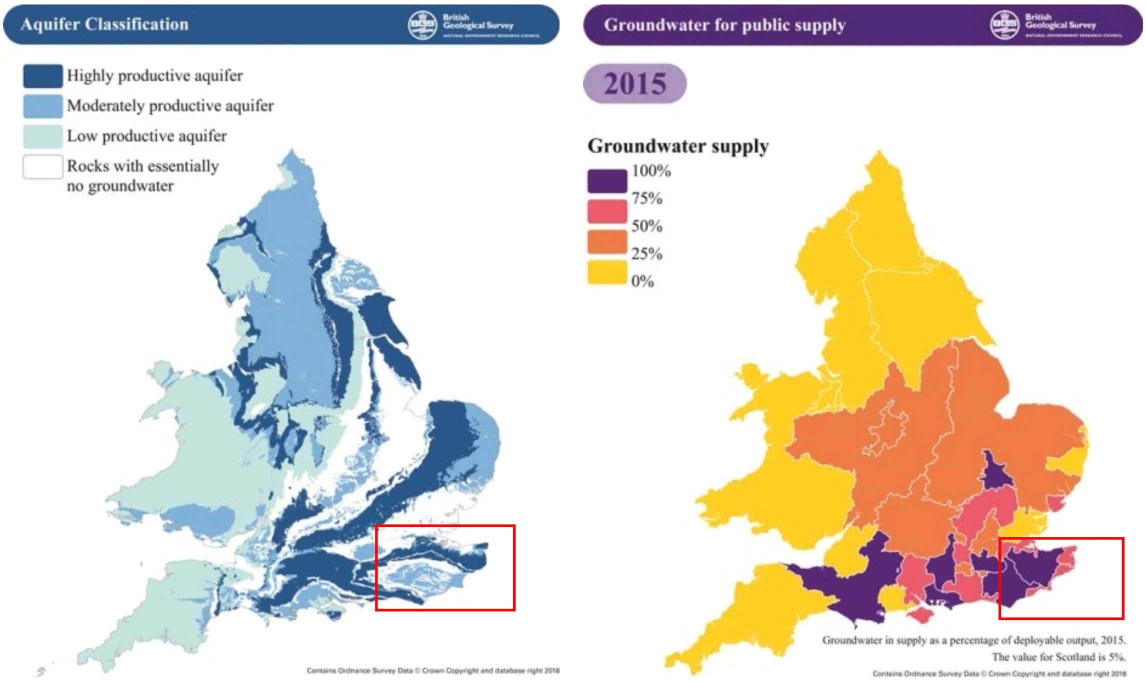


FIGURE 1 AQUIFER CLASSIFICATION SHOWS THE NORTH AND SOUTH DOWNS AREAS AS HIGHLY PRODUCTIVE AND GROUNDWATER FOR PUBLIC SUPPLY SHOWS BETWEEN 75- 100% EXTRACTION OF GROUNDWATER IN 2015 FROM THE SOUTH EAST OF ENGLAND, INCLUDING KENT. (BRITISH GEOLOGICAL SURVEY, 2015)

Surface water is the water found above ground in the form of rivers, streams, lakes, reservoirs, and oceans. It is replenished by rain and is decreased by evaporation and seepage into groundwater (CDC, 2009). In the UK climate change is expected to increase bursts of heavy rainfall leading to severe risk of damage to communities and ecosystems from surface water flooding (Committee on Climate Change**,** 2018). Annually, damage to communities from surface water flooding in the UK totals over £300 million with this amount expected to increase by 40% to 2050 if efforts are not made to mitigate this (Committee on Climate Change, 2018). Additionally, the risk is multiplied with the increase of impermeable surfaces including tarmac and paving through urbanisation of the countryside and the inability of existing and new drainage systems to cope with the overload (Committee on Climate Change**,** 2018).

Ground and surface water are protected resources under the EU Water Framework Directive 2000/60/EC and the Environment Agency Drinking Water Protected Areas Safeguard Zones **(**DrWPAs). Within the DrWPA scheme the Environment Agency has worked with local water supply companies to assess the risk of ground/surface water pollution, identify the specific pollutants as well as designate nitrate vulnerable zones (NVZ) in the UK. The aim is to protect drinking water and ensure that it is not being polluted with substances requiring it to undergo additional treatment to be safe for human consumption (Environment Agency, 2019).

It is clear that there are many schemes and initiatives in place to protect ground and surface water and prevent pesticide leaching and run-off within the UK and although there is a lot of information available it is questionable whether this is easily accessible or has direct actionable recommendations for the relevant stakeholders involved. However, with the broad range of agricultural industries and diversification into new industries like viticulture, there needs to be a shift to regional and/or sector specific protection schemes that tailor to the local industrial environment. This is where a viticulture specific Environmental Land Management scheme would be transformative as the ability to catch a new industry on the rise and implement best practice is unique. Conducting research with a view to protect the future of the community and using this as the foundation for land management schemes will ultimately gain significant ground compared to having to change habits in established sectors.

Types of Water Pollution

Soil, surface water, and groundwater may become contaminated with hazardous compounds because of natural activities (geologic erosion and saline seeps) and human activities (industry, agriculture, wastewater treatment, construction, and mining). Although arguably, natural events like erosion often go hand in hand with human activities like land cultivation and urbanisation. Contaminants include both organic and inorganic compounds comprising of heavy metals, nitrate, phosphate, inorganic acids, and organic chemicals from sources including waste materials, explosives, pesticides, fertilizers and pharmaceuticals (Arthur et al., 2005).

Within the EU, statutory drinking water limit for a single pesticide is 0.1 µg L^{-1} and 0.5 µg L^{-1} for total pesticides present and in the 2018 Water Inspectorate Report, there were 36 areas in the UK meeting the limit for pesticides glyphosate, metaldehyde and propyzamide. Even historically banned substances are entering the water system with oxadixyl, a fungicide used in potatoes for downy mildew, expecting to be detected above the legal limit in Jersey surface water until 2025 (Baliwick Express, 2020) and recently detected in levels over the limit in Severn Trent in 2019 via a contaminated borehole despite the substance being banned in 2003 (Chief Inspector, 2019). This illustrates the long-term effects of pesticides contamination on the water supply in the UK.

Point source pollution relates to industrial effluents and the U.S. Environmental Protection Agency (EPA) provides a brief definition as “any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack.” In viticulture, point source pollution originates from improper storage, handling, mixing, and cleaning areas for pesticides, fertilisers, and fuel.

Non-point source pollution results from run-off following rainfall when contaminated water and sediment moves over the ground and into local water courses. For example, off-target losses onto surrounding vegetation and soil which is carried to water sources after heavy rain. Because the pollutants can come from many places, the total amount of pollutant injected into the ecosystem may be higher than in point-source pollution, although the concentration will be lower.

Erosion is linked to non-point source pollution and it is expected to increase globally via dry (wind) and wet (rain) conditions because of climate change. Within agriculture this is generally through water run-off from heavy rains and the sector typically accounts for 75-95% of land erosion and effects up to 76% of farmland in England (Avery, 2012). Diffuse pollution from agricultural sediment and surface water run-off has been identified as the greatest contributor (66%) to groundwater contamination in England (Avery, 2012).

