**From:** Amy Wheelton (Councillor)
**To:** Oaklands Farm Solar
**Subject:** Application by Oaklands Farm Solar Limited for an Order Granting Development Consent for Oaklands Farm
**Date:** 25 October 2024 13:53:17
**Attachments:** image001.png
image002.png
image003.jpg
Oaklands speech 22102024.docx
Field drainage guide (2024).pdf
CREW_NFMProject_Land_Drainage-FINAL.pdf
Building-on-our-food-security.pdf

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EN010122

Good Afternoon

Further to the Issue Specific Hearing and Open Floor Hearing dated 22 & 23 October 2024 please find attached:

- My Open Hearing Speech
- AHDB Field Drainage Guide – referenced at both Issues Specific and Open Hearing
- Crew Center of Expertise for Waters - referenced in my speech
- CPRE Document - referenced in my speech

Below is a link to photos and videos of the NSIP Oaklands site and specifically the 74 acre track and brook line, I gained these some months ago and feel they may be of interest to the inspector now he has been to site visits, due to the size I can only send as a link:

[redacted]

Should you require any further information please do not hesitate to contact me, please acknowledge receipt.

Regards

Amy Wheelton

**Amy Wheelton**
**Independent Seales Ward District Councillor**
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Good afternoon,

To aid you Sir I can forward my speech this week or by deadline 5 at the latest and any quotes, documents and appeals that are referenced as I speak are fully referenced in my written submission but to keep to the 10 minutes I do not mention the referencing in full now.

I speak on behalf of local residents as ward District Councillor, but I am also speaking to you, as an expert, in Agriculture, and as per the first open hearing I have farmed all my life, attended Harper Adams University, and was a National Farmers Union Group Secretary. I have also diversified my farm and have installed solar and battery on my green offices, plus I have 2 GSHPs. I should add, I also farm land adjacent and next to this site at Walton on Trent and live, own and protect, the scheduled monument referred to in this application.

I have been quite shocked by this process, and I hold the planning inspector in the highest regard for his direct and enquiring questions, but the applicants seem to cut and paste and not directly answer them, the standard response seems to kick the can down the road to 40 years' time with the DEMP, to mitigate matters and refer to the 3 most recent southern solar farms given. It is quite simple you cannot mitigate Otter, Skylark, Barn Owl and Newt nesting and living habitat destruction. The applicants openly admit in responses Skylark nesting grounds will be gone, the choice will be for the inspector to destroy these habitats or leave them, I do not envy you Sir.

In earlier questions the applicants have stated the 50 acres of this farm not under panels or batteries will be used to continue the existing Dairy herd and please note they do not own a sheep nor have they ever, a neighbour over winters some sheep on temporary grass lays some years, so I look forward to this mystical sheep flock the owner owns grazing under the panels, it is a dairy and arable farm currently and has been for my lifetime.

I have researched NSIPs in detail and cannot find one where 74 acres of temporary haul track is required for access due to the traffic issues locally, this track decimates mature woodland and causes ecological devastation, crossing a brook 3 plus times where Otters reside, giving zero climate change benefit and within the National Forest.

Since the last hearing a further Burton bridge has a permanent 7.5-ton weight restriction just up the road here at Branston, the main route off the A38 into Burton, that is 3 routes now weight and width restricted over the river Trent to the site, a further road from 5 lanes End, called Hennerst Hill, is being 7.5t restricted - another route closed off into Burton to protect residential amenity from a local Logistics company causing issues on the A444. There is nowhere locally to mitigate the traffic, which is often now at standstill, this alone should be a reason for the sites lack of suitability.

With a further 5 BESS proposed on its periphery the cumulative impact of traffic, heritage, landscape and character, is not only frightening for residents but on a scale wholly against the current SDDC local plan and NPPF. The site has a strong sense of detachment, time and place, a rural community preserved from intrusive urbanisation. The mitigations themselves such as 3m high unmanaged hedges, fences and cameras on poles creates a fundamentally negative impact on the landscape, if you have to grow something 3m to hide something, it should not be there in the first place. Appeals won against solar within Derbyshire at Alfreton (05/12/24 APP/M1005/W/22/3299953) were to protect residential amenity and Landscape and Character, this gives weight to this **not** being the right place for this installation, similarly a Bess was refused at Calow Chesterfield. (10/07/2017 APP/R1038/W/17/3173683).

Whilst I am aware you may not give the new SDDC Local Draft Plan any weight, which is out for consultation now. A further 14 483 homes on BMV land are proposed and the increased area of up to 68 hectares of employment land at the brownfield Drakelow site, designated for Energy purposes under the existing current policy BNE12 is of worthy note. This site is adjacent to the operating 18 MW steam turbine incinerator at Drakelow, this area already addresses the climate change need, with a second incinerator at appeal within 3km, two neighbouring battery stores on farms. The 360-acre Haunton Solar farm just over the close border in Staffordshire, plus a farmer run biomass plant at Haunton. Simply BESS and Solar should be on rooftops and brownfield sites not on Best & Most Versatile land (BMV), as the fastest growing District in the UK we have plenty of rooftops.

My questions about the building of this site on sub aquifers shown in the geology reports, and the safety of my water supply and boreholes are not addressed in anyway. It is simply not possible to guarantee there will not be a fire in battery storage, they happen and are evidenced hence an appeal upheld at the Pound Road Bess, Hawkchurch (16/02/2024 APP/U1105/W/23/3319803) for the reason of unacceptable levels of pollution to aquifers and the significant risk to local residents and the environment.

I note the Applicants are unable to provide proof of them not being in financial difficulties now or in 40 years' time, bonds should be in place, a new precedent is needed, or we will see the disaster we have with our water infrastructure and sewage, the can must not be kicked for our children and grandchildren to deal with. I also note in the SDDC Local Impact Report (LIR) the costs to SDDC of the obligations, enforcement, BNG for 40 years has not been addressed - there is no local benefit for residents only a potential increase in Council Tax, all costs, index linked including the DEMP should be in a bond now.

The crux of this application has not changed it comprises of 398 acres of solar and 74 acres of haul track, it will remove 472 acres of 67% BMV agricultural land, **permanently**. I do not accept the applicants stock answer that it is not an issue as the area is only 0.003% of the BMV land in England, I set out the reasons below.

CREW Center of Expertise for Waters (01/07/2012) estimated in 2000 that within the UK 60.9% of agricultural land was drained, Wheater & Evans (2009) note that a significant proportion of the most agriculturally productive land in England and Wales is dependent on flood protection and land drainage and suggest that with increased importance currently being placed on future food security, land management options may need to be re-evaluated to reduce flood risk and to maintain standards of land drainage in areas of national agricultural importance. The Environment Agency (RSuDS June 2012 Chapter 9 Technical Annex) showed ADAS data from 2002 that the maximum area drained as a percentage of hectarage in the East Midlands is 39% and minimum area 31% and in the West Midlands it is a maximum 19% and minimum area 16%. This proves some land, which is drained BMV, is far more valuable than other land, a rare commodity as this site is land drained.

The applicants wish to kick the can and the DEMP to 40 years to decide how to deal with the problem of buried infrastructure and cut the cables at

0.7m deep, leave the buried infrastructure in the ground, polluting the SSSI River Mease and soil forever, at one point recently stating in the DEMP pull out the buried plastic ducts, an impossible ridiculous suggestion. They now state in the latest DEMP the cutting of cables at 0.7m deep will allow land drainage which is ridiculous as this occurs, as it has at my farm within the last 5 years at 1.1 meters deep. A mole drain can then operate at 0.6 meters deep running into the land drains. It is a fact that land drainage goes in at 1.1 to 1.2 meters deep in permeable soils, this is backed up by the bible on drainage, AHDB Field Drainage Guide, with a section on drain depth. I should add it's a little rich of the applicants to part quote me in Deadline 4 Applicants responses (2nd written questions page 18, 5.2a) but at least they openly admit taking out the infrastructure they wish to leave in the ground would stop the land returning to BMV and undo the soil improvements, however if it cannot be drained it will no longer be BMV a simple fact backed up with data.

The CPRE's (2022 Building on Food Security) key findings stated that flooding as a result of climate change poses a further risk to BMV loss with almost 60% of our most productive Grade 1 land already sitting on Environment Agency's Flood Zone 3.

75% of East midlands Grade 1 BMV is at the highest risk of flooding as it is in flood zone 3. East Midlands is one of 3 regions to have experienced the highest absolute losses of BMV agricultural land from development projects between 2010-2022, the highest of grade 3a BMV.

This ground is Potato Cyst Nematode (PCN) free, not tested as requested in my questions, making this BMV even more valuable as you can only grow potatoes every 6 to 7 years  and this area is renowned for supplying crisping potatoes to the Walkers Midlands factories.

It can be argued this loss of BMV will accelerate in the next decade due to Climate Change and with climate mitigation strategies such as ELMS (Environmental Land Management), BNG (Biodiversity Net Gain) and nutrient neutrality schemes. The permanent or long-term losses of good agricultural land will have a negative impact on strategic food supplies.

Grades 1,2 and 3a BMV land is protected for that reason and this policy should be adhered to backed up by recent appeals for Solar and BESS.

The Lullington, Swadlincote, Derbyshire appeal (APP/F1040/W/22/3313316 18/04/23) stated whilst the collective benefits arising are significant the harm caused by allowing the development of just below 50% of the sites BMV hectarage, over a period of 40 years, would be of greater significance, similarly (5/4/2022 APP/K2610/W/21/3278065) Cawston Norfolk BESS appeal for the same reasons.

In conclusion Agricultural land (Farmers Guardian 30/08/24) is one of the most valuable natural assets in the UK. In 2014, Andrew Montague-Fuller from Cambridge University produced a report entitled, The Best Use of Agricultural Land, which warned the UK maybe running out of land for food production and could face a potential shortfall of two million hectares by 2030. He argued we needed to put more land aside for the food needs of a growing population, **I do not disagree**.

There are many reasons this application should not go ahead, traffic, cumulative effect, landscape and character, heritage, sub aquifers and SSSI and soil pollution but in planning terms it is quite simple any proposal on BMV land needs to be justified by the most compelling evidence and there is none, nowhere in national or local policy guidance does it state declaring a climate emergency implies a precedence over all considerations, this land will be lost to BMV as will the ecological habitats, **permanently**, if this application is allowed.

Thank you, Sir,

Amy Wheelton 22/10/2024 NSIP Oaklands Open Hearing.

AHDB

# Field drainage guide

## Principles, installations and maintenance

Funded by your levy

AHDB

ahdb.org.uk

# Contents




This guide, funded by AHDB and with a contribution from the Catchment Sensitive Farming initiative, was written by Kirk Hill, Robin Hodgkinson, David Harris and Dr Paul Newell Price, ADAS.

AHDB is grateful to all those who have commented and contributed to this publication.

Photographs courtesy and copyright of ADAS, Farm Services Limited, Mastenbroek, Miles Drainage Limited, OPICO and Polypipe Civils.


# Introduction

## What is field drainage?

Field drainage is installed to rapidly remove excess soil water to reduce or eliminate waterlogging and return soils to their natural field capacity. Drains can be used to control a water table or to facilitate the removal of excess water held in the upper horizons of the soil.

A good drainage system will reduce the risk of detrimental waterlogging to acceptable levels.

Where soils are coarsely textured and well structured, the soil may be freely draining enough to support field operations and crop growth without the need for artificial drainage systems. Field drains should be considered in the following situations:

- **Heavy clay soils:** These are slowly permeable and, without drainage, can be waterlogged for long periods, particularly in areas of high rainfall
- **Medium-textured soils in high-rainfall areas:** Drainage may be needed to reduce vulnerability to compression, slaking and compaction
- **Light-textured soils:** These soils are highly permeable, but drainage may be required to provide water table control in low-lying areas
- **Springs:** Drains are used to intercept springs before they reach the surface; this helps prevent erosion, localised waterlogging and poaching, and the intercepted water, if clean, may be used as drinking water for stock

There has been a general reduction in organic matter levels in arable soils over the past 70 years. This makes them more susceptible to waterlogging and more in need of drainage.

## History of field drainage in the uk

Around 6.4 million hectares of agricultural land in England and Wales have been drained with piped systems.

The rate at which land was drained increased rapidly during World War II, as part of the drive to increase food production, and peaked during the 1960s to 1980s, when grant aid was available.

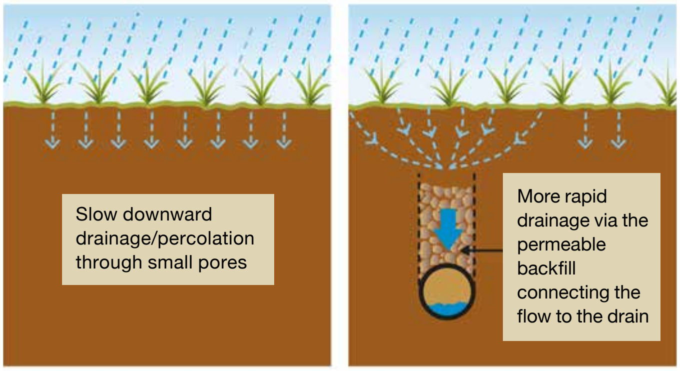



Figure 1. Drainage of heavy soil

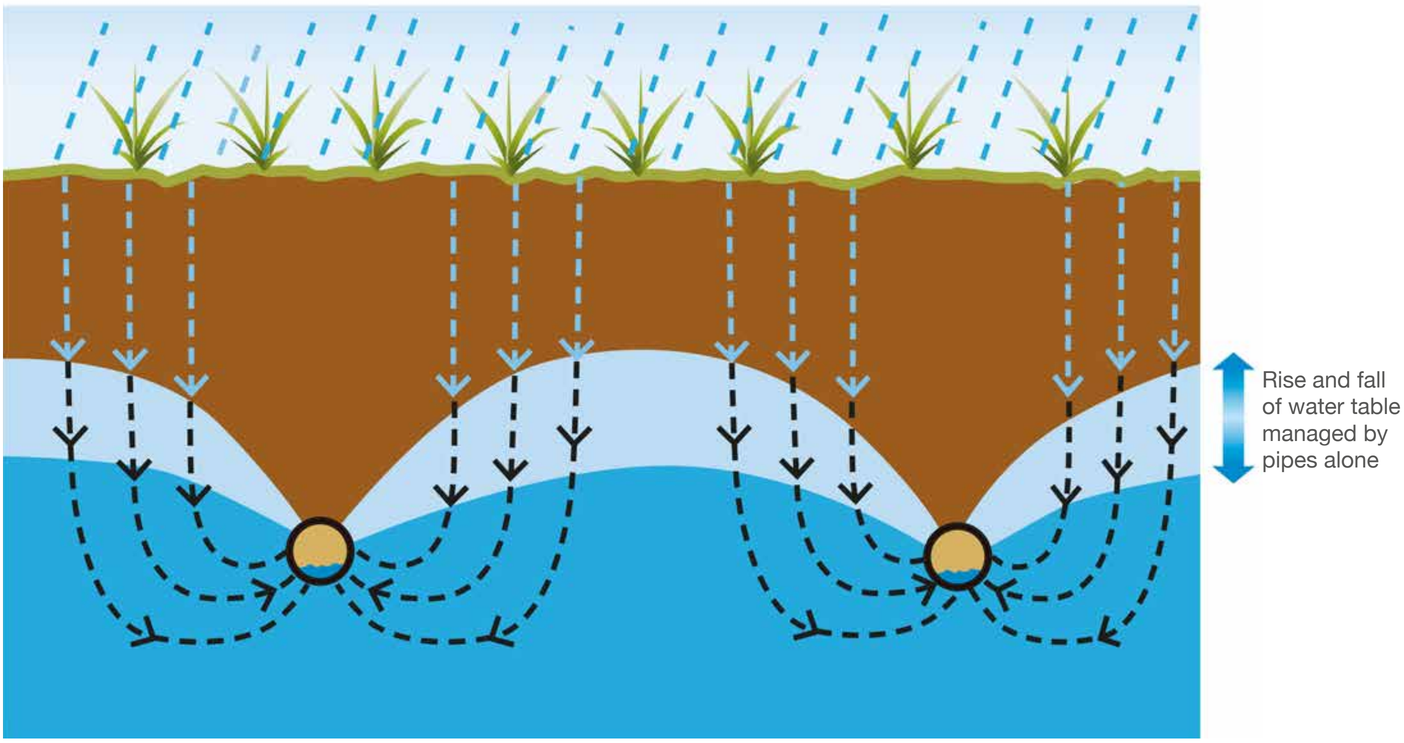



Figure 2. Water table control on permeable soils

# Benefits to the farm business

In some years, drainage can make the difference between having a crop to harvest and complete crop loss; or whether or not the land can be accessed to harvest the crop.

The benefits of field drainage to the farm business are substantial, but installation can be expensive. The magnitude of the benefit varies considerably with climate, soil type and land use, so it is important to carry out both environmental and cost–benefit assessments before installing or managing field drainage systems.

**Drainage is a long-term investment. Given good maintenance, a useful life of at least 20 years can be expected and some systems can last many decades longer.**

Good field drainage reduces the peak surface water run-off rates by increasing the availability of storm-water storage within the soil. Rainfall then percolates down through the soil into the drains, producing a more balanced flow after storms. This reduces the risk of flooding and soil erosion, not only within the field but also further downstream in the catchment.

## The cost of installation

The cost of installing a new comprehensive field drainage system varies greatly according to the scale and intensity of the system.

Based on 2024 prices, typical costs per hectare are around:

- £2,500–£3,500 with permeable backfill
- £1,400–£2,000 without permeable backfill

## Improved plant performance

- Improved crop yield and quality
- More rapid warming of soils in spring, improving germination
- Improved environment for soil organisms
- Better access to water and oxygen for plant roots
- Better crop uptake of soil mineral nitrogen

## Better access to land

- Reduced duration/risk of autumn waterlogging
- Quicker accessibility of fields following any period of wet weather
- Crop inputs more likely to be applied at optimum time
- An extended growing and grazing season

## Improved speed of work and fuel use

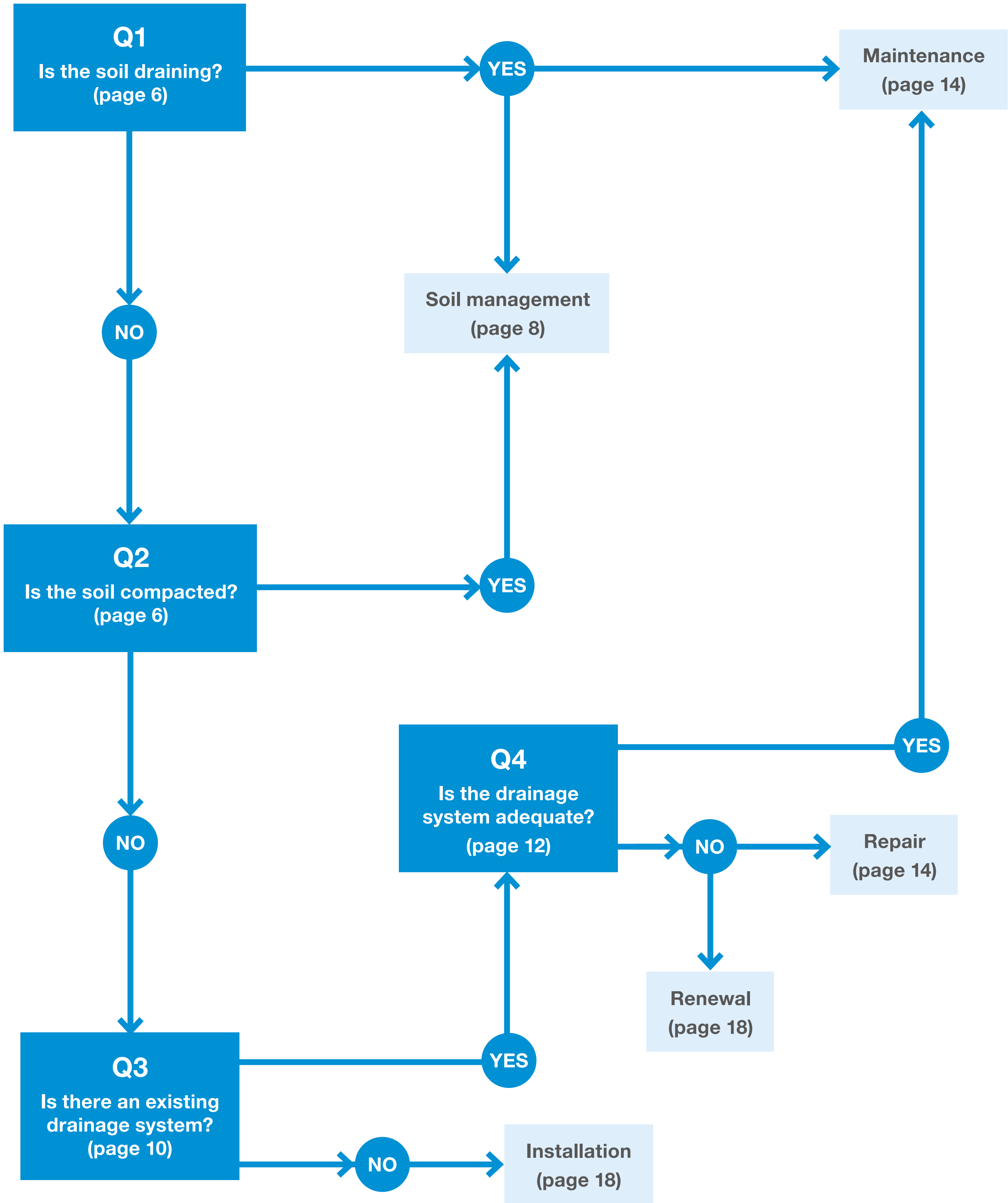
- Better traction
- Fewer cultivation passes
- Reduced draught forces
- Reduced wear and tear
- Fewer wet areas to avoid

## Benefits to soil structure and the environment

- Less structural damage to soils
- Reduced frequency and extent of livestock poaching
- Better water infiltration
- Reduced surface run-off and erosion
- Reduced phosphorus and pesticide losses to water
- Decreased potential for slug activity and reproduction

## Reduced risks to livestock health

- Reduced survival of parasitic larvae
- Snails carrying liver fluke do not thrive
- Footrot and foul of the foot are less common
- Udder hygiene for grazing stock is improved
- Reduced risk of soil contamination during silaging operations


Q1
Is the soil draining?
(page 6)
YES
Maintenance
(page 14)
Soil management
(page 8)
NO
Q2
Is the soil compacted?
(page 6)
YES
Q4
Is the drainage system adequate?
(page 12)
YES
NO
Repair
(page 14)
NO
Renewal
(page 18)
Q3
Is there an existing drainage system?
(page 10)
YES
NO
Installation
(page 18)

# Identifying the need for drainage

## Evidence of poor drainage

The evidence of poor drainage may be obvious in the form of surface ponding or saturated topsoils.

Prolonged waterlogging under the surface may not be so obvious. Poor drainage conditions may be identified by:

- Poor crop health or yields: overlaying a yield map onto a field drainage map can identify problem areas
- High surface run-off rates and soil erosion
- Limited field access without rutting or poaching (animal hoof damage) compared with other fields in the area
- The presence of wet-loving plant species, such as common rush and redshank
- Susceptibility to drought due to poor root development and limited rainfall percolation into the soil

If drainage problems are widespread across the field, it may be that:

- Soil management is not adequate
- No drains have been installed
- Mole drains need to be renewed
- In flatter fields, the outfall may simply be blocked
- The drainage system requires maintenance or has reached the end of its useful life

### Environment

Surface run-off may occur, which can result in transport of faecal material, sediment, soilborne diseases (e.g. clubroot), nutrients or agrochemicals to watercourses.

Figure 3. Surface ponding

Figure 4. Areas of grassland may become heavily poached at times when soil conditions in other fields on similar soils do not lead to poaching

Figure 5. Saturated topsoils

Figure 6. Areas within arable fields may be waterlogged, resulting in crop loss or soil damage due to wheel ruts

## Is the soil draining?

Examining the soils to determine if they are naturally freely or slowly draining or have damaged structure should be the first action when drainage problems are suspected.

**Without good soil structure, soil drainage will be poor, whether it be by natural drainage or pipes.**

Compacted layers can restrict surface water from reaching underlying drainage systems. If compacted layers are identified, remedial action should be undertaken to remove them before considering field drainage maintenance or reinstallation.

It is essential to routinely assess soil structure. This can easily be incorporated into the farm soil sampling programme and should be completed in spring or autumn. Examine the soil at several points in the field to a depth of:

- Arable land: at least 600 mm
- Grassland: at least 500 mm

### Soil structure

✔ Well-developed structure is evident from the ease of digging and if the soil readily breaks down into small structural units with many vertical fissures

✗ Soils with poor structure are hard to dig and break down into larger dense blocks, with poor penetration by water, air and roots

### Soil colour

Greyish-coloured soils and soils with rusty or grey-coloured mottles are signs of poorer drainage.

### Soil texture

The higher the clay content, the more likely the soil is to be naturally poorly drained.

### Root development

✔ Deep rooting indicates good structure

✗ Shallow rooting with many fine horizontal roots and tap roots that are diverted horizontally indicate the presence of compacted layers

### Perched water table

Soil compaction occurs when soil particles are compressed, reducing the space (pores) between them. This restricts the movement of vital air and water through the soil.

When soil water is present, dig a pit (to a depth where the soil becomes drier) to aid diagnosis. Saturated soils overlying a layer of dry soil after a period of heavy rain may indicate the presence of a compacted layer preventing drainage.

It is not uncommon to find both naturally and artificially compacted layers (pans) in susceptible soils. Plough pans can develop if a field is repeatedly ploughed to the same depth.

If the pan, whether artificial or natural, is limiting water infiltration and/or root growth, it should be removed by subsoiling or topsoil loosening.

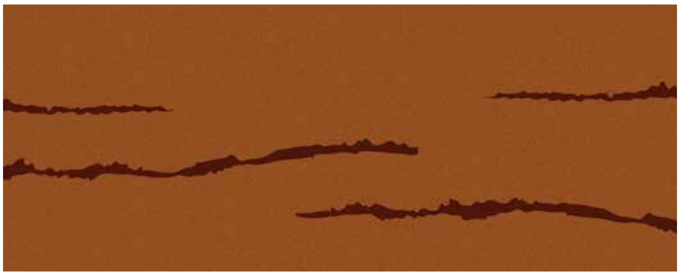


Figure 7. Natural pans – often very hard bands of soil particles cemented together by iron and manganese

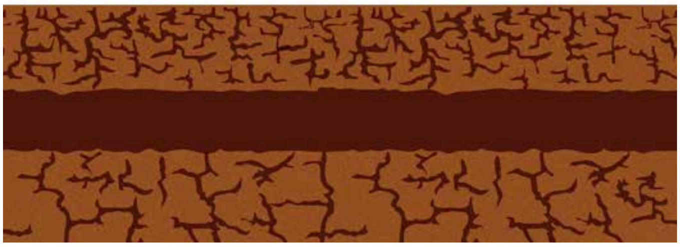


Figure 8. Compaction pans – dense layers caused by farm machinery operation; often 50–100 mm thick, they generally have a platy structure and frequently contain crop residues

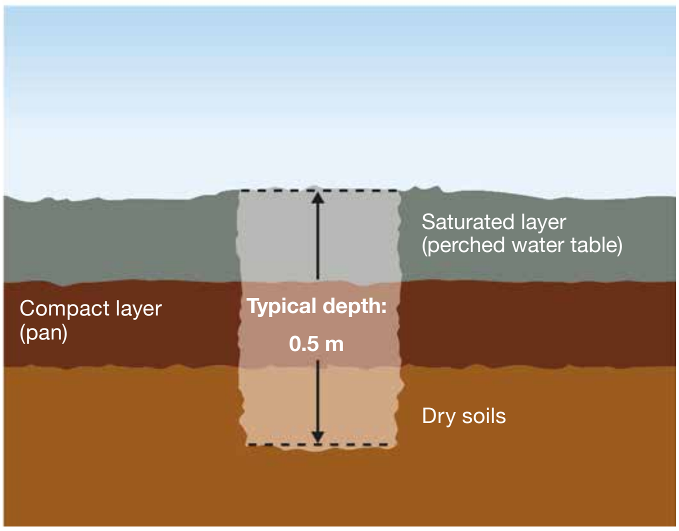



Figure 9. Soil inspection pit extending below the compacted layer

# Soil management for effective drainage

## Effective drainage relies on good soil management

If soil examination identifies compacted layers that act as a barrier to water movement, remedial action should be undertaken to remove them before considering new drainage.

