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ALC Technical Review Part 2 - Climate, site and interactive limitations

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ALC Technical Review Part 2 - Climate, site and interactive limitations

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Executive Summary

The Agricultural Land Classification of England and Wales (ALC)[1] provides a framework for classifying agricultural land into six classes (ALC grades 1, 2, 3a, 3b, 4 and 5) according to the extent that climatic, soil and site characteristics restrict agricultural use. The limitations may affect the range of crops which can be grown, the level and consistency of yield and the associated cost of farming the land.

Given that the guidelines were published over 30 years ago, it is possible that the threshold limits for establishing grading for some factors are no longer valid. In addition, the development of GIS and remote sensing techniques provide ways to assess land capability criteria that were not possible when the ALC guidelines were published in 1988. This review assesses the evidence base to support site limitations imposed by aspect, wind, frost, microrelief, flooding, irrigation and erosion. It builds on earlier work which reviewed the evidence base for site limitations imposed by gradient and soil limitations imposed by soil texture, stoniness and depth (Rollett and Williams, 2019, Report SPEP2018-19/12).

Climatic limitations

Climate has a major and, in places, overriding influence on land quality by controlling both the range of agricultural uses and the cost and level of production. The current ALC guidance is that where the overall climate is liable to be modified significantly by local factors (i.e. aspect, wind or frost), the effect on grading should be assessed on the basis of expert agrometeorological advice. Consequently there is currently no specific guidance within the ALC in relation to limitations from aspect, frost or wind.

Aspect

The amount of solar radiation that a location receives depends on a variety of factors. Aspect, the compass direction in which the land/slope faces (e.g. south or west) can have a marked influence on the amount of solar radiation that a site receives. Although, the influence of a favourable aspect may be reduced or negated by exposure. In addition, where the slope is ≤11° (i.e. ALC 1-3b) then the effect of aspect on the amount of solar radiation received will be limited.

Overall, the complex relationship between aspect, slope and local topography means that it is difficult to make any specific recommendations to account for aspect within the ALC guidelines. Also, aspect is likely to be a limiting factor only on those sites with a slope >11° (i.e. ALC grades 4 and 5) where other factors are likely to be more limiting (e.g. exposure or rainfall). For those reasons, no change to ALC guidance in relation to aspect is recommended.

Frost

- Low temperature injury can occur in all plants and frost damage occurs when ice forms inside the plant tissue and injures the plant cells. However, for some crops the exposure to a period of cold temperatures is essential for subsequent development.
- Climatic criteria are considered first when classifying land for the ALC; a single grade is given for overall climate limitations. The main parameters used are average annual rainfall and accumulated temperature (AT0). AT0 is the accumulated temperature >0°C for January to June (the critical growth period for most crops). Hence, to some extent, the climatic criteria already includes a measure of the risk of frost at any site. Where winter or spring frosts occur more frequently or for long periods the AT0 will be lower than at warmer sites which are less prone to frost. However, in some cases land will be Grade 1 overall for climate despite the risk of frosts that could be potentially damaging to sensitive crops.

[1] http://publications.naturalengland.org.uk/publication/6257050620264448?category=5954148537204736

- Some of the crops grown on land classified as ALC 1 or 2 (e.g. potatoes, vegetables etc.) may be at risk from frost damage. Consequently, there may be merit in including frost risk for ALC categories 1 and 2 land. The number of days of spring frost may be a suitable criterion to consider for assessment, as late frosts are likely to be more damaging than winter frost. For example those areas with weak short-term frosts (<5 days) could be assessed as ALC 1 whereas sites that were otherwise ALC 1 but subject to late season frosts that could damage sensitive crops such as maize, potatoes and some vegetables could be downgraded e.g. to ALC2. High resolution frost risk maps, such as that produced by Bell *et al*. (2020) for Wales[2] could be used to identify the level of frost risk. Guidance on using and accessing this resource could be included within updated ALC guidelines. However, further development of the frost risk map would be required to include England, which is currently outside the mapped area.

Wind

- Crop damage by wind may include leaf tearing, stem damage or uprooting. Wheat, oats, barley, maize and oilseed rape crops are particularly susceptible to wind damage by lodging. Currently, ALC guidelines acknowledge that persistent strong or cold winds can be damaging to crops or cause stress to livestock, especially in wet weather.
- The Soil Survey of England and Wales (SSEW) produced a wind exposure map in 1980, based on the effect of the wind on vegetation. Wind exposure classes ranged from sheltered (approximate wind speed, <3 m/second, no effect on tree growth) to extremely exposed (approximate wind speed, 8.4 m/second, heather absent or prostrate). This information could be made available (e.g. by publishing the map on a website) to assess the risk of wind exposure. However as wind speeds and exposure may vary greatly over short distances due to topography, aspect etc. it may be appropriate to carry out site specific wind speed measurements to validate wind exposure risk.
- For annual crops, the risk of wind damage is particularly high in summer, when crops tend to be tallest and driest. Consequently, it would be of benefit to identify those areas at high risk of wind damage in summer. Environment Systems have produced a wind exposure map for Wales which categorises wind as weak, moderate or strong (**Figure 12** shows the risk to crops from summer wind) which could be used to identify sites where crops may be susceptible to wind damage. Similarly to the SSEW map, large areas of eastern Wales are characterised in the weak wind category (i.e. damage to crops is unlikely). However, as noted above, map categories are only indicative of the wind risk at any site and onsite assessment will be required to make accurate assessments of the risk of wind exposure.

Site limitations

In the ALC, the assessment of site factors (gradient and micro-relief) is primarily concerned with the way in which topography influences the use of agricultural machinery and hence the cropping potential of the land (MAFF, 1988). Flood risk is also regarded as a site limitation as it is usually associated with well-defined topographic features.

Microrelief

- Changes in microrelief can increase the effect of slope gradient on the efficiency and safety of machinery operations. Currently there is no detailed guidance on accounting for microrelief in the ALC and it is stated that 'the degree of limitation should be assessed in relation to the hindrance to mechanical operations'. As a result, it is suggested that, in some cases where the gradient of the land is ≤7° but the land has many depressions or rocky outcrops then it may be necessary to downgrade the land to ALC grade 3b (from 1, 2 or 3a) to reflect the level of hindrance to mechanical operations. However, where grade according to slope is already ≥4 (i.e. the gradient

[2] Bell *et al*., (2020). Capability, Suitability and Climate Programme: Application of ALC and UKCP18 Data for Modelling Crop Suitability. Report to Welsh Government.

of the land is ≤18°) then downgrading according to microrelief is unlikely to be necessary. A footnote to Table 1 (grade according to gradient) could replace the current section on microrelief, which gives no specific guidance on how this limitation should be accounted for. Additional text could be used to clarify (or provide examples) of the types of microrelief that might cause sufficient hindrance to machinery operation to require downgrading.

Flooding

Flooding can have a direct impact on crop vigour and yield through waterlogging (where only the below ground parts are affected) or submergence (where both the above and below ground parts of the plant are under water). However, the overall effect on plant growth is related to the duration of inundation, waterlogging, soil temperature and the stage of crop development at which waterlogging occurs. This is reflected in the current ALC guidelines which recognise that frequency, duration and timing of flooding is key to the impacts on farm practices and crop yields. Grading according to flood risk in summer (defined by the ALC as mid-March to mid-November; which accounts for the main growing period in spring, summer and autumn) is more restrictive than that for winter.

The ALC categories for short (<48 hours) and medium (>2 days and <4 days) flood duration broadly align with literature values which suggest that 48 hours is the critical period after which plants begin to suffer from oxygen deprivation. The long duration category (>4 days) would seem precautionary but recognises the wide ranging effects of flooding, not just on plants but on soil workability and access to land.