Non-point and diffuse pollution are the most likely to occur in viticulture and therefore it is these areas that this review will focus on, with particular attention paid to the role of cover-crops in preventing surface water run-off, spray drift as well as bio- and phytoremediation of the soil with the aim to protect clean and plentiful water within the Kent Downs AONB.

Pesticides in Viticulture

Grapes receive the highest rate of synthetic pesticides than any other crop at an average of 2g of pesticides to every 3kg of grapes harvested (Pesticide Action Network, 2008). Additionally, a 2008 study into contents in wine showed that chemicals sprayed in vineyards persist in wine at levels often above the legal limits set for drinking water with fungicide pyrimethanil (Scala) exhibiting 85% transfer rate into the finished product (Pesticide Action Network, 2008).

Pesticides, except herbicides, are typically applied within the vine canopy. However, there are multiple pathways which can lead to contamination of the environment and the soil. This includes ground and air deposit through mist from sprayers where small droplets drift into the air or large droplets bounce/shatter from the leaf surface (Allagui, Bahrouni and M'Sadak, 2018).

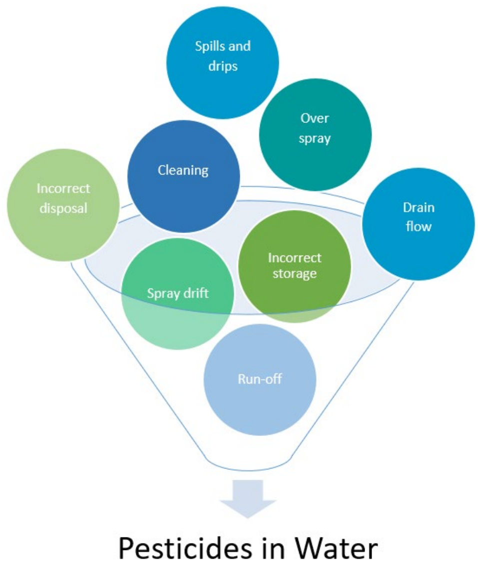


Figure 2 Pathways of pesticide contamination in viticulture including point and non-point sources

Figure 3 Vine shoot after bud-burst showing small target area for pesticides (Hambledon Vineyard, 2013)

Pesticide retention and ground deposition rates are related to sprayer equipment, the pesticide formulations and the climatic factors during and following a spray application (Allagui, Bahrouni and M'Sadak, 2018). Off-target losses can be costly and are usually mitigated through equipment calibration, spray formulation, timing and weather monitoring as well as operator training. However, even with all measures reasonably accounted for, there is still a risk on environmental contamination with each spray application. Technology has evolved even in the last 10 years to reduce off-target losses including spray adjuvants and electrostatic, low drift and low volume spray machines. However, viticultural sprays start as early as bud burst, meaning the target area is very small within the first few months of the growing season, ultimately increasing the opportunity for off-target losses.

Heavy metals have been used in commercial pesticides for generations and the most common are classified as potentially toxic elements (PTEs) which includes zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and mercury (Hg) (Nicholson and Chambers, 2008). Although serious health problems in humans and animals occurring through ingestion of Cd, Pb, As, Cr and Hg have seen many of these banned in the last century. Soil properties such as pH, and texture also affects pesticide properties and mobility across a range of geography and their leaching losses and plant uptake are small in comparison to the total amounts applied in agriculture (Nicholson and Chambers, 2008). Nevertheless, heavy metals will slowly accumulate in the topsoil leading to phytotoxic effects on plants, interference with microbial processes including nitrogen fixation as well as transfer of zootoxic elements to humans and animals through crop uptake or livestock grazing (Nicholson and Chambers, 2008).

Whilst the chemical pesticides that are permitted in viticulture in the UK pose low-moderate leaching risks, the run-off from incorrect spray application or heavy rains post application due to slopes and watercourse proximity, incorrect disposal and drift can lead leaching in the soil and water. Although it is now banned in the UK as of 2020, the use frequency of metaldehyde (Gusto 3) in viticulture is unknown and its polar nature means that it cannot be removed through typical carbon filtration practiced at most water treatment facilities, meaning it ended up in drinking water.

Glyphosate (Round Up) is widely applied in many agricultural settings, including viticulture to control a broad spectrum of weeds. Although it is has a low leachability potential and is classified as non-persistent, it is the metabolite aminomethylphospnic acid (AMPA) that is persistent, soluble and has a high rating for particle bound transportation meaning it can be transferred easily from the soil to the air and into water (University Hertfordshire, 2020). There is increasing research into this area and in 2019 one of the UK's most widely used fungicides chlorothalonil was banned due to potential toxic effects of metabolites in groundwater as well as effect of aquatic life and bees (The Guardian, 2019). This shows increasing awareness, recognition, and regulatory action into the effects of breakdown products and the leaching potential of widely used pesticides that were once considered safe.

Nitrate and phosphate contamination of water through leaching of chemical fertilisers through the soils has also been well documented and has serious human health and environmental effects including 'blue baby syndrome' (World Health Organisation, 2020) and eutrophication which causes dense plant growth and premature ageing of the water system, decline in aquatic ecosystems and potential production of cyanobacteria and release of toxin β-N-methylamino-l-alanine (BMAA). Concerningly, this toxin has been linked to neurodegenerative diseases including Parkinson's and Alzheimer's through environmental exposure. Cyanobacteria are also consumed by fish and other aquatic creatures with studies finding BMAA in seafood, even leading to suggestions that people living in certain locations and those with particular diets are more at risk (Discover Magazine, 2011).

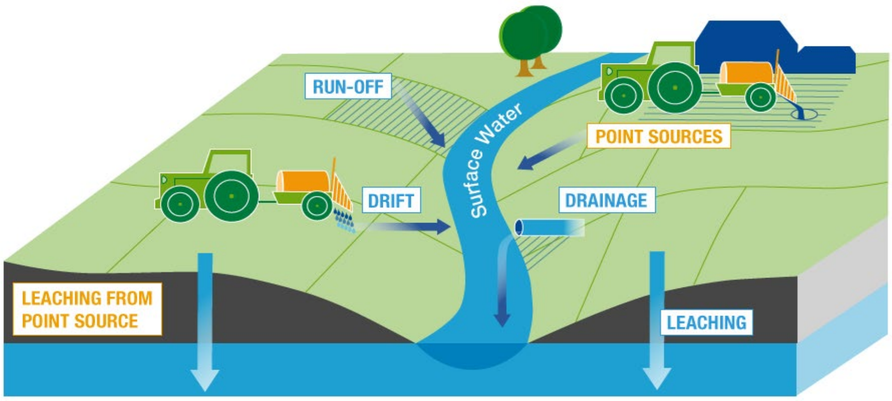


Figure 4 Representation of the ways ground and surface water can be contaminated through point and non-point source pollution in agroecosystems (BASF, 2020)

In viticulture chemical fertilisers can be applied to the soil (pre-planting) or as a foliar feed via a range of sprayers after the vines have been established. Those most used are very soluble forms of nitrogen (N) and phosphorous (P) which are designed for use in climates where rainfall averages <600mm per year. Although it is classified as drier than other regions in the UK, Southern England had a long-term average rainfall from 1981-2010 of 793.9mm annually (Met Office, 2020). Additionally, the area is subject to high rainfall in winter and early spring which can lead to flooding due to soil saturation. Summer thunderstorms and flash flooding are also common with the most recent storms in Kent in August 2020 predicted to bring up to 30-40mm in 1 hour (Kent Live News, 2020).