**Maintaining a good soil structure may avoid the need for capital investment.**

Minimise soil damage by reducing:

- Field trafficking
- Weight of machinery
- Tyre pressures
- Poaching of livestock
- Overworking of the seedbed

Other potential solutions include the use of low-pressure tyres, minimum tillage, controlled traffic farming and fixed wheelings, avoiding turnout in poor soil conditions, and considering the placement of livestock feeders and drinkers and livestock tracks.

## Subsoil and topsoil loosening

When soils are wet, they are easily damaged by cultivation, machinery traffic and livestock trampling. If the soil structure has been damaged, subsoil or topsoil loosening (normally referred to as ‘subsoiling’ and ‘sward lifting’, respectively) in suitable conditions can be used to help restore the structure of a damaged soil. It can also be used to improve subsoil permeability.

Slit aerators can also be used in grassland fields but should only target the top 10 cm. Research has shown that they can increase infiltration rates, but good conditions are needed below the target area or they can just move water more quickly towards a drainage problem.

## Operating notes

### 1. Suitable conditions

Topsoil loosening and subsoiling should only be carried out when the soil at working and loosening depth is in a ‘dry’ and friable condition, so that it will shatter rather than smear. Examine soils early in the operation to ensure effective shattering is occurring.

For arable subsoiling, both the soil surface and the compacted layer should be ‘dry’ to avoid soil structural damage.

For topsoil loosening in grassland using a ‘sward lifter’-type machine, the ideal conditions are when the soil surface is slightly moist, to allow disc and tine leg entry while avoiding excessive sward tear, and the lower topsoil is moist to dry, to enable ‘lift’ and loosening.

### 2. Choice of soil-loosening equipment

Winged subsoilers (as seen in Figure 10), developed in the 1980s, shatter the soil much more effectively than conventional subsoilers. They require higher draught force but can disturb a volume of soil two to three times greater than a conventional subsoiler, resulting in more effective disturbance.

The use of leading tines can result in an increased volume of soil disturbed without increasing the draught, but they are not suitable for grassland as they cause considerable surface disturbance.

Topsoil looseners (as seen in Figure 11) or ‘sward lifters’ for grassland incorporate a leading disc, a vertical or forward-inclined leg and a tine leg and a packer roller behind to minimise sward tear and surface disturbance.

Figure 10. Winged subsoiler

Figure 11. Topsoil loosener for grassland

## 3. Depth

It is best practice to use a depth wheel or rear packer roller to maintain a constant tine depth.

Aim for tines to be about 25–50 mm below the base of the compacted layer, up to a maximum depth of approximately 450 mm below ground level.

Maximum depth may be limited by shallow field drains, rock or the critical depth of the tine (related to tine width and soil conditions). Normal drain depth is around 700 mm below the soil surface.

For subsoiling to result in improved drainage, the depth to which the soil is loosened must be just greater than the depth down to the top of the permeable backfill.

This will connect the fissures and allow water to move to the permeable fill over the drains.

## 4. Spacing between tines

- Conventional subsoiler: up to 1.5 times the tine depth
- Winged subsoiler: up to 2 times the tine depth
- With leading shallow tines: up to 2.5 times the tine depth

After a trial run, dig down and examine the effect. Spacing can be adjusted, where possible, to achieve the desired degree of soil disturbance.

## Avoiding re-compaction

Recently loosened soils are very sensitive to re-compaction.

Avoid running over land that has already been subsoiled. In grassland, avoid grazing after autumn loosening and cut rather than graze in the first spring after treatment.

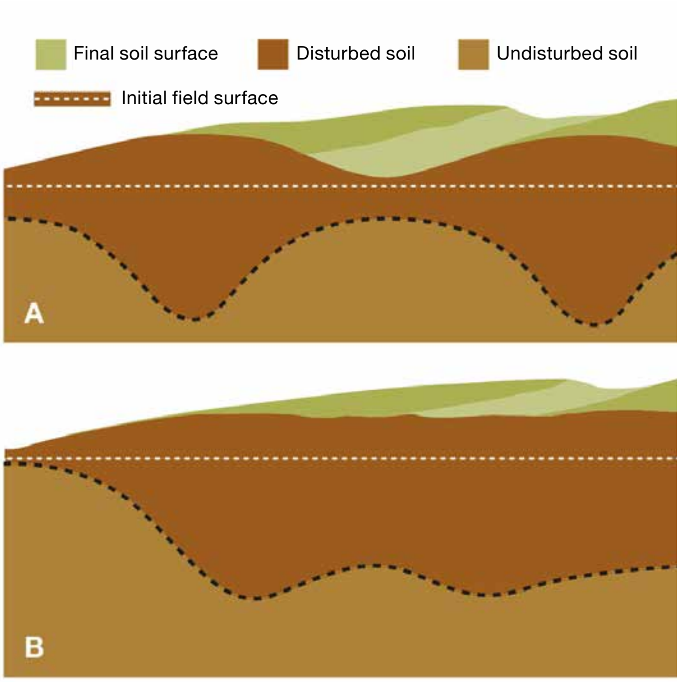



Figure 12. A is an example of tines set too wide and B shows tines correctly set

## Further information

- A guide to better soil structure (Cranfield University) **landis.org.uk/downloads**
- Soil management **ahdb.org.uk/greatsoils**
- Think soils (Environment Agency) **gov.uk/managing-soil-types**
- Principles of subsoiling videos on the Practical Pig app (**practicalpig.ahdb.org.uk**)

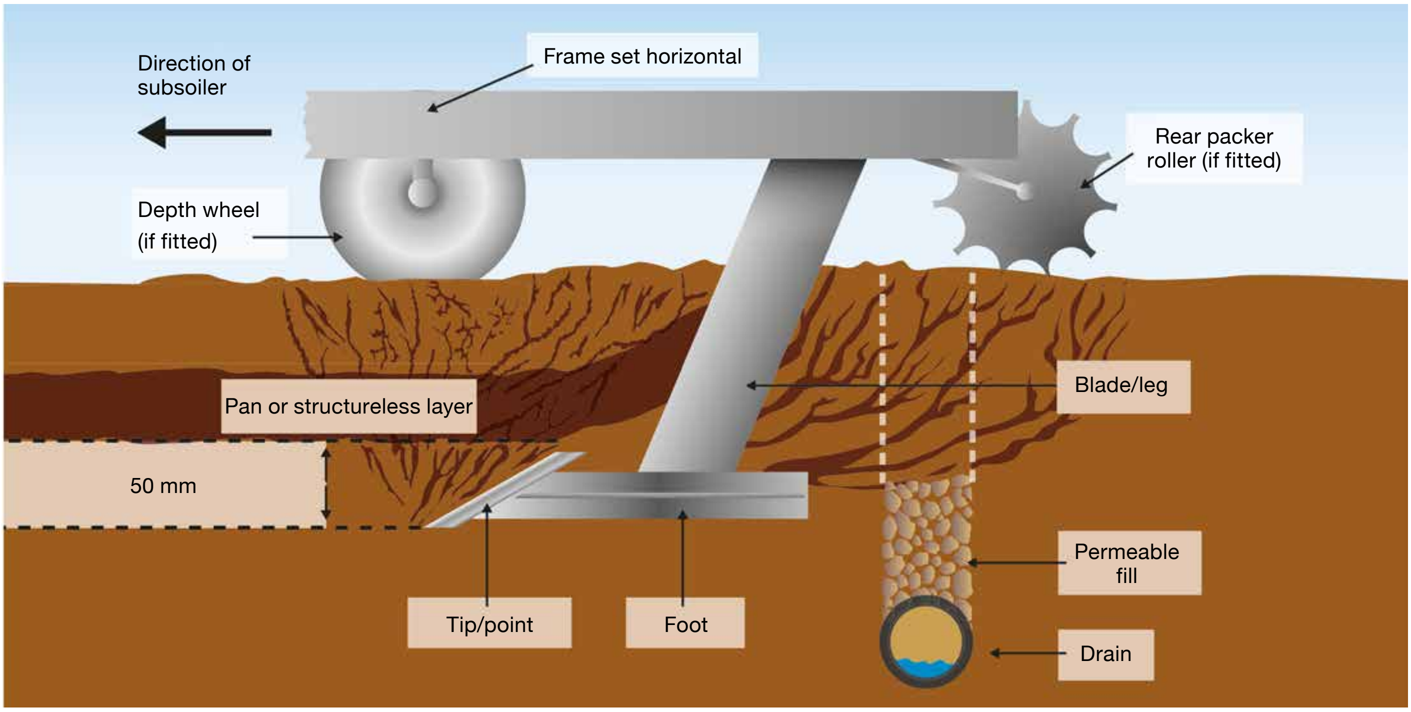



Figure 13. Subsoiler operation

# Identifying an existing drainage system

## Existing drainage

Fields are likely to already have some form of field drainage if they have heavy soils or medium soils in heavy rainfall areas or a naturally high water table. The system may, however, not be functioning properly or may be inadequate for the current farming needs.

## Typical drainage layouts

A field can contain a combination of different layouts or be drained irregularly, depending on the surface slopes across the field. If smaller fields have been merged into one, the outfalls may be found at the low points of each original field and not the current field.

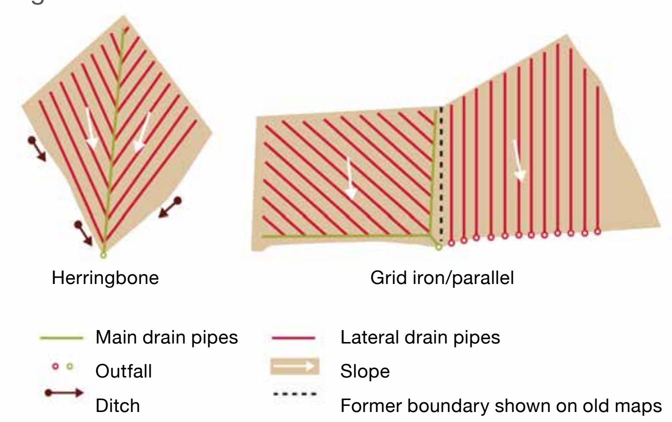



Figure 14. Typical drainage layouts

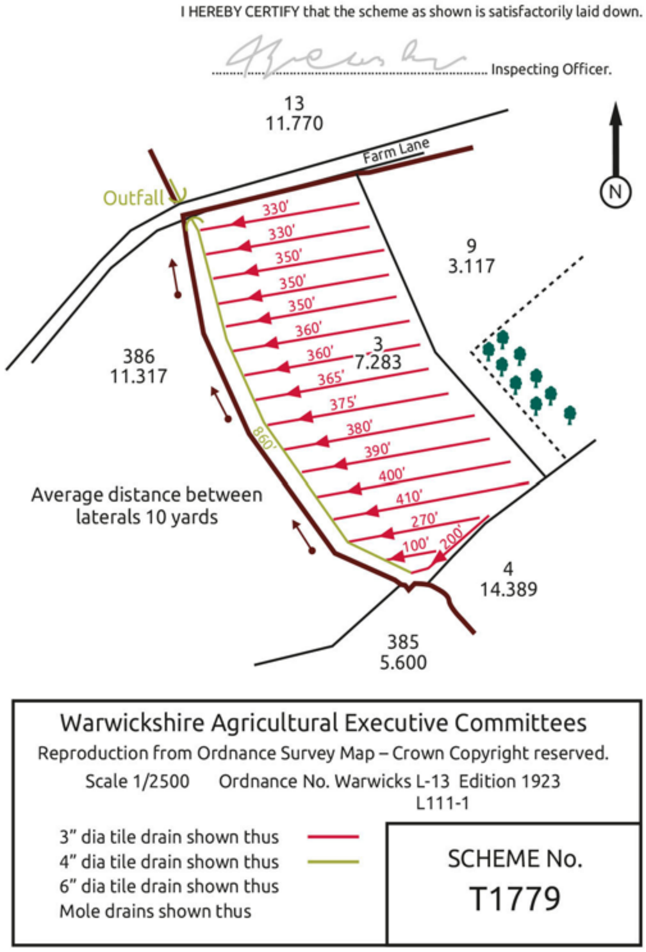



Figure 15. Example final drainage plan

## Understanding drainage plans

On many farms, final drainage plans are available that detail exactly what type of drainage was installed and where it is within each field. Final plans are normally accurate and, provided the key above-ground features shown are visible, should enable the drains to be found.

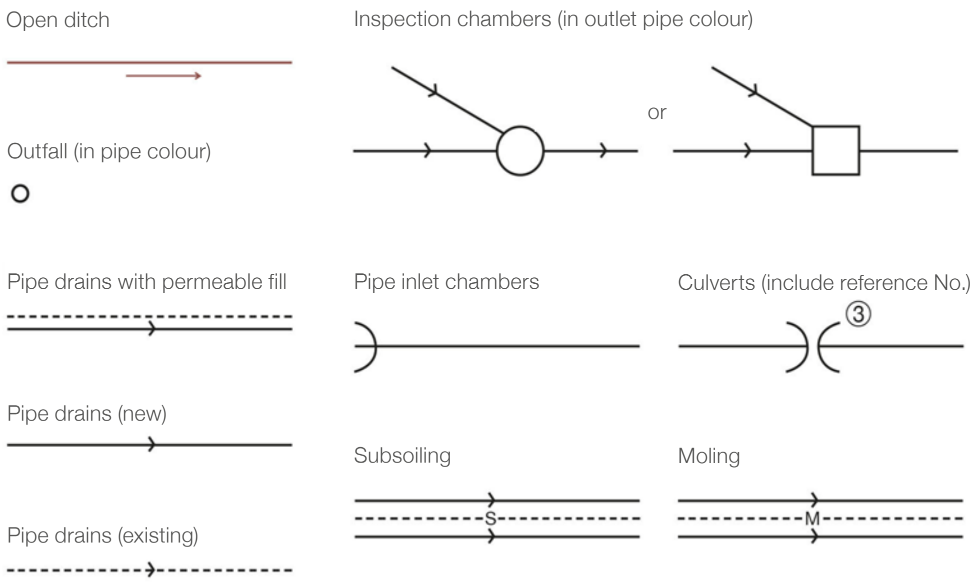
Ensure it is a final drainage plan, not a proposal. A final plan may include the words 'completion' or 'as built' and should always be signed.

### Standard symbols and colours

**Plastic pipes**

| Diameter mm | Colour |
| --- | --- |
| 60 mmØ | Red |
| 80 mmØ | Purple |
| 100, 110, 125 mmØ | Green* |
| 160 mm, 170 mmØ | Blue* |
| 200, 225 mmØ | Yellow* |
| Over 225 mmØ | Black |

*Indicate diameter



## In the absence of a final drainage plan

Local drainage contractors may hold copies of any final record plans. If the land has been recently acquired, the previous owners may hold the plans.

### Creating your own drainage plan

1. **Produce a sketch map** showing the ditches and the direction in which they flow, along with the dominant direction of slope in each field. It may also be helpful to mark any removed field boundaries or ditches, as one large field may contain several small drainage schemes.
2. **Locate any visible outfalls.** These are generally found at the lowest points within a field. There may be more than one outfall, depending on the layout of the drainage scheme.

- Walk the ditches after rainfall: you may hear an outfall running that you cannot see
- The best time to look for outfalls is in winter when drains are running and vegetation growth is reduced
- Even if an actual pipe is not visible, seepage from the bank or an area where the bank has receded can indicate the location of a drain outfall
- If the ditch is badly overgrown, it may be necessary to clear vegetation
- If the ditch has become silted up or the pipe blocked, the ditch may first need to be cleared – typically, to at least 1 m below the adjacent field level

Figure 16. Drainage ditch

3. **Look for field surface signs.** Some features may only be apparent in a certain light during the day or during particular ground moisture conditions.

- Aerial photographs available online may reveal the lines of the drains, although they may be confused with other features, such as underground pipelines
- Slight linear depressions may be visible on the field surface
- The crop may vary in quality or colour over the line of a drain
- The soil may be drier directly over the drain than between drains
- Localised wet areas or small depressions ('blow holes') may be found upslope of a blocked drain

Figure 17. A 'blow hole'

4. If the outfall cannot be found by visual inspection alone, or surface signs need to be confirmed, it may be necessary to **dig trenches across the most likely locations** for drains.

## Health and safety

Before excavating any trenches, ensure that:

- There are no underground cables or pipelines present that may be hazardous or damaged
- Personnel do not enter a trench unless adequate precautions have been taken to prevent trench collapse

Some helpful information can be found at **hse.gov.uk**

Figure 18. Signs indicating potential underground hazards

# Assessing an existing drainage system

## Risk management

An effectively designed field drainage system should afford a level of protection against waterlogging that is appropriate to the value of the crop, land access and other benefits. It should be designed to drain the field effectively up to an appropriate return period, usually based on crop value.

Thinking of drainage as insurance, a higher-value crop may justify a more intensive field drainage system than, for example, grassland, which may be able to better tolerate a small amount of waterlogging. Equally, improved drainage may attract high-value horticulture crops into the rotation, increasing the rental value.

The degree to which drainage systems provide protection against waterlogging should be matched with the value of the crops to be grown. A typical high-value crop would need to be protected against all rainfall, except very infrequent rainfall events, whereas grassland warrants a lower level of protection.

The following waterlogging risk frequencies are typically used for design:

- Very high-value specialist crops: 1 in 25 years
- Horticultural crops: 1 in 10 years
- Root crops: 1 in 5 years
- Intensive grass and cereals: 1 in 2 years
- Grassland: 1 in 1 year

## Is the existing system adequate?

There are a number of reasons why an existing field drainage system may be inadequate for current needs:

- The scheme may have been designed to work with mole drains that have since collapsed and need renewal
- The drainage system may have reached the end of its useful life (e.g. blocked or collapsed)
- The land use may have changed since the system was installed
- The drains may have been installed without permeable backfill

On soils where permeable backfill is required for optimum performance, the scheme may work well initially due to the soil disturbance during trenching. With the passage of time, however, the soil will return to a more consolidated, less permeable condition that may limit water movement.

It can be difficult to recognise the signs of crop stress on fields where old drains are gradually becoming less effective and where only some crops in the rotation may be affected by stress. When deciding whether the existing field drainage system is adequate, take into account the history of the field and whether it has been deteriorating. Consider:

- Year-on-year variation in yield
- Instances of delayed cultivation or harvest due to field conditions
- Past damage due to poor drainage
- Frequent blow holes may be a sign that pipes are too small or are blocked downstream
- Increases in the presence of moisture-loving plants

Figure 19. Crop loss due to drainage problems

## Assessing the costs and benefits of field drainage

While field drainage can have economic, practical and environmental benefits, installation can be expensive.

Drainage can also exacerbate water pollution and impact negatively on some habitats. It is, therefore, important to carry out an environmental and cost-benefit assessment before installing or carrying out maintenance on field drainage systems.

Production benefits resulting from drainage are most likely to be obtained in areas of high rainfall or on:

- Heavy clay soils, especially where arable or intensive livestock production is practised
- Medium soils where potatoes, other root crops or high-value crops are grown
- Low-lying permeable soils where the groundwater level comes close to the land surface in winter or after rainfall

In many cases, it is better for both agricultural production and the environment to remove excess water by field drainage, but there are cases when the production benefits are outweighed by the costs and there are opportunities to mitigate climate change, flooding, protect water quality or create wildlife habitats by allowing field drainage to deteriorate.

Waterlogged land may be low value agriculturally but it may have biodiversity benefits or help to reduce flooding risk.

Sacrificing an area of waterlogged land may reduce costs by acting as a sediment trap and reducing the need for costly activities, such as watercourse dredging. Suitable areas where drainage might be allowed to deteriorate could include land adjacent to watercourses, natural wetlands and ribbon areas at the base of steep slopes, particularly on intensive grassland on heavy soils in the centre and west of the UK.

For more information for farmers in priority areas at risk of water pollution, contact Catchment Sensitive Farming: **gov.uk/catchment-sensitive-farming**

### Environment

In the Mires on the Moors project (a partnership between South West Water, two National Park Authorities and other organisations, such as the Environment Agency), drainage ditches on Dartmoor and Exmoor were blocked to restore peatland. This increases the carbon and water storage on the moor and slows the flow of water off the moor so that storm and flood damage is reduced, sediment settles out and drinking water quality is improved. Read more on **www.exmoormires.org.uk**

## The impact of field drainage on pollution risk

The relationship between field drains and pollution can be contradictory.

### Positive points

Maintaining good field drainage and good soil structure reduces waterlogging

↓

This reduces the likelihood of causing soil compaction through untimely field operations

↓

This decreases surface run-off, soil erosion and the loss of sediment and associated pollutants, such as phosphorus, to water

### Negative points

When soils are wet or dry with deep cracks and rain falls within a few days of agrochemical application…

↓

…field drains can provide a rapid route for water enriched with ammonium, phosphorus, pesticides, fine sediment or other associated pollutants

↓

Drains are most effective at providing a conduit for agricultural pollutants when newly installed or in fields with deep cracking clays

### Remember

- Best practice should always be followed when applying manures, fertilisers and agrochemicals to avoid losses via surface run-off or field drains
- Organic manures should not be applied to land within 12 months of pipe or mole drainage installation
- Organic manures should not be applied to drained land when soils are wet and drains are running
- Organic manures should not be stored within 10 m of a field drain

# Maintenance and repairs

## Ditches and outfalls

If ditches become infilled and outfalls are not kept clear, the field drainage system will cease to function effectively, leading to the need for more expensive maintenance or premature renewal.

In flat areas, in particular, blocked culverts and ditches can lead to waterlogging over large areas of land, restricting drainage upstream. This can cause flooding and soil erosion as the water backs up and tries to find an overland route to escape.

Given the significant cost of installing a new field drainage system, cleaning ditches and clearing outfalls is a simple, cheap and effective method of improving the effectiveness of existing systems.

Ditches are best cleared in autumn to minimise soil and crop damage.

## Ditch maintenance

Fencing off ditches and watercourses from livestock can reduce maintenance needs by preventing bank damage and erosion.

It can also protect water from sediment and microorganisms in livestock manures, which impact water quality and ecology.

## Blocked outfalls

The most common cause of drainage system deterioration is the failure to keep outfalls clear. This can cause the whole drainage system to fail, resulting in poor drainage, pipe siltation and possibly even blow holes across the field over time.

### Environment

Ditches can be an important habitat for aquatic plants, invertebrates, amphibians, birds and small mammals. Timing of clearance operations or ditch maintenance may have implications for wildlife. Avoid disturbing breeding or nesting animals.

Localised over-digging of ditch beds can form small shallow pools that benefit invertebrates. The ditch will function as long as it has stable banks, the overall gradient is consistent such that it does not reduce drainage efficiency and it is deep enough to allow drainage outfalls to discharge.

Figure 20. Cleaning ditches is a simple way of improving the effectiveness of drainage systems

Figure 21. A blocked outfall can often be cleared in a matter of minutes with a spade

## Pipes

### Blockage by tree or hedge roots

**When designing the drainage system,** trees and hedges should be avoided wherever possible. When this is not possible, a sealed pipe should be used for any pipes within a tree rooting zone or within 1.5 m of a hedge.

**If a blockage occurs,** it may be possible to dig up the pipe on one or both sides of the blockage and use rods to clear the roots, but the section of pipe will often need to be replaced with a sealed pipe.

### Environment

Take care to avoid unnecessary damage to tree roots or disturbing archaeological remains.

## Pipe siltation

If drain outfalls are left submerged or blocked for a long period of time, siltation of the pipes may occur. This can be difficult or impossible to remedy.

Other than as a result of damaged or blocked pipes, siltation most commonly occurs on fine sandy and fine silty soils.

If pipe siltation is not too severe, it may be possible to rod the drains clear or to employ a contractor with specialist drain jetting equipment.

Figure 22. Silted clay drain

Where pipe siltation is a naturally recurring problem, a drainage system with separate outfall pipes for each drain is best. This allows easier access for cleaning operations.

Figure 23. Drain jetting

### Ochre

Ochre is a generic term used to describe deposits that form in drains when soluble iron leaching out of the soil in drainage water comes into contact with air and is oxidised, at which point it becomes insoluble. It can also be caused by bacterial growths that secrete iron.

In some cases, a drainage scheme may fail completely due to ochre accumulation. In these cases, redrainage is only worthwhile if future ochre development is unlikely.

#### Preventing ochre formation

- Soils rich in iron may be prone to ochre and there is little that can be done to prevent ochre formation
- There are methods that attempt to prevent the build-up of ochre, but these can be specialist, intensive and often not very successful

#### Removing ochre

- Regular rodding or jetting may remove the ochre
- If the pipe slots or permeable fill is blocked, the benefits may be limited or nil

#### Design

- Where ochre is a problem, systems with separate outfall pipes for each drain are best, as they allow easier access for clearance operations

Figure 24. Drainage outfall blocked by ochre

## Replacing field drains

When replacing a field drain, the same diameter (or metric equivalent) drain should be used as the drain being replaced. If the drain is a carrier drain or culvert, increasing the pipe diameter would reduce the risk of blockage or excess flows collapsing the pipe in the future. However, care may be needed to avoid increasing flood risk downstream. Expert advice should be sought if in doubt.

## Mole drains

Mole drains are unlined channels formed in a clay subsoil. They are used when natural drainage needs improving in particularly heavy or calcareous clay subsoils that would require uneconomically closely spaced pipes for effective drainage.

Mole drains act as closely spaced pipe drains and conduct water to the permanent pipe drains or direct to open ditches.

Mole drains are not suitable for controlling rising groundwater or areas prone to flooding.

Soils should have a minimum of 30% clay for best results. Clay gives the soil the ability to hold together and reduces the chances of the channel collapsing after the mole is pulled.

Sand content should be less than 30%. The soil should be free of stones at the mole drain depth.

Mole drains are formed by dragging a ‘bullet’ (effectively, a round-nosed cylindrical foot shaped like a bullet, with slight tapering towards the tail) followed by an expander (a cylindrical plug of slightly larger diameter than the bullet) through the soil to form a circular semi-permanent channel – i.e. a natural pipe with fissuring in the soil above the channel.