For simplicity, it is suggested that there could be a single grade relating to flood risk based on the stricter limits in the current grading according to summer flood risk. For example, rare flooding of short duration would be categorised as ALC grade 2 for the risk in summer and as ALC grade 1 for winter. In addition, the current additional recommendation for downgrading where soils of low permeability are present should be made more explicit as a footnote to the flood risk table.

In practice it may prove difficult to easily grade land according to the current ALC flood risk guidance as data on the extent and duration of flooding are not easily available. However, data on the frequency of flooding can be accessed online from the Environment Agency or Natural Resources Wales, which would provide an indication on the risk of flooding annually. However, further investigation would be required to confirm the most suitable data for this purpose. For the estimated 10% of land that would not be ALC grade 1 for flood risk then more detailed data/information on localised flood risk may be required.

Interactive limitations

The physical limitations which arise from interactions between climate, site and soil are soil wetness, droughtiness and erosion.

Irrigation

Irrigation can be used to ‘correct’ any moisture deficit and enhance the potential of agricultural land especially in drier areas. The demand for irrigation varies significantly from year to year depending on the weather and summer rainfall; compared with total national freshwater abstractions, agricultural irrigation is only a minor use (1 to 2% of total water use), although it can be the largest abstractor from some catchments in dry summers. In addition, since over half of all irrigated production is in catchments defined as being ‘over-abstracted’ or ‘over-licensed’, there are concerns regarding the environmental impact of any future increases in water demand.

Current ALC guidance in relation to irrigation is not specific, i.e. there is no table of values that indicate the effect of irrigation on grading. In addition, ALC guidance for irrigation is only applicable to a small area of land growing a small range of crops, where the application of water can increase the grading of land. Given the negative impacts that abstraction can have on local water resources where water is scarce it is suggested that irrigation should not be taken into account in ALC grading. This will help ensure that cropping is appropriate to local conditions.

Soil erosion

The effects of soil erosion on land quality are typically associated with rill/gully formation or loss of soil depth, particularly on sloping land. This may reduce the range of crops that can be grown or markedly increase production costs. These factors are taken into account in the ALC grades for gradient, microrelief and soil depth and only on rare occasions will erosion not be quantified by these other assessments of limitation. It is suggested that the text on soil erosion included in ALC guidelines should be reviewed to include more detailed guidance on the factors that are likely to increase erosion risk.

Introduction

The Agricultural Land Classification of England and Wales (ALC) provides a framework for classifying agricultural land according to the extent to which its physical or chemical characteristics restrict agricultural use. The limitations may affect the range of crops which can be grown, the level and consistency of yield and the associated cost of farming the land. The ALC grade describes the capability of the land for a range of potentially suitable crops

The ALC was devised and introduced in the 1960s and it provided a framework for classifying land into five classes (ALC grades 1-5) according to the extent that climatic, soil and site characteristics limited agricultural production. Following a review of the system the ALC was updated in the 1970s to divide ALC grade 3 land into sub-grades 3a, 3b and 3c. Subsequently, the system was further updated in the 1980s following extensive review and testing, when it was decided that there was no longer the need for a three-fold sub-division of Grade 3 land and the grade 3C was removed. In addition, the criteria used to assess climatic limitations and climate-soil interactions were updated based on the best and most up to date information available at the time.

In 2019, land is still graded in accordance with the guidelines and criteria established in 1988 (MAFF, 1988). Given that the guidelines were published over 30 years ago, it is possible that the threshold limits for establishing grading for some factors are no longer valid. In addition, major advances in technology since 1988 mean that there may be new ways to assess certain criteria that were not previously possible (e.g. GIS or remote sensing). This review assesses the evidence base to support climate limitations imposed by aspect, wind and frost, site limitations imposed by microrelief and flooding, and interactive limitations imposed by irrigation and soil erosion. It builds on earlier work which reviewed the evidence base for site limitations imposed by gradient and soil limitations imposed by soil texture, stoniness and depth (Rollett and Williams, 2019, SPEP2018-19/12).

Objectives

For ALC criteria in relation to aspect, wind, frost, microrelief, flooding, irrigation and erosion:

- Review the technical literature in relation to aspect, wind, frost, microrelief, flooding, irrigation and erosion.
- Assess whether the limits for each grade/sub-grade are still relevant and correct for each criteria.
- Where appropriate, recommend new thresholds for each criteria.

The Agricultural Land Classification

The principal physical factors influencing agricultural production are climate, site (e.g. gradient or microrelief) and soil. These factors, together with interactions between them, form the basis for classifying land into one of five grades; Grade 1: excellent quality to Grade 5: poor quality. Grade 3 is further divided into two sub-grades designated 3a and 3b (MAFF, 1988). The top three grades (1-3a) are defined by Section 3.54 of Edition 10 of Planning Policy Wales (Welsh Government, 2018) and the National Planning Policy Framework for England (Ministry of Housing, Communities & Local Government, 2019) as the 'best and most versatile' (BMV) agricultural land and are suitable for a wide range of crops.

The main limiting physical factors are identified as: climate, soil wetness, soil droughtiness, gradient, flooding, soil texture, soil depth, soil stoniness, soil chemical properties and soil erosion. The final ALC grade given to a location is the lowest grade from any of the 10 criteria (i.e. the most limiting factor). Certain criteria (i.e. soil droughtiness, soil wetness and workability, gradient, topsoil stone content and soil depth) have bespoke, in field, assessment methods to directly arrive at an ALC Grade. Flooding is similar but depends on third party data that is often not easily available. Other criteria (i.e. micro-relief, chemical, erosion, frost, aspect, exposure and irrigation) are considered in the ALC Guidelines. However, these are on a case by case basis with no specific threshold values to directly arrive at an ALC Grade.

In Wales, grade 1 land is located in small pockets of lowland North East and South Wales (**Figure 1**) and in England, around The Wash and on the North West coast near Ormskirk (**Figure 2**). Similarly, Grade 2 land is mainly located in lowland North and South Wales, Anglesey and Pembrokeshire and in Eastern England. Grade 3 land is more widely distributed and is located in low lying coastal and inland areas of Wales, river valleys (e.g. the Wye and Severn) and along the Welsh/English border; in England Grade 3 land predominates. Finally, Grade 4 and 5 agricultural land is located in the central upland areas of Wales and the north/north east uplands of England. Only agricultural land of Grade 3a and above will typically be suited to tillage and horticultural crops (MAFF, 1988).