Concerns over pesticide and nitrate leaching in the UK led the Environmental Agency to establish the Drinking Water Protection Areas and to designate potential Nitrate Vulnerable Zones (NVZ) and Drinking Water Safeguard Zones (surface and groundwater) with specific regulations on the use of chemicals. The chalk bedrock and Greensand in the Kent AONB aids leaching as water and contaminants can easily percolate into the aquifer. The online safeguard map provided by the Environmental Agency is a useful tool which can be used to identify areas at risk of ground/surface water pollution and nitrate leaching. An example can be seen in FIGURE 5 where the highlighted area shows the Medway Catchment in Kent and identifies multiple nitrate vulnerable zones and drinking water safeguard zones in relation to ground and surface water.

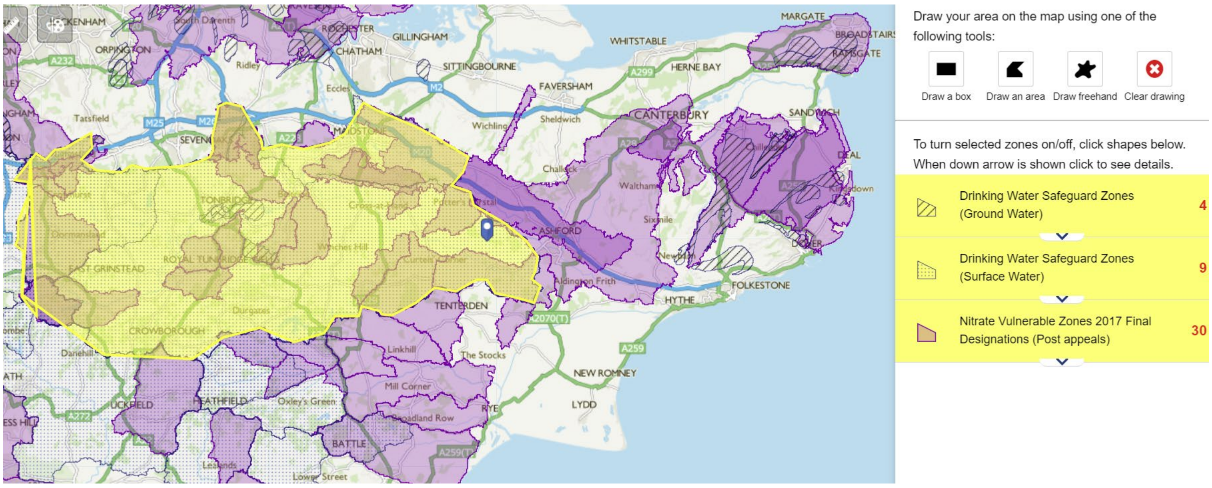


Figure 5 Example of Drinking Water Protection Areas online tool which shows drinking water safeguarded and nitrate vulnerable zones within the Medway Catchment in Kent. Within the area there are 30 NVZs and 13 DWSZ (Environmental Agency, 2020).

The WineGB Sustainable Wines accreditation is a landmark scheme which provides a framework to protecting the environment. The quarterly bulletins also cover various aspects of viticulture and winemaking including Integrated Pest Management (IPM) and biodiversity. Additionally, although there are fact sheets and advice linked through the Voluntary Initiative, this is tailored towards livestock and arable farmers and there is no information available within the tool which would advise viticulturists of alternative chemical treatments or practice which would mitigate pollution of water in these areas. It is tools like this that should be widely publicised within the agricultural sectors in Kent, ultimately leading to better understanding and practice within the industry. However, there must be sector relevant best practice advice and funds accessible, so users are able to take direct action based on this information.

The use of heavy metals copper and zinc as fungicides in viticulture is common, with the widespread application of copper oxychloride and mancozeb (combination with zoxamide or bethivalicarbisopropyl). As of 2020, both are legally permitted in conventional systems in the UK to treat downy mildew (*Plasmopara viticola*) and have been identified as having general antimicrobial effects and serious long term implications on soil fertility, soil microbes and crop growth (Nicholson and Chambers, 2008). Copper has other indirect effects on plant growth through mineralisation inhibition of N and P.

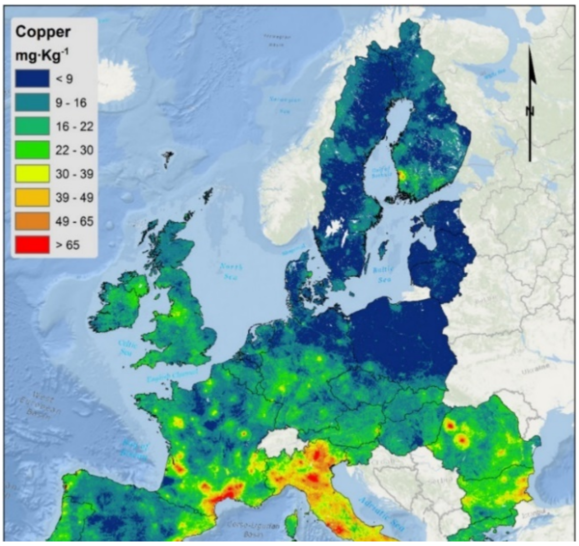


Figure 6 Map of copper concentration (mg-kg-1) in topsoil within the European Union (Europa EU, 2018). Hotspots can be seen in the south of France and throughout Italy where there are high density of vineyards and olive groves. As of 2018, Italy and France produced the highest amount of wine in the world at 54.8 and 49.1 million hectolitres respectively (BK Wine Magazine, 2018). France and Italy were also in the top 3 of highest pesticide purchases in 2016 (Eurostat, 2020)

Copper toxification of soil is a major concern globally and in the EU, the highest Cu concentrations are found in wet areas that experience frequent fungicide treatments which incorporates the South East of England. Within this, vineyards were found to have three times the average Cu concentration in the soil with 49.26 mg/kg compared to the overall average of 16.85 mg/kg. This was followed by olive groves (33.49 mg/kg) and orchards (27.32 mg/kg)

(Europa EU, 2018). A map showing the copper concentration of topsoil in the EU can be found in FIGURE 6 with the South East of England showing between 22-30mg/kg of Cu in the topsoil.

Although effects of copper toxification on grapevines and on drinking water for humans is limited, it is the effect on soil and aquatic ecosystems which is of the most concern. Earthworms are important for generating organic matter which adsorbs pesticides as well as reducing soil compaction which relieves erosion risk. Studies have found significant reduction in fertility, abundance and avoidance to soils spiked with heavy metals including field trials using copper oxychloride (Moboeta et al, 2003). Other studies show that they exhibit toxic responses in soils where the concentrations are as low as 9-16 mg kg^{-1} (Van Zwieten, Stovold and Van Zwieten, 2007). A little understood but expanding research area is the role of subterranean fauna in the water cycle. For example, stygobites are groundwater invertebrates which are very susceptible to human activity.