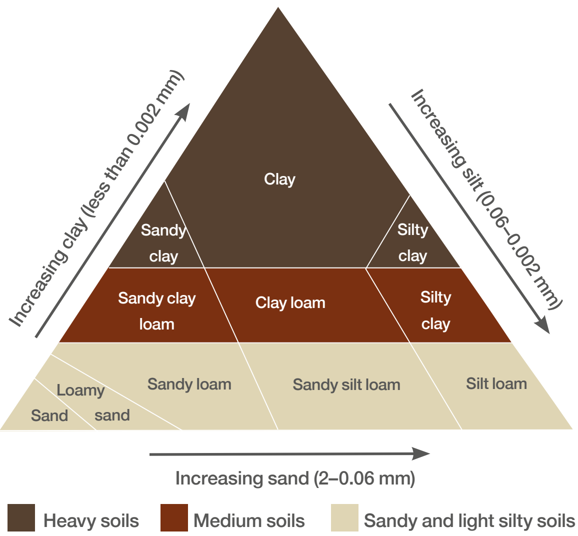



Figure 25. Soil texture classification
Source: Controlling soil erosion (Defra, 2005)

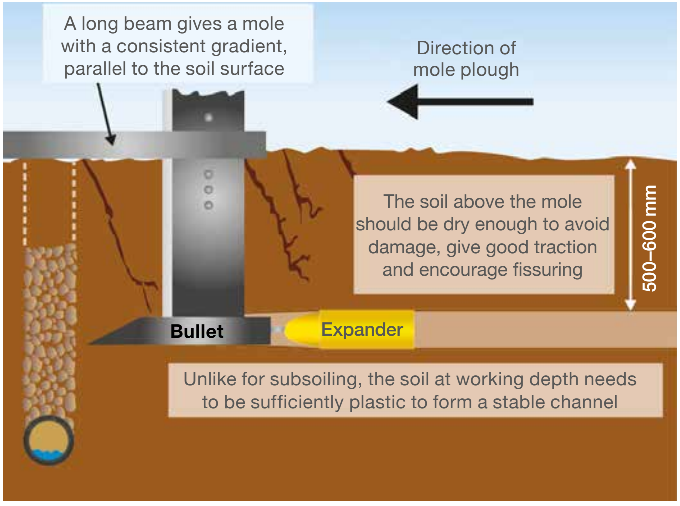



Figure 26. Appropriate conditions for forming mole drains

### How long do mole drains last?

The longevity of mole drains depends on a number of factors, including:

- Soil texture (high clay content is better)
- Soil calcium content (high levels of calcium will increase longevity)
- Climate (wetter conditions will reduce longevity)
- Slope (too shallow or too steep will reduce longevity)
- The moisture conditions in which the moles were formed

Mole channels in very stable, clay soils (clay content ~45%) can last over 10 years, but the method can still be effective in soils with at least 30% clay, particularly calcareous soils.

Typical lifespan in suitable soils ranges from five to ten years, but it can be reduced where patches of sandier soil occur, leading to premature collapse. Bad soil management can seal off the routes by which water reaches the mole drains.

If the pipe drainage system was designed to be supplemented by mole drains, it is good practice to renew mole drains on a cycle of around once in every five years.

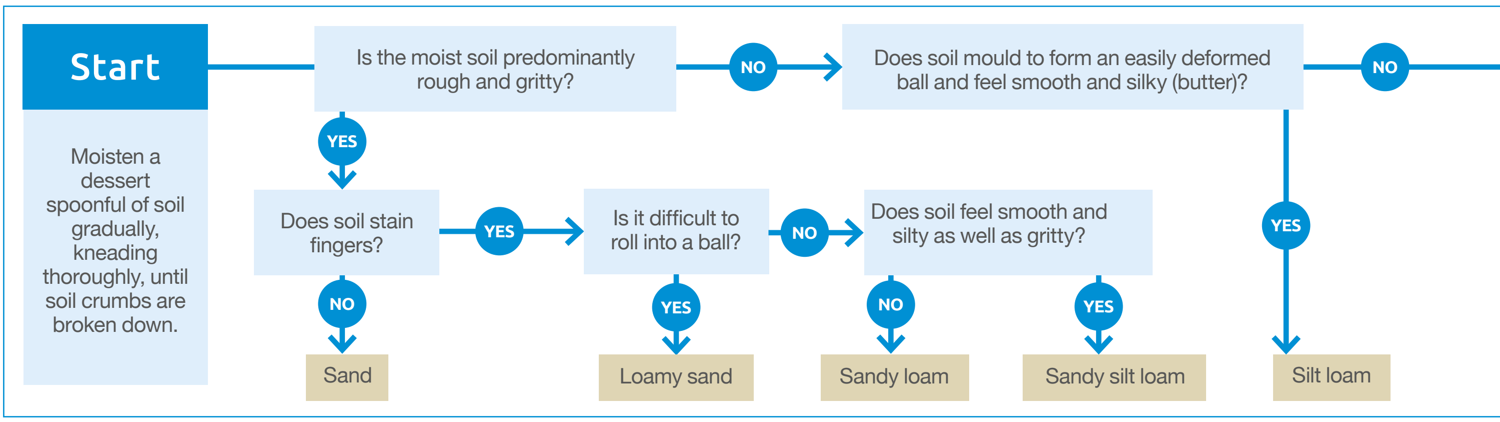



Figure 27. Appropriate conditions for forming mole drains
Source: Controlling soil erosion (Defra, 2005)

# Installing mole drains

## 1. Suitable conditions

To achieve satisfactory results, the soil in the vicinity of the mole channel needs to be moist enough to form a channel but not dry enough to crack and break up and not soft enough to slough off and form a slurry.

Moling should be undertaken when:

- The soil at working depth is plastic, i.e. it forms a 'worm' without cracks when rolled on the hand
- The soil surface is dry enough to ensure good traction and avoid compaction

The drier the soil above moling depth, the greater the fissuring produced and the more efficient the water removal.

These conditions are most likely to arise during May to September/October, depending on the season and location.

## 2. Depth

Optimum mole depth depends on the soil type and the conditions when the moles are installed.

Generally, moles are pulled at 500–600 mm depth. Often, when first mole draining, the shallower depth is used, due to tractor limitations in tight, compacted soils. As the soil structure improves over time, they can often be pulled deeper, although care must be taken not to damage piped drains.

Moles less than 400 mm deep are liable to be damaged by tractors and animals during, or immediately after, rain and tend to be short-lived.

A rule of thumb is that the expander to mole-draining depth ratio is 1:7 (for example, a 70 mm diameter should have a mole depth of 490 mm).

## 3. Points to note

- It is essential that the 'bullet' is drawn through the permeable backfill over the pipe drains
- The mole plough should be in good condition, with minimal wear to the 'bullet' and tip
- Set up the mole plough so the 'bullet' is parallel to the ground surface when at working depth; a poorly set up mole plough will produce a poor channel and increase the draught requirement
- If the soil is liable to smearing, removal of the expander will reduce channel smearing, increasing the potential for water to enter the mole drain and reducing draught requirements
- When moling, dig a pit to expose the channel formed; it should be round and there should be fissuring above it
- Install moles at 2–3 m spacing, or closer on unstable soils
- Moles should be drawn up and down the slope across the lateral drains, making sure that they cross and connect with the permeable backfill over the drains
- Pull the plough out as soon as the mole plough has crossed the last drain: blind ends accumulate water
- If large stones are encountered, pull all the moles uphill and pull out after the channel has been disrupted

To aid decision-making, keep a record of where at least one of the most recent mole drains was pulled to allow examination of the mole drains by excavating a profile pit. This should be done just downslope of a lateral drain and, if still functioning, the mole drain should be reinstated afterwards with a short length of pipe.

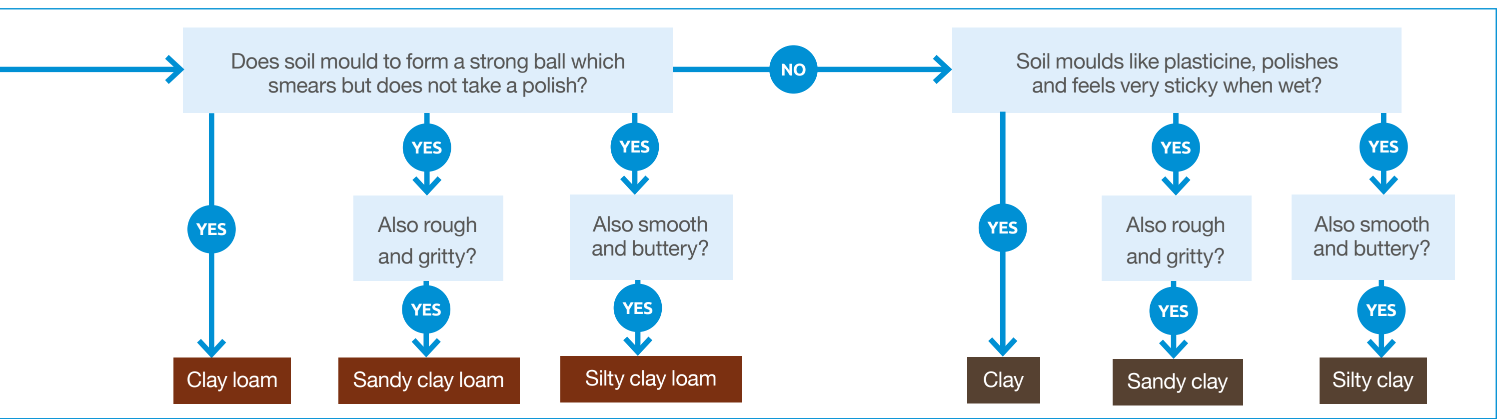


Figure 28. Installing land drains and stone backfill

## Factors to consider when designing a new drainage system

### Drain depth

**In slowly permeable soils**, research has shown that (unless there is a specific crop need) lateral drain depths greater than 0.75 m give no additional benefit. Drains simply need to be deep enough to avoid damage from soil implements.

**In permeable soils, where the drains control the depth of the water table,** deeper drains allow the spacing between drains to be increased. Drain depths in such soil types are typically 1.2–1.5 m.

**Maximum drain depth** is often limited by the depth of the ditches or watercourses into which the drains discharge. These can be deepened, but only to the level of the downstream channel.

Figure 29. Recently installed drains

### Drain spacing

Drain spacing has always varied according to local custom, but it has become more standardised in recent years. The correct spacing can be calculated using theoretical equations, but this is not often done in practice.

**In heavy clay soils**, the theoretical correct drain spacing will almost always be so small as not to be economically viable. Where soil conditions are appropriate, wide-spaced drains with permeable backfill supplemented with mole drains are the best choice. Pipe drain spacing for a mole drainage system can be as wide as 80 m, although 40 m is more typical. The main limiting factors are soil stability and landform.

**On land with soils not suitable for moling**, a modern system would have a spacing of 20–25 m with permeable backfill over the drains. The effectiveness of this type of system will rely greatly on maintaining good soil structure, sometimes aided by subsoiling.

Figure 30. Installing mole drains

**If permeable backfill is not used**, drain spacing in the region of 10 m will be needed, but this is unlikely to be as effective as a scheme using permeable backfill.

**In permeable soils with a rising groundwater**, the drain spacing will be determined by the depth of the drains and the level at which the groundwater is to be controlled. Permeable backfill is not usually needed.

## Outfall availability and gradient

Outfall availability and gradient have an impact on the efficiency of the drainage system. As a comparison, a bath/shower is designed to slope and has a strategically positioned plughole (outfall) to drain the water. Lack of available outfall and/or gradient to enable water to drain away materially affects the efficiency of the field drainage system.

## Drain diameter

In the UK, drain diameters are calculated using the procedures set out in MAFF/ADAS Reference Book 345 (The design of field drainage systems). This method takes account of:

- Soil type and slope: speed of water movement
- Land use: the degree of risk that is acceptable depending on the crop value
- Climate: rainfall intensity
- Type of drainage system: for example, mole drains must not be left submerged for more than 24 hours and, therefore, excess water must be evacuated rapidly

The rainfall figures used in the method set out in MAFF/ADAS Reference Book 345 are now outdated and in some areas may not match current rainfall patterns. They also take no account of potential future increases in storm intensities due to climate change. However, these remain the current guidelines.


Figure 31. Installing land drains with laser gradient control

Figure 32. Install drains at an appropriate depth and constant gradient (fall)

## Use of permeable backfill

Permeable backfill refers to the gravel/stone chippings applied to the trench above the drain, typically to the base of the topsoil.

The use of permeable backfill has been a long-debated subject, primarily due to the significant associated cost. There are many examples of very old drainage systems without permeable backfill that still have some function; however, research indicates that on drained clay soils without permeable backfill, while the drains may initially function well, the permeability of the soil in the drain trench decreases with time.

Best practice is to install sufficient permeable backfill so that a connection exists between the drain trench and the cultivated layer. As a minimum, the permeable backfill layer should connect with the mole drains or any fissures caused by subsoiling.

If mole drains are to be installed over the pipes, the use of permeable backfill is essential to provide a hydraulic connection between the mole channels and the drain.

The performance of drains installed without permeable backfill cannot be rejuvenated by subsoiling.

The one circumstance where permeable backfill is never required is where the function of the drainage is to control a rising water table in a coarsely textured soil.

Figure 33. Mole plough

Figure 34. Permeable backfill in trench over drain

## Site

Field drainage should be planned carefully to avoid negative impacts on water bodies used for drinking-water abstraction, fisheries or Sites of Special Scientific Interest (SSSIs) sensitive to raised nitrate levels. Field drains and outfalls could be designed to discharge into a wetland buffer area before flows enter a watercourse or be directed away from sensitive water bodies. Field drains should not be installed within at least 10 m of a slurry or silage store.

Sustainable drainage systems (SuDS) or novel approaches, such as bioreactors, can be used with field drainage systems to trap sediment and slow water/soil run-off and to filter pollutants in drainage water.

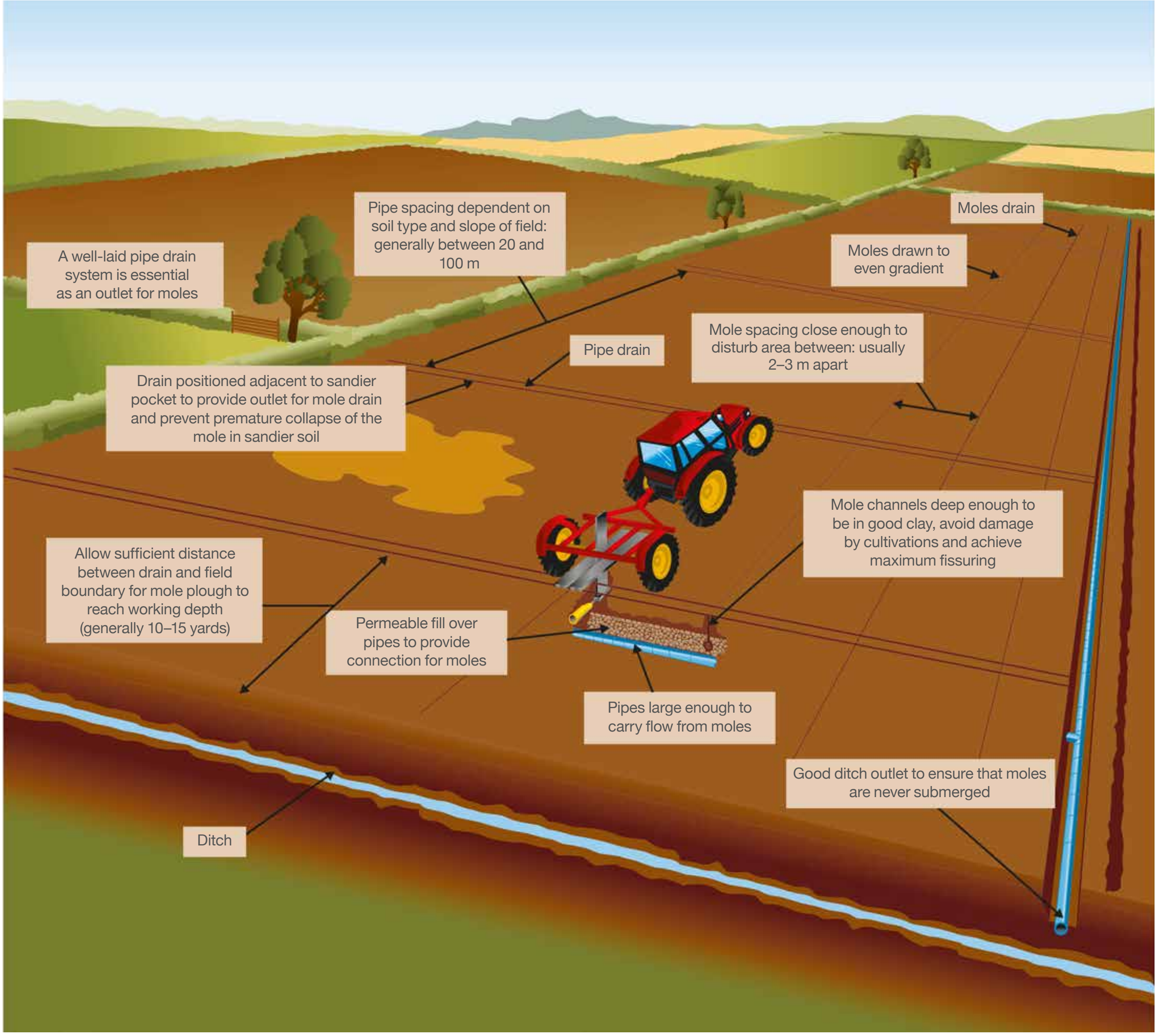



Figure 35. Layout of piped drainage and mole drains

## Environment

### Outfalls

New outfalls should be positioned sensitively at ditches and ponds to avoid damaging habitat. Land drains should not divert water away from areas that may depend on this water for drinking, washing or habitat. Diverting flows can also increase the risk of flooding and infrastructure failure.

### Conservation

A new drainage scheme can provide an opportunity to create new conservation features. Old farm ponds that have silted up could be reopened to provide a habitat and catch pit for eroding soils, and ditches could be over-dug into localised ponds.

Government-funded schemes may be available for a range of land management options and capital items that can be used to reduce the negative impacts of field drainage on water quality or to create/improve wetlands and ditch habitats. These include the creation of wet grassland, ditch management and buffering of water bodies. For more information, see **gov.uk/guidance/countryside-stewardship-manual**

## Selecting a designer

Before engaging an independent field drainage consultant, it is important to determine if they have adequate experience and qualifications. A specialist designer will have a thorough understanding of the needs and management of the soils, as well as of field drainage.

To enable them to determine if a new drainage system is required or whether maintenance of the existing system and/or improved soil management may be adequate to resolve the problem, a designer should always:

- Discuss any problems you have with the site and how you intend to manage the site in the future
- Survey the soil types, soil conditions, existing drainage systems, field topography, proximity to utility services and other features that may affect the final design
- Consider potential environmental impacts, drainage law and economic feasibility

Given the scale of the investment that a new drainage system represents, it is recommended that independent advice is sought with regard to the design.

**Using an experienced consultant designer will ensure that the scheme is the best and most economically appropriate to meet the requirements.**

### Environment

Archaeological features can be damaged by field drain installation and drains may conflict with the conservation of a wetland or water habitat or species. Where relevant, contact Natural England, the drainage authority or a county archaeologist before commencing work.

## Selecting a contractor

To install a new comprehensive field drainage system, it is essential to employ a specialist land drainage contractor with access to specialist machinery that can install and backfill drains rapidly. A drainage machine shapes the trench bed and can set a consistent gradient, even in the flattest of fields. A specialist contractor should fully understand field drainage requirements and employ the approved standards and materials.

The National Association of Agricultural Contractors (NAAC) is a trade association and has a list of members on its website (**naac.co.uk/findacontractor**) which can be a useful starting point for selecting a land drainage contractor. Not all drainage contractors are members of the NAAC, however.

Recommendations from others in the local farming community can be another helpful source of information.

Contractors may have different approaches to dealing with the scale, access and physical aspects of the location, so quotes may vary.

### Health and safety

It is advisable to request:

From the contractor:

- A risk assessment and method statement (RAMS)
- Verification that they have sufficient public liability insurance cover

From the designer:

- Verification that they have sufficient professional indemnity insurance cover

## Land drainage law

A landowner has an obligation to accept the natural flows of water from adjoining land and must not cause any impedance to these flows that would cause injury to adjoining land. 'Natural water flows' refers to water that has not been diverted from its natural path, artificially increased or had the run-off flow rate changed (e.g. by the construction of unauthorised paved areas within the catchment).

This means that if a landowner neglects or fills in their ditch, such that water may not freely discharge from higher neighbouring land, the landowner is guilty of causing a nuisance. In this situation, the landowner or occupier of the higher land may ask the Agricultural Land Tribunal to make an order requiring the landowner guilty of nuisance to carry out the necessary remedial works. It must be emphasised, however, that it is usually far better to attempt to resolve such situations by amicable discussions with the offending party first, as they may be unaware of the nuisance.

If the neglected ditch in question runs directly along the boundary between respective ownerships, the assumption that would be made is that the owner of the original hedge is also the owner of the ditch. On watercourses, the ownership boundary is assumed to be down the middle of the bed. Only clear evidence to the contrary, such as the deeds to the land, will rebut this assumption.

No ditch or watercourse should be piped, filled in, restricted or diverted without the approval of the regulatory authority, for example, the local authority or the EA, NRW, SEPA, NIEA or the local internal drainage board. Consent may be needed for works within 8–10 m of the bank top of a watercourse. Uncultivated or semi-natural land is protected under the Environmental Impact Assessment Regulations (Agriculture) and should not be drained without prior approval from the relevant national body.

## Standards, materials and quality

There are two fundamental standards to which any designer will be working:

- Reference Book 345: The design of field drainage pipe systems (MAFF/ADAS, 1982)
- Technical Note on Workmanship and Materials for Land Drainage Schemes (ADAS, 1995)

Within these primary standards, there will be a number of decisions to be made about the design specification.

### Pipe type

Currently, all new drainage schemes are installed using plastic pipes, although many older schemes were installed with clay pipes and may be replaced with the same.

**It is essential that a material designed for use in field drainage is used.**

Consideration should be given to the use of twin-wall or ductile iron pipes or gravel pipe surround where there is a risk of pipe crushing.

Figure 36. Modern perforated plastic drainage pipe

### Permeable backfill type

- The material used must be hard and durable when wet and when dry
- The bulk of the material should be in the range 5–50 mm
- The material should not contain more than 10% fines

Figure 37. Washed gravel permeable fill over drain

### Outfall type

Most modern outfalls are installed with glass-reinforced concrete headwalls; however, the actual outfall type may vary according to its location.

Figure 38. Precast concrete headwall (type K)

### Filter wrap

Filter wrap is a geotextile barrier around the outside of the pipe to prevent soil particles entering the drain. It is not commonly used in the UK, as research has shown that pipe sedimentation is not usually a problem if the pipes have been laid and maintained properly. There are, however, some cases with fine, sandy soils when filter wrap can be beneficial.

Filter wrap should never be used where there is a risk of ochre.

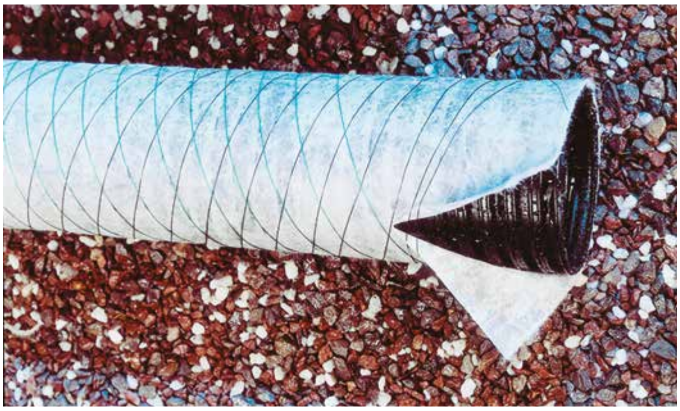


Figure 39. Single-wall pipe wrapped in geotextile

## Molescroft Farm, Beverley, East Yorkshire

### The farm

- 485 ha farm with deep loam and alluvial clay soils
- Land is at or below 5 m above sea level and suffers from waterlogging
- Arable cropping: wheat, barley, oilseed rape, field beans and vining peas
- 10% of the farm is in Higher Level Stewardship and grazed by cattle and sheep appropriate to meet the requirements

### The problem

The problem field had a full tile drainage system installed in the 1980s, but:

- Wet patches had started to appear
- Crops had to be drilled early to avoid soil damage and poor establishment
- The cost of weed control had increased due to the lack of opportunity for stale seedbeds
- Recent wet seasons had resulted in patchy crops with increased weed problems and soil damage

The main drain was found to be completely blocked by willow roots and some tiles were misaligned.

### The solution

The solution was to drain a 6 ha area of the field, with new plastic pipes installed between the existing tiles and gravel backfill used to improve effectiveness.

### The outcome

- New drainage has made the field far easier to work and manage
- It was the highest-yielding field in the following harvest year
- Lower inputs of herbicides were required

### The cost

The total cost of the upgrade was £14,500 (£2,417/ha).

Maintenance costs estimated at approximately 1% of capital cost (£25/ha/year).

Benefits estimated at a total of £229/ha/year:

- Typical yield increased from 7 t/ha to 8.75 t/ha, a total of £175/ha/year
- Herbicide costs were reduced by £30/ha/year
- Better soil structure reduced subsoiling costs by 25%, saving £3/ha/year, and cultivation costs by £21/ha/year

**Simple payback period**

$$\frac{\text{Cost}}{\text{Benefits}} = \frac{\text{£2,417}}{\text{£229 - £25}} = \text{12 years}$$

### Comment

Once the investment has been paid off, the benefits may continue to be received for many years (provided maintenance is sustained).

These calculations assume average changes to costs and returns; however, extreme weather will have a far greater effect. It is difficult to factor in random occurrences, such as the avoidance of significant crop loss due to waterlogging, and the decision to invest in drainage should be made on a field-by-field basis. The costings do not take into account the cost of finance or increased land value.

## Evershot Farms Ltd, Melbury Osmond, Dorset

### The farm

- 1,500 ha farm, largely on heavy, poorly drained soils
- Rainfall is over 1,000 mm/year
- Stocking: 900 cows and 2,500 mule ewes; heifers are contract reared off the farm
- Cropping: mainly grassland with about one-third cut for silage; maize is no longer grown
- The farm has a 750 kW biogas plant

### The problem

The aim is for cows to be turned out in late March and housed from mid-September, but the grazing season can be very variable from year to year.

Maize was causing significant soil damage.

### The solution

The solution was to replace maize with Italian rye-grass, introduce whole-crop wheat to balance the ration (and save on purchased straw) and drain a 10.2 ha field, including:

- A main drain with laterals and headwalls at outlets
- Digging out the ditches downstream to obtain sufficient fall
- Moling to increase connectivity every five years at reseeding

### The outcome

- Soil problems are now avoided and increased rainfall infiltration minimises run-off
- The field is accessible two weeks earlier and for two weeks longer
- The Italian rye-grass has increased yield (from 37 t/ha to 45 t/ha) and forage value
- Reduced risk to operations and increased forage quality and dry matter yield

### The cost

The total cost of the drainage was £5,245/ha (£48,500 for the drainage, plus £5,000 on ditching), plus maintenance at £52/ha and additional annual silage-making costs of £132/ha.

Benefits estimated at a total of £595/ha/year:

- The change from maize to grass silage has produced a higher dry matter yield and greater forage value from four cuts
- The change to Italian rye-grass resulted in an increase in forage value
- Cultivation savings:
  - Moving to grass, the cultivation savings were £105/ha/year
  - The average annual cost of moling was the same as subsoiling
- Forage savings (total of £490/ha) from:
  - Increased value of silage (at previous yield level): 37 t/ha at £4/t gives £148/ha
  - Increased yield of silage: 8 t/ha at £34/t gives £272/ha
  - Value of additional grazed forage: £70/ha

$$\frac{\text{Cost}}{\text{Benefits}} = \frac{\text{£5,245}}{\text{£595 - £52 - £132}} = \text{13 years}$$

### Comment

Once the investment has been paid off, the benefits may continue to be received for many years (provided maintenance is sustained).

These calculations ignore the potential for extreme weather, without drainage, to result in significantly lower forage yields, soil damage and increased housing and forage requirements. Wet conditions during silage making can result in contamination from soil, leading to poor fermentation, poor milk yield and potential health problems. The costings do not take into account the cost of finance or increased land value.