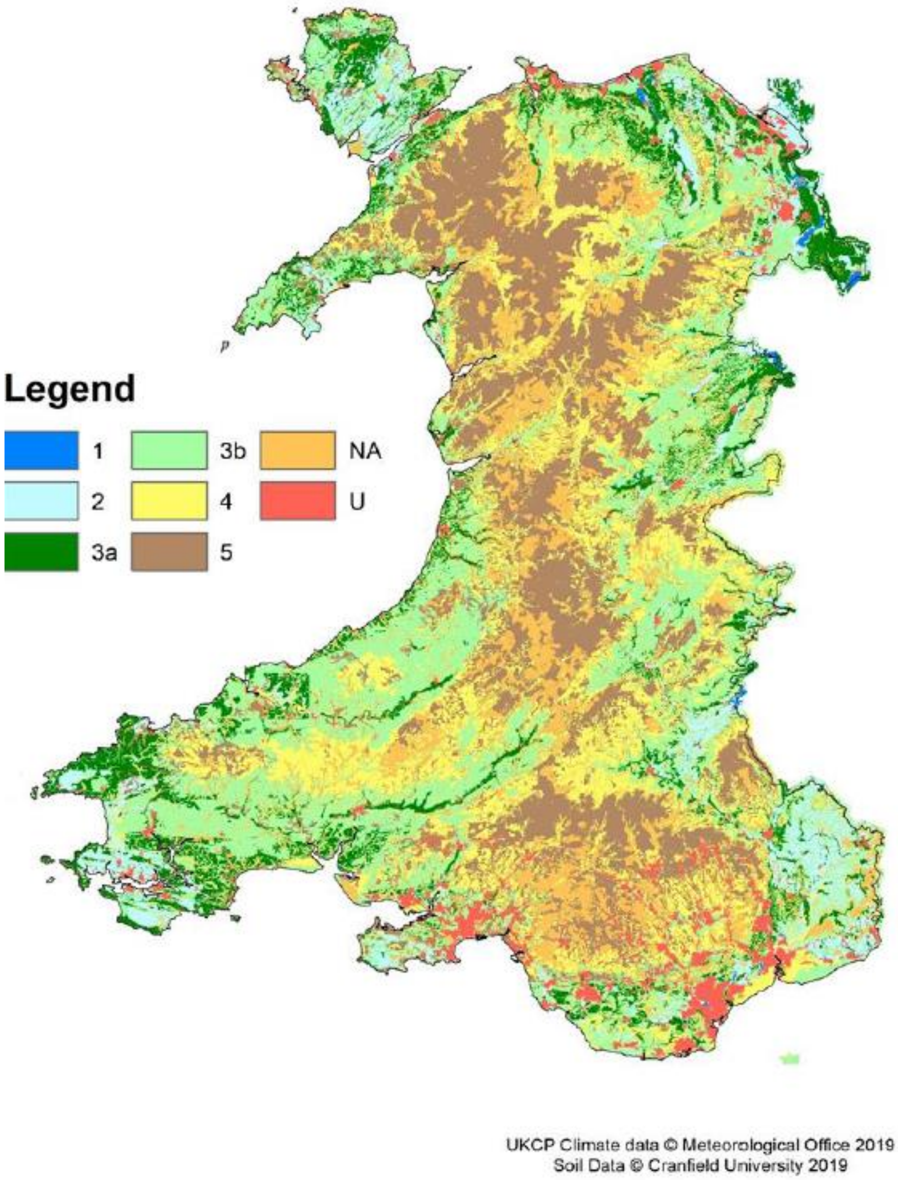

Figure 1. Predictive agricultural land classification (ALC) map for Wales (Source: Keay and Hannam, 2020).

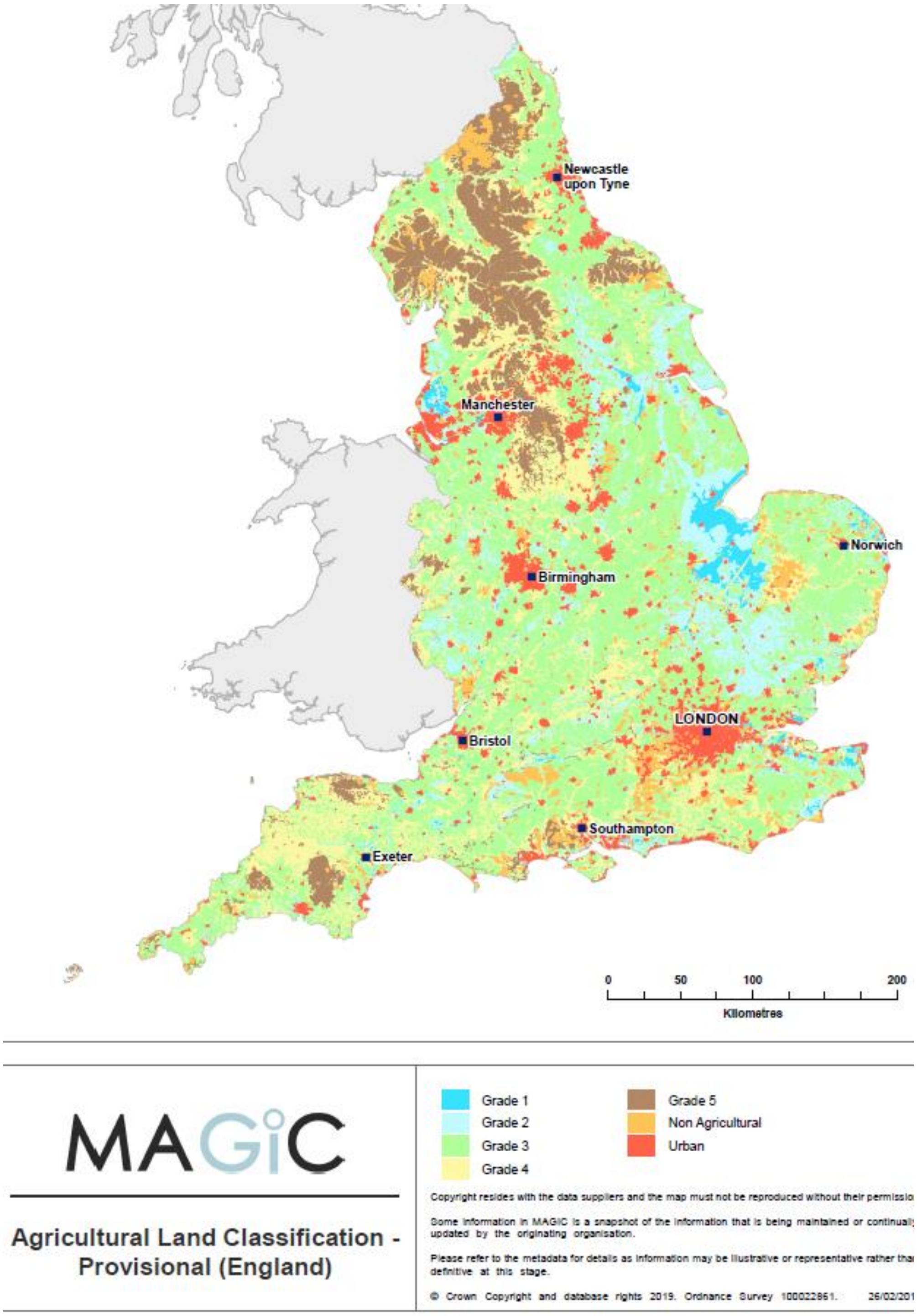

Figure 2. Agricultural land classification (ALC) for England.

Climatic limitations

Climate has a major and, in places, overriding influence on land quality by controlling both the range of agricultural uses and the cost and level of production. The most fundamental influence of climate is on the potential for plant growth, by determining the energy available for photosynthesis. However, climate also influences soil wetness, soil aeration, the number of field capacity days and the ease of access to land to carry out field operations.

In climatic terms, the most limited areas are both the wettest and coldest and conversely the climate is regarded as more favourable as temperature increases and rainfall moderates (MAFF, 1988). The main climatic factors currently considered in the ALC are temperature (accumulated temperature January to June-AT0) and rainfall (average annual rainfall-AAR), although account is also taken of local factors such as exposure, aspect and frost risk. Climatic criteria are considered first when classifying land as severe limitations will restrict land to low grades irrespective of favourable soil or site conditions.

Aspect

The amount of solar radiation that a location receives depends on a variety of factors at the global scale including latitude, season, time of day, cloud cover and altitude. At the local scale radiation is additionally controlled by surface slope, aspect and elevation (Allen *et al*., 2006). Aspect, the compass direction in which the land/slope faces (e.g. south or west) can have a marked influence on the amount of solar radiation that a site receives.