Fish and crustaceans are exposed to copper through diffuse pollution and they are 10-100 times more sensitive whilst algae are 1,000 times more sensitive to its toxic effects compared to mammals although the hard water coming from chalk aquifers in Kent offers toxicity protection due to higher levels of calcium ions (Solomon, 2009). Nevertheless, other serious impacts which are not mitigated by hard water include interference with fish olfaction leading to reduced ability to feed, intake of food and ultimate decline in health and population. This means that although Cu is not directly toxic to fish, it has other indirect effects which contribute to their overall health. Other noted effects of Cu at environmentally realistic concentration between 10-20 µg/L caused impairment to reproduction of sea scallops, minnows, and several species of adult fish. This is important when considering the role of different fish in balancing the food chain whether predator or prey and the role of the fishing industry in supporting the community in Kent. As of 2020, there were 80 full-time and 120 part-time fishing vessels operating out of Dungeness, Folkestone, Ramsgate, Whitstable and Queenborough (In Your Area, 2020). Further to this, of the fishing vessels registered at the Port Authority of Hastings the overwhelming majority is <10m which suggests that these are small to medium sized community enterprises rather than large national/international commercial ventures. Taking this into consideration along with the effects of BMAA on humans outlined earlier, it highlights the importance of a holistic view on pesticide input in viticulture and the potential negative effects on the ecosystem, economy, and public health within Kent if diffuse pollution mitigation steps are left unchecked.

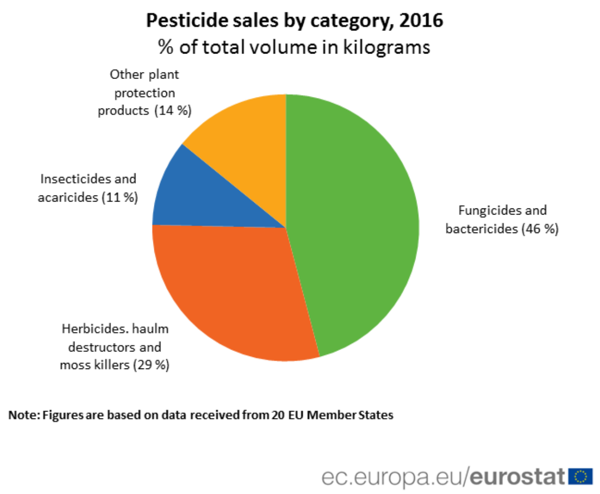


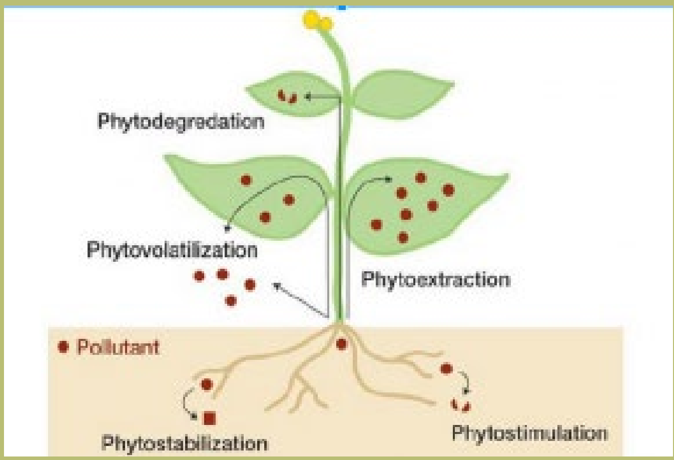
Figure 7 Pesticides sales by category in the EU in 2016 (Eurostat, 2020)

Between 2011 and 2018, sales of pesticides within the European Union remained stable at 360,000 tonnes per year (Eurostat, 2020). Within this, fungicides and bactericides were the top selling group followed by herbicides contributing to 46% and 29% of sales in 2016, respectively. This is a key finding as it demonstrates agriculture's reliance on pesticides and their widespread application even with the negative media attention and increasing awareness of their adverse environmental and human health effects within consumers.

Recommendations

Phytoremediation

The occurrence of pesticides in soil and water has led to the novel and innovative use of plants to decontaminate land termed phytoremediation. The technique has been gaining traction globally due to the multitude of plant species across the world coupled with its ease of implementation. Phytoremediation can be done indirectly or directly by providing either physical barriers or utilising plant metabolism to remediate contaminants in the environment through several complex mechanisms. FIGURE 8 outlines the ways in which plants can transform contaminants in the soil.



Phytodegradation involves uptake and breakdown of non-volatile substances within the plant leaves and stems.

Phytovolatilisation is the transformation of a toxic substance within the plant with the transformed non-toxic chemical released through the leaves via evapotranspiration.

Phytoextraction involves the removal and transformation of a toxic contaminants in the soil into a substance that is no longer toxic within the plant. This can be done through uptake by the roots and enzymatic modification within the plant. It is important that the plant can translocate the substance from root to shoot.

Phytostabilization focuses on reducing mobility of heavy metals and other contaminants within the soil by root accumulation or rhizosphere immobilisation. Microbial activity and addition of soil amendments may also aid the degradation of pesticides which prevents leaching and diffuse pollution.

Phytostimulation is a synergy with *biodegradation* of chemicals by root-living arbuscular mycorrhizal fungi. This can also include the degradation of substances in the soil through release of enzymes from the plant roots, also termed *rhizodegradation*.

Figure 8 Pathways of phytoremediation in plants. Picture taken from Debating Science (2013)

At present, approximately 400 plant species with the ability to uptake high quantities of heavy metals and store them in their stems have been identified. These include plant families *Asteraceace, Brassicaceae, Caryophyllaceae, Poaceae, Violaceae* and *Fabaceae*. *Brassicaceae* alone has 87 species which are classified as hyperaccumulators (Ghosh and Singh,2005).

Phytoremediation is especially suited for large scale sites where land removal is not possible and sites with low input or concentrations of contaminants for "polishing effect" to maintain soil health despite the need for pesticide application (Schnoor, 1997). It has been promoted as having low capital and operational costs which can be further offset by targeting low impact energy crops for bio-fuel (Arbor, 2015). This is a significant incentive which would not only generate further income for landowners, but also put viticulture on the map as a leader in innovation in the fight against climate change and fossil fuel substitution. This is especially pertinent when considering that vineyards only occupy 20-30% of the land area used for planting, with essentially 70-80% of the land not generating income or providing any significant contribution to the ecosystem services within the area.

Plants selected for phytoremediation should be able to outcompete weeds, generate high biomass (>3t/acre), possess a vigorous root system, hyperaccumulate target contaminants as well as tolerate environmental stress conditions including human input of chemicals (Arbor, 2015). It is this last point which leads the review away from native chalkland plant species in Kent due to their sensitivity to increased fertility and chemical input. Nevertheless, there is still opportunity investigate other, more hardy native plant species and grasses and even those typically classified as 'weeds' for their phytoremediation effects. Indeed, Prabakaran et al., (2019) investigated the use of invasive species for remediation of contaminated land due to their ability to adapt uninhabitable environment. It must be noted that introduction of invasive species is not recommended in the Kent Downs AONB however, if there is a way of managing already present invasive species for beneficial outcomes, this should be investigated.