# Glossary

| | |
|---|---|
| **Compaction** | The process by which the soil density increases due to trafficking or soil working when conditions are unsuitable, i.e. too wet |
| **Culvert** | A short length of pipe installed to allow access over the ditch or watercourse |
| **Drain jetting** | Removal of deposited sediment from a drain using a high-pressure water jet |
| **Field capacity** | The moisture content of the soil after excess water has drained away |
| **Filter wrap** | A geotextile barrier wrapped around the pipe to prevent particles entering the pipe |
| **Friable** | Soil where the aggregates crumble easily into smaller pieces |
| **Infiltration** | Water entering the soil e.g. through rainfall |
| **Laterals** | The drains installed, usually parallel to each other, to intercept soil water and transport flows to the main drain |
| **Mains** | Drains installed to collect the water from several laterals and transport it to a ditch |
| **Mole drains** | Unlined channels formed in a clay subsoil |
| **Natural water flows** | Water that has not been diverted from its natural path, artificially increased, or had the run-off flow rate changed, such as by the construction of unauthorised paved areas within the catchment |
| **Ochre** | Insoluble deposits that form in drains when soluble iron leaches out of the soil, into drainage water, and becomes oxidised. It can also be caused by bacterial growths that secrete iron |
| **Outfall** | Point at which the main drains or individual laterals discharge into a ditch |
| **Percolation** | The process of water moving down through the soil to depth |
| **Perched water table** | Saturated layer above compacted soils |
| **Perforated drainage pipe** | A slotted drainage pipe, which is used to collect water from the soil |
| **Poaching** | Damage to the soil surface caused by animal hooves |
| **Slaking** | The collapse of the soil aggregates as the soil wets up rapidly |
| **Water table** | The saturated zone of the soil |

# Further information

## Other sources of information

Catchment Sensitive Farming:
**gov.uk/catchment-sensitive-farming**

Catchment Sensitive Farming officers provide free advice and support to farmers in priority catchments to reduce water pollution. This includes information on soil and water management and a review of field drainage.

National Association of Agricultural Contractors (NAAC):
**naac.co.uk**

Think soils (Environment Agency):
**ahdb.org.uk/thinksoils**

A guide to better soil structure (Cranfield University):
**www.landis.org.uk/downloads**

Geographic information for Great Britain:
**magic.gov.uk**

Countryside stewardship manual (Natural England):
**gov.uk/guidance/countryside-stewardship-manual**

Environmental permits for flood defence:
**gov.uk/permission-work-on-river-flood-sea-defence**

Guidance on owning a watercourse:
**gov.uk/guidance/owning-a-watercourse**

Flood and coastal erosion risk management R&D (Environment Agency):
**gov.uk/government/publications/national-flood-and-coastal-erosion-risk-management-strategy-for-england--2**

Pinpoint best practice information sheets (The Rivers Trust):
**theriverstrust.org/our-work/farm-advice/best-practice-advice-sheets-for-farmers**

Constructed farm wetlands: A guide for farmers and farm advisers in England (Wildfowl and Wetlands Trust):
**wwt.org.uk/farmwetlands**

Sustainable drainage systems: Maximising the potential for people and wildlife (RSPB and Wildfowl and Wetlands Trust):
**www.wwt.org.uk/uploads/documents/2019-07-22/1563785657-wwt-rspb-sustainable-drainage-systems-guide.pdf**

Godwin, R. J. and Spoor, G. (2015). Choosing and evaluating soil improvements by subsoiling and compaction control. In Ball, B. C. and Munkholm,L. J. (eds). *Visual Soil Evaluation: Realising Potential Crop Production with Minimum Environmental Impact.* CABI, Wallingford, UK.

## Video demonstrating the principles of subsoiling

AHDB Pork has produced a series of videos demonstrating the general principles of subsoiling. The videos look at cultivation depth, choice of machine and the effects of tines and wings.

The videos are available to watch online at **youtube.com/AHDBPork** and on the Practical Pig app (**practicalpig.ahdb.org.uk**).

# Further information

## AHDB GREATsoils

AHDB provides a range of practical information on improving soil management for farmers, growers and advisers. Whether you need an introduction to soil biology or a detailed guide to soil structure, AHDB has the information and guidance to support you.

Information for grassland, pig producers, arable and horticultural crops is available at **ahdb.org.uk/greatsoils**

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# Natural flood management (NFM) knowledge system: Part 3 - The effect of land drainage on flood risk and farming practice

**Final Report**

**01/07/2012**

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# Contents

## Executive summary

Land drainage is typically classified as either surface or subsurface and is widespread throughout developed countries. Substantial drainage has been undertaken during various periods in history and it is estimated that within the United Kingdom 60.9% of agricultural land is drained. In Scotland there was a dramatic increase in drainage after the Second World War, mostly due to the need to increase food production aided by a rapid development in mechanised installation; increased drainage was also evident during a period of agricultural intensification in the 1960s and 1970s. In Scotland the aim has often been to lower the water table to encourage vegetation cover more suitable for livestock grazing. Whilst drainage was common for grazing land, extensive land drainage was also undertaken in upland regions for commercial forestry operations. It should not be doubted that land drainage has shaped the way society has grown and developed.

While offering benefits that may improve yield, agricultural and forestry drainage have altered the rate of water runoff and increased peak flows during heavy rainfall and can result in diffuse pollution. It can therefore have a significant impact on the landscape, biodiversity and downstream hydrological processes.

Land Drainage is now recognised as having an impact on peak flows however, the extent of any potential changes is uncertain and likely to be site specific. Reviews of drained sites indicate a variety of responses. A number of studies found that field drainage could increase or decrease peak drain flows by as much as two to three times; the behaviour appeared to depend on soil type, antecedent conditions and rainfall event. Fundamentally, the key factor is the relative importance given to two processes; increasing flood flows due to the ability of drains to carry water faster than subsurface flow through the soil and reduced flood flows due to an increase in soil storage capacity created by lowering the water table. Which of these processes exerts the greatest influence will depend on various factors including: drainage density and geometry, hydraulic conductivity, drain and surface roughness, topography, event size, and antecedent conditions. Although not conclusive, authoritative studies have linked land drainage derived increased flood risk to dry catchments and arterial network geometry.

Drain blocking, commonly undertaken by installing a series of permanent dams in a drain, can be used to help restore a site to its pre-drained condition. However, a number of studies report that while drain blocking of peatland has benefits for the ecosystem, the impact on peak flows and flood volumes is not clear. Controlling the volume of flow through an existing drainage network in a manner which allows peak flow control while also maintaining water table levels appropriate for agriculture offers an alternative to permanent blocking. This review has found that there may be an opportunity to meet the needs of agriculture whilst managing diffuse pollution and flood risk by deploying real-time control as a method of dynamically controlling land drainage.

# 1.0 Introduction

The first Scottish National Flood Risk Assessment, produced by the Scottish Environmental Protection Agency (SEPA, 2011), reports that approximately one in 22 of all residential properties and one in 13 of all non-residential properties in Scotland are at risk from flooding, and notes that the average annual damage to homes, businesses and agriculture from all sources of flooding is estimated to be between £720 million and £850 million. In addition, climate change trends suggest that Scotland will experience more frequent extreme weather events, including intense summer rainfall (SEPA, 2012). Given these predictions, there is a clear need to ensure appropriate flood management processes are in place. Over time, the approach to flood management has changed: an initial focus on land drainage and flood defence throughout the 1950s, 60s and 70s moved towards a flood control and then a flood management approach in the 1980s and 90s. Whilst, these approaches had a strong focus on engineering measures, a more integrated and sustainable flood management (SFM) approach is currently being adopted. In Scotland, SFM was established in legislation as part of the Water Environment and Water Services (Scotland) Act in 2003, which also transposed the European Water Framework Directive (WFD) (EU, 2000) into Scots law. The WFD requires the development of river basin management plans which promote sustainable water use in a way which protects and improves the water environment. Described as "the most substantial piece of EC water legislation to date" (Potter *et al*., 2011), the river-basin management approach stresses the interrelationship between water management and land use. Scotland's first comprehensive river basin management plan was produced in 2009 (SEPA, 2009).

It is increasingly becoming understood that effective management of river basins in terms of water resources (floods, droughts, recreation and biodiversity) requires the integrated management of both land and water practices (O'Donnell *et al*., 2011). This integrated approach is also recognised as a requirement at smaller scales. For example, Abdel-Dayem (2006) notes that in most countries drainage systems are "...not designed to address simultaneously water management, disease control, drainage water reuse and flood management" and suggests that an approach to managing drainage from an integrated water and land perspective is essential.

Within this context, this report is one of three produced for CREW to verify the current state of knowledge on NFM. It briefly reviews the historical development of land drainage and looks at the impacts on flood risk from land drains and the recent move towards drain blocking.

# 2.0 Land Drainage

## Drainage types

***"Drainage is typically classified as either surface or subsurface drainage"***

Land drainage is typically classified as either surface or sub-surface drainage. Surface drainage is gravity driven and generally involves the use of shallow trenches or ditches (often referred to as grips). A simple example of this approach to drainage are 'lazy beds' where a series of trenches are constructed with the removed soil piled up between to create a ridge and furrow effect.

Sub-surface drainage can be either gravity driven or directly pumped. This type of drainage can be created using deep open/covered ditches, trenches or by installing perforated pipe systems. This is commonly referred to as tile drainage.

## Agriculture and forestry practices

***"While offering benefits that may improve yield, agricultural and forestry drainage have altered the rate of water runoff and increased peak flow during heavy rainfall"***

Land drainage offers a number of benefits for agriculture and forestry including: reclamation of land, intensification of current practice, land use change and reduced production costs (Morris, 1992). Drainage can influence the scale of cultivation, crop selection, irrigation and fertilization practices, and field structure (Herzon & Helenius, 2008). In a review of the role of agriculture in sustainable flood management, Kenyon *et al*. (2008) report that it is generally acknowledged that incentives provided to farmers to drain agricultural land have altered the rate of water runoff and increased the peak flow during heavy rainfall. The same study noted that certain agricultural practices including bog, pond and wetland drainage were recognised as being significantly responsible for increasing downstream flood risk since they reduced natural flood storage capacity and increased runoff.

In terms of forestry management, in recent decades the use of once common practices such as aggressive drainage ditching to prepare wet soils and direct connection of drainage ditches to natural watercourses have been proscribed (Jacobs Engineering, 2011).

## Environmental Impacts of Drainage

**''Drainage has a significant impact on the landscape, biodiversity and downstream hydrological processes''**

Land drainage is recognised as playing a key role in agricultural and environmental sustainability. A review by The World Bank in 1993 identified inadequate or inappropriate drainage as perhaps the most severe long term problem reducing the benefits of irrigation, encouraging adverse river morphology and leading to noxious environmental effects (Abbot & Leeds-Harrison, 1998).

Blann *et al*., (2009) note that in the US, the most prominent effect of artificial drainage has been the direct elimination of wetland and riparian habitats. They report that less than half of the 221 million acres of wetland estimated to have been present in the United States at the end of the nineteenth century currently remain and suggest that most of these historic losses of wetlands are attributable to drainage for agriculture. Similar impacts were also noted for Canada where agricultural drainage has accounted for between 81 and 85% of wetland losses in southern Ontario (Walters & Shrubsole, 2003) and for Austria and Denmark where land drainage was cited as ''probably the single most important measure which has adversely affected the landscape (loss of wetlands, small scale structures in the landscape), the biodiversity and the hydrological cycle'' (Scheidleder *et al*., 1996).

Several impacts of peatland drainage have been noted including changes in the peat structure, erosion of the ditches, increased aerobic decomposition due to the lowering of the water table and increased leaching of nutrients (including dissolved organic carbon - DOC) and an associated increase in water colour (Armstrong *et al*., 2010). Land drainage affects the water budget of the whole catchment by altering soil water storage, groundwater storage, the proportion of rainfall subject to evapotranspiration, and rates and volumes of water export. Artificial drainage of peatlands lowers the water table in areas directly adjacent to the drain, with the strongest influence downslope of the drain (Holden *et al.*, 2006). In addition to lowering the water table, drained blanket peat shows greater volumes of sub-surface through-flow than overland flow (Holden *et al.*, 2006). As well as these local impacts, there are acknowledged adverse effects on downstream hydrological processes including increases and decreases in flood peaks (Holden *et al*., 2004; Holden *et al*., 2006) and increases in baseflows (Robinson, 1985).

## 3.0 Historical Development of Land Drainage

### Historical Impact

***"Land drainage has shaped the way society has grown and developed"***

The potential of drainage to transform landscapes and agriculture and its importance in shaping history is well recognised. For example, a review of drainage in West Lancashire argues that "...drainage of this land, resulting in its transformation from some of the worst land in the country to some of the best, was a major contributor not only to the agricultural success of the region, but also to Lancashire's industrial success." (Gritt, 2008). Another study notes that within the United States, by 1920, the amount of agricultural land made available through drainage was far greater than the amount of land opened by irrigation and suggests that the development of societies around the now intensely managed and highly productive 'Corn Belt' of the Grand Prairie of East Central Illinois was the result of growth due to "... the energetic drainage enterprises of the Midwestern US and the Canadian Great Plains in the late-nineteenth and early twentieth centuries." (Imlay & Carter, 2012).

### Geographical extent

***"Land drainage is widespread throughout developed countries"***

Within Europe, significant areas of land have been modified by drainage to increase agricultural production. In 1998 it was estimated that around 34% of farmland in Northwest Europe was drained with much higher drainage concentrations in some countries (Blann *et al*., 2009). For example, in 2000 it was estimated that within the United Kingdom 60.9% of agricultural land was drained, while 51.4% of agricultural land was drained in Denmark and 91% in Finland (Wiskow & van der Ploeg, 2003). Areas outside of Europe are also extensively drained. For example, by 1987 more than 17% of U.S. cropland (up to 30% in the Upper Midwest) had been altered by artificial surface or subsurface drainage (Pavelis, 1987). Within the UK, whilst drainage was common for grazing land, extensive land drainage was also undertaken in upland regions for commercial forestry operations (Dunn & Mackay, 1996). Open ditch drainage, sometimes referred to as gripping, has historically been a common land management practice in UK upland blanket peats (Ballard *et al*., 2011a). For example, in the twentieth century more than 9,000 km of drains were dug in the moorlands of the North Pennines (Natural England, 2011).

### The development of drainage in the UK

***"Substantial drainage has been undertaken during various periods in history driven by agricultural demands"***

Within Scotland, numerous methods have been used historically to lower the water table and improve the soil, one of the earliest reported methods being the *lazy-beds* of the Highlands and Islands (Green, 1979). Government funding of public loans for large-scale drainage were available from the 1840s onwards (Gritt, 2008). In the UK, about £12M was loaned in the period 1850-78 by government and private drainage companies. This was a period of agricultural prosperity and expansion and drainage played an important role being termed “the great improvement of the age” (Chambers & Mingay, 1966). Although a period of agricultural depression towards the end of the nineteenth century led to very little drainage being carried out (Robinson, 1990), substantial land drainage was undertaken in the early part of the nineteenth century although this cannot now be accurately quantified. However, the introduction of a grant system in the 1940’s to support drainage resulted in accurate records of work undertaken. From these records it is possible to gain a general impression of the extent of drainage prior to the introduction of the grant system. For example, in 1976/77 nearly fifty per cent of the grant applications in the southern half of Scotland were recorded as being to deal with failure of existing drains (Green, 1979).

In Scotland and the rest of the UK there was a dramatic increase in drainage after the Second World War, mostly due to the need to increase food production by improving the land for sheep and grouse farming (Armstrong *et al.*, 2010, Ballard *et al*., 2011a, Holden *et al*., 2007; Stewart & Lance, 1983) aided by a rapid development in mechanised installation (Ritzema *et al*., 2006); increased drainage was also evident during a period of agricultural intensification in the 1960s and 1970s (Posthumus *et al*,. 2008, Ballard *et al*., 2011a). Although it is now recognised that drainage generally only results in local drawdown of the water table (Robinson, 1986; Stewart and Lance, 1983), the aim was to lower it to encourage vegetation cover more suitable for livestock grazing. Since the 1980’s, when government subsidies ceased, little new land has been drained (Wheater & Evans, 2009). At the same time public support for agricultural/drainage development became greatly affected by emerging environmental awareness, as these land management activities were perceived to harm or compete with a number of environmental values (Smedema, 2011). However, maintenance of land drains has continued, although to varying degrees with many becoming blocked (O’Connell *et al*., 2007).

## 4.0 Land Drainage and Flood Risk

### Historical association with flooding

**“Historically a number of claims have been made stating upstream land drainage had increased damages resulting from floods.”**

As noted by Nicholson (1953), “The connection between field drainage and flooding in rivers has been a subject of debate for centuries”. While land drainage and associated management practices have been identified as having a significant impact on upland hydrological processes (Reed *et al*., 2009), as well as on biological and chemical processes (Wheater & Evans, 2009), there is still limited knowledge available regarding the links between land drainage and management in upland rural catchments and hydrological and flooding mechanisms downstream.

Historically a number of claims have been made stating upstream land drainage had increased damages resulting from floods. For example, after severe flooding occurred as a result of exceptionally heavy rainfall over south-east Scotland and north-east England in 1948, a study by Learmonth (1950) concluded that the runoff generated by the rainfall was “as high in proportion to the size of catchment area as any recorded in Britain” and suggested that it had been increased and the flood peak reached earlier in areas that had been artificially drained. The report noted that “The 1948 flood apart, it may be a matter of national importance that recent hill drainage schemes are causing violent and flashy spates in many and widespread areas.”

## Drainage today

***"While drainage is now recognised as having an impact on peak flow, the extent of any potential changes is uncertain and likely to be site specific."***

While the potentially detrimental impacts of drainage, at both local and global scales are now recognised (Holden *et al*., 2004), opinion regarding the downstream effects of drainage remains divided: some supporting the fact that drainage speeds up the movement of water towards the stream channels (e.g. Robinson, 1986; Nicholson *et al*., 1989; Ballard *et al*., 2010, Ballard *et al*., 2011a), whilst others consider drainage reduces maximum flows (e.g. Newson & Robinson, 1983; Iritz *et al*., 1994). As reported by O'Connell *et al.* (2007) evidence suggests that both situations can occur. In a review of a number of studies they found that field drainage could increase or decrease peak drain flows by as much as two to three times; the behaviour appeared to depend on soil type, antecedent conditions and rainfall event. Fundamentally, the key factor is the relative importance given to two processes: increasing flood flows due to the ability of drains to carry water faster than subsurface flow through the soil and reduced flood flows due to an increase in soil storage capacity created by lowering the water table. Which of these processes exerts the greatest influence will depend on various factors including: drainage density and geometry, hydraulic conductivity, drain and surface roughness, topography, event size, and antecedent conditions (Ballard *et al*., 2011b).

## Downstream impacts of drainage

**"Reviews of drained sites indicate a variety of responses to drainage. These variations may be due to the characteristics of the individual sites, seasonal changes, variations in climate patterns and antecedent conditions, or changes in drainage efficiency over time."**

A comprehensive report detailing field and catchment studies relating to land drainage was produced by the Institute of Hydrology in 1990 (Robinson, 1990). Although now dated, this key report reviewed data from numerous published and unpublished field drainage experiments where flows were measured from both drained and undrained land and covers aspects of drainage density, soil water storage, the impacts of different drainage systems and the extent and location of drainage within a catchment. In general it was found that at wetter sites (high rainfall and/or high clay content) peak flows are reduced, whilst at drier sites (lower rain, more permeable soils) peaks are increased. The author suggests that the likely effect of artificial drainage (to worsen or reduce flood risk) at the field scale may be assessed from measurable site characteristics including the soil water regime and the physical properties of the soil profile. In addition, baseflow was found to be higher from drained than undrained land at both field and catchment scales. The review also looked at catchment scale arterial channel improvements and found that they lead to larger flow peaks downstream, due to higher channel velocities and a reduction in overbank flooding and storage. The combined effect of field drainage and arterial works was found to increase stream flow peaks independent of whether maximum flows were increased or decreased at the field scale. The influence of drainage on response times was also found to be significant at regional scales.

While a smaller review of 22 agricultural land drainage schemes in England found that flooding was reduced after installation of drainage in 80% of the areas which had previously flooded (Morris, 1992), its focus was on the condition of the drained areas not on the downstream impact.

A more recent review by Jacobs Engineering (2011) includes an analysis of studies of three experimental catchments (Blacklaw Moss, Llanbrynmair and Coalburn). In Blacklaw Moss (Lanark, Scotland), a 7 ha experimental site was instrumented for 5 years from 1959-1964. After a 3-year calibration period the land was drained by cutting open ditches about 40cm wide and 36cm deep at 9 metre spacings. Although there was little difference in storm characteristics between the two periods, there was a large increase in the observed flood peaks mainly due to an increase in the flashiness of the site thought to be due to the channel network speeding up flows by shortening the slower flow paths through the soil to the channels (Robinson, 1990). Despite the drainage, there was very little compensating increase in the available storage capacity of the soil. The time taken to peak was reduced by more than a factor of ten, the percentage runoff increased from 46% to 58%, and the peak of the unit hydrograph increased by a factor of 2.6.

In Llanbrynmair (central Wales), a peat moorland catchment was progressively drained over a 4-year period until 70% of the area was affected. Unit hydrographs from before and after the drainage showed similar hydrological effects to those at Blacklaw; open drainage resulted in a much peakier storm flow response. The location of the drainage was found to be significant. Drainage of the higher land resulted in a much peakier runoff response at the outlet. However, subsequent drainage of the valley bottom led to no further increase in peaks, although the catchment response time shortened. This was interpreted as the result of earlier flows from the areas near the gauge becoming desynchronised from the arrival of flows from the more distant parts of the catchment. The effect of location of drainage was also reported by Acreman (1985) for the extensive pre-planting upland drainage that occurred in the Ettrick catchment in southern Scotland and by Wisler & Brater (1949) who noted that in addition to the extent of drainage in a catchment, its location was important for influencing flood flows: “In the lower portions of a drainage basin, speeding up the runoff process is likely to decrease flood flow, whereas slowing down the process may increase the flood peak. In the upper reaches, the effects may be just the opposite”.

Hydrological data from the third catchment, Coalburn (northern England), was collected for 5 years before the whole catchment was subject to the ploughing of open drains about 5 m apart and aligned with the ground slope. Water from these drains was either intercepted by deeper drains or allowed to connect directly to the natural water course. In the 5-year period after the drainage the time to peak reduced on average by 22%, although the effect diminished over the following 20 years (Robinson *et al*., 1998). However the authors note the apparent effectiveness of the drainage may be influenced by the establishment of forest cover. They suggest that the increase in catchment flashiness is a result of a greater density of drainage channels which speeds up the removal of surface waters while the reduction in efficiency over time is the result of reduced hydraulic efficiency of the drains as the furrows become colonised by vegetation and filled with leaf litter. Vegetation has become re-established in the bases of many peatland drains. This vegetation and litter will influence the rate of water transport through the drains and into downstream channels (Holden *et al*., 2008a). In a study looking at the hydrological impacts of drainage ditch cleaning on two pairs of artificially delineated catchments in drained peatland forests in Finland, ditch cleaning was found to lower the level of the water table in sites where a shallow peat layer was underlain by mineral soil. In sites with deep peat formation, the water table showed no detectable response to ditch cleaning. Runoff data suggested that annual runoff clearly increased after ditch cleaning (Koivusalo *et al*., 2008). However, the authors note that a model simulation was unable to reproduce the pattern of results and suggest that the catchments assessed were perhaps not hydrologically isolated and therefore the validity of the results is questionable – a point which highlights the difficulty in using field studies to assess hydrological impacts.

The speed of water delivery may also be influenced by the presence of natural pathways such as pipes within the soil. In a review of 160 blanket peat catchments, Holden (2005, 2006) notes that moorland gripping is the most important control on hillslope pipe frequency in blanket peats; more pipes are found where land drainage has occurred.

While the general consensus from these studies suggests that drainage leads to increased downstream flashiness, the degree of response was found to vary. The variations may be due to the characteristics of the study sites, differing drainage patterns and locations within the catchment, differing study seasons or durations, or variations in climate patterns and antecedent conditions. For example, the underlying moisture content of the site (Robinson, 1990) and the design of the arterial channel network (Robinson, 1990 & Jacobs Engineering) may be factors which underlie any increase in flood risk.  In addition, Holden *et al*. (2006) indicate that the long-term response of peatlands to drainage differs from short-term responses. A point emphasised by Worrell *et al*. (2007b) who conclude that “care should be taken when making inferences from studies of peatland response to management change when the studies describe responses over different time periods”.

## 5.0 Drain Blocking

### Overview

***“Drain blocking, commonly undertaken by installing a series of permanent dams in a drain, can be used to help restore a site to its pre-drained condition.”***

The objective of drain blocking is to reduce the connectivity of the artificial drains, slowing down the movement of water across and from the drained area and allowing water to remain in the soil for longer, resulting in raised water tables and increased residency times. Whilst a number of studies have reported these effects (e.g. Armstrong *et al*., 2010; Worrall *et al*., 2007a), the scale of the responses has varied. Drains are generally not completely refilled but are blocked by a series of dams. Numerous blocking techniques have been applied with varying degrees of success including: peat dams, straw and heather bales, plastic piling or sheeting, plywood or wooden planks, stone dams, or a combination of approaches. A report by Jacobs Engineering (2011), looking at Natural Approaches to Flood Management under the Flood Risk Management (Scotland) Act 2009 includes a comprehensive review of upland drain blocking.

In the UK, the oldest drain blocks were installed in the late 1980s (Armstrong *et al*., 2010) and there has been a significant increase in the practice of drain-blocking over recent years. In a move towards reaching ‘favourable’ or ‘unfavourable recovering’ condition for 95% of the SSSIs in England by 2010, large scale drain-blocking initiatives were implemented by the UK government (English Nature, 2003). One example of an ongoing restoration project is the North Pennines Area of Outstanding Natural Beauty’s ‘Peatscapes’ project which is enabling the blocking of thousands of kilometres of drainage channels (Natural England, 2011). One site benefiting from this is the Bowes Moor SSSI, an extensive tract of moorland in south-west Durham. The ‘peatscapes’ project along with other moorland management initiatives led to the establishment of an Environmental Stewardship Agreement in 2007 which is helping to fund a programme of land management including drain blocking. By 2010 all the drains on Bowes Moor had been blocked and this along with the last remaining management changes led to an assessment of 100 per cent of the land in recovering condition (Natural England, 2011). While this and similar recent projects have the potential to provide some valuable catchment scale evidence, Ramchunder *et al*. (2009) reported that approximately £500M had been spent on drain-blocking in northern England in the previous five years despite limited understanding of the full environmental effects of the practice.

## Peatland drain blocking

**"While a number of studies report that drain blocking of peatland has benefits for the ecosystem, the impact on peak flows and flood volumes is not clear."**

Despite significant resources being invested in drain-blocking on blanket bog, there are few published studies on its effectiveness in restoring hydrological or ecological function (Bellamy *et al*., 2012) and the processes involved are not well understood. In addition Holden *et al*., (2011) note that "Even if full hydrological function is eventually restored at blocked sites the timescales involved appear to be greater than may have been anticipated by most restoration agency-funded monitoring programmes".

While a number of studies report that peat drain blocking has benefits for the ecosystem such as increased biodiversity, habitat restoration and carbon sequestration ( Bellamy *et al*., 2012, Wallage *et al*., 2006; Worrall *et al*., 2007b) the impact on peak flows and flood volumes is not clear.