There are three types of solar radiation: direct radiation (travels directly from the sun to the ground), diffuse radiation (scattered by atmospheric particles) and reflected radiation (**Figure 3**). Incoming radiation (shortwave) is reflected off clouds, absorbed by the atmosphere or passes through to the Earth's surface. The heat generated by absorption is emitted as longwave infrared radiation, some of which radiates out into space.

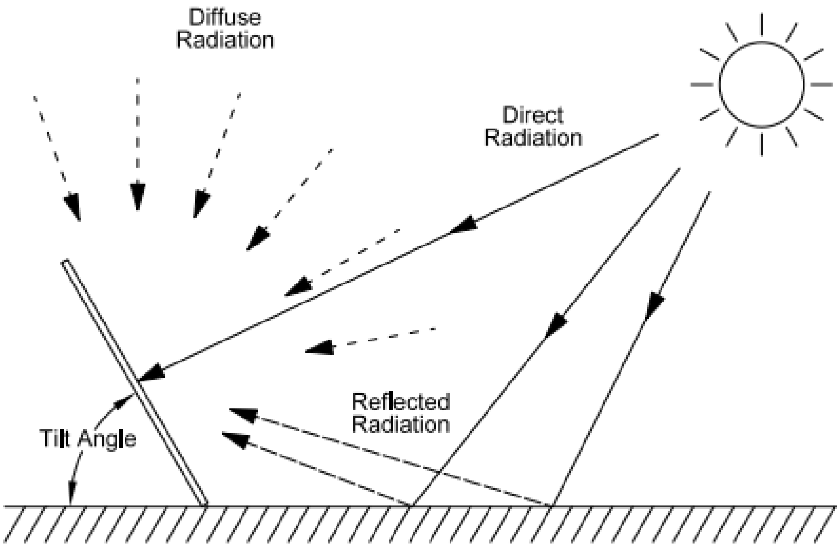

Figure 3. Types of solar radiation (Source: Mallon *et al*., 2017).

The south side of a slope will receive more direct solar radiation than the north side (in the northern hemisphere). Daily and accumulated temperatures in spring and summer are higher on slopes with a southerly aspect than those facing in a northerly direction. However, diffuse solar radiation, cloud cover and long wave radiation exchange act to lessen the differences in net radiation flux between different aspects (Bennie, 2008). For example, Oliver (1991) found that north-facing slopes received consistently low net radiation in winter, with little variation between days, due to the lack of direct radiation, while south-facing slopes had lower mean values than summer, but considerable variation between sunny and cloudy days.

Radiation intensity varies with slope angle such that differences due to aspect are more marked on steeper slopes. This is illustrated in **Figure 4** below which shows that as the slope angle is increased there is a greater difference between the radiation received on south and north slopes than when the slope is less (e.g. 15°) or there is no slope. In addition, it demonstrates that slope to the north has a larger effect on radiation than a slope to the south.

Consequently, where land is classified as ALC 1-3b and slopes are ≤11° then the effect of aspect on the amount of solar radiation received will be limited. Keay *et al* (2013), noted that slope was the most limiting factor at only *c.*9% of sites and that >80% of sites would be in Grade 1/2/3a for slope (i.e. slope ≤7°). This suggests that aspect would be expected to influence the amount of radiation received at a small minority of sites. Even for sites where slopes are steeper and land is graded as ALC 4 and 5, local topography may have a greater influence on incoming solar radiation than aspect.

The influence of a favourable aspect may be reduced or negated by exposure. In addition, in valleys, the relationships are often more complex due to the effect of shading, which can moderate the benefits of a southerly aspect and increase the penalties on north facing slopes (MAFF, 1988). **Figure 4**c illustrates the effect of nearby topography on incoming solar radiation, which is 'blocked' as a result of modelled changes to the slope of surrounding ridges. This suggests that under certain conditions topography can create lower radiation environments on a south facing slope than on a north facing slope and highlights the complexity of factors that govern the radiation received at any particular site.

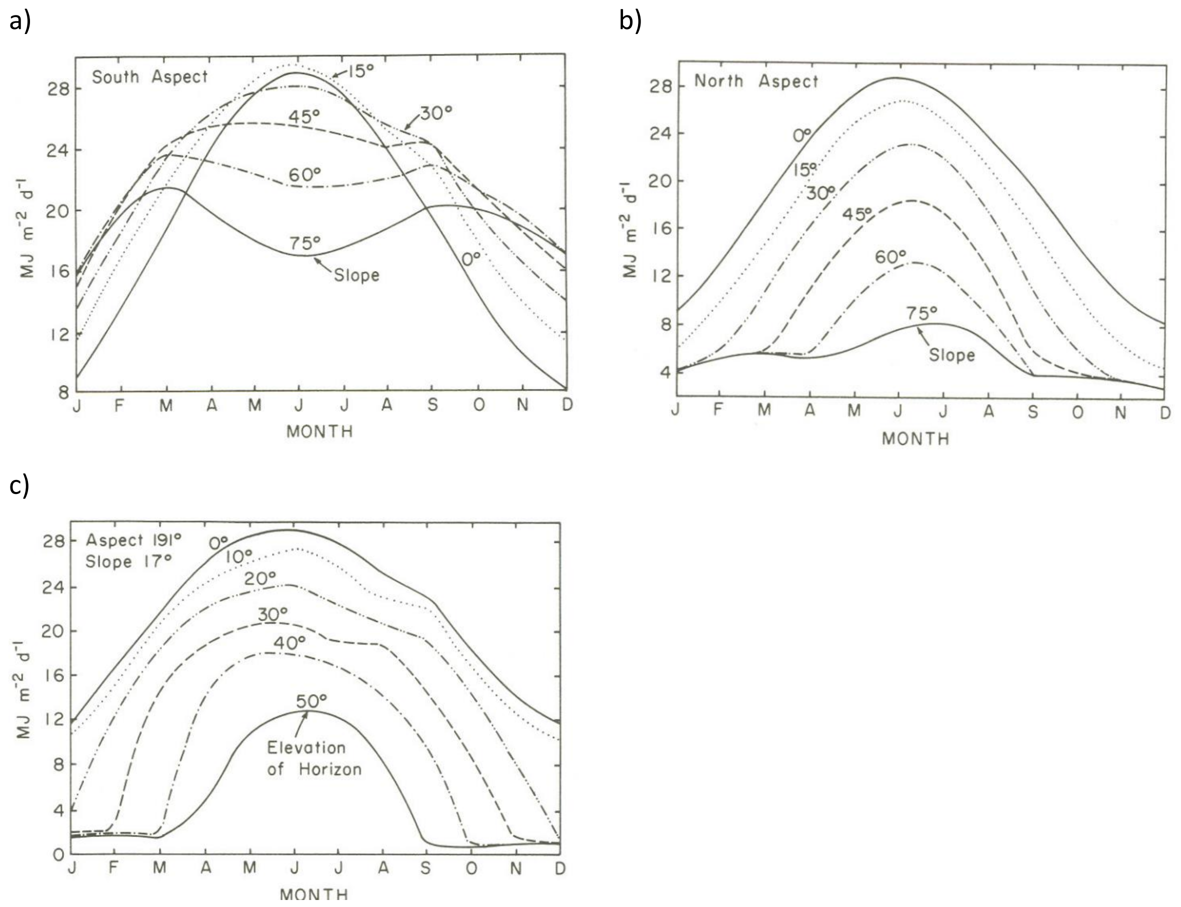

Figure 4. Radiation received on a) south-facing, b) north-facing sites with different slopes and c) on a south-facing slope with variation in the height of surrounding ridges (Source: Flint and Childs, 1987).