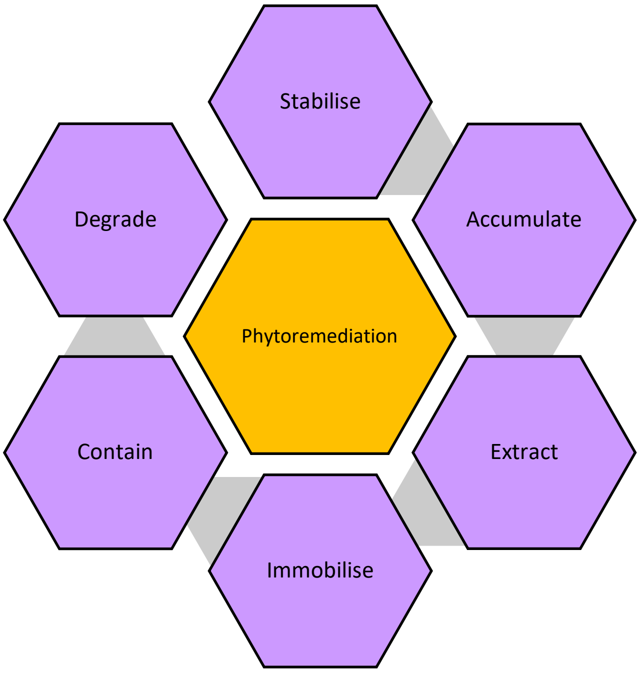


Figure 9 Six overarching goals of phytoremediation implementation to prevent pesticide comtamintation of water.

Although the portfolio of permitted pesticides in viticulture as of 2020 is relatively limited (45 total), the usage of chemicals to protect grape quality and vine health is widespread, with even organic producers using heavy metal containing fungicide copper oxychloride to control downy mildew infections. Demand for organically grown wine is also on the rise, meaning that although herbicide and insecticide input in these vineyards is eliminated, reliance on copper formulations to control downy mildew in wine grapes is likely to grow too as more vineyards adopt organic practices and resistance to synthetic fungicides increases.

Figure 10 Indian Mustard (Brassica juncea) used as a winter cover-crop in a vineyard in Sonoma county California (West Wines, 2015)

Although it is not a native species, there are reports of vineyards utilising Indian Mustard (*Brassica juncea*) as a winter cover crop in the vine rows to prevent erosion as well as provide organic matter and insect habitat (FIGURE 10). This crop species has also been identified as a potential copper hyperaccumulator, providing a barrier to protect toxification of soil and watercourses.

A wide array of research investigating the use of phytoremediation in agriculture spans many different plant species, continents and sectors particularly due to the low capital investment and operational costs paired with high potential benefits gained from a financial, environmental and social responsibility perspective.

Plants have been used in in vineyard studies to remediate toxic levels of Cu and De Conti et al (2018) showed that inter-cropping in vineyards with native Brazilian grass species *Paspalum plicatulum* and *Axonopus affinis* was an effective way to promote the growth of young grapevines in comparison to a monocropping scenario. This was principally due to reduced Cu bioavailability even in moderate and low levels (40mg Cu kg^{-1}). They concluded that maintaining native grasses was beneficial and helped contribute to soil protection, nutrient cycling and reduced intervention in the production system (FIGURE 11).

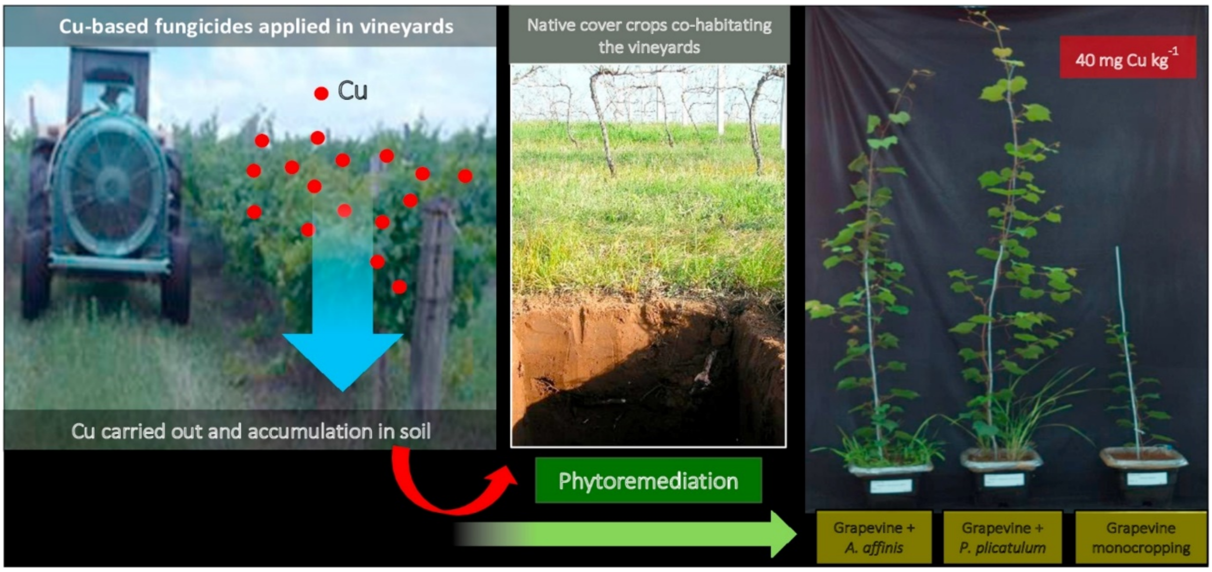


Figure 11 Representation of the ways Cu can be introduced into vineyards and the differences in growth between young grapevines grown with native grasses compared to monocropping situation (De Conti et al., 2018)

Species from the plant family *Asteraceae* have also been identified as suitable candidates for removal of pollutants from soils in urban areas due to their hyper accumulative nature (Nikolić and Stević, 2015). In viticulture, Andreazza et al, (2015) analysed the nutrient uptake, copper phytoaccumulation, translocation factor (TF), and bioaccumulation factor (BCF) after 57 days in *Asteraceae* family sunflower (*Helianthus annus L.*) and concluded that increase in the BCF suggested it could be used for remediation of copper contaminated vineyard soils. Although these results are promising and sunflowers can potentially be used as pre-planting remediation in contaminated soils, their use in established vineyards is unlikely due to their height and water requirements which will increase disease pressure and competition for resources (light, water, nutrients) with the vines, but they will also make the vineyard rows unworkable. In fact, other low growing (<1m) *Asteraceae* species may be preferable in this instance and within Kent there are several native species which could be included as part of a test and trials research programme for removing copper from soils.

Under vine cover-crops in vineyards have also been investigated as an alternative for herbicide use by outcompeting weeds, controlling soil erosion and leaching as well as balancing vine vigour by reducing available water. Studies in United States show a disparity in results with regards to vine health with researchers in New York state concluding that under vine cover crops can produce better balanced vines whilst reducing management costs nitrate leaching (Vanden Heuvel, 2017). Whereas researchers in Pennsylvania also demonstrated a signification reduction in nitrate leaching compared to the herbicide treatment, but a financial loss due to reduction in yields and vine size (Centinari, n.d.).

It can be suggested that under vine as well as interrow cover crops should be considered as part of a phytoremediation strategy to prevent nitrate leaching however, there must be investigation as to the suitability of the plant species as to not detrimentally affect vine health.

Cover-crops can be divided into 3 categories:

1. Temporary annual grasses (barley, annual ryegrass, vetch)
2. Permanent reseeding annual grasses and legumes (perennial ryegrass, timothy, white clover)
3. Perennial grasses and legume (tall fescue)

Each of the categories calls to be managed in a different way and will provide different remediation outcomes. This means there should be clear recommendations and information available to growers, which means investment into research. An example of this can be taken from USDA factsheet for Napa Valley where a toolkit for using plants to prevent soil erosion and water contamination in vineyards is available open access with specific seed mixes recommended (Blake, n.d.).