The runoff response from drained blanket peatlands is generally found to have reduced times to peak, increased peak flows and a quicker recession (e.g. Ballard *et al*., 2011b; Holden *et al*., 2006; Robinson, 1986; Stewart & Lance, 1991). Blanket peat bogs are now classed as both EU and UK Biodiversity Action Plan priority habitats (JNCC, 2008) and there is a significant focus on actions to restore these environments. In a review of 56 peatland restoration projects, Holden *et al*. (2008b) found that most projects were focussed on restoring both ecological and hydrological function. However, despite hydrological function being reported as the second most important justification factor for the projects, after biodiversity, the largest area of uncertainty expressed by the peat restoration project personnel was in understanding peatland hydrology. Additionally, it was noted that in general there is a lack of pre-restoration monitoring which is required to allow the establishment of baseline hydrological conditions.

## Downstream impacts of drain blocking

**"Drain blocking has been found to decrease or increase peak flows depending on local conditions"**

Drain blocking is generally acknowledged to alter hydrological routing, resulting in non-continuous flow, and reducing or preventing the delivery of water through artificial networks. However, only a few studies have directly investigated the impact of drain blocking on peak flow hydrographs. In addition, there is currently little evidence available demonstrating large scale impacts (Ramchunder *et al.,* 2009). A similar point was made by Grayson *et al.* (2010) who noted that despite a lack of reliable evidence of the impact on the flood peak downstream of grip blocking, flood mitigation is increasingly used to justify the expenditure on peatland restoration.

Drain blocking has been found to decrease or increase peak flows depending on local conditions (Rose & Rosolova, 2007; Wilson *et al*., 2010; Wilson *et al*., 2011). Holden *et al*. (2008a) report that drain-blocking significantly reduces the velocity of flows across the bog surface, as well as reducing the rate and volume of water flowing out through drains at peak times. Other studies have shown an increase in overland flow after blocking (e.g. Shantz & Price, 2006), which may be the result of raised water table levels. The impact of drainage on water tables was noted by Price (2003) who reported that after drain-blocking water-table levels increased to similar heights as intact peatland and Armstrong *et al*. (2010) who found shallower and less variable water table levels on sites with blocked drains compared to control sites. The areal extent to which drainage influences water table level is quite limited in blanket peats, due to very low hydraulic conductivities. As a result, drain spacing has a significant impact on both the short and long term effects of drainage (Ballard *et al*., 2011b). A study by Kladivko *et al*. (2004) also noted the importance of drain spacing - in a study of nitrate leaching to subsurface drains they reported that annual drain flow increased from 12 to 15 to 21% of annual precipitation as the drain spacing decreased from 20 to 10 to 5 m. In addition to spacing, the location of the drains has a significant influence on their efficacy. For example, a few ditches running across a steep slope may have a greater influence on peat saturation and decomposition across the catchment than a much denser ditch network on relatively flat terrain (Holden *et al*., 2006). By considering topographic location, ditches with the greatest impact could be identified leading to efficient targeting of resources for ditch blocking (Lane *et al*., 2003; Lane *et al*., 2004);

## Modelling studies

***"Simulations from a number of modelling studies suggest drain blocking will reduce peak flow."***

A number of modelling studies have been undertaken to try to predict how effective peatland drain blocking will be. The SCIMAP (Sensitive Catchment Integrated Modelling and Analysis Platform) study (Lane *et al*., 2003) investigated drain blocking using a model that linked a hydrological model to a detailed digital elevation model. They concluded that a catchment scale model that represents the spatial arrangement of drains and their connectivity to the drainage network is needed to

a) determine the catchment scale impact of drainage or drainage blocking on downstream runoff; and,

b) to identify which channels would be most effective to block.

Ballard *et al*. (2010) used a simplified physics based model to simulate the flood response of a 200m x 200m plot of upland peat. The simulations suggested that on average drain blocking leads to the greatest reduction in flooding for sites with larger drain spacing, steeper drain angle, steeper slope, rougher plant cover, smoother drains and a thin acrotelm (The upper layer of a peat bog, in which organic matter decomposes aerobically). However the results showed substantial variability, with both increases and decreases in peak flow predicted depending on the event and parameter set used.

A study by Johnson (2007), used a hydraulic model to estimate predicted impacts on floods due to the blocking of artificial drains at Glendey, a catchment located within the headwaters of the River Devon in the Ochills, Scotland. The results suggested a 4% to 6% reduction in peak outflow and a 72% to 75% reduction in peak flow velocity with the lower outflow reduction being estimated for the biggest event that was believed to represent a 0.04 annual probability event (25-year event). However, the drained area also had an artificial watercourse running through it that was realigned into a meandering channel. The results are therefore likely to reflect both the effects of drain blocking and the effect of re-arranging the watercourse flow path.

In a case study looking at land management practices in the Ripon catchment (Rose & Rosolova, 2007), sensitivity testing was used as a means of indicating potential catchment scale impacts on flood generation resulting from changes in runoff characteristics from farms and sub-catchment areas. Individual sub-catchment rainfall-runoff models, in the form of Probability Distributed Moisture (PDM) models were linked together via an ISIS flood routing model in order to simulate flows at the catchment outlet. The impact of the proposed land management changes were represented in the PDM models by alterations to specific PDM model parameters affecting the rapid runoff component, the condition of soil moisture store and the hydrograph timing. The impact of moorland drainage blocking in controlling the generation and rate of runoff was also investigated. Results indicated that the worst case land change scenario (combining soil degradation across the whole catchment with moorland drain maintenance) resulted in peak flow increases in Ripon, compared to the baseline case, of between 20% for smaller scale floods and 10% for more extreme floods. In contrast, the best case land improvement scenario (drain blocking) resulted in flood peak magnitude reductions in Ripon by up to about 8% when compared to the baseline case. The timing of the flood peak in Ripon was altered by up to 75 minutes as a result of the scenarios, though changes to the timing of the hydrographs generated in the moorland areas were attenuated by the time they had reached Ripon partly as a result of being channelled through areas of flood plain storage.

## 6.0 Drainage Management

***"Controlling the volume of flow through an existing drainage network offers an alternative to permanent blocking that may allow peak flow control while maintaining water table levels appropriate for agriculture"***

While drain blocking offers a method by which land can potentially be restored to its pre-drainage condition, this approach may not be appropriate where there remains a need for land drainage to meet agricultural requirements. In these situations, some form of managed drainage may offer a solution. As an alternative to permanently blocking drains, a number of practices can be used to control the flow volume within an existing drainage network. These generally use a water control structure (e.g. a gate or weir) to temporarily block or reduce the volume of flow within the drain. Flow volume can be reduced by raising the level of the outflow of the drain so that varying depths of water are allowed to be transported within the drainage system.

### Drainage Water Management

***"Controlled drainage is shown to both reduce drained water volumes and increase crop yield"***

Singh *et al.* (2007) report that several studies have shown reductions in subsurface drainage through shallow or controlled drainage practices with values ranging from 25 to 44%. A number of studies were undertaken looking at drainage water management (DWM) in Midwestern USA (Ale *et al.*, 2009, 2010, 2012). The DWM practice reviewed involves the use of a water control structure which controls the height above the drainage ditch base at which outflow occurs. The structure is raised after harvest, reducing outflow volume and the delivery of nitrate to ditches and streams during the off-season and lowered in early spring and autumn so there is free flow from the drain before field operations such as planting or harvest. It may also be raised again after planting if there is a need to store water for midsummer crop use.

In model simulations for a variety of drain spacings and operational strategies, Ale *et al*. (2010) found DWM showed great potential for reducing annual drain flow. The long-term average (1915–2006) annual drain flow reduction due to DWM varied between 52 and 55% for all drain spacings and operational strategies considered.

In a modelling study undertaken to determine the optimal DWM operational strategy ( Ale *et al*., 2009), simulations suggested dates of raising and lowering the outlet which minimised winter drain flow and maximized yield of 0–20 days after planting and about 4–6 weeks before crop maturity respectively. However, the date depended on the antecedent moisture condition. The preferred height of control above the drain was found to be 50 cm. They found that implementation of DWM 10–85 days after planting during the crop season, and in the non-growing season resulted in a statistically significant reduction of the average annual drain flow by 60% (38–96% reduction in individual years). The predicted increase in surface runoff was not found to be significant. Subsequent to their previous studies, Ale *et al*. (2012) noted that while numerous field and modelling studies had reported significant reductions in annual drain flow with DWM, of the order of 20–58%, in order to assess the impacts of large-scale adoption of these practices, the effects at watershed scale would need to be quantified.  In an expansion of their previous modelling to watershed scales, results indicated that DWM decreased the average annual (1985–2009) predicted drain flow from 11.0 to 5.9 cm.

In a different study of similar control mechanisms (Woli *et al*., 2010), the outlet level for a free drainage system was constantly set at the drainage ditch base, while the outlet level of the controlled system was raised to within 15cm of the soil surface at approximately November 1st of each year, and lowered back down to the base level at approximately March 15th of the following year. The controlled drainage was found to be effective in reducing ditch flow with a three-year average depth of 10.7cm of flow compared to 41cm from the free drainage. In addition the controlled drainage greatly reduced nitrate export.

An experimental facility representing a hypothetical 6-ha agricultural basin was used in another study to assess four different land drainage systems (1. open ditches with free drainage and no irrigation, 2. open ditches with controlled drainage and subirrigation, 3. subsurface corrugated drains with free drainage and no irrigation, 4. subsurface corrugated drains with controlled drainage and subirrigation) (Bonaiti & Borin, 2010). Results showed a variation in the percentage of rainfall drained depending on the system applied (Average rainfall percentage drained: 1: 18%; 2: 10%, 3: 50%, 4: 10%). The authors suggest that the reduced volumes resulted from the combined effects of reduced peak flow and reduced number of days with drainage and proposed that controlled drainage along with subirrigation could be applied at farm scale with advantages for water conservation.

Similar results for reduced flow were reported in a number of other studies investigating drainage management options (Konyha *et al*., 1992, Ma *et al*., 2007; Luo *et al*., 2008;, Luo *et al*., 2010).

## 7.0 Conclusion

Drainage involves many different processes and produces different responses depending on environment and conditions. Therefore any generalisation of whether drainage causes or reduces flooding is by necessity an over-simplification of the complex processes involved. Additional complexity is added when trying to identify the effects of drainage independently from the cumulative effects of other changes that may have altered the hydrological processes including land use change, surface and groundwater withdrawals, and river channel alterations.

While field drainage has been shown to both increase and decrease peak flows, general opinion suggests that drainage leads to increased downstream flashiness with higher peak flows and a reduced time to peak. However any associated increased flood risk is highly site specific and is dependent on factors such as drainage pattern and location within the catchment, characteristics of the soil and underlying hydrological pathways. Some evidence suggests that the restoration of water table levels through drain blocking will also increase flashiness through increased overland flow although in general the limited number of studies currently available show a decline in both peak discharge volume and velocity after restoration. While these apparent conflicts in the effects of both drainage and drain blocking may be due to the variation between different study sites and durations, or variations in climate patterns and antecedent conditions the uncertainty which lies beneath these conclusions demonstrates the uncertainty still surrounding the hydrological impacts of drainage and drain blocking and highlights the need for further study if a fuller understanding of the impact of drainage and drain blocking on peak flow events is to be achieved.

While drain blocking remains a preferred practice, despite the uncertainty regarding impacts on downstream flood risk, it is recognised that land drainage may still be a requirement in some areas. Whilst the amount of flood damage that currently effects the agricultural sector is limited (less than 1 percent) (Evans *et al*., 2004a, Evans *et al*., 2004b), Wheater & Evans (2009) note that a significant proportion of the most agriculturally productive land in England and Wales is dependent on flood protection and land drainage and suggest that with increased importance currently being placed on future food security, land management options may need to be re-evaluated "…to reduce flood risk and to maintain standards of land drainage in areas of national agricultural importance".

Given the need to ensure sufficient land is drained to meet growing food production needs, drainage water management practices that alter the volume of drainage through the use of control structures may offer a solution that both reduces downstream flood risk and provides workable agricultural land. While current studies of drainage water management have looked at seasonal control of drainage volumes, real-time control based on soil moisture levels or downstream flow volumes may offer an alternative approach. While no current studies were found assessing the potential for real-time control (of weirs etc) in agricultural drainage, a number of studies report the potential for its use for managing other hydrological processes including urban wastewater systems (Vanrolleghem *et al*., 2005); combined sewer systems (Darsono & Labadie , 2007), storm sampling techniques (Gall *et al*., 2010), soil salinity control (Park & Harmon, 2011) and urban groundwater works (Bauser *et al*., 2012). There may be an opportunity to meet the needs of agriculture whilst managing diffuse pollution and flood risk by deploying real-time control technology.

# 8.0 Appendix 1 – NFM knowledge database

The publications summarised in this Appendix formed the evidence base for this report. As it was not possible to undertake a comprehensive review of the very substantial body of NFM literature relating to agricultural drainage, source selection was based on studies where the main focus was on impacts on runoff volume rather than on water quality or improved agricultural production. In addition, an emphasis was put on post 2009 publications, which may have been missed by earlier literature reviews (O'Connell *et al*., 2007; Blann *et al.,* 2009; Jacobs Engineering, 2011).

The data is presented using the following format:

| | |
|---|---|
| **Source** | Author and date of publication (refer to **References** for full details) |
| **Location** | Location of study site |
| **Methodology** | Field data, modelling or review. |
| **Key Points** | Summary of relevant information |

| | |
|---|---|
| **Source** | Ale *et al*. (2009) |
| **Location** | Purdue University Water Quality Field Station, USA. |
| **Methodology** | The hypothetical effects of drainage water management operational strategy on hydrology and crop yield were simulated using DRAINMOD, a field-scale hydrologic model. |
| **Key Points** | This study looked at different drainage water management systems.<br>Preferred timetables for raising and lowering the outlet during the crop period were identified as 0–20 days after planting and about 4–6 weeks before crop maturity with the timing depending on the antecedent moisture condition. Under dry soil conditions, the outlet may be raised soon after planting while wet soil allowed raising of the outlet to be delayed by a week.<br>It was found that by controlling the volume of water drained both during crop growing (10–85 days after planting), and for a period during the non-growing season a statistically significant reduction of the average annual drain flow (60%, 38–96% reduction in individual years) could be achieved. The predicted increase in runoff by 85% (0% to 493% in individual years) was not found to be significant. |

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|---|---|
| **Source** | Ale *et al*. (2010) |
| **Location** | Purdue University Water Quality Field Station, USA. |
| **Methodology** | The hypothetical effects of drainage water management operational strategy on hydrology and crop yield were simulated using DRAINMOD, a field-scale hydrologic model. |

| | |
|---|---|
| **Key Points** | This study looked at different drainage water management systems.<br>Modelled results suggest drainage water management showed great potential for reducing annual drain flow. The long-term average (1915–2006) annual drain flow reduction due to drainage water management varied between 52 and 55% for all drain spacings and operational strategies considered.<br>Depending on the growing season and operational strategy, about 81 to 99% of the annual drain flow reduction occurred during the non-growing season. |

| | |
|---|---|
| **Source** | Ale *et al*. (2012) |
| **Location** | Purdue University Water Quality Field Station, USA. |
| **Methodology** | A distributed modelling approach was developed to apply the field-scale DRAINMOD model at the watershed scale. |
| **Key Points** | This study looked at drainage water management systems.<br>Numerous field and modeling studies conducted in North Carolina and the Midwest of the United States and Canada have reported significant reductions (20 – 58%) in annual drain flow and nitrate load as a result of drainage water management.<br>Results from watershed scale modelling indicated that drainage water management:<br>• decreased the average annual (1985–2009) predicted drain flow from 11.0 to 5.9 cm<br>• decreased the total nitrate load through subsurface drainage from 236 to 126 ton |

| | |
|---|---|
| **Source** | Armstrong *et al*. (2010) |
| **Location** | - |
| **Methodology** | Review |
| **Key Points** | This study combined an extensive UK-wide survey of blocked and unblocked drains across 32 study sites and intensive monitoring of a peat drain system that has been blocked for 7 years.<br>Dissolved organic carbon concentrations were found to be significantly lower (28% lower) in blocked drains with a resulting decrease in colouration.<br>This pattern was not consistent at all sites.<br>The authors note that while blocking may be a useful tool for reducing dissolved organic carbon concentrations and colour there will be a number of sites where no significant change will occur. |

| | |
|---|---|
| **Source** | Ballard *et al*. (2011a) |
| **Location** | - |
| **Methodology** | A physics-based model that couples four one-dimensional models to represent a three-dimensional hillslope, allowing for the exploration of flow and water table response throughout the model domain for a range of drainage configurations and peat |

| | |
|---|---|
| | properties. |
| **Key Points** | Drainage of peatlands will increase peak flows.<br>Drain blocking will not necessarily always reduce peak flows: some cases show negligible changes in runoff while other cases indicate an increase in peak flows. |

| | |
|---|---|
| **Source** | Ballard *et al*. (2011b) |
| **Location** | Oughtershaw Beck, UK, |
| **Methodology** | A physics-based model that couples four one-dimensional models to represent a three-dimensional hillslope, allowing for the exploration of flow and water table response throughout the model domain for a range of drainage configurations and peat properties. |
| **Key Points** | Drained peatlands typically have a shorter time to peak, higher peak flow and a quicker recession than undrained areas.<br>Drained peatlands typically are associated with increased water table fluctuations.<br>The areal extent of influence of the water table drawdown due to the drains is quite limited, due to very low hydraulic conductivities; therefore drain spacing plays a significant role in both short and long term effects.<br>The effect is not uniformly distributed, the most significant impact being immediately downslope of a drain. |

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|---|---|
| **Source** | Bellamy *et al*. (2012) |
| **Location** | Forsinard Flows National Nature Reserve, Sutherland, UK. |
| **Methodology** | Field study |
| **Key Points** | Drain-blocking has a negative effect on vegetation indicative of drier conditions and bog degradation.<br>In some cases drain-blocking can improve the ecological functioning of blanket bogs by increasing cover of healthy bog vegetation.<br>Cover of species indicative of bog recovery was greater where the drains had been blocked for the longest time. |

| | |
|---|---|
| **Source** | Blann *et al*. (2009) |
| **Location** | North America |
| **Methodology** | Comprehensive review of agricultural drainage in the US |
| **Key Points** | This is a comprehensive review of the impact of land drainage on ecosystems in the US.<br>By 1987 more than 17% of U.S. cropland (up to 30% in the Upper Midwest) had been altered by artificial surface or subsurface drainage.<br>The addition of subsurface drainage to lands already drained by surface drainage may result in field and catchment-scale changes in hydrology and water quality.<br>Subsurface drainage typically alters the total water yield from a field or small watershed, not just the timing and shape of the hydrograph.<br>The increase in total runoff tends to be relatively minor (~10%) but occurs because subsurface drainage may increase the proportion of total annual precipitation that is discharged to surface waters via subsurface flow relative to the amount that is stored semi-permanently, evaporated, or transpired. |

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|---|---|
| **Source** | Bonaiti & Borin (2010). |
| **Location** | N E Italy |
| **Methodology** | Field experiment on an experimental facility representing a hypothetical 6-ha agricultural basin with four different land drainage systems (1. open ditches with free drainage and no irrigation (O), 2. open ditches with controlled drainage and subirrigation (O-CI), 3. subsurface corrugated drains with free drainage and no irrigation (S), 4. subsurface corrugated drains with controlled drainage and subirrigation(S-CI)). |
| **Key Points** | Measured drainage volumes (% of annual rainfall) showed reductions of average volumes for controlled drainage with irrigation when compared to free drainage of 8% in open drains and 40% for subsurface drains. Reduced drained volumes resulted from the combined effects of reduced peak flow and reduced number of days with drainage.<br>The authors suggest that controlled drainage and subirrigation can be applied at farm scale in northeast Italy, with advantages for water conservation. |

| | |
|---|---|
| **Source** | Bullock *et al*. (2012) |
| **Location** | - |
| **Methodology** | - |
| **Key Points** | The 2011 Durban Climate Summit agreed that developed countries could voluntarily include emissions from drained peatlands in their carbon accounting, but also allows inclusion of reductions due to re-wetting. This leaves open the possibility that peatland restoration could be acknowledged in future emissions trading and that rights holders could be rewarded for preserving peat in situ through tradable permits for carbon storage. |

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|---|---|
| **Source** | Dunn & Mackay (1996) |
| **Location** | River South Tyne at Alston |
| **Methodology** | Physically based distributed modelling (SHETRAN), with a fine grid resolution on a very simple hill-slope model |
| **Key Points** | Little difference was found in the total runoff volume between the undrained and drained model simulations but drainage accelerated surface runoff and the simulations for the drained model show both a higher and earlier peak discharge<br>The mechanism of water transport varied:<br>• Undrained model: 81% of the total runoff from direct surface runoff, 19% subsurface flow<br>• Drained model: 53% of the total runoff from direct surface runoff, 47% subsurface flow<br><br>Water levels varied<br>• Undrained model: level of sub-surface runoff remained fairly constant throughout the year<br>• Drained model: slight lowering in water level that varied throughout the year |

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|---|---|
| **Source** | Gritt (2008) |
| **Location** | West Lancashire |
| **Methodology** | Historical review |
| **Key Points** | This study reviews the impact drainage has had on Lancashire.<br>The authors suggest that drainage of the land, resulting in its transformation from some of the worst land in the country to some of the best, was a major contributor not only to the agricultural success of the region, but also to Lancashire's industrial success. |

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|---|---|
| **Source** | Herzon & Helenius (2008) |
| **Location** | Temperate and boreal zones of the Northern Hemisphere |
| Review | Review |
| **Key Points** | The major regulating functions of the drainage network within cultivated catchments include:<br>• transfer of water and soluble nutrients from the fields<br>• water retention and nutrient recycling<br>• processing of phosphorus and nitrogen by vegetation<br>• mitigation of herbicides in vegetation and sediment<br>• modifying erosion rate and transfer of soil-bound nutrients<br>• supporting pollination and pest control functions.<br>The relative values of ditches in draining land, control of water flow and chemical transfer, and as a wildlife habitat are likely to vary greatly regionally and even locally. |

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|---|---|
| **Source** | Holden (2005) |
| **Location** | UK |
| **Methodology** | Field survey using consistent application of ground-penetrating radar |
| **Key Points** | A survey of 160 British blanket peat catchments showed soil pipes in all catchments.<br>Gripping (open land drains) is the most important control on hillslope pipe frequency in blanket peats; there are more pipes where land drainage has occurred. |

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|---|---|
| **Source** | Holden (2006) |
| **Location** | UK |
| **Methodology** | Remote mapping using GPR and historical records of drainage installation |
| **Key Points** | Drainage induced desiccation is followed by rapid pipe network expansion through erosion of material along flow paths.<br>Desaturation causes peat to shrink and crack.<br>Summer surface peat desiccation and winter freeze-thaw activity alter peat .<br>Water flow enlarges the pipes and allows pipe networks to expand.<br>No evidence that pipe network development reaches a threshold beyond which its growth slows (although data were only available for artificial drainage systems up to 80 years old).<br>Streamflow response to peat drainage may continue to change over long time periods as pipe networks expand. |

| | |
|---|---|
| **Source** | Holden *et al*. (2006) |
| **Location** | Moor House National Nature Reserve, north Pennines, UK, |
| **Methodology** | Field study of two catchments drained with open-cut ditches in the 1950s |
| **Key Points** | Ditching originally resulted in shorter lag times and flashier storm hydrographs but no change in the annual catchment runoff efficiency.<br>During 2002 and 2004, the hydrographs in the drained catchments, while still flashy, were less sensitive to rainfall than in the 1950s.<br>Gradual changes to peat structure could explain the long-term changes in river flow, which are in addition to those occurring in the immediate aftermath of peatland drainage. |

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|---|---|
| **Source** | Holden *et al*. (2007) |
| **Location** | - |
| **Methodology** | - |
| **Key Points** | Drainage has played a fundamental role in the history of British farming.<br>Until the 20th century most land drainage was focussed on 'improving' lowlands for agriculture by lowering the water table.<br>The drainage resulted in changes in water flow paths through and over moorland soils.<br>The benefits of upland drainage in terms of reduced runoff due to increased soil storage capacity are countered by the resulting higher flow velocities in the ditches speeding up the discharge of the water into the river.<br>Current practices of drain blocking are occurring in a similar manner to that of drain creation in the 20th Century; with limited consideration of natural processes and no real understanding of the role of each site in terms of its local setting and within the catchment as a whole. |

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|---|---|
| **Source** | Holden at al. (2008a) |
| **Location** | Upper Wharfe catchment, UK |
| **Methodology** | Experimental field study |
| **Key Points** | Even if a peatland surface remains fully vegetated, if the vegetation type is altered then flow velocities could change leading to alterations in the timing of runoff delivery from slopes to streams.<br>Reestablishment of Sphagnum on degraded (especially bare) peatlands may therefore be important for reducing the potential for sheet erosion and downstream flood peaks more than Eriophorum or Eriophorum-Sphagnum mixes. |

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|---|---|
| **Source** | Holden *et al*. (2011) |
| **Location** | Oughtershaw Moss, a blanket peat catchment located in the headwaters of the River Wharfe, northern England |
| **Methodology** | Field study using transects of automated water table recorders |
| **Key Points** | Hydrological changes induced by 40 years of drainage were not reversed over the 6–7 year period since drain blocking occurred.<br>Many of the components of water table dynamics at the blocked site were intermediate between those found at the drained and intact sites.<br>While blocked drains showed shallower water table levels than drained sites, several components of the water table record (e.g. depth exceedance probability curves, seasonality of water table variability, and water table responses to individual rainfall events) were symptomatic of slow recovery of hydrological function.<br>Even if full hydrological function is eventually restored at blocked sites the timescales involved appear to be greater than may have been anticipated by most restoration agency-funded monitoring programmes. |

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|---|---|
| **Source** | Imlay & Carter (2012) |
| **Location** | East central Illinois |
| **Methodology** | Historical review |
| **Key Points** | The amount of agricultural land reclaimed by drainage by 1920, mainly in the Midwest, far exceeded that opened by irrigation in the West.<br>A distinctive social order in east central Illinois emerged from, and was shaped by, an agrarian structure that had developed in response to marshy, unpredictable conditions before drainage began in the late 1800s. The beneficiaries of the old order capitalized on the new opportunities presented by drainage enterprises, to create a 'hydraulic society' on the prairie. |

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|---|---|
| **Source** | Kenyon *et al*. (2008) |
| **Location** | Scotland |
| **Methodology** | Policy review using Delphi study |
| **Key Points** | A number of factors were identified as having potentially led to an increased risk of surface water flooding in Scotland over the past 50 years.<br>Panellists agreed that incentives provided to farmers to drain agricultural land have altered the rate of water runoff and increased the peak flow during heavy rainfall.<br>Most panellists thought certain agricultural practices (drainage of ponds and natural wetlands, upland areas and lowland raised bogs) had been highly responsible for increasing downstream flood risk since they resulted in the loss of natural flood storage capacity and increased runoff. |