As a consequence of the differences in solar radiation, in warm and dry climates, southern aspects are more prone to drought, failure of crops and damage by erosion. In cool climates, northern aspects are prone to more frost damage and delay in the development of vegetation (Mueller *et al*., 2007). Even within areas of moderate topography, ecologically significant gradients in soil moisture and near-surface air and soil temperature can occur between north- and south-facing slopes (Bennie *et al*., 2008). For example, a 2.5–3 °C annual mean temperature difference was recorded between adjacent slopes in a British calcareous grassland by Rorison *et al*. (1986); a difference roughly equivalent to that encountered in a shift of 5° in latitude or 500 m in altitude (Barry, 1992 cited by Bennie *et al*., 2008).

Conclusions for ALC guidance on aspect

The current ALC guidance is that where the overall climate is liable to be modified significantly by local factors, the effect on grading should be assessed on the basis of expert agrometeorological advice. Aspect is also recognised as locally important in other land classification guidance. For example, the New Zealand Land Use Capability Survey Handbook[3] suggests that "additional factors like aspect, elevation and distance to watercourse may also be relevant" (main factors

[3] See Appendix 1 for summary of the New Zealand LUC, German SQR and Canadian SQRS

are rock type, soil, slope angle, erosion type/severity and vegetation cover) (Lynn *et al*., 2009). The New Zealand guidance has no specific 'rules' for dealing with aspect but does suggest that regional units can be further sub-divided at the farm-scale, for example, according to shady and sunny aspects if this is useful for more targeted management. The Muencheberg Soil Quality Rating (SQR) manual[3] for Germany also notes that "slope aspects and relief position are also important factors of soil quality". Again there is no specific guidance for accounting for aspect in quality assessments.

Overall, it is concluded that due to the complex relationship between aspect, slope and local topography it would be difficult to make any specific recommendations for accounting for aspect within the ALC guidelines. Also, aspect is likely to be a limiting factor only on those sites with a slope >11° (i.e. ALC grades 4 and 5) where other factors are likely to be more limiting (e.g. exposure or rainfall). For those reasons, no change to ALC guidance in relation to aspect is recommended.

Frost

Low temperature injury can occur in all plants. Frost damage occurs when ice forms inside the plant tissue and injures the plant cells (Snyder and de Melo-Abreu, 2005). Frost damage can be direct when ice crystals form inside the cell (i.e. intracellular) or indirect when freezing occurs inside the plant but outside the cells (i.e. extracellular). Plants resist low temperatures by 'hardening' which involves mechanisms of avoidance and tolerance of freezing.

However, for crops that overwinter, including perennial fruit crops and certain vegetable crops such as cauliflower, the exposure to a sufficiently cold temperatures is essential for subsequent development. For apple, periods of low temperatures (<12°C) are needed to induce dormancy in early winter and also a further period of low temperature (e.g. 1000 hours at 6-9°C) is required for dormancy release (Heide and Prestrud, 2005). Spring flowering bulbs such as daffodil and crocus also require a period of winter chilling.

The average number of days with frost varies widely across Wales. The main controls are distance from the sea and altitude, but the ability for cold air to drain into inland valleys is another important factor (Met Office, 2020a). An 'air frost' occurs when the temperature at 1.25 metres above the ground falls below 0°C, whereas 'ground frost' refers to a temperature below 0°C measured on a grass surface. Spring frosts can cause serious damage to fruit crops and may check the growth of arable crops and the assessment of frost risk is more significant in relation to the better quality land (e.g. ALC classes 1 and 2) where the more sensitive crops are likely to be grown.

Frost risk is closely related to topography and may be localised. Frost pockets (e.g. dips in the ground or valley bottoms) are areas that are particularly at risk from frost, especially where there is little direct solar radiation. Other factors that increase frost risk are elevation, lack of exposure to wind (i.e. still air) and soil type (sandy soils lose heat faster than other soil types).

On average there are 45 days with air frost in both England and Wales (2000-2019), with the frostiest months being January (10 days), February (10 days) and December (9-10 days) (Met Office, 2020b). Sites along the west coast of Wales typically have fewer than 25 days of air frost each year and inland the number ranges from 40 to 80 days, generally increasing with distance from the coast. Similarly, in England the east and south coasts, Devon and Cornwall have the fewest days of air frost; the frostiest areas are the upland areas to the north-west of England.

Met Office maps are available which indicate, the number of days of air or ground frost in winter (December-February), spring (March-May), summer (June-August) and autumn (September-November) (**Figure 5** to **Figure 8**). Ground frost occurs on average on about 40 days each year on coasts and over 110 days well inland, with a similar distribution to air frost. These maps provide a broad overview of the risk of frost in any area. More detailed information is available for locations that are close to a Met Office climate station but these are limited in number.

Recent work by Bell *et al*. (2020a) has categorised Wales according to the risk of frost in winter or spring, ranging from hardly any frost to frequent strong frosts lasting many days (**Figure 9**). These maps have a much more detailed resolution than the Met Office maps and may be more appropriate for assessing the risk of frost at a site level for Wales. However, the Environment Systems maps does not cover England and a similar resource is not available.