Although there is ample opportunity within viticulture to utilise phytoremediation, there are few investigations – apart from copper toxification – and none in the UK which signals a need for research into this area. Looking at the major risks associated with pesticide and nitrate contamination to water sources and the effects of climate change on the water system, implementation of research studies through test and trials to identify native species for use as an Environmental Land Management scheme for viticulture is pertinent. TABLE 1 provides SWOT analysis highlighting several advantages and limitations that should be considered.

The Power Plants research initiative carried out at the former site of the White Bay Power Station in Rozelle, Sydney, Australia is a prime example of collaborative phytoremediation for public goods (Power Plants, 2018). The project gained lots of media attention, public recognition as well as producing an award-winning film and gaining an AILA award for landscape architecture design. Further information can be found on the Power Plants website however, it is suggested that this project is used as a framework for phytoremediation trials in viticulture within the Kent Downs AONB.

Rural Sustainable Drainage Systems

Figure 12 Examples of Sustainable Drainage Systems used in urban developments to prevent flash flooding and erosion as well as treatment of water before it enters watercourses (Hydrologia Sostenible, 2020)

Traditional drainage systems discharge large quantities of water into lakes, rivers, streams and estuaries without treatment and the need for reducing peak storm flow in urban areas has been identified using Sustainable Drainage Systems. These systems have proven effective and incorporate soft engineered buffers to collect, store and clean the water before releasing it into the environment. Examples of these can be seen in Figure 12.

Unfortunately, this has not been widely adopted in agriculture (Avery, 2012) although Scottish government has a rural payments initiative which comes under its agri-environment climate scheme and covers establishment of swales, wetlands and ponds. Examples of payment amounts can be seen in Table 2 in the Appendix. Information and design guides are freely available through other NGOs and governmental bodies including Scotland's Centre for Expertise for Waters (CREW) which has developed a practical design and build guide for farmers in partnership with Abertay University (Table 5, Appendix) These resources and access to funding are essential to get farmers and viticulturists on board in protecting watercourses.

Due to the position of diffuse pollution as the main contributor to ground and surface water contamination, implementation of RSuDS to treat water and prevent erosion within viticulture should go hand in hand with phytoremediation strategies. Keeping soil on the farm or in the vineyard is not just beneficial for landowners, it is also beneficial for the community and DEFRA estimated that 2.2 million tonnes of soil are eroded every year with a cost of £45 million to tax payers and production loss of £9 million (DEFRA, 2009). Water companies also spend heavily on removal of pesticides, increasing the cost of water in the community. For example, removal of metaldehyde from drinking water by Anglian Water required £600 million to build the treatment centre with an additional £17 million to operate per year, equating to 21% increase in water bills (Ibrahim et al., 2019).

However, it must be noted that direct uptake by plants is most efficient within the rootzone which limits the ability for the technique to improve water quality below this level. Nevertheless, it is an effective barrier to erosion preventing leaching, run-off and future issues relating to pesticide contamination of local water sources which is a major consideration in the face of hydrological alterations due to climate change.

Rural Sustainable Drainage systems (RSuDS) can be developed to control contaminant delivery with focus on interception. The categories include sediment traps, swales, wetlands, infiltration basins and woodland shelter belts. Within these, there is ample opportunity to employ a range specific plants that would act as barriers and remediators within the ecosystem. Again, these above ground drainage designs are cost-effective and simple to implement and within the scope of ELM, it is an attainable goal which can be monitored effectively.

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SWOT Analysis

Table 1 SWOT analysis of phytoremediation and RSuDs an as ELM scheme to protect water resources from pesticide and nitrate leaching in the Kent Downs AONB

STRENGTHS	WEAKNESSES
• Applied *in situ*	• Management of plant matter after phytoremediation
• Do not need expensive equipment or specialists to implement	• Limited research into UK native species and ability to remediate or effects on vine health – will need further development
• Cheaper than conventional remediation	• Uncertainty on bioavailability of pollutants
• Simple to install trial plots in vineyards	• Potential to introduce an invasive species
• Easy to maintain in practice	• Potential for contaminants to enter food chain
• Easy to access materials, seeds and plants	• Uncertainty on the possible negative effects to wine quality
• Socially accepted	• Restricted to sites with low contamination
• Ties in with Environment Agency, EU and governmental water protection schemes as well as Biodiversity Action Plan	• Potential to harbour vine pests or increase disease occurrence
• Fast establishment	• May need additional fertilisation
• Competition for weeds and reduced herbicide input	• Needs to be resistant to traffic injury
• Cover-cropping already practiced by some viticulturists	• Single species plantings can encourage pests and pathogens
• Lots of research being conducted globally and frameworks to follow	• Cannot remediate groundwater that is already contaminated
OPPORTUNITIES	**THREATS**
• Provides education and research	• Lost traction due to lack of research and funding
• Can be applied as part of a long term “polishing effect” strategy	• Improperly conducted research trials which yield unreliable results
• Aids biodiversity by providing habitat and contributes to public goods	• Potential to introduce or harbour vine pest species within the plants
• Wide adoption by viticulturists due to access to funding and ease of implementation	• Potential negative effects on vine health and vineyard profitability
• Potential remediation of historic/future land and water contamination	• Lack of actionable information available for stakeholders to implement techniques
• Demonstrate innovation and dedication to environmental sustainability	• Lack of understanding or concern for pesticide and nitrate contamination of water resources
• Implement best practice early within a young and burgeoning industry	• ‘Stuck in our ways’ landowners who don’t want to try new techniques

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Practices for Viticulture And Potential Research Areas

Practice	Method	Justification
Hyperaccumulators for pesticide remediation	Interrow planting of hyperaccumulators to prevent pesticide and nutrient leaching into ground water and stabilise chemicals that could run-off into local water sources.	It is unrealistic to suggest complete disuse of pesticides in viticulture in the UK due to the cool and wet growing conditions. Instead, there is opportunity to take advantage of the unused land to support the WFD and DrWPA initiatives as well as wider Biodiversity Action Plan.
Surface stabilising plants to prevent erosion and diffuse pollution	Interrow planting of species which will work to stabilise topsoil and prevent wind and water erosion.	Prevent particle bound transport of pesticides and nutrients to water sources which are major aspects of diffuse pollution in agriculture. These plants can be permanent or seasonal and incorporated as part of a wider RSuDS strategy.
Organic matter (OM) generating plants to adsorb pesticides and reduce chemical fertiliser input	Interrow planting of species targeted for delivering green mulch and regeneration of OM and nutrients.	Reduce the need for chemical herbicides and fertilisers. Green mulch will suffocate weeds and provide habitat for small mammals and insects. Organic matter from the breakdown will also adsorb heavy metals like copper, preventing it from contaminating the soil and water system.
Winter and early season biomass generating plants to reduce off-target pesticide losses and leaching	Interrow planting of winter and early season biomass generating plants to prevent pesticide and nutrient run-off during heavy rains in winter as well as off-target pesticide losses into the soil and spray drift early in the season when vine canopy is small.	Winter and early spring rains are largely responsible for pesticide leaching and pollution of water as erosion increases due to lack of ground cover. In viticulture, short inter-row grass or bare ground in new vineyards will perpetuate this, especially on slopes. In vineyards with high frost risk, winter cover crops must be terminated before the frost period around bud burst and early season cover crops must be low growing.