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|---|---|
| **Source** | Kladivko *et al*. (2004) |
| **Location** | Field study |
| **Methodology** | Southeast Indiana |
| **Key Points** | In drier years, drain flow volume is lower and also tends to be a lower percentage of total precipitation.<br>The horizontal spacing between parallel drains exerts a fundamental control on the drainage volume.<br>Drain flow losses are greater per unit area for narrower drain spacings: annual drain flow increased from 12 to 15 to 21% of annual precipitation as the drain spacing decreased from 20 to 10 to 5 m. |

| | |
|---|---|
| **Source** | Koivusalo *et al*. (2008) |
| **Location** | - |
| **Methodology** | Field study of two pairs of artificially delineated catchments in drained peatland forests in Finland |
| **Key Points** | The response to ditch cleaning differend depending on peat depth: water table levels were lowered in sites with shallow peat layers while in sites with deep peat formation, the water table showed no detectable response.<br>Annual runoff increased after ditch cleaning.<br>The authors note that a model simulation was unable to reproduce the pattern of results and suggest that the catchments assessed were not hydrologically isolated and therefore question the validity of the results. |

| | |
|---|---|
| **Source** | Konyha *et al*. (1992) |
| **Location** | North Carolina |
| **Methodology** | A field-scale hydrologic model (DRAINMOD) was used to simulate the hydrology of two North Carolina muck soils under four water-management methods over 33 years: conventional drainage using open field ditches (CNVL), improved subsurface drainage using pipes (IMPP), Controlled drainage where water level control structures used during the growing season (CTR1) and Controlled drainage where water level control structures used all year except during planting and harvest (CTR2). |
| **Key Points** | With CVNL the soil differences had considerable influence on the hydrology. The soil with high hydraulic conductivity resulted in better subsurface drainage.<br>Both soils were well drained using IMPP and the hydrologic differences between the two soils were less noticable.<br>CTR1 increased surface runoff and decreased subsurface drainage, compared to IMPP.<br>For CTR2, subsurface drainage was further reduced while surface runoff increased.<br>The impact of a water-management system was found to be soil specific, but in general improved subsurface drainage decreased surface runoff and reduced the volume of runoff that leaves at high flow rates while controlled-drainage systems |

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| | tended to increase the volume leaving at high flow rates.<br>Impacts of drainage practice were less noticeable for larger events. |

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| **Source** | Luo *et al*. (2008) |
| **Location** | YinNan Irrigation District |
| **Methodology** | A controlled drainage experiment was conducted during the growing seasons of 2004 and 2005 |
| **Key Points** | Controlled drainage reduced drainage discharge by 50–60%. |

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| **Source** | Luo *et al*. (2010) |
| **Location** | Data from South Central Minnesota |
| **Methodology** | Long-term simulations using DRAINMOD-NII |
| **Key Points** | Both shallow drainage and controlled drainage may reduce annual drainage discharge by 20–30%, while impacting crop yields from 3% (yield decrease) to 2%, depending on lateral drain spacing.<br>Controlled drainage showed the greatest potential to reduce annual drainage volumes. |

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| **Source** | Ma *et al*. (2007) |
| **Location** | Nashua, Iowa |
| **Methodology** | The Root Zone Water Quality Model (RZWQM) was applied to evaluate various management effects in several previous studies |
| **Key Points** | Analysis of simulated results from an experimental study initiated in 1978 at Nashua, Iowa for management effects (tillage, crop rotation, and controlled drainage) on crop production and N loss in drain flow showed a 30% reduction in average annual drain flow with controlled drainage compared with free drainage when the drain depth was 1.20 m.<br>Controlled drainage also promoted lateral subsurface flow, simulations showed an increase of 17%. |

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| **Source** | Meijles & Williams (2012) |
| **Location** | A regional scale case study of the Drentsche Aa catchment in the province of Drenthe, The Netherlands |
| **Methodology** | Policy review |
| **Key Points** | Land management policies and the resulting land use change resulted in the watershed of the river Drentsche suffering from desiccation, low base flow levels and a short response time to rainfall, including high runoff peaks.<br>One of the largest changes was demonstrated to have been brought about by extensive field drainage. |

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| **Source** | Newson &Robinson (1983) |
| **Location** | - |
| **Methodology** | - |
| **Key Points** | Artificial drainage reduced the peak rates of outflow into the river network due to a general lowering of the water table, providing an increase in the storage capacity of the soil, and encouraging the movement of water in deeper soil horizons. The authors warn that this result cannot necessarily be extrapolated to other situations. |

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| **Source** | Posthumus & Morris (2010) |
| **Location** | The Laver and Skell catchments in North Yorkshire; the Parrett catchment in Somerset; the Eden catchment in Cumbria; the Upper Severn catchment in Montgomeryshire, Wales; and the Hampshire Avon catchment in Wiltshire |
| **Methodology** | Fieldwork |
| **Key Points** | While most of the interviewed farmers recognised the need to reduce soil erosion and diffuse pollution, they were less willing to accept responsibiliy for controlling storm-water runoff from farmland that might contribute to flooding downstream unless it would be organised and compensated for by the government.<br>One farmers thought: "... We had a government that was paying farmers 60% to drain all the wetlands, ..., all this sort of thing. And now they turn around paying that sort of money to reinstate it...farmers are government-oriented, it always has been like, you know. And we're led by them."<br>Extensive land drainage in North Yorkshire is thought that to have contributed to an increased frequency of flooding downstream.<br>In Somerset, flood risk was thought to be aggravated by more frequent heavy rainfall events, runoff from hard surfaces and development in floodplains. Land drainage was acknowledged as a contributing factor to flooding, but this reduces flood risk in the floodplains and is thus a good practice according to the farmers.<br>Targeting high-risk areas of runoff with professional advice and locally appropriate control measures is likely to be the most effective approach to reducing runoff . |

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| **Source** | Posthumus *et al*. (2008) |
| **Location** | North Yorkshire |
| **Methodology** | |
| **Key Points** | Runoff and subsurface drainage from farmland acts as a pathway, causing flooding in downstream receptor areas.<br>This is influenced by several factors including the extent of soil compaction, the efficiency of land drains and the connectivity of flow paths.<br>During a stakeholder workshop, most participants thought that land drainage had increased flood generation as rainfall water is |

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| | discharged quicker into the watercourses. |

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| **Source** | Potter *et al*. (2011) |
| **Location** | UK |
| **Methodology** | Policy |
| **Key Points** | Events in the 1990s and turn of the century at Boscastle and Carlisle highlighted the cumulative impact of land drainage, urbanisation and river regulation over the previous decades |

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| **Source** | Ramchunder *et al*. (2009) |
| **Location** | UK |
| **Methodology** | Review |
| **Key Points** | While approximately £500M has been spent on drain-blocking in northern England in the last five years the full environmental effects of drain-blocking remain uncertain.<br>Drainage and burning of peat often lead to altered runoff regimes.<br>Peatland drainage lowers the water table directly adjacent to the drain, and more specifically downslope of the drain.<br>In addition to lowering the water table, drained blanket peats exhibit more deep throughflow than saturation-excess overland flow.<br>The magnitude of the response to drainage is complicated by variations in plant species/peat type, drain patterns and spacing/density and the section of the catchment in which drainage takes place.<br>There are long-term differences in the hydrological response of drained catchments over time.<br>While drain blocking has been noted to reduce discharge by over 70% there is little evidence as yet at a larger scale than that of the hillslope to indicate any hydrological impacts related to drain-blocking. |

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| **Source** | Ritzema *et al*. (2006) |
| **Location** | The Netherlands |
| **Methodology** | Review |
| **Key Points** | Subsurface drainage was widely introduced in many parts of the world in the late 20th century as the theoretical understanding of drainage and salinity control gained became established<br>This was further accelerated by rapid developments in mechanized installation from the 1940s onwards.<br>New drainage materials (plastic drain pipes and synthetic envelopes) resulted in lower transportation and installation costs. |

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| **Source** | Rose & Rosolova (2007) |
| **Location** | 120km$^2$ catchment draining through Ripon in North Yorkshire, which includes the rivers Skell and Laver, and Kex Beck. |
| **Methodology** | Individual sub-catchment rainfall-runoff models, in the form of Probability Distributed Moisture (PDM) models were linked together via an ISIS flood routing model in order to simulate flows at the catchment outlet. |
| **Key Points** | Sensitivity testing was used to indicate the potential impact of changes in runoff characteristics from farms and sub-catchments on catchment scale flood generation.<br>The impact of moorland grip drainage blocking in controlling the generation and rate of runoff was also investigated.<br>Results indicated that the worst case degradation scenario (combining soil structural degradation across the whole catchment and additional moorland grip maintenance) led to increased peak flows in Ripon compared to the baseline case of between 20% for smaller scale floods and 10% for more extreme floods.<br>The best case improvement scenario (moorland grip blocking) led to a reduction of flood peak magnitudes in Ripon by up to about 8% when compared to the baseline case.<br>The timing of the flood peak in Ripon was altered by up to ±1.5 hours as a result of the scenarios, though changes to the timing of the hydrographs generated in the moorland areas were attenuated by the time they had reached Ripon. |

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| **Source** | Scheidleder *et al*. (1996) |
| **Location** | - |
| **Methodology** | Review |
| **Key Points** | In Austria and Denmark land drainage was cited as ‘‘probably the single most important measure which has adversely affected the landscape (loss of wetlands, small scale structures in the landscape), the biodiversity and the hydrological cycle’’ |

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| **Source** | Singh *et al*. (2007) |
| **Location** | Iowa |
| **Methodology** | Deterministic hydrologic model (DRAINMOD) using long-term (1945-2004) hydrologic simulations to predict the effects of drainage water management on subsurface drainage, surface runoff and crop production |
| **Key Points** | Simulation results indicate the potential of a trade-off between subsurface drainage and surface runoff as a pathway to remove excess water from the system.<br>Controlled drainage reduced subsurface drainage (9-18% compared to conventional (free) drainage) while surface runoff increased (31-54%).<br>The water table remains shallower in the case of controlled drainage as compared to free drainage.<br>Controlled drainage might increase the excess water stress on crop production, and thereby result in slightly lower relative yields.<br>The authors suggest field experiments are needed to examine the pathways of water movement and assess the total water balance. |

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| **Source** | Smedema (1993) |
| **Location** | - |
| **Methodology** | - |
| **Key Points** | The performance of installed subsurface drainage systems is considerably influenced by soil management practices.<br>These influences can be both positive and negative. For example, rootzone drainage is severely limited when the upper soil layers are subjected to compaction practices while the effects of drainage on early workability are enhanced by practices that increase the proportion of organic matter in the soil. |

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| **Source** | Smedema (2011) |
| **Location** | - |
| **Methodology** | Policy |
| **Key Points** | Drainage development rain fed agricultural land is driven by a combination of forces and conducive conditions: mainly the state of agricultural development and the economics of improved drainage.<br>In the 1980's public support for agricultural drainage was greatly affected by emerging environmental awareness.<br>Some adverse drainage development conditions can be overcome by appropriate government policies and interventions. |

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| **Source** | Sutherland (2010) |
| **Location** | Upper Deeside, Scotland |
| **Methodology** | Policy & farming |
| **Key Points** | Farmers were found to actively consider environmental regulations and grant opportunities as part of processes for farm development or securing additional land.<br>While according to a Farming and Wildlife Advisory Group (FWAG) Advisor "A lot of the older farmers will see putting agricultural land into sort of wildlife management as alien, because they've spent all of their lives draining them and improving them", farmer engagement in environmental schemes is becoming a widely accepted practice.<br>There is some evidence that the social practice of observing other farmers' innovations is beginning to include environmental actions: one farmer after attending an open day on an organic farm in a nearby region favourably reviewed the other farmer's wetland drainage system, which created a habitat for wildlife for part of the summer, but drained the water to provide additional grazing for the remainder of the year. |

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| **Source** | Wallage *et al*. (2006) |
| **Location** | Oughtershaw Beck, a headwater tributary of the River Wharfe, northern England |
| **Methodology** | Field/ Experimental study |
| **Key Points** | Dissolved organic carbon and water colour production from a site where the drains had been blocked three years prior to measurement was significantly lower than the adjacent drained site, but also significantly lower than that from undrained moorland: a process of store exhaustion and flushing may have been operating. Drain blocking alters the composition of DOC making darker-coloured humic substances more dominant compared to the intact site.<br>The dominance of water flow paths in peat varies depending on water table depth in conjunction with antecedent conditions and topographic position. |

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| **Source** | Walters & Shrubsole (2003) |
| **Location** | Zorra Township, located within the Thames River valley, Ontario. |
| **Methodology** | Review of processes for approval for drainage |
| **Key Points** | Agricultural drainage has accounted for between 81 and 85% of wetland losses in southern Ontario.<br>Wetland management and agricultural drainage illustrate the conflict between economic development and natural values. |

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| **Source** | Wheater & Evans (2009) |
| **Location** | - |
| **Methodology** | Review |
| **Key Points** | Sheep numbers in Great Britain doubled between 1950 and 1990 as a result of farm support payments based on stock numbers and at the same time the amount of improved pasture in upland areas increased as a result of draining, ploughing, and reseeding, financially supported by government and EU incentives.<br>Runoff response from drained fields varies seasonally, depending on antecedent moisture conditions.<br>Runoff from drained land may be faster or slower than from undrained land depending on the nature of the soil and its management, as well as the timing and intensity of rainfall.<br>As a result of the increased importance being placed on future food security drainage and blocking practices may need to be re-evaluated to both reduce flood risk and maintain standards of land drainage in areas of national agricultural importance. |

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| **Source** | Wilson *et al*. (2010) |
| **Location** | A degraded Welsh upland blanket bog, Lake Vyrnwy catchment (mid-Wales) |
| **Methodology** | - |
| **Key Points** | Results show a reduction in peak flows and increases in water residency after rainfall.<br>Average flow rates from both drains and streams declined after drain-blocking, largely due to a reduction in the time spent at peak flows.<br>After drain blocking, the rate of water table level recovery varied and was influenced strongly by slope, aspect and peat depth. The water table was also more stable.<br>There was a strong overall increase in surface water in response to blocking, ranging up to approximately 40% more after blocking.<br>The study demonstrated the importance of small and large scale topography in determining the degree of any response.<br>This study showed strong catchment scale differences in response, and a very gradual recovery of water tables. |

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| **Source** | Wilson *et al*. (2011) |
| **Location** | Wales |
| **Methodology** | A landscape scale experimental study on an upland peatland in Wales that has been restored through drain-blocking. |
| **Key Points** | The water table response to storm events changes after drain blocking, with levels rising higher and taking longer to recede to antecedent levels.<br>Peak flow hydrographs from drains show considerable change after restoration, with lower peak flow rates, less runoff and less rainwater being released during the event.<br>The results suggest<br>• drain blocking leads to higher and more stable water tables that are able to better resist drought periods<br>• even with a reduced potential storage, restored peatlands can exhibit less flashy flood responses and provide better retention of rainfall even during peak events.<br>• Peak flow responses in both drains and upland streams were less severe, with more rainfall being retained within the bog<br>While the authors suggest that restoration leads to a more buffered system and more moderate responses to extreme events they note that the most severe events covered in the study had return periods of 2 years therefore it was not possible to conclude if extreme events would show similar or different flood responses. |

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| **Source** | Wiskow & van der Ploeg (2003). |
| **Location** | Leine river in Northern Germany |
| **Methodology** | A two-dimensional drainage model |
| **Key Points** | Drain discharge was found to be inversely and nonlinearly related to drain spacing across a range of spacings from 5 to 50 m.<br>• Narrow spacing prevents the water table from rising into the rooting zone of a growing crop and allows it to fall quickly after a storm. Water storage is limited therefore drainage systems may add to river floods in periods with excess precipitation, especially if drainage is employed at a large scale<br>• Larger spacing, that allows soil saturation, may increase soil water retention. While the drainage performance will be reduced, restricted drainage efficiency may help to reduce the risk of winter floods. |

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| **Source** | Woli *et al*. (2010) |
| **Location** | A private farm Near DeLand in Piatt County, east-central Illinois |
| **Methodology** | Field study |
| **Key Points** | Controlled drainage was extremely effective in reducing tile flow with a three-year average of 10.7cm of flow compared to 41cm from free drainage.<br>The outlet level for the free drainage system was set at the tile depth for the duration of the study, while the outlet level of the controlled system was raised to within 15cm of the soil surface on or close to November 1st of each year, and lowered back down to the level of the tile on or close to March 15th of the following year. |

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| **Source** | Worrall *et al*. (2007a) |
| **Location** | Whitendale catchment, UK |
| **Methodology** | Field study: 54 stream and drain sites were sampled on an approximately weekly basis |
| **Key Points** | There is a significantly higher water table in peat adjacent to blocked drains.<br>Whenever runoff occurred from a blocked drain it was always more discoloured than prior to blocking.<br>During the 10 months following drain-blocking no catchment scale change in river water colour could be determined.<br>No drain-blocking technique was demonstrably better or worse than any other with respect to time for which there was flow in the drain.<br>No evidence that drain-blocking was an effective technique for reducing water discolouration and DOC at the catchment scale in the short-term; however the short-term response of a peatland to drain-blocking may not be the same as the long-term response. |

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| **Source** | Worrall *et al*. (2007b) |
| **Location** | Trout Beck catchment, UK |
| **Methodology** | Modelling using a combination of empirical equations |
| **Key Points** | The model predicted that drained catchments export more dissolved organic carbon (DOC), increases are of the order of 15–33% over a 10-year period depending upon the drain-spacing.<br>When drainage is blocked, improvements in DOC export are predicted but the magnitude of the decrease is critically dependent upon the drain-spacing and for the larger drain-spacings no decrease may be observed. Improvements in DOC export after blocking are shown to lessen over time. |

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CREW centre of expertise for waters

The Scottish Government

The countryside charity

# Building on our food security

July 2022

# Contents

# Executive summary

Maintaining agricultural capacity to deliver significant levels of domestic food production is critical. This must be achieved in the context of addressing and adapting to climate change, reversing the loss of nature and meeting increasing demands on land for other social goods — not least affordable housing and renewable energy.

With enough previously developed 'brownfield' land to provide 1.2 million homes, and south-facing rooftops that could meet much of our energy needs, we have a chance to tackle the climate, housing and cost-of-living crises without sacrificing our farmland. Adjusting our farming sector to a post-Brexit model of subsidies should support the necessary move away from damaging intensive farming practices and towards a more multifunctional approach to using land — reconciling food production with better management for natural and cultural heritage, and for public access. Policies that are put in place now will be crucial in ensuring the most efficient use of our land in the face of these challenges.

This report by CPRE, the countryside charity, looks to quantify rates of built development on farmland identified as Best and Most Versatile (Grades 1, 2 and 3a) in the Agricultural Land Classification (ALC) used by government. The review covers development between 2010 (the date of the last published government-commissioned review) and 2022. Our report is also the first to look at national rates of development specifically on Grade 1 and 2 land. We propose alternative policy measures which would result in better outcomes for this valued land and more sustainable options for building the new homes we need. Our recommendations aim to influence the full review of the National Planning Policy Framework (NPPF) expected in 2023.

There are clearly many competing priorities for our land, but it is essential to preserve our most productive agricultural land from long-term loss; the NPPF[1] aims to protect best and most versatile land from development, but evidence shows that this is not being achieved in practice. In recent years, substantial losses have been reported for housing development that could have been built on suitable brownfield land instead. And as we know, once this precious asset is built on, it is lost for good.

## Our key findings include:

- In the past 12 years we have lost over 14,000 hectares of prime agricultural land to development, including 287,864 houses — equivalent to the productive loss of around 250,000 tonnes of vegetables and enough to provide nearly two million people with their 5-a-day for an entire year.
- 2022 saw the greatest number of hectares of BMV land planned for development — equating to a 100-fold increase on the number of hectares of BMV land built on in 2010.
- Flooding as a result of climate change poses a further risk, with almost 60% of our most productive Grade 1 land already sitting in the Environment Agency's Flood Zone 3.
- Since 2010, planning appeals which involved BMV land have had a 46% allowance rate in comparison to a total appeals allowance rate of 25%.
- The East of England has lost 3,232 ha of BMV land since 2010 — the greatest absolute loss within a single region.
- The BMV land surrounding our towns and cities (almost a quarter of the total, and a valuable resource for feeding these populations) is being developed at a rate nearly twice that of the national average.

## CPRE therefore recommends that the government should:

- Consult on and publish a national land use strategy that provides an integrated framework for local policy and decision-making on both planning and farming.
- Incorporate the following guidelines in the new NPPF to ensure the loss of valuable farmland is minimised:
  - a brownfield first policy
  - a greater steer towards medium- and high-density new housing
  - a firm presumption against development on BMV land — the higher the ALC grade, the greater the weight which should be attached to its protection.
- Require site-specific surveys to be mandatory on any development proposals involving more than 1 ha of land, unless it is clear that the site will not contain BMV land.
- Require local authorities to identify and track development on BMV land in their district.

# Introduction

Maintaining agricultural capacity to deliver significant levels of domestic food production is critical. This must be achieved in the context of addressing and adapting to climate change, reversing the loss of nature and meeting increasing demands on land for other purposes — not least affordable housing and production of renewable energy. There is a particular need to move away from intensive farming practices and towards a more multifunctional approach to using land, reconciling food production with better management for natural and cultural heritage.

Appropriate identification, protection and use of our most productive land for food production will be a vital part of our national food security. The Government Food Strategy published in June 2022 stated that:

> “We have some of the best performing farms in the world, with 57% of agricultural output coming from just 33% of the farmed land area”[2].

It is therefore essential that we preserve the most productive agricultural land from long-term loss, but the evidence shows that, in practice, our national policies do not achieve this; recent years have seen substantial losses to housing development that could have been accommodated on suitable brownfield land instead.

Harnessing upcoming changes to land use policy can result in alternative policy measures which would result in better outcomes for our most productive land, as well as more sustainable options for building the new homes and energy facilities we need.

## Our Best and Most Versatile agricultural land

While all our land is of great value and potential for myriad reasons, the planning system's 'Best and Most Versatile' (BMV) classification is given to the agricultural land that is regarded as the most valuable in terms of its food producing potential. BMV land was first identified and classified in response to the demand for self-sufficiency following the Second World War. Land is identified as BMV (either Grade 1, 2 or 3a; there are six grades altogether) using the Agricultural Land Classification (ALC). The mapping of agricultural land is maintained by Natural England. Land which is classified as one of these three grades is deemed the most flexible in terms of the range of crops which can be grown, while also requiring lower inputs to produce high crop yields.

### Agricultural land classifications:

#### Grade 1:
Excellent quality agricultural land — land with no (or very minor) limitations and high and less variable yields. A very wide range of agricultural crops can be grown, such as apples and pears, salad crops, soft fruit, and winter harvested vegetables.

#### Grade 2:
Very good quality agricultural land — land with minor limitations that affect crop yields, cultivations or harvesting. Generally high yielding land but may be lower or more variable than Grade 1.

#### Grade 3a:
Good quality agricultural land — land which can consistently produce moderate to high yields of a reduced variety of arable crops, such as cereals, sugar beet and potatoes.

#### Grade 3b:
Moderate quality agricultural land — capable of producing moderate yields.

#### Grade 4:
Poor quality agricultural land — land with severe limitations.

#### Grade 5:
Very poor quality agricultural land — land with very severe limitations.

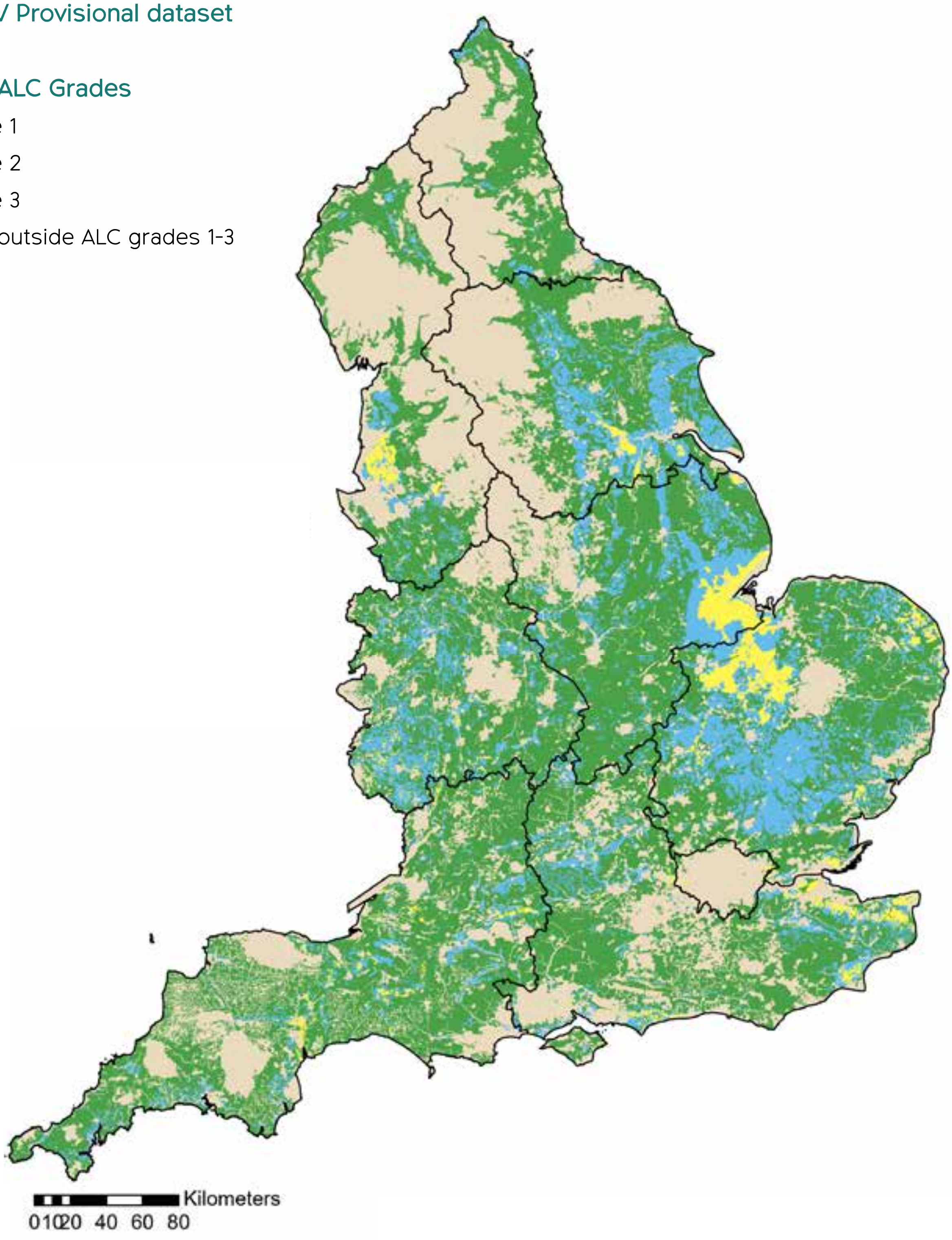
The process of grading agricultural land requires assessing factors which affect the site and its interactions, including: climate, aspect, gradient and soil. Crucially, the classification of BMV land does not consider the current agricultural use of the land, instead basing its grade on its inherent potential.

## Figure 1

### Map of BMV Provisional dataset

### Provisional ALC Grades

- Grade 1
- Grade 2
- Grade 3
- Land outside ALC grades 1-3



## BMV: Protected through policy but not monitored

Identifying where the Best and Most Versatile agricultural land is located is a vital process for enabling the planning system to deliver on its sustainable development objectives. Identifying the locations of BMV land informs decisions on how farms and soils might be affected by a development, with the overall purpose of protecting the land from inappropriate or unsustainable proposals.

The National Planning Policy Framework (NPPF) states that:

> 'Planning policies and decisions should contribute to and enhance the natural and local environment...' by 'recognising the intrinsic character and beauty of the countryside and the wider benefits from the natural capital and ecosystem services – including the economic and other benefits of the best and most versatile agricultural land...'

(Chapter 15, para. 174b). The NPPF also encourages local planning authorities to try to prioritise areas of poorer quality land for development over BMV.

In addition to national planning policy, legislation requires local planning authorities to consult Natural England (the government's adviser for the natural environment) on all non-agricultural applications which result in the loss of more than 20 hectares of BMV land but are not included in their local development plan[3]. National Planning Practice Guidance for the natural environment provides planning authorities with information on the value of protecting BMV and planning for its future use[4]. Furthermore, undertakings to protect BMV land were made in the Government's 25 Year Environment Plan of 2018[5], which states that the sustainable and efficient use of natural resources is vital to improving the environment.