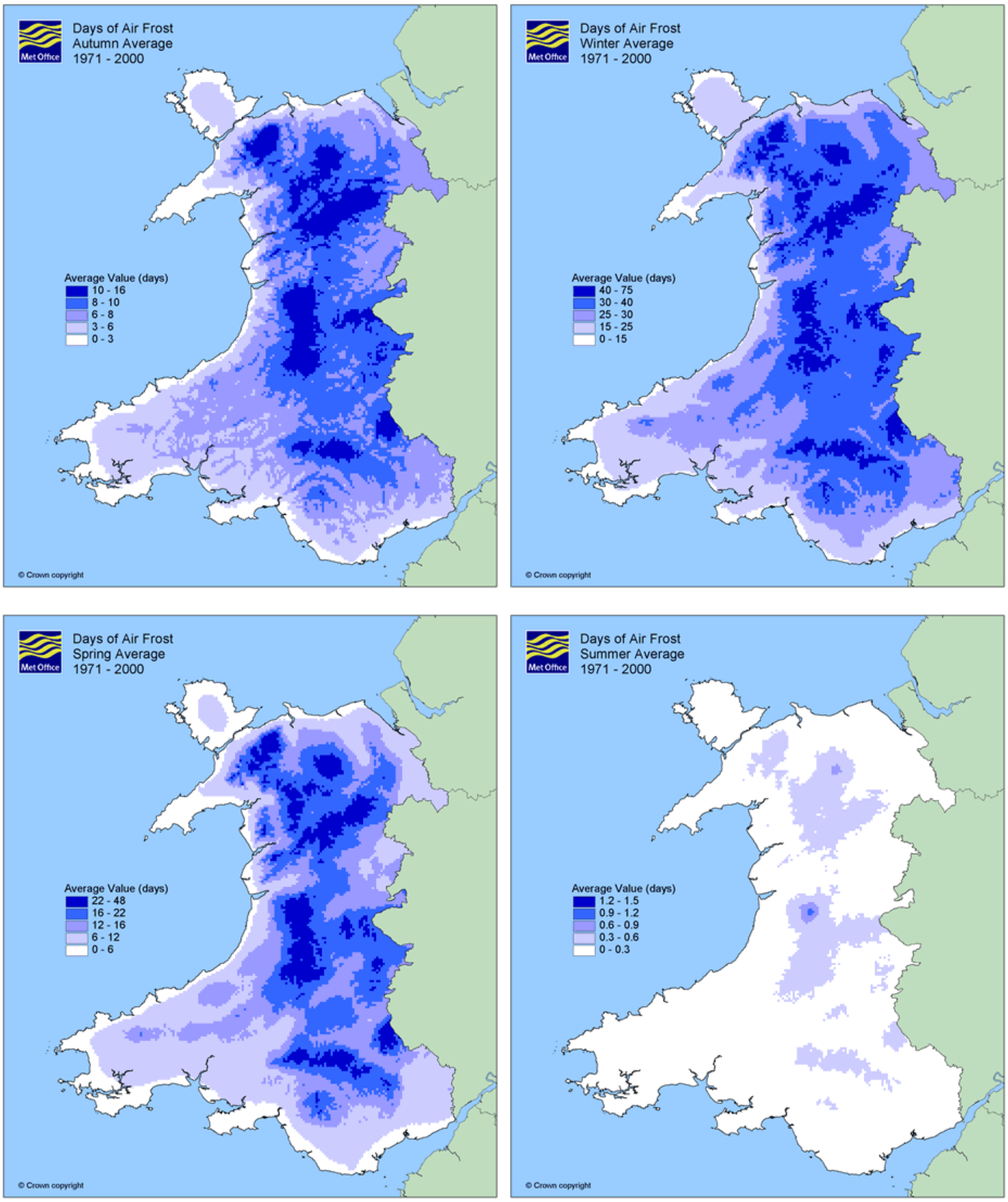

Figure 5. Days of air frost in autumn, winter, spring and summer for Wales between 1971 and 2000 (Source Met Office[4]).

[4] https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gcjszmp44

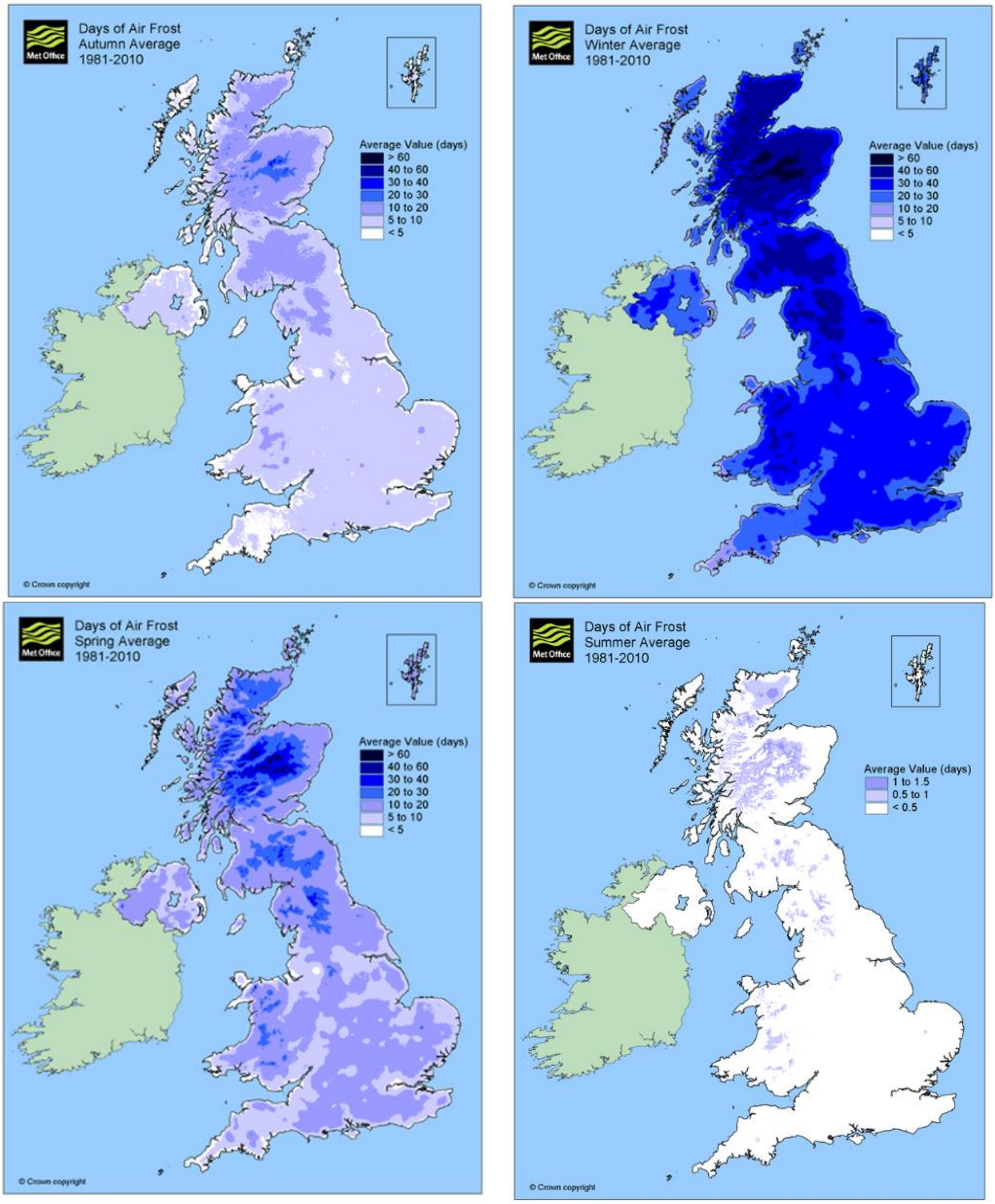

Figure 6. Days of air frost in autumn, winter, spring and summer for the UK between 1981 and 2010 (Source Met Office[4]).