Practice	Method	Justification
Microbial support plants to enhance the degradation of pesticides within the soil and prevent leaching	Interrow planting of species which are known to support rhizospehere microbial communities which aid in breakdown of pesticides and their metabolites preventing leaching into groundwater	Rhizodegradation is a key element of phytoremediation. Colonisation of plant and vine roots with mycorrhizal fungi is shown to have many benefits on health and nutrient uptake as well as vine yield. Biodviersity underground as well as above ground is essential for soil health.
Support of subterranean and terrestrial species to encourage biodiversity	Interrow planting of species that will support both underground and aboveground ecosystems. Nectar pollen for insects, cover for small mammals and prevention of pesticide accumulation leaching for earthworms and stygobites	Work with the BAP objectives to provide habitat for insects, mammals and birds not classified as pests. For example, known phytoremediators can be mixed with nectar and pollen generating plants to work as a factor in Integrated Pest Management. In most instances, monocropping of phytoremdiators should be avoided as this increases the chances of harbouring pest species. This is a particularly interesting and complex subject area which warrants future research to determine the optimum mix of plants.
Low impact energy plants for biofuel. Cultivation of perennial energy crops including herbaceous grasses.	Interrow planting of low impact energy plants for bio-fuel harvesting to include native grasses or location relevant crop species which generate high biomass.	Income for landowners, innovation, mitigate climate change effects through substitution of fossil fuels, prevent pesticide run-off and top-soil loss through erosion. The ability to make money on previously unused land may open up barriers to entry including maintenance and perceived threats to vine health and wine quality which could have negative financial impacts.
Cultivation of aromatic plants in contaminated soils for production of essential oils	Interrow planting of native aromatic plants e.g. chamomile for production of essential oils	Reduce risk of introducing contaminants into the food chain by using non-forage crops and mitigate costs of disposal. Research has shown that the concentration of certain contaminants, including heavy metals, is not significantly conferred to aromatic crops used for essential oil production.

Potential Plant Species

Common Name	Latin Name	Family	Lifecycle	Occurance	Effect	Size (cm)	Commercially Available	Example Price	Example Retailers	Reference
Alpine Pennycress	*Thlaspi caerulescens*	*Brassicaceae*	Perennial	Non native	Hyperaccumulator. Zn, Cd extraction	15–40	No	x	x	Takahashi, 2008;Vassilev et al., 2004
Basket Willow	*Salix viminalis*	*Salicaceae*	Perennial	Native	Zn, Ni, Pb	<600	Yes Cuttings	£6.50/10 pieces	Hatton Willow	Mleczek et al., 2010
Celery leaved buttercup	*Ranunculus sceleratus*	*Ranunculaceae*	Annual	Native	Hyperaccumulator. Cu, Pb extraction	50	No	x	x	Farahat and Galal 2018
Chamomile	*Chamaemelum nobile*	*Asteraceae*	Perennial	Native	Heavy metals	<30	Yes Seed	£14.25/250g	Just Seed	Pandey, Verma and Singh, 2019
Curled dock	*Rumex crispus*	*Polygonaceae*	Perennial	Native	Cd, Pb, Zn, petroleum, hydrocarbons and radionuclides	100	No	x	x	Zhuang et al., 2007
Field pennycress	*Thlaspi arvense*	*Brassicaceae*	Annual	Native	Bio-fuel, former waste sites		Yes Seeds	£11.50/10g	Emorsgate Seeds	AgMRC.,2018; Barnswell, 2005
Indian Mustard	*Brassica juncea*	*Brassicaceae*	Annual	Non native	Hyperaccumulator, Cu, Pb, U	15-60	Yes Seed	£45.90/500g	Mole Seeds	US EPA, 1999
Meadow Buttercup	*Ranunculus acris*	*Ranunculaceae*	Perennial	Native	Crude oil	100	Yes Seed	£105/kg	Emorsgate Seeds John Chambers Wildflower Seeds	Xie, 2017
Oxeye Daisy	*Leucanthemum vulgare*	*Asteraceae*	Perennial	Native	Crude oil, petroleum	50-70	Yes Seed & Plant	£15.80/100g £85/150	Wildflowers UK Landlife Wildflowers	Noori et al., 2018

Perennial Ryegrass	*Lolium perenne*	*Poaceae*	Perennial	Native	Atrazine, nitrate leaching	<50	Yes Seed	£6/kg	Emorsgate Seeds Cotswolds Seeds	Sanchez et al, 2019, Carlton et al, 2017
Red clover	*Trifolium pratense*	*Fabaceae*	Perennial	Native	Nitrate extraction	<50	Yes Seed	£9/kg	Cotswolds Seeds Farm Seeds	Taylor, 2017
Ribwort plantain	*Plantago lanceolata L.*	*Plantaginaceae*	Perennial	Native	Nitrate leaching, atrazine	50	Yes Plants	£85/150	Landlife Wildflowers	Carlton et al, 2017; Sanchez et al, 2019
Sunflower	*Helianthus annus*	*Asteraceae*	Annual	Non native	Hyperaccumulator. Cu	100+	Yes Seed	£4.75/kg	Cotswolds Seeds Farm Seeds	Andreazza et al, 2015
White clover	*Trifolium repens*	*Fabaceae*	Perennial	Native	Pb, Zn, diesel remediation, nitrate leaching	10-30	Yes Seed	£8/kg	Grass Seed Store Cotswolds Seeds Farm Seeds	Bidar et al 2008; Xi et al, 2018; Carlton et al 2017

Summary

There is abundant opportunity to implement phytoremediation as a stand-alone strategy or as a wider Rural Sustainable Drainage System. Contamination of water resources is a rising concern in regulatory and consumer groups alike. The reliance of the communities in the Kent Downs AONB on groundwater resources to provide safe drinking water and habitats for wildlife is crucial. Agricultural activity is due to increase with the rising population and effects of climate change on the production systems – including increased need for pesticides and water for irrigation.

Viticulture is a relatively new sector within the broad agricultural industry in Kent and there is a push towards secondary and intermediate education with Plumpton College as well as sustainability within wine businesses (WineGB Sustainability Scheme). This provides a starting point, but the difficulty in changing practices should not be underestimated which is why it is crucial to get growers and landowners on board early.