No monitoring of the use of BMV land, or loss of it to development, has been reported by government since 2010[6]. In fact, to CPRE's knowledge, no national monitoring of development on land in the highest two grades (1 and 2) has ever been reported. This is in clear contrast to protected landscape designations of National Parks and Areas of Outstanding Natural Beauty, where land use patterns are monitored by the Department for Environment, Food & Rural Affairs (DEFRA), and Green Belts, where development rates are monitored by the Department for Levelling Up, Housing and Communities (DLUHC).

### Green Fingers in The Blue Finger

The 'Blue Finger' is a strip of Grade 1 agricultural land in north east Bristol that runs north into South Gloucestershire and is home to a number of community growing initiatives. Grow Wilder is a nature-friendly farming and gardening initiative run by Avon Wildlife Trust, while the Edible Futures market garden produces high quality salads and vegetables for the local community using environment friendly practices. Both these projects show the immense value that can be gained by communities and nature through the use of BMV land at the edge of towns and cities. Despite this, the Blue Finger has also suffered inappropriate development, with a new bus junction being developed through it in 2015. Changing national planning policies to require local plans to consider local food growing could play an important role in better protecting these often overlooked soils.

## Our best agricultural resource under threat

Despite national planning policy stating that the presence of BMV land should be considered when making planning decisions, this is not being achieved in practice. Shifts in policy which once focused on prioritising securing food production have now moved towards achieving 'sustainable development', which has resulted in increased losses of greenfield land in order to fulfil government housing delivery targets.

How we use our land resource is only going to become more important as the impacts of the climate emergency become evident, with significant areas of BMV land at risk of permanent flooding. Climatic change, especially rainfall patterns and accumulated temperatures, may also lead to changes in agricultural land quality that will reduce the extent of BMV land.

The purpose of this report is to build upon the previous research undertaken by DEFRA to review the effectiveness of BMV policy, in 2010 and 2004, which found considerable losses of high-grade agricultural land to development. We will explore the current extent of BMV land in England, analyse the current pressures placed on this land, and discuss policy measures which will result in better outcomes for people and the environment.

### A note on the different BMV datasets used

A number of datasets have been used in this report. Information on the extent of BMV land grades and development data in England was obtained and analysed from the following datasets:

- Provisional ALC 1:250,000 dataset (available at www.magic.gov.uk) — this dataset categorises BMV land into Grade 1, 2 and 3 and was used to identify developments which have taken place on BMV land.
- Post 1988 ALC Site Data (DEFRA, available from Natural England) — a dataset of detailed individual site survey data which classifies 2.8% (or 325,200 ha) of England's rural land into Grade 1, 2, 3a and 3b. This is out of a total area of 972,052 ha of detailed survey data available (8% of England's rural area).
- 'Likelihood of Best and Most Versatile' (BMV) land/ ALC Strategic Map (DEFRA, available from Natural England, received April 2022) — a predictive dataset at a scale of 1:250,000 which uses a combination of detailed ALC post-1988 surveys, provisional ALC data, climatic data and National Soil Resources Institute information to assess soil association areas by their likely proportion of BMV land. The likelihood maps do not distinguish individual grades, instead the categories are: High likelihood (areas where more than 60% of the land is likely to be BMV), Moderate likelihood (20-60% of the land is likely to be BMV) and Low likelihood (less than 20% of the land is likely to be BMV)
- Glenigan Report commissioned by CPRE on development proposals and decisions on BMV agricultural land (Glenigan.com)

## How much BMV land is there and where is it?

In 2012 Natural England[7] estimated that Grades 1 and 2 together formed about 21% of all farmland in England, with Grade 3a covering a further 21%. At that time DEFRA[8] estimated that the total area of farmed land in England was 8.9m hectares, suggesting that just under 3,750,000 ha of farmland (42%) was BMV in 2012.

Across rural England, there has been limited detailed surveying of BMV land. Datasets that exist which try to quantify how much land is classified as Grade 1, 2 or 3a are largely based on strategic analyses of land quality. Due to the predictive nature of assessing BMV land quantities, there are several datasets using different methodologies to provide estimates. We explore the 'Provisional ALC', 'Post 1988 detailed survey', and 'Likelihood of BMV' mapping datasets in the following tables.

Table 1 shows the hectares of Grade 1, 2 and 3 according to the 'Provisional' mapping produced via reconnaissance mapping in 1966. It also describes the hectares of Grade 3a land which have been identified through the Post 1988 detailed mapping. This dataset only assesses 8% of rural England, and in the light of the 2012 Natural England estimate mentioned above, the true quantity of this land type will be much (possibly as much as 1.5 million ha) higher. Table 1 shows that, which the data we have available, there is an estimated 2,272,782 ha of BMV (Grade 1, 2 and 3a) land across England. This is largely concentrated across the East Midlands, East of England, South West and Yorkshire and the Humber regions.

### Table 1

The hectares of Grade 1 and 2 land according to the 'Provisional' dataset and the hectares of Grade 3a according to the 'Post 1988' dataset in England. Data: Provisional ALC 1:250,000 dataset; Post 1988 ALC Site Data.

| Region | Grade 1 | Grade 2 | Grade 3a (Identified) | BMV Total (Grades 1, 2 and identified 3a) |
|---|---|---|---|---|
| East Midlands | 105,864 | 398,622 | 5,654 | 510,140 |
| East of England | 104,133 | 506,487 | 8,169 | 618,789 |
| London | 4,128 | 7,895 | 77 | 12,100 |
| North East | | 16,497 | 2,760 | 19,257 |
| North West | 29,134 | 79,143 | 4,812 | 113,089 |
| South East | 47,361 | 173,095 | 13,395 | 233,851 |
| South West | 37,318 | 220,045 | 17,033 | 274,396 |
| West Midlands | 13,584 | 186,845 | 7,847 | 208,276 |
| Yorkshire and the Humber | 13,064 | 260,449 | 9,371 | 282,884 |
| Total | 354,586 | 1,849,078 | 69,118 | 2,272,782 |

# Analyses

## Development on BMV land

The dataset obtained from development consultancy Glenigan was used to determine the hectares of BMV land which had been built on since 2010. This provided us with information on the developments which have taken place on BMV land according to the Provisional ALC dataset. As the Provisional ALC dataset does not provide subdivision of Grade 3, we used the Post 1988 detailed survey ALC dataset to identify which Grade 3 land was its respective Grade 3a category, where this detailed survey information was available (see above for further detail on this dataset).

From our available data we found that, between 2010 and 2022, there were 14,415 hectares of Grade 1, 2 and identified Grade 3a agricultural land covered by development (Figure 2). Of this, 8,035 ha were used for private housing developments totalling 287,864 houses. Another 1,400 ha were used for renewable energy developments including solar, illustrating that housing developments have had 55% of the impact on BMV land take.

In total, this 14,415 ha represents a 0.6% loss of our total identified BMV agricultural land of 2,272,782 ha (Table 1). Figure 2 also highlights that since 2010, there has been an overall increase in the amount of BMV agricultural land used for new developments, with a particular spike for projects with a start date of 2022. A total of 61 ha of identified BMV land was converted to development in 2010; this increases 100-fold in 2022, which sees project starts covering 6,500 ha of prime agricultural land and the highest rate of development identified to date.

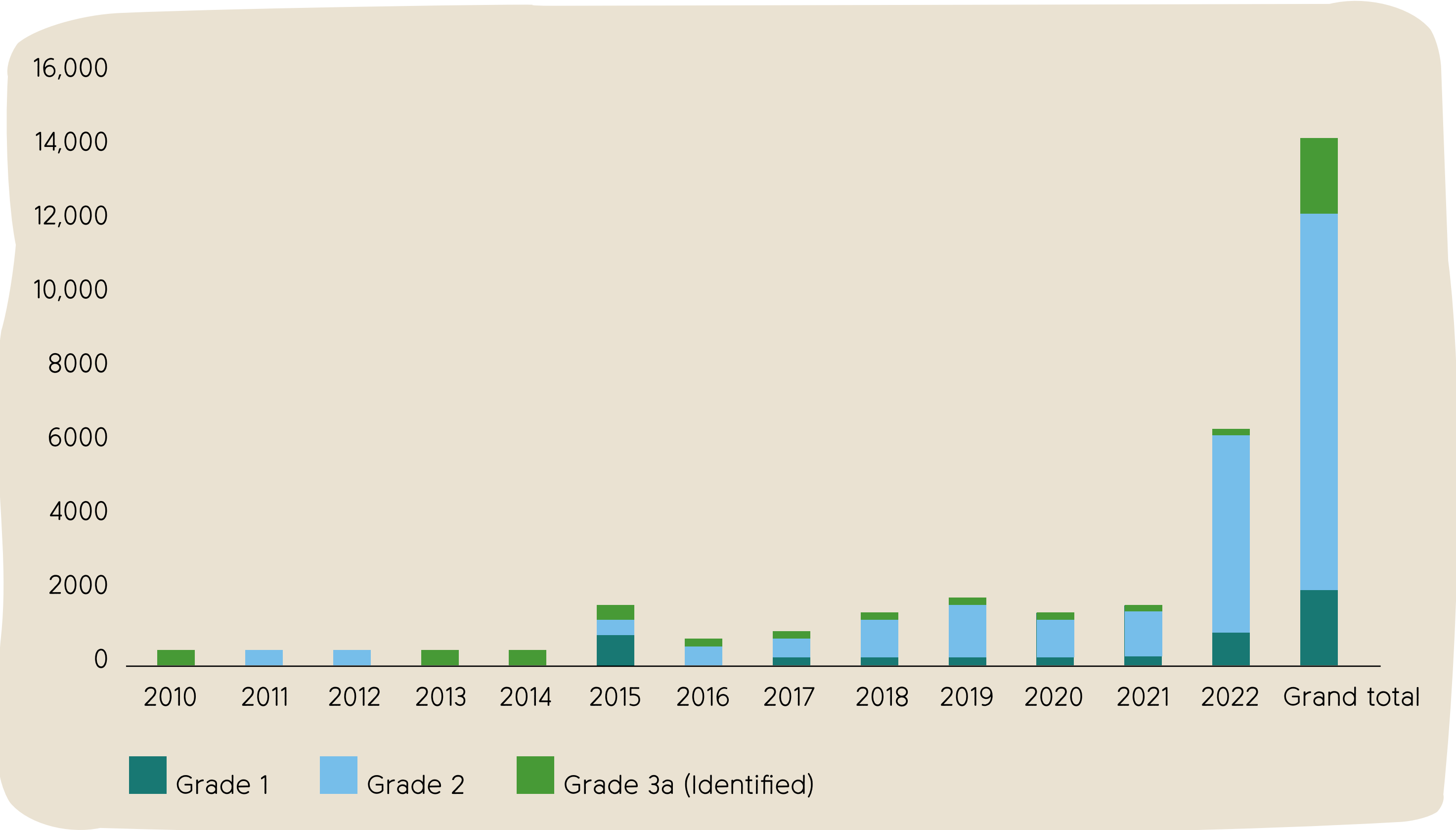
On first impression a 0.6% loss in our total BMV agricultural land sounds insignificant. However, the Food Foundation's Veg Facts series[9] found that, in 2018, only 1% of the UK's agricultural land was used to produce 52.7% of our vegetables — equivalent to 2.4 million tonnes[10] from 137,360 ha, or on average, 17.5 tonnes per hectare. If we extrapolate this production rate to the 14,415 ha BMV land developed in England, this is equivalent to losing the production of around 250,000 tonnes of vegetables — enough to provide nearly two million people with their 5-a-day for an entire year[11]. However, this calculation does not account for the higher crop yields from BMV agricultural land, meaning the production loss is likely to be higher than this.

For CPRE, the key point is that the loss of this land is unnecessary and avoidable. We have highlighted, through our State of Brownfield reports, that there is a plentiful and constantly replenishing supply of suitable previously developed (brownfield) sites available for housing development in each English region — more than enough to accommodate the housing that has been built on BMV land. In addition, there is plenty of potentially suitable alternative space for renewable technologies — particularly for solar panels on existing rooftops.

The general increase in the rate of development shown here is likely to be due to a gradual weakening of national planning policies on BMV, as well as on brownfield land and housing density. As previously discussed, the NPPF asks local planning authorities to consider the economic benefits of high-grade agricultural land when making planning decisions. But this is a demotion of BMV relevance within policy when we consider that the 1997 edition of the government's Planning Policy Guidance note 7 had a firm presumption against building on BMV; this was supported by the 'brownfield first' and minimum residential density policies contained in PPG3 after 2000 — both of which served to minimise the need to build on productive farmland.

## Figure 2

Shows the number of hectares of BMV land lost to development since 2010. Hectares lost of Grade 1 and 2 land are based on the 'Provisional' dataset and hectares lost in Grade 3a are based on available detailed survey information in the 'Post 1988' dataset. Data: Provisional ALC 1:250,000 dataset; Post 1988 ALC Site Data; Glenigan. See Table A1 for figures.



## The regional profile of BMV development

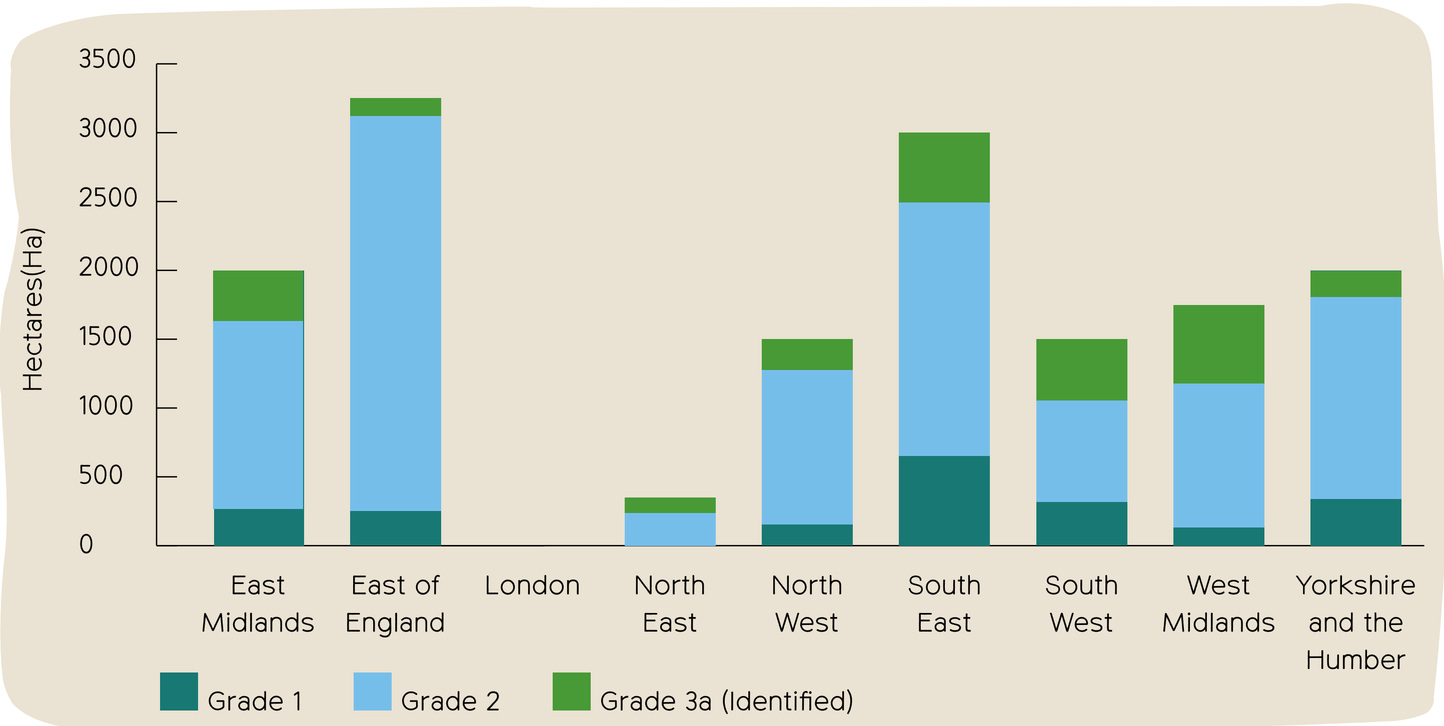
The same datasets were used to evaluate the regional differences in the overall loss of BMV agricultural land between 2010 and 2022, the result of which can be seen in Figure 3 and Tables 2 and 3.

There have been three regions (East Midlands, East of England and the South East) which have experienced the highest absolute losses of BMV agricultural land from development projects between 2010 and 2022 (Figure 3 and Table 2). In particular, the East of England has seen high levels of development on BMV land, having lost over 3,200 hectares over the past 12 years. This is followed closely by the South East region losing 2,920 hectares of BMV land overall, including the greatest regional loss of Grade 1 (excellent quality agricultural land) BMV land at 577 hectares.

Our BMV agricultural land is not spread evenly throughout the country; as previously highlighted, the top regions for the proportion of BMV are the East of England, East Midlands and Yorkshire and the Humber, so it would stand to reason that these areas would have some of the highest losses. However, Table 2 also shows that with over 1% loss each, the North East, North West and South East have seen the highest proportions of BMV land lost to development. Going further into the data, Yorkshire and the Humber has seen had the highest proportional loss of Grade 1 land, at over 3.5%, while the East Midlands, West Midlands and South East have lost 7%, 6% and 4%, respectively, of their Grade 3a land (Table 3).

### Figure 3

The hectares of Grade 1, 2 land according to the 'Provisional' dataset and the hectares of Grade 3a according to the 'Post 1988' dataset in England, which have been developed since 2010, by region. Data: Provisional ALC 1:250,000 dataset/ Post 1988 ALC Site Data/ Glenigan. See Table A2 for breakdown of figures.



### Table 2

Shows the total hectares of BMV in each region, the number of those hectares which have been developed and the percentage developed as a proportion of the total area of BMV land in that region*. Data: Provisional ALC 1:250,000 dataset; Post 1988 ALC Site Data.

| Region | BMV Total | BMV Developed | Proportion developed (%) |
|---|---|---|---|
| East Midlands | 510,140 | 1,970 | 0.39 |
| East of England | 618,789 | 3,232 | 0.52 |
| London | 12,100 | 2 | 0.02 |
| North East | 19,257 | 314 | 1.63 |
| North West | 113,089 | 1,255 | 1.11 |
| South East | 233,851 | 2,920 | 1.25 |
| South West | 274,396 | 1,316 | 0.48 |
| West Midlands | 208,276 | 1,629 | 0.78 |
| Yorkshire and the Humber | 282,884 | 1,777 | 0.63 |
| Total | 2,272,782 | 14,415 | 0.63 |

* BMV figures derived from total sum of 'Grade 1', 'Grade 2' in Provisional dataset and 'Grade 3a (Identified)' in the Post 1988 dataset.

### Table 3

The percentage of Grade 1, 2 and Grade 3a (identified) which has been developed in that region since 2010 as a proportion of the total area of each category in that region*. Data: Provisional ALC 1:250,000 dataset; Post 1988 ALC Site Data; Glenigan.

| Region | Grade 1 | Grade 2 | Grade 3a (Identified) |
|---|---|---|---|
| East Midlands | 0.22 | 0.33 | 7.37 |
| East of England | 0.23 | 0.57 | 1.26 |
| London | 0.05 | - | - |
| North East | - | 1.52 | 2.29 |
| North West | 0.38 | 1.23 | 3.60 |
| South East | 1.22 | 1.04 | 4.04 |
| South West | 0.84 | 0.31 | 1.93 |
| West Midlands | 0.66 | 0.56 | 6.23 |
| Yorkshire and the Humber | 3.53 | 0.45 | 1.47 |

* BMV figures derived from total sum of 'Grade 1', 'Grade 2' in Provisional dataset and 'Grade 3a (Identified)' in the Post 1988 dataset.

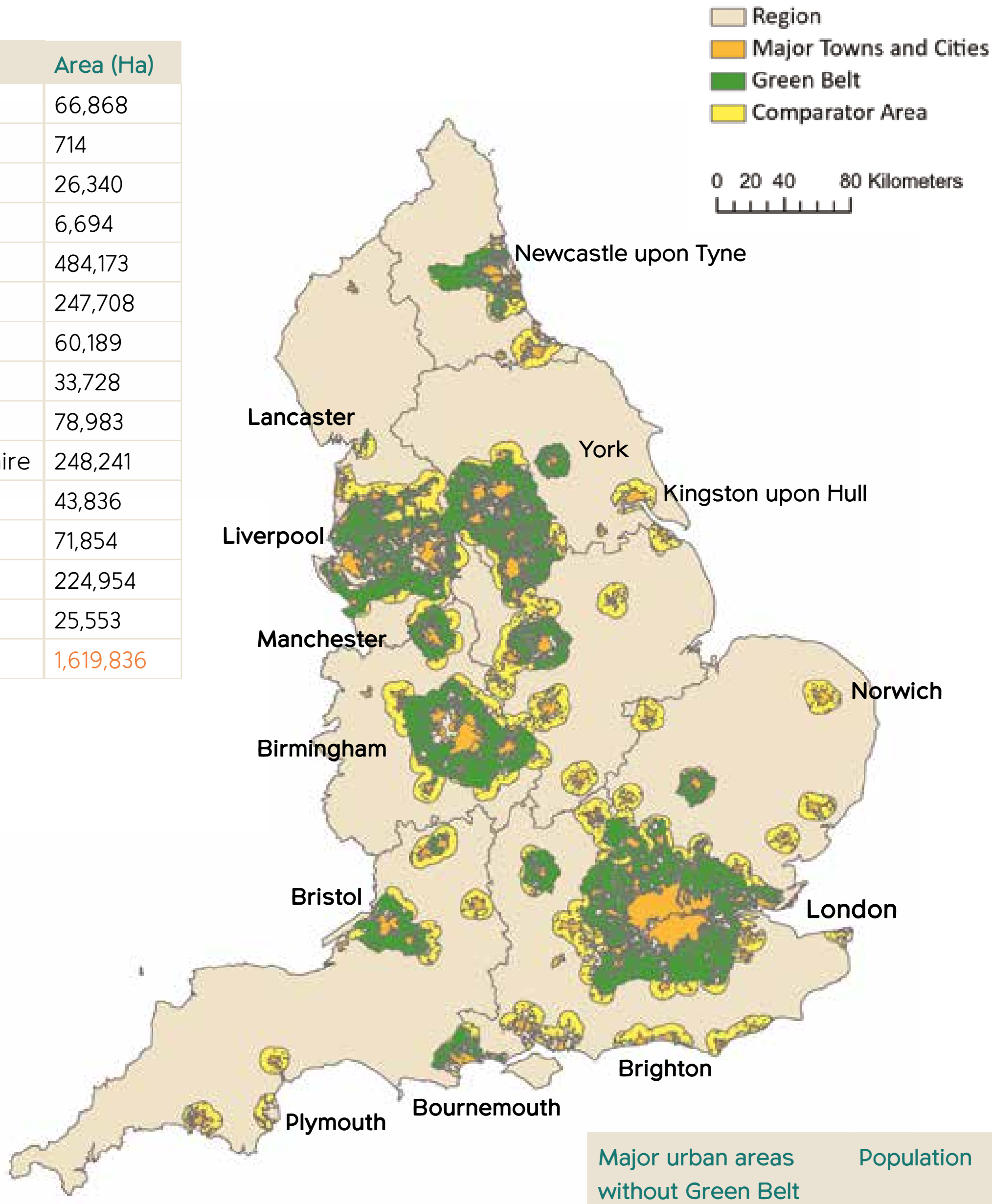
## BMV around towns and cities

This part of the research looks at BMV development in areas designated as Green Belt, as well as areas of undesignated and largely undeveloped land around large towns and cities. Together, these areas of land make up around 22% of England's land area (Figure 4)

### Figure 4

### Countryside around towns including:
Green Belt (green); other large towns & cities without Green Belts (yellow)

| Green Belt | Area (Ha) |
|---|---|
| Avon | 66,868 |
| Burton and Swadlincote | 714 |
| Cambridge | 26,340 |
| Gloucester and Cheltenham | 6,694 |
| London | 484,173 |
| North West | 247,708 |
| Nottingham and Derby | 60,189 |
| Oxford | 33,728 |
| SW Hampshire and SE Dorset | 78,983 |
| South Yorkshire and West Yorkshire | 248,241 |
| Stoke on Trent | 43,836 |
| Tyne and Wear | 71,854 |
| West Midlands | 224,954 |
| York | 25,553 |
| Total | 1,619,836 |




| Major urban areas with Green Belt | Population |
|---|---|
| London | 7,215,900 |
| Birmingham | 970,900 |
| Liverpool | 469,000 |
| Leeds | 443,250 |
| Sheffield | 439,870 |
| Bristol | 420,560 |
| Manchester | 394,270 |
| Coventry | 303,480 |
| Bradford | 293,720 |
| Stoke on Trent | 259,250 |
| Wolverhampton | 251,430 |
| Nottingham | 249,650 |
| Derby | 229,400 |

| Major urban areas without Green Belt | Population |
|---|---|
| Leicester | 303,580 |
| Kingston upon Hull | 301,420 |
| Plymouth | 243,800 |
| Southampton | 234,250 |
| Reading | 232,660 |

Safeguarding the land around our urban centres for nature-friendly farming allows for the connection between urban and rural economies to be rebuilt. This offers multiple benefits, such as securing access to locally produced foods for our urban centres; creating jobs through increased generation of goods and services; and providing green spaces and educational opportunities for city dwellers. The promotion of ecological farming practices in our urban fringe also has many benefits which will support existing government goals for the sequestration of carbon and promotion of biodiversity. The use of our urban fringe BMV land for ecological farming offers us the optimal return in regard to all of these benefits. However, due to its location, BMV land in the urban fringe is unique in that it will face a higher development threat than other areas of BMV land.

Our analysis found that there are 537,262 hectares of BMV classified land in the countryside around towns and cities; 23.6% of all England's BMV is in these areas, making the urban fringe representative of the wider countryside in this sense.

Table 4 shows the amount of development which has occurred on BMV land in countryside around towns and cities. In total, 5,565 hectares have been lost — over a third of England's total BMV loss and 1% of the total BMV land available in these areas. The regions which have been hardest hit by BMV development in countryside around their towns and cities are the East Midlands, North East, South East and South West. Grade 3a is experiencing the highest losses, with the East Midlands losing nearly 8% of its total identified 3a land while the North West and South East have lost 4% and 5% respectively.

### Table 4

The hectares of Grade 1, 2 and 3 land according to the 'Provisional' dataset and the hectares of Grade 3a and 3b according to the 'Post 1988' dataset around towns and cities, which have been developed since 2010. Data: Provisional ALC 1:250,000 dataset; Post 1988 ALC Site Data; Glenigan.

| Region | Grade 1 | Grade 2 | Grade 3a (Identified) | BMV Total |
|---|---|---|---|---|
| East Midlands | - | 547 (0.94) | 266 (8.53) | 813 (1.31) |
| East of England | 18 (0.15) | 1,012 (0.86) | 21 (0.59) | 1,051 (0.79) |
| London | 2 (0.06) | - | - | 2 (0.02) |
| North East | - | 102 (2.01) | 35 (2.37) | 136 (2.09) |
| North West | 60 (0.21) | 392 (0.94) | 128 (4.25) | 580 (0.79) |
| South East | 363 (2.18) | 548 (0.85) | 268 (5.34) | 1,178 (1.37) |
| South West | 168 (1.96) | 332 (1.30) | 60 (1.39) | 559 (1.46) |
| West Midlands | 14 (0.53) | 599 (0.77) | 230 (3.93) | 843 (0.98) |
| Yorkshire and the Humber | - | 347 (0.97) | 55 (0.94) | 402 (0.96) |
| Total | 625 | 3,878 | 1,062 | 5,565 (1.03) |

## Development through Appeals

Local planning authorities make the decisions on whether a planning application should be given permission after weighing up many different variables as required by national planning policies. If an authority decides that a planning application should not be given permission, the applicant has a six-month window to decide if they would like to appeal that decision to the Secretary of State.