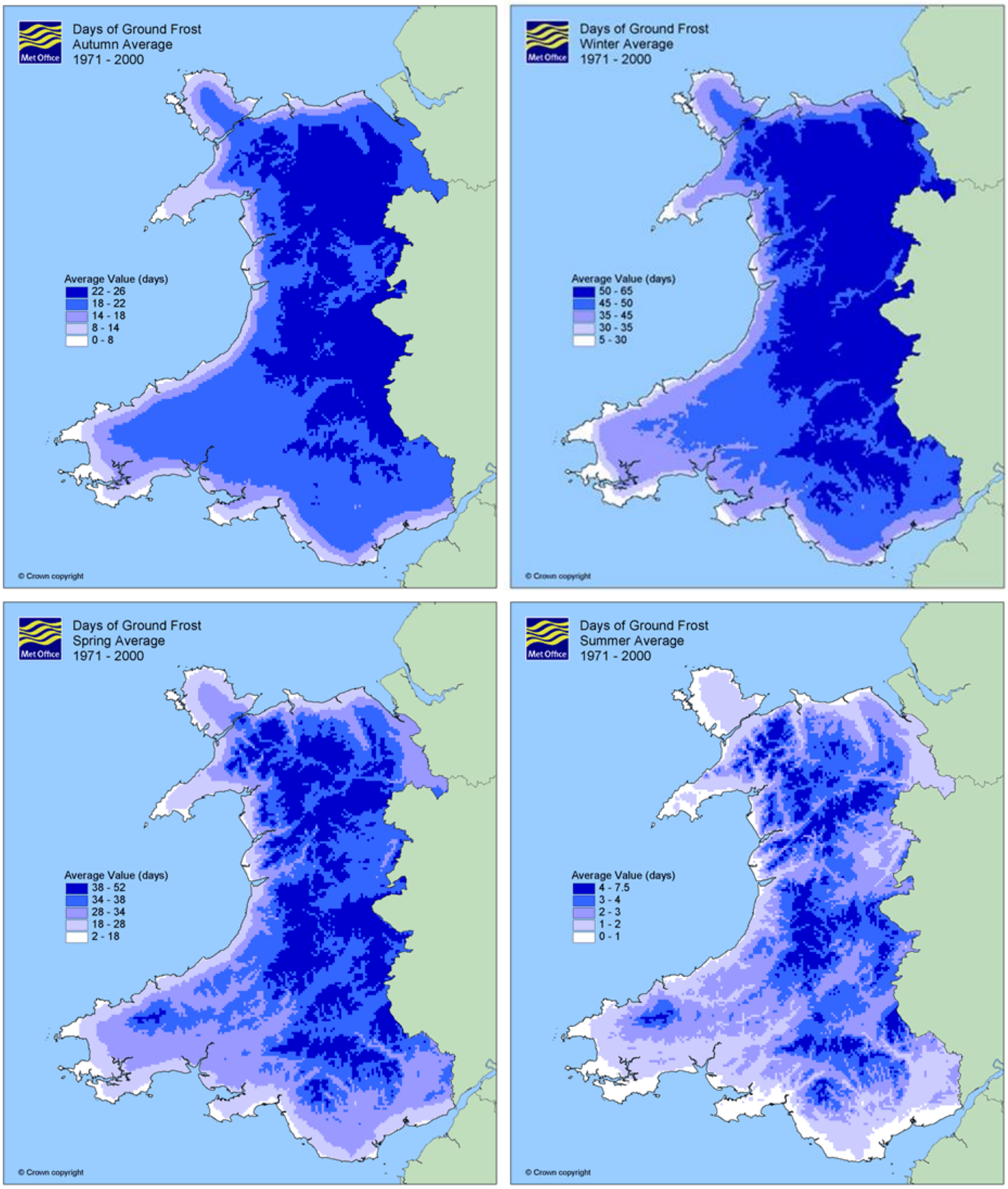

Figure 7. Days of ground frost in autumn, winter, spring and summer for Wales between 1971 and 2000 (Source Met Office[4]).

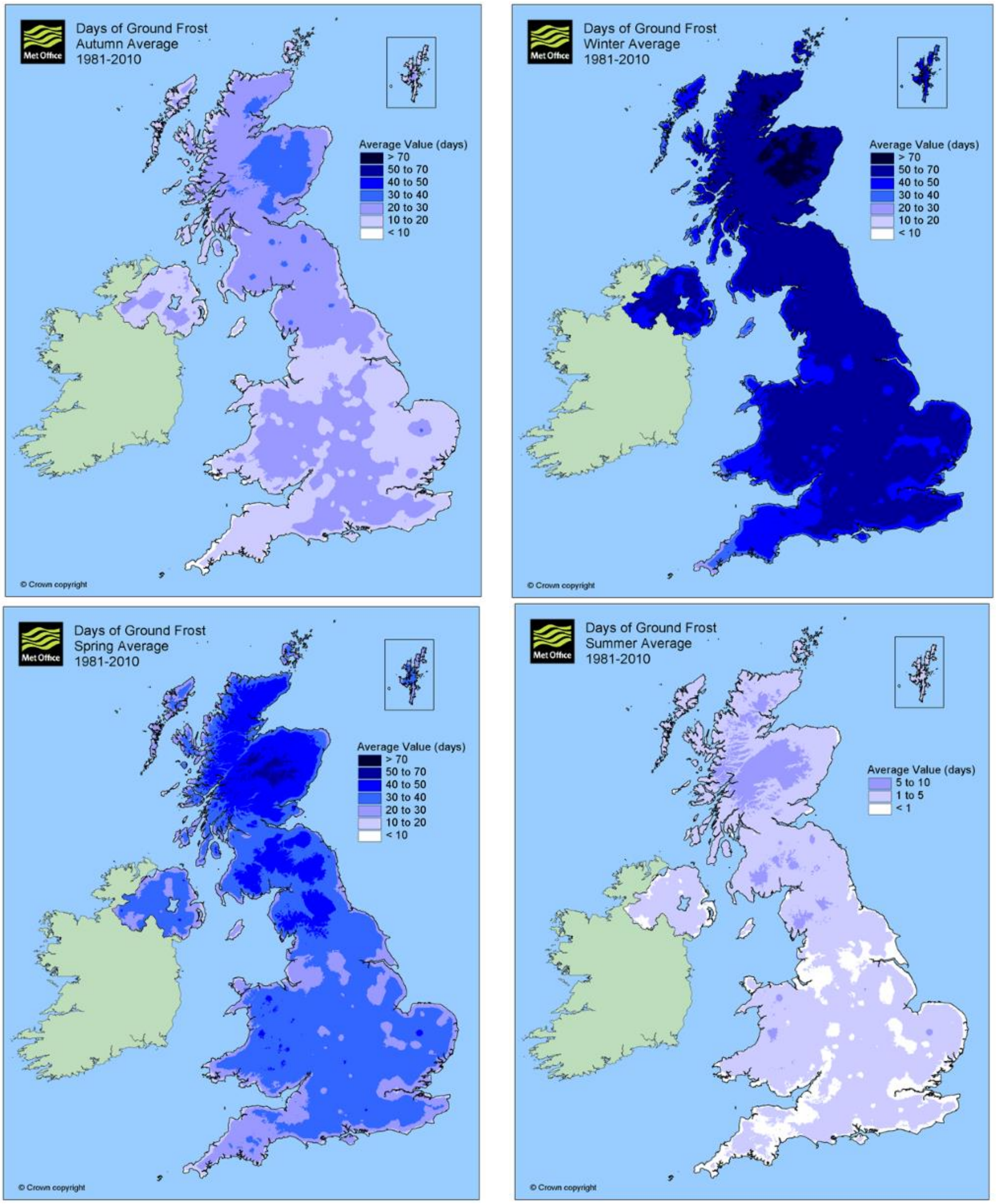

Figure 8. Days of ground frost in autumn, winter, spring and summer for the UK between 1981 and 2010 (Source Met Office[4]).

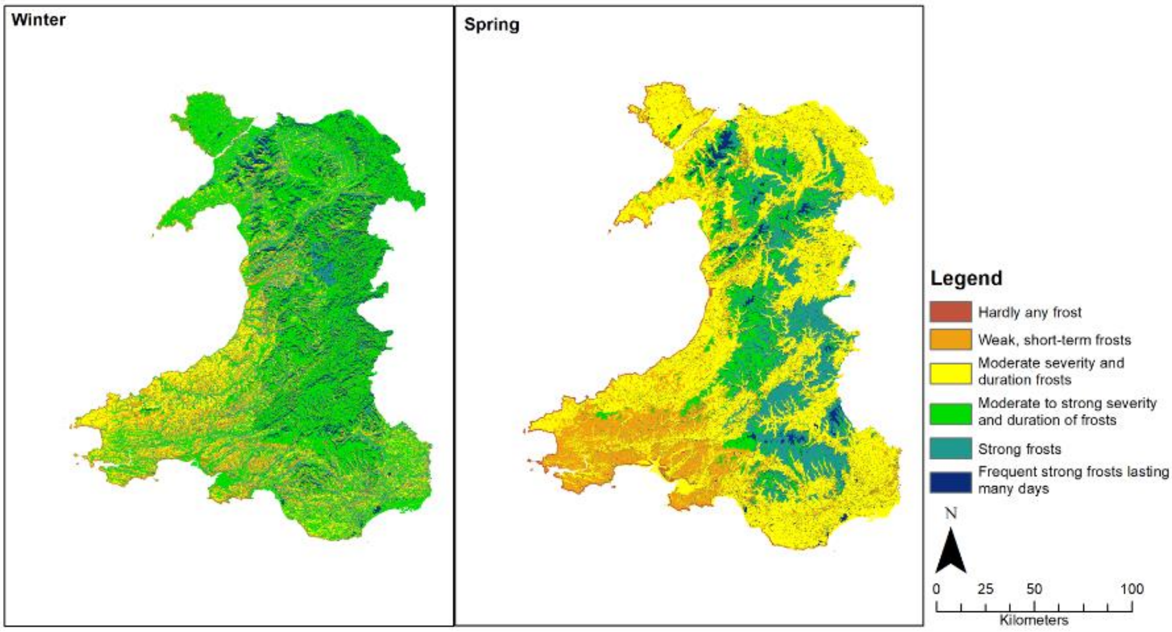

Figure 9. Detailed map of frost risks in winter and spring (Source: Bell *et al*., 2020a).