Utilisation of cover-crops in agriculture is by no means a novel idea however, it is the strategy to protect water resources and mitigate pesticide usage which provides a different perspective to the typical angle of biodiversity. FIGURE 13 demonstrates the holistic view which can be taken within the proposed ELM scheme of utilising native plants for phytoremediation and RSuDS, providing landowners with the ability to contribute to positive environmental outcomes from many angles despite their initial objective

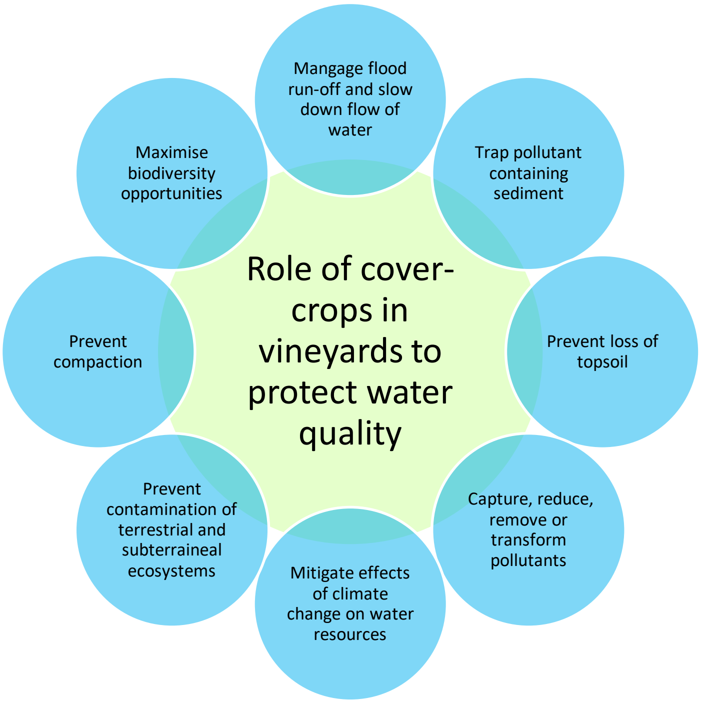

Figure 13 The role of cover-crops in vineyards to protect water quality is multifaceted with overlapping objectives and outcomes. For example, Landowner A wants to manage the flow of water from flash floods as it is causing the loss of topsoil, reducing vine yields, and increasing expenditure on soil replacement. Through ELM funding, they build and maintain a swale containing native grasses and wildflowers to slow the flow of water. Through test and trials, these grasses have been investigated for their phytoremediation effects on pesticides and some of the mixes contain complimentary native wildflowers included for their supply of nectar to pollinators and predatory insects which contribute to IPM. Additionally, the grasses trap contaminated sediment allowing it to be removed and disposed of safely. All these actions work together to prevent contamination and protect water resources, despite the financially motivated initial objective.

For growers, there is a grey area between the need to protect your livelihood as well as the environment which signals that complete abandonment of pesticide use in many agricultural settings is not realistic. Although there has been heavy investment into production of more environmentally friendly products with lower leachability within agrichemical companies over the last decade, there is still a long way to go to finding suitable alternatives in every sector. Ultimately, the continued use of and reliance on organic and inorganic pesticides will have short- and long-term impacts on many aspects of the ecosystem importantly, water resources. Within viticulture there is a unique opportunity to take action by using plants to prevent water contamination. Taking a holistic approach, viticulturists can also incorporate the use of Rural Sustainable Drainage System designs within their growing system as both barriers and remediators.

"[The] ***first priority is to prevent any new land contamination occurring by effective influencing and regulatory control of potentially polluting activities. Voluntary remediation or remediation under the planning regime is strongly encouraged…Effective pollution prevention measures are expected to be adopted, maintained and monitored by developers and operators to prevent new land contamination from occurring. The Environment Agency expects developers, operators and landowners to act responsibly for cleaning up historic land contamination and preventing new pollution, in accordance with guidance"***

Environmental Agency approach to groundwater protection Section J (Environment Agency, 2018)

Section J3 of the Environment Agency's approach to groundwater protection, encourages landowners to take responsibility for their own pollution. In summary, it is not enough to use the latest spraying technology and chemical formulations. To protect water resources, every reasonable, realistic preventative measure must be taken with as few barriers to entry as possible. Actionable recommendations based on research are needed to prevent new and clean up historic land contamination. Although there is a plethora of information available to landowners, it is the lack of sector specific, open access resources and research, that is potentially fuelling the knowledge gap. The focus is, simple and cost-effective actions viticulturists can take to protecting water in the Kent Downs AONB under the ELM scheme, with the aim of taking these to trial stages in the future. These actions will not only use public money for public goods but provide an example of best practice and innovation, elevating England's viticulture sector on the global scale of sustainability.

Appendix

Payment Examples

Table 2 Types of payments and activities by Scottish Government for development of RSuDS (CREW., 2015)			
Type of RSuDS	**Activity**	**Payment**	**Conditions**
Sediment traps	Excavate and form sediment trap	£10.50/m^2	Bund height must be less than 1.3 metres, unless designed by a qualified engineer. Fencing must be provided to protect people and livestock. Only run-off which currently discharges direct to a watercourse or freshwater drain and which does not fall within the definition of slurry may be conveyed to a sediment trap / bund. Run-off from pesticide handling or washdown areas must not be conveyed to a sediment trap / bund where a rural sustainable drainage system pond or wetland is being used in conjunction with the sediment trap, the pond or wetland must be located downstream of the sediment trap
	Create bund	£7.50/ m^2	
Ponds	Create treatment pond	£15.00/ m^2	Run-off (except roof run off) must first enter a sediment trap or swale prior to the pond. Only run-off which currently discharges direct to a watercourse or freshwater drain and which does not fall within the definition of slurry or silage effluent may be conveyed to a pond. Run-off from pesticide handling or washdown areas must not be conveyed to a retention pond. Fencing should be provided to protect people and livestock existing ponds must not be used. You must obtain planning permission, or have confirmation that planning permission is not required for your proposed pond
Wetland	Wetland with a proprietary lining	£9.00/ m^2	Run-off from pesticide handling or washdown areas must not be conveyed to a wetland.
	Wetland with a soil lining	£7.00/ m^2	

			Fencing must be provided to protect people and livestock. Existing wetlands must not be used you must obtain planning permission, or have confirmation that planning permission is not required for your proposed wetland. Where a proprietary lining is used, a receipt for the liner will be required run off (except roof run off) must first enter a sediment trap or swale prior to the wetland
Swales	Treat, control and slow run off	£21.75/ m^2	Only run-off which currently discharges direct to a watercourse or freshwater drain and which does not fall within the definition of slurry or silage effluent may be conveyed to a swale. Run-off from pesticide handling or washdown areas must not be conveyed to a swale

Costs of Land Remediation

Table 3 Cost comparison of land contamination versus phytoremediation with fine rooted Grasses (E. Drake, Exxon, Anandale, NJ, personal communication as cited in *Schnoor, 1997)*

Type of Treatment	Range of Costs $/ Ton
Phytoremediation	$10-35
In situ Bioremediation	$50-150
Soil Venting	$20-220
Indirect Thermal	$120-300
Soil Washing	$80-200
Solidification/Stabilization	$240-340
Solvent Extraction	$360-440
Incineration	$200-1,500

Table 4 Treatment time, costs and additional factors of phytoextraction versus conventional clean-up methods (Phytotech Technical Summary, 1997 as cited in Schnoor, 1997)

Type of Treatment	Cost/m^3 ($)	Time Required (months)	Additional factors/	Expense Safety Issues
Phytoextraction	15-40	18-60	Time/land commitment	Residue disposal
Fixation	90-200	6-9	Long-term monitoring	Leaching
Landfilling	100-400	6-9	Long-term monitoring	Leaching
Soil extraction	250-500	8-12	5,000 m3 minimum Chemical recycle	Residue disposal

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Additional Information and Example Frameworks

Table 5 Additional information and example frameworks which can aid implementation of phytoremediation and RSuDS in viticulture within Kent Downs AONB	
Agency	**Link**
CREW Scotland	RSuDS Design Guide
USDA	Vineyard Cover-cropping for erosion Napa Valley
University of Newcastle, Sydney, Aus	Power Plants research study

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