The Planning Inspectorate is a government agency which has the power, acting on behalf of the Secretary of State, to overturn a refusal of planning consent by a local planning authority (LPA) if it believes the LPA decision was unsound. In major cases the final decision may be taken by the Secretary of State who can overrule the planning inspector's recommendation. For this part of the research, CPRE analysed appeal decisions from 2010 onwards which include reference to BMV land, to gain understanding of how much weight the presence of BMV land has in planning decisions by the inspectorate.

Table 5 shows that since 2010, there have been 147 appeals that mention BMV land within the appeal report. Of these, 67 were allowed and 80 dismissed, an overall allowance rate of 46%. Appeals which were allowed used 788 ha of BMV land, with over half of this land take occurring in 2015 and 2016. This is much higher than the average rate at which all appeals are allowed (about 25%) but also consistent with the rate at which appeals involving a public inquiry are allowed. Most, if not all, appeals involving BMV land would need an inquiry due to the heightened controversy.

Further analysis into appeal reports showed us that the most common reason quoted for an application appeal to be allowed was due to the local planning authority not having a five-year housing land supply, quoted in 22 of the appeal reports. Of the 87 appeals which were dismissed, 12 gave 'significant' weight to the presence of BMV land while 10 gave 'moderate weight'. The presence of BMV land in 33 dismissed appeals played either a 'limited', 'modest' (or 'some') or no role in the appeal ultimately being rejected. This raises the question of how much value is being placed on the presence of BMV land by DLUHC and the Planning Inspectorate within the wider context of meeting housing targets in a district.

A recent comment made by Lord Benyon in a Lords debate on food security[12] remarked that

**'very strict rules relate to both planning and the use of the best agricultural land',**

in relation to a major solar development which has been given permission on BMV land in Suffolk. However, with almost half of appeals involving BMV land being allowed by the Planning Inspectorate, it could be reasonably argued that these policies are not strong enough.

## Housing development versus BMV protection

September 2021 saw an appeal for 118 houses on a BMV site in West Sussex allowed by the Planning Inspectorate. The development of the site resulted in a loss of 4.5 ha of Grade 2 and 3a agricultural land, as well as 2 ha of a nitrate mitigation site, and was described as 'not ideal' in the inspector's report. Driven by Chichester's out-of-date Local Plan, the development of this BMV land was described as 'inevitable' due to constraints on land from the protected South Downs National Park and Chichester Harbour AONB, limiting other development site opportunities to meet the councils housing needs. Current national planning policy results in these trade-offs between different land uses, whereas policy should allow for a more integrated decisions and better outcomes.

The introduction of a national land use strategy, together with more local influence over the implementation of land management policy, would allow for more integrated policies and decision-making, and better outcomes, addressing the wasteful pattern of development often driven by the requirement for a district to meet its housing targets. The outcome should be living more within environmental limits and being able to expand environmental capacity rather than continue to shrink it. In England, there is also an important equity dimension to land use: there is an increasingly urgent need to spread or 'level up' development and quality of life more fairly between the pressurised south of the country and the relatively neglected midlands and northern regions.

### Table 5

Shows the number of allowed and dismissed appeal decisions which have mentioned BMV land within the Planning Inspector's report. Data: Compass; CPRE analysis

| Year | Allowed | Dismissed | Allowed Area (Ha) | Allowed Rate (%) |
|---|---|---|---|---|
| 2010 | - | - | - | - |
| 2011 | - | 3 | - | 0 |
| 2012 | 1 | 3 | 4 | 25 |
| 2013 | 3 | 1 | 11 | 75 |
| 2014 | 3 | 4 | 77 | 43 |
| 2015 | 7 | 17 | 366 | 29 |
| 2016 | 17 | 28 | 117 | 38 |
| 2017 | 12 | 6 | 38 | 67 |
| 2018 | 4 | 5 | 11 | 44 |
| 2019 | 3 | 2 | 7 | 60 |
| 2020 | 4 | 5 | 45 | 44 |
| 2021 | 11 | 8 | 71 | 58 |
| 2022 | 2 | 1 | 40 | 67 |
| Total | 67 | 80 | 788 | 46 |

# Future threats: Flooding

The land losses resulting from permanent development on land classified as BMV is further compounded if we consider other current and future pressures on this land. Farmland is severely damaged when hit by flooding, causing delays to the harvest and a reduction in yields. For this analysis, we look into the current flooding threat BMV land faces.

The Environment Agency produces maps of flood risk to support food risk assessments in planning. Using the 'Flood Map for Planning (Rivers and Sea) - Flood Zone 3' dataset (data.gov.uk)[13] we determined how much of the Provisional ALC mapping fell into these areas. Flood zone 3 represents areas of the highest risk of flooding.

Table 6 shows that an estimated 212,319 ha of all England's Grade 1 BMV land is within flood zone 3 areas — this means 59.8% of all England's Grade 1 BMV land is at the highest risk of flooding. The regional profile of flood risk shows that 75% and 95%, respectively, of the East Midlands and East of England Grade 1 land is at the highest risk of flooding, shown on (Figure 6 a and b).

The figures presented here are representative of the current threat posed by flooding, but the consequences of climate change are likely to increase the threat posed by flooding even further. The Met Office predicts that the intensity of rain will increase and that, by 2070, rainfall in the summer will have increased by 20%, with a 25% increase in winter[14]. The implications of climate change will have severe consequences for the loss of BMV land and our resulting food security. Protecting BMV land from permanent development now is vital if we are to maintain a supply of BMV land as climate change progresses. Our analysis found that around 450 hectares of BMV land have already been used to build flood defence developments, suggesting that we are already seeing the impacts on climate change on this land.

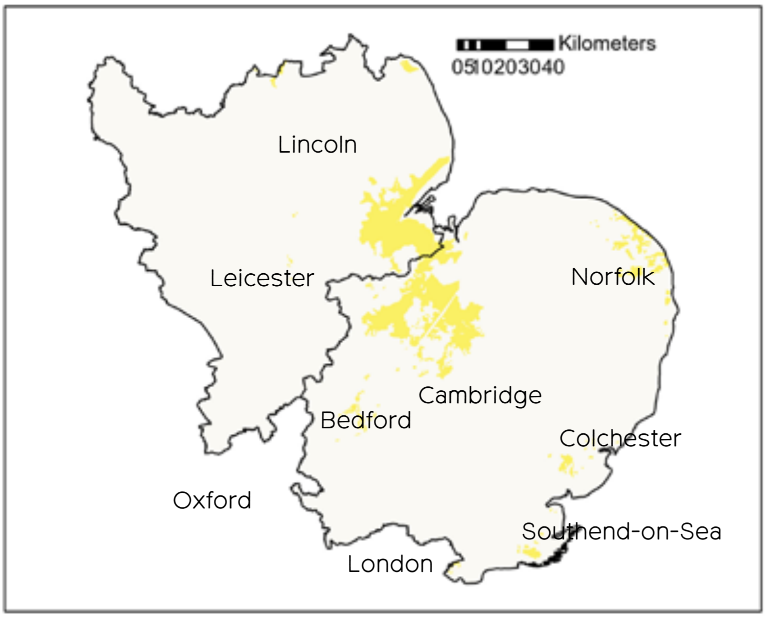
### Table 6

The hectares of Grade 1, 2 and 3 land according to the Provisional dataset which fall into Flood Zone 3 by region. Data: Provision ALC 1:250,000 dataset / Environment Agency[15]

| Region | Grade 1 | Grade 2 | Grade 3 | Total |
|---|---|---|---|---|
| East Midlands | 79,903 | 121,191 | 105,897 | 306,991 |
| East of England | 98,784 | 89,969 | 87,797 | 276,550 |
| London | 130 | 15 | 1,077 | 1,222 |
| North East | - | 5,153 | 16,732 | 21,885 |
| North West | 6,625 | 10,965 | 41,290 | 58,880 |
| South East | 6,994 | 24,256 | 51,944 | 83,194 |
| South West | 1,606 | 14,956 | 82,424 | 98,986 |
| West Midlands | 1,426 | 9,349 | 44,525 | 55,300 |
| Yorkshire and the Humber | 16,851 | 58,736 | 97,000 | 172,587 |
| Total | 212,319 | 334,590 | 528,686 | 1,075,595 |

Figure 6a shows the Grade 1 classified land within the East Midlands and East of England regions. Figure 6b shows the Grade 1 land (as in Figure 6a) and those areas which are considered to be in 'Flood Zone 3'

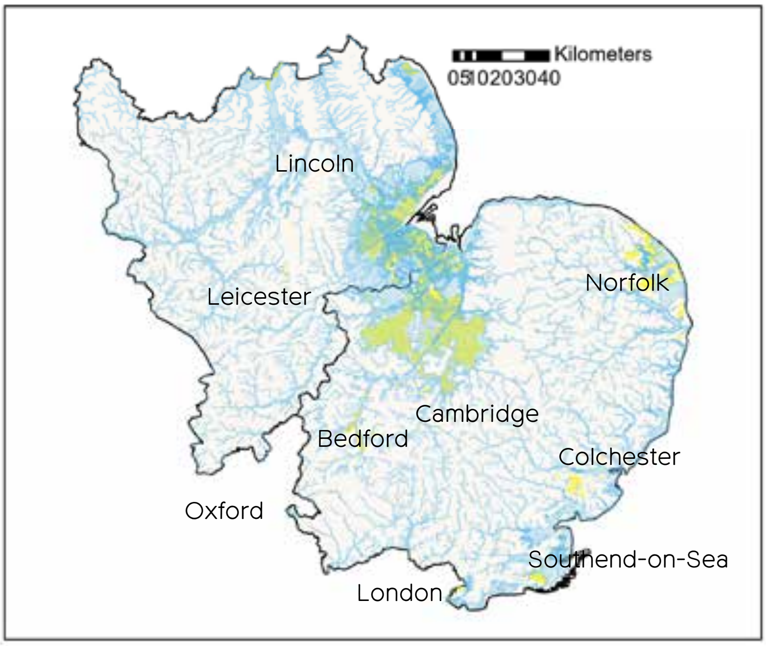
## Figure 6a




### Legend

- Grade 1
- Flood zone 3
- East Midlands and East Region

## Figure 6b






# Conclusion and recommendations

This report has found that current planning policy is not sufficient in protecting our BMV agricultural land and that we continue to needlessly place development on this valuable resource. We have seen a trend of increasing amounts of BMV land being used for development since 2010, likely resulting from continued pressure on Local Planning Authorities to find land within their districts to meet their nationally imposed housing targets. The effects of housing pressure are surfacing in the usual hot spots for development such as the East of England and South East, in addition to high BMV land take in the West and East Midlands, likely resulting from a lack of land use strategies across the country. However, drawing solid conclusions on the status of development on BMV land will continue to be difficult until more accurate and up-to-date information is available on exactly where BMV land is. As a result, the figures we have stated in this report are indicative but are likely to be conservative estimates.

It is vital that we maintain as much of our domestic food production as possible. As recent events have shown, the food security of the country increasingly hangs in the balance. Meanwhile, the pressures on our most productive land will only continue to increase as we experience more damaging effects from the changing climate. Protecting our BMV agricultural land should be of top priority.

CPRE therefore reccommends that the government should:

- Consult on and publish a national land use strategy that provides an integrated framework for local policy and decision-making on both planning and farming.
- Incorporate the following guidelines in the new NPPF to ensure the loss of valuable farmland is minimised:
    - a brownfield first policy
    - a greater steer towards medium- and high-density new housing
    - a firm presumption against development on BMV land — the higher the ALC grade, the greater the weight which should be attached to its protection.
- Require site-specific surveys to be mandatory on any development proposals involving more than one hectare of land, unless it is clear that the site will not contain BMV land.
- Require local authorities to identify and track development on BMV land in their district.

# Annex

## Methods

Development on BMV land analysis: To understand the quantities of BMV land which have been built on since 2010, we used several spatial datasets from Natural England and a development dataset obtained from development consultancy, Glenigan. The majority of information on the ALC Grade of soils throughout the country is based on the old system which does not include Grades 3a and 3b, instead placing both of these Grades into an aggregated Grade 3. Using GIS tools and the Post 1988 dataset, we were able to determine which developments in our dataset fell into Grade 3a land, and as a result could be considered BMV for our findings. It should be noted that the post 1988 dataset covers only 8% of rural England, and as a result, we were only able to identify 3% of the Grade 3 land which fell into Grade 3a or 3b.

### Appeals analysis:

During April 2022, CPRE collated inspector reports from planning appeals platform, Compass. A key word search was conducted using the phrases 'BMV' and 'Best and Most Versatile' to identify the relevant appeals.

### Flooding risk analysis:

To assess the risk to faced by BMV to Flooding, CPRE used the existing 'Provisional' mapping dataset and the Environment Agency's flood risk for planning, flood zone 3 datasets, to understand where areas of BMV land were falling in relation to high flood risk areas. Using GIS tools these two spatial datasets were overlaid, and the intersect between flood zone 3 and Grade 1 areas was measured.

## Complementary tables of figures

### Table A1

Shows the number of hectares of BMV land lost to development since 2010. Hectares lost of Grade 1 and 2 land are based on the 'Provisional' dataset and hectares lost in Grade 3a are based on available detailed survey information in the 'Post 1988' dataset. Data: Provisional ALC 1:250,000 dataset; Post 1988 ALC Site Data; Glenigan.

| Row Labels | Grade 1 | Grade 2 | Grade 3a (Identified) | BMV total |
|---|---|---|---|---|
| 2010 | 1.15 | 59.03 | 1.29 | 61.47 |
| 2011 | 1.87 | 102.32 | - | 104.19 |
| 2012 | 39.26 | 1.68 | - | 40.94 |
| 2013 | 3.94 | 107.36 | 0.87 | 112.17 |
| 2014 | 5.08 | 94.25 | 16.00 | 115.33 |
| 2015 | 484.44 | 278.42 | 197.17 | 960.04 |
| 2016 | 34.85 | 363.94 | 17.28 | 416.07 |
| 2017 | 110.04 | 414.43 | 81.07 | 605.54 |
| 2018 | 132.88 | 855.15 | 139.44 | 1,127.47 |
| 2019 | 220.71 | 1,252.16 | 313.40 | 1,786.27 |
| 2020 | 93.03 | 802.42 | 172.10 | 1,067.55 |
| 2021 | 154.91 | 1,158.48 | 222.79 | 1,536.18 |
| 2022 | 752.38 | 4,637.93 | 1,091.94 | 6,482.26 |
| **Total** | **2,034.5** | **10,127.6** | **2,253.4** | **14,415.5** |

### Table A2

The hectares of Grade 1, 2 and 3 land according to the 'Provisional' dataset and the hectares of Grade 3a and 3b according to the 'Post 1988' dataset in England, which have been developed since 2010, by region. Data: Provisional ALC 1:250,000 dataset; Post 1988 ALC Site Data; Glenigan.

| Region | Grade 1 | Grade 2 | Grade 3a (Identified) | BMV Total (Grade 1, 2 and identified Grade 3a) |
|---|---|---|---|---|
| East Midlands | 238 | 1,315 | 417 | 1,970 |
| East of England | 243 | 2,887 | 103 | 3,232 |
| London | 2 | - | - | 2 |
| North East | - | 251 | 63 | 314 |
| North West | 111 | 971 | 173 | 1,255 |
| South East | 577 | 1,802 | 541 | 2,920 |
| South West | 313 | 674 | 329 | 1,316 |
| West Midlands | 90 | 1,050 | 489 | 1,629 |
| Yorkshire and the Humber | 461 | 1,178 | 138 | 1,777 |
| **Total** | **2,035** | **10,128** | **2,253** | **14,415** |

## Supplementary analyses

### Likelihood of BMV land dataset

While the analyses in this report provide us with some insight into the quantities of BMV land which have been developed, the limited size of the Post 1988 Site Survey dataset means it is difficult to determine the true extent of BMV land take due to limited knowledge of the relative proportions of Grade 3a and 3b land.

Due to this, complementary analyses using Natural England's 'Likelihood' of BMV land dataset were undertaken to gain a strategic insight into the BMV land take for development and give some initial indication as to the full extent of BMV land being lost. This dataset is used to show the best available estimate of agricultural land quality at the date of compilation (April 2022) expressed in terms of the proportion of land likely to be classified as BMV, either 'High', 'Moderate' or 'Low' (see Box 2 for the breakdown of these categories).

As the Likelihood dataset is based on a proportion of land being BMV, our results have been made on conservative estimates which account for the probability that a development may not be on BMV land. For example, 60% of the total estimated land take is presented in Table 3A for the 'High' category, 40% of the land take for 'Moderate' and 20% for the 'Low' category.

Table A3 shows the likelihood of an area of land being either Grade 1, 2 or 3a, details of the likelihood categories can be found in Box 2. The areas of England which are likely to have high proportions of BMV land are predominantly found in the East of England, followed by the East and West Midlands, and Yorkshire and the Humber.

### Table A3

Shows the hectares of land within England which fall into 'High', 'Moderate' or 'Low' likelihood of being BMV land. Data: Likelihood of 'Best and most versatile' (BMV) land/ALC Strategic Map

| Region | High | Moderate | Low |
|---|---|---|---|
| East Midlands | 540,193 | 481,762 | 341,292 |
| East of England | 945,344 | 431,137 | 216,432 |
| London | 8,057 | 6,164 | 7,831 |
| North East | 75,387 | 199,734 | 431,093 |
| North West | 240,429 | 232,307 | 679,513 |
| South East | 410,838 | 625,829 | 430,315 |
| South West | 477,820 | 667,416 | 938,988 |
| West Midlands | 519,162 | 392,691 | 187,285 |
| Yorkshire and the Humber | 511,336 | 241,719 | 573,304 |
| Total | 3,728,566.00 | 3,278,759.00 | 3,806,053.00 |

Our analysis found that it is likely that 18,772 hectares of BMV land have been used for development since 2010 — this is equivalent to 0.44% of the total BMV land available in England (Table A4) according to this dataset. Two regions, the East Midlands and West Midlands, have had the greatest BMV land losses in total terms and as a proportion of the amount of BMV land they have available, with 4,194 hectares (0.72%) and 3,631 hectares (0.72%), respectively. Figure A1 shows that the general trend since 2010 has been an increase in the use of BMV land for development (with particular peaks in 2019 and 2022) and that the usage of High Likelihood land has been increasing in particular. It is important to note that the relatively smaller numbers in the 'Low' category is likely due to our development dataset being based on the 'Provisional' BMV dataset, and as a result will not be a complete picture of all development on BMV land.

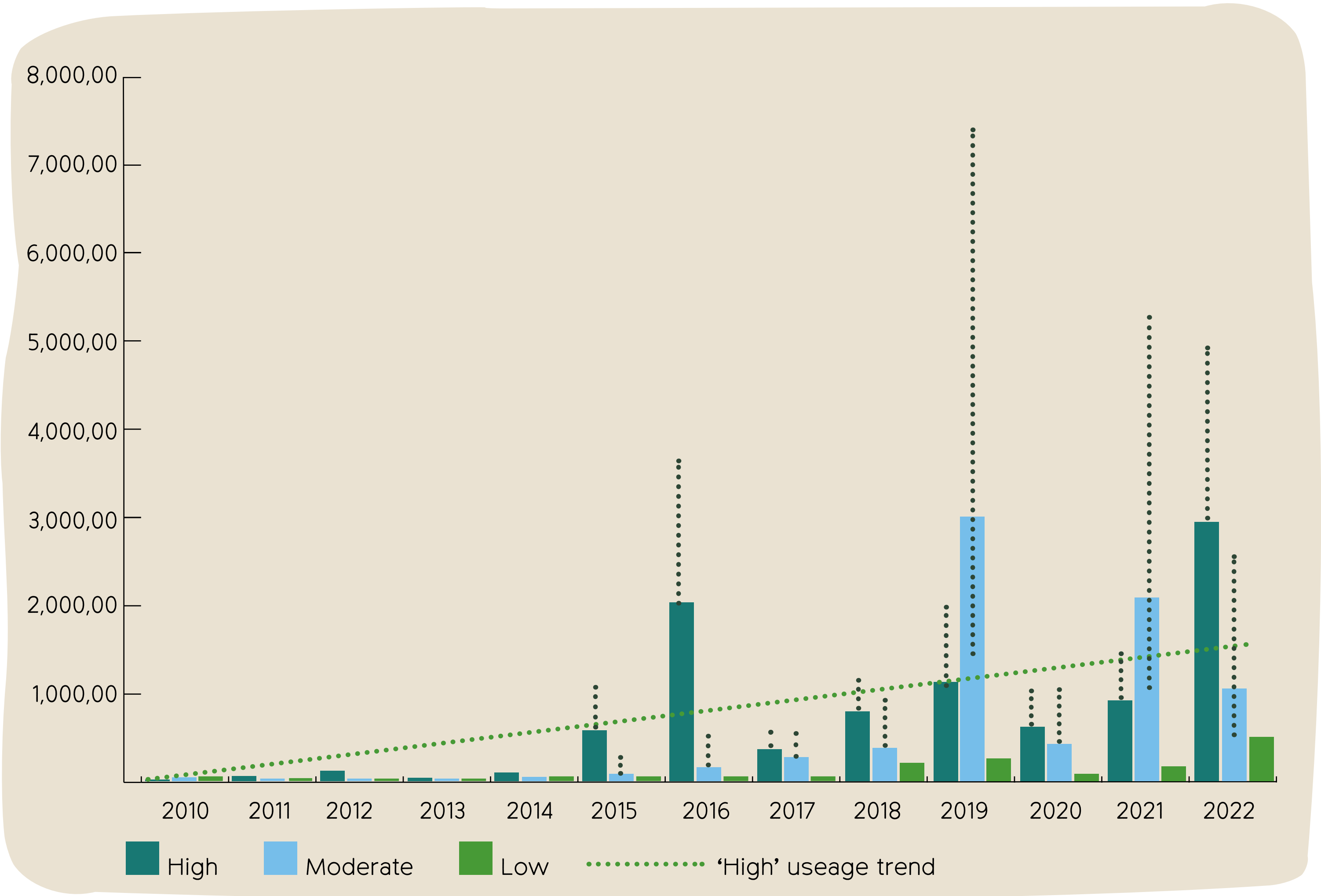
### Table A4

Shows the hectares of land within England which fall into 'High', 'Moderate' or 'Low' likelihood of being BMV land which have been developed, along with the percentage of this development as a proportion of the amount of that land type available in that region. Data: Likelihood of 'Best and most versatile' (BMV) land; ALC Strategic Map; Glenigan.

| Region | High | Moderate | Low | Total |
|---|---|---|---|---|
| East Midlands | 3,215 (0.99) | 834 (0.43) | 145 (0.21) | 4,194 (0.72) |
| East of England | 1,790 (0.32) | 438 (0.25) | 131 (0.30) | 2,360 (0.30) |
| London | 10 (0.20) | 48 (1.95) | 15 (0.99) | 73 (0.83) |
| North East | 89 (0.20) | 286 (0.36) | 225 (0.26) | 601 (0.28) |
| North West | 760 (0.53) | 419 (0.45) | 114 (0.08) | 1,292 (0.35) |
| South East | 1,044 (0.42) | 601 (0.24) | 222 (0.26) | 1,867 (0.32) |
| South West | 713 (0.25) | 473 (0.18) | 382 (0.20) | 1,568 (0.21) |
| West Midlands | 813 (0.26) | 2,762 (1.76) | 56 (0.15) | 3,631 (0.72) |
| Yorkshire and the Humber | 1,276 (0.42) | 1,755 (1.82) | 156 (0.14) | 3,187 (0.62) |
| Total | 9,709 (0.43) | 7,617 (0.58) | 1,446 (0.19) | 18,772 (0.44) |

## Figure A1

Shows the hectares of land within England which fall into 'High', 'Moderate' or 'Low' likelihood of being BMV land which have been developed. Error bars show variation within the likelihood category. Trendline shows the rate of 'High' probability land being developed since 2010. Data: Likelihood of 'Best and most versatile' (BMV) land/ALC Strategic Map/ Glenigan




## Explanatory note re Digital ALC data

### There are four digital Agricultural Land Classification (ALC) datasets:

- Provisional ALC 1:250,000 dataset. Also available to view and down load from the website www.magic.gov.uk (select 'interactive map' then 'landscape' topic and a scale of 1:250 001 to view).
- Pre 1988 ALC site data – individual sites surveyed in more detail by MAFF (including subdivisions of Grade 3 Land) before 1988; individual sites mapped at varying scales and level of detail from 1:5,000 to 1:50,000 (typically 1:10,000). Older data for land assessed under 'old' ALC guidelines which have now been superseded. Original paper maps and reports have been scanned by DCS and held in 'Filestore' (password access). Survey files and other soil records are stored with TNT.
- Post 1988 ALC site data - individual sites surveyed in more detail by MAFF (including subdivisions of Grade 3 Land) between 1989 and 1999; individual sites mapped at varying scales and level of detail from 1:5,000 to 1:50,000 (typically 1:10,000). The most detailed and up to date dataset. Original paper maps and reports have been scanned by DCS and held in 'Filestore' (password access). Survey files and other soil records are stored with TNT.
- Likelihood of 'Best and most versatile' (BMV) land – (sometimes referred to as ALC Strategic Map) is derived from existing ALC, ALC climate data and Soil Association data (not current NSRI dataset but that originally digitised by FRCA from the published paper soil maps).

Defra is nominally the owner of all this data but Natural England acts as its guardian. Natural England is the only body holding the data, including all the paper site survey records which support them, and is the main source of expertise. (Julie Holloway is the national lead and Defra would refer all enquiries they receive to Julie).

The attached explanatory leaflet gives further background http://naturalengland.etraderstores.com/naturalenglandshop/product.aspx?ProductID=88ff926a-3177-4090-aecb-00e6c9030b29. The work on minerals and waste planning referred to in this leaflet is a statutory Natural England responsibility so we also use the data for day to day planning advice. It is also underpins the technical advice which Natural England uses to assist planners and others, including Defra, the public and consultants on soils and agricultural land in land use planning and related land evaluation work.

Natural England releases most of this ALC data in a digital format (subject to restrictions on the likelihood of BMV land dataset and pre 88 ALC data). As the digital requests are relatively few it is either done through the national GI Unit or (more commonly) from the GI people in Reading or Bristol, who used to have national responsibility for this. There is a protocol for the release of ALC data which is currently being updated, but there is a working draft, currently on the 'N' Drive at N:\Evidence\Science Development & Delivery\Geology, Landscape & Soils\ALC (filename: draft ALC data release procedure NE version Nov 08).

Gill Shaw is also running a project to get the site data more readily accessible including links to the scanned original site maps and reports (of which there are approximately 6000).

### Digital Data supply:

1. Natural England can supply Provisional ALC data (stored on Natural England repositories) to contractors and/or the public. It is also available on www.magic.gov.uk to download.

2. If people receive requests for the Pre or Post 1988 digital datasets (site specific surveys which include subdivisions of Grade 3 land) or 'Likelihood of best and most versatile land' data, they may wish to consult either Julie Holloway or Gill Shaw in the first instance.

3. The 'Likelihood of best and most versatile land' dataset should be accompanied by an explanatory note. Due to licence restrictions the digital dataset can only be supplied to public bodies or their contractors. There is no licence restriction on paper map extracts.

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# References

[1] National Planning Policy Framework, paragraph paragraph 174 [b] available at: www.gov.uk/guidance/national-planning-policy-framework

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