Conclusions for ALC guidance on frost

The current ALC guidance is that where the overall climate is liable to be modified significantly by local factors, such as frost the effect on grading should be assessed on the basis of expert agrometeorological advice. This in line with other land suitability rating systems (e.g. New Zealand, Germany and Canada) which also give no detailed guidance on frost risks but acknowledge that this is a potential limiting factor. For example, in the Canadian Land Suitability Rating System-LSRS[3] (where suitability is scored on a points basis), frost is included as a 'modifying factor', which suggests a percentage deduction (in the climate score) based on the risk of frost before the regional average (AIWG, 1995) date of the first frost. In the New Zealand LUC, climatic limitations include 'unseasonable or frequent frost and/or snow' and is one of the criteria used in allocation of land use subclasses, along with erodibility, excessive wetness and rooting zone limitations (Lynn *et al*., 2009). The New Zealand climate is not dissimilar to that of England and Wales, in terms of frost risk. On average New Zealand has around 25 days of air frost although there is a marked difference in the average for South Island (38 days) and North Island (9 days)[5]. In contrast, the risk of frost is typically greater in Canada, although the climate is varied with the number of frost days in some areas being >250, British Columbia and Ontario typically have the most frost-free days[6].

Climatic criteria are considered first when classifying land for ALC; and a single grade is given for overall climate limitations. The main parameters used are average annual rainfall and accumulated temperature (AT0). AT0 is the accumulated temperature >0°C for January to June (the critical growth period for most crops). Hence, to some extent, the climatic criteria already include a measure of the risk of frost at any site. Where winter or spring frosts occur more frequently or for long periods the AT0 will be lower than at warmer sites which are less prone to frost. However, in some cases land will be Grade 1 overall for climate despite the risk of frosts that could be potentially damaging to sensitive crops.

Some of the crops grown on land classified as ALC 1 or 2 (e.g. potatoes, vegetables etc.) are more vulnerable to frost than crops grown on other ALC category sites. Consequently, there may be merit in including frost risk, as part of the climate assessment for land ALC categories 1 and 2. This could be based on the number of days of spring frost, which are potentially more damaging than winter frosts. For example those areas with hardly any frost or weak, short-term frosts (<5 days) could be assessed as ALC 1 whereas sites that were otherwise ALC 1 but subject to a greater risk of late frosts could be downgraded to ALC 2.

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[5] http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Atmosphere-and-climate/frost-warm-days.aspx

[6] https://climatedata.ca/

For Wales, the assessment of frost risk could be done through the use of high resolution maps, such as those produced by Environment Systems. Guidance on using and accessing this resource could be included within updated ALC guidelines. However, in order to ensure consistency further development of the frost risk map to include England would be required before any updates could be implemented.

Wind

Crop damage by wind may include leaf tearing, stem damage or uprooting. Wheat, oats, barley, maize and oilseed rape crops are particularly susceptible to wind damage by lodging (Gardiner *et al*., 2016). In addition, high wind speeds can blow shallow rooted brassicas over and uproot them.

Lodging can take the form of stem lodging due to the bending or breaking of the lower culm internode or root lodging due to failure of root anchorage. The type and location of lodging varies between cereal species, the agronomy applied to the crop, and the growth stage of the plant. At flowering, the most common form of lodging in wheat and barley is root lodging. But there can also be stem lodging in one of the bottom internodes, especially where the supply of nitrogen is high (Berry *et al*., 2000). “Brackling” (failure of middle internodes) is common in barley. Internode buckling or creasing is also common in the lodging of maize, although it almost always occurs within a few centimetres of a node due to a localized concentration of stress (Robertson *et al*., 2015). Stem failure in general tends to become more common as harvest approaches and the stem weakens as it dries out (Berry *et al*., 2004). In order to reduce damage, suitable species, appropriate cultivation and nutritional management is essential according to local conditions.

Currently, ALC guidelines acknowledge that persistent strong or cold winds can be damaging to crops or cause stress to livestock, especially in wet weather. Upland areas, and land which stands above the surrounding countryside, are often exposed. Many coastal districts are exposed to strong, salt-laden winds and their effects can extend for several miles inland. (MAFF, 1988). Wind speed is strongly influenced by topography. In general, wind velocities increase with altitude and decrease with distance from the west coast, while the funnelling of winds along valleys, particularly in the uplands, may result in consistently higher wind speeds.

The ALC also acknowledges the role of wind in erosion, although this is restricted to a narrow range of susceptible soil types, mainly affecting sandy and peaty soils in arable production. Wind erosion is unusual in Wales where sandy/light soils are uncommon, although it is a problem in some areas of England, in particular East Anglia.

The Soil Survey of England and Wales (SSEW) produced a wind exposure map in 1980, based on the effect of the wind on vegetation. Wind exposure classes ranged from sheltered (approximate wind speed, <3 m/second, no effect on tree growth) to extremely exposed (approximate wind speed, 8.4 m/second, heather absent or prostrate). **Figure 10**, illustrates the wind exposure classes for Wales; large areas of the country are classified as sheltered, particularly in the east of the country and in the lee of the higher ground. In addition, for selected coastal areas, the SSEW also compiled wind roses (**Figure 11**) which show the strength of the wind (thicker bars indicate stronger winds) and wind direction (longer bars indicate the prevailing direction). It is likely that although the wind data (1960-1974) used in the SSEW is dated it is still indicative of the probable wind strength/direction in any area; future climate projections for wind remain uncertain (Brown *et al*., 2016). The SSEW map could be made available (e.g. by publishing the map on a website) to assess the risk of wind exposure, albeit that wind speeds and exposure may vary greatly over short distances due to topography, aspect etc. Where a more detailed assessment of wind speed/direction is required a period of on-site monitoring may be required.

For annual crops, the risk of wind damage is particularly high in summer, when crops tend to be tallest and driest. Consequently, it would be of benefit to identify those areas at high risk of wind damage in summer. Bell *et al*. (2020a) have produced a wind exposure map for Wales (not England) which categorises wind as weak, moderate or strong (**Figure 12** shows the risk to crops from summer wind) which could also be used to identify sites where crops maybe susceptible to wind damage. Similarly to the SSEW map, large areas of eastern Wales are characterised in the weak wind category (i.e. damage to crops is unlikely). However, as noted above, map categories are only indicative of the wind risk at any site and onsite assessment will be required to take account of more localised wind conditions.

Online resources such as the European Wind Atlas (which is searchable by name, area or postcode), can also be used to establish the windiness of any site (**Figure 13**). However, the Atlas only gives the annual mean (and minimum/maximum) wind speed at different heights and does not indicate the seasonality of wind speeds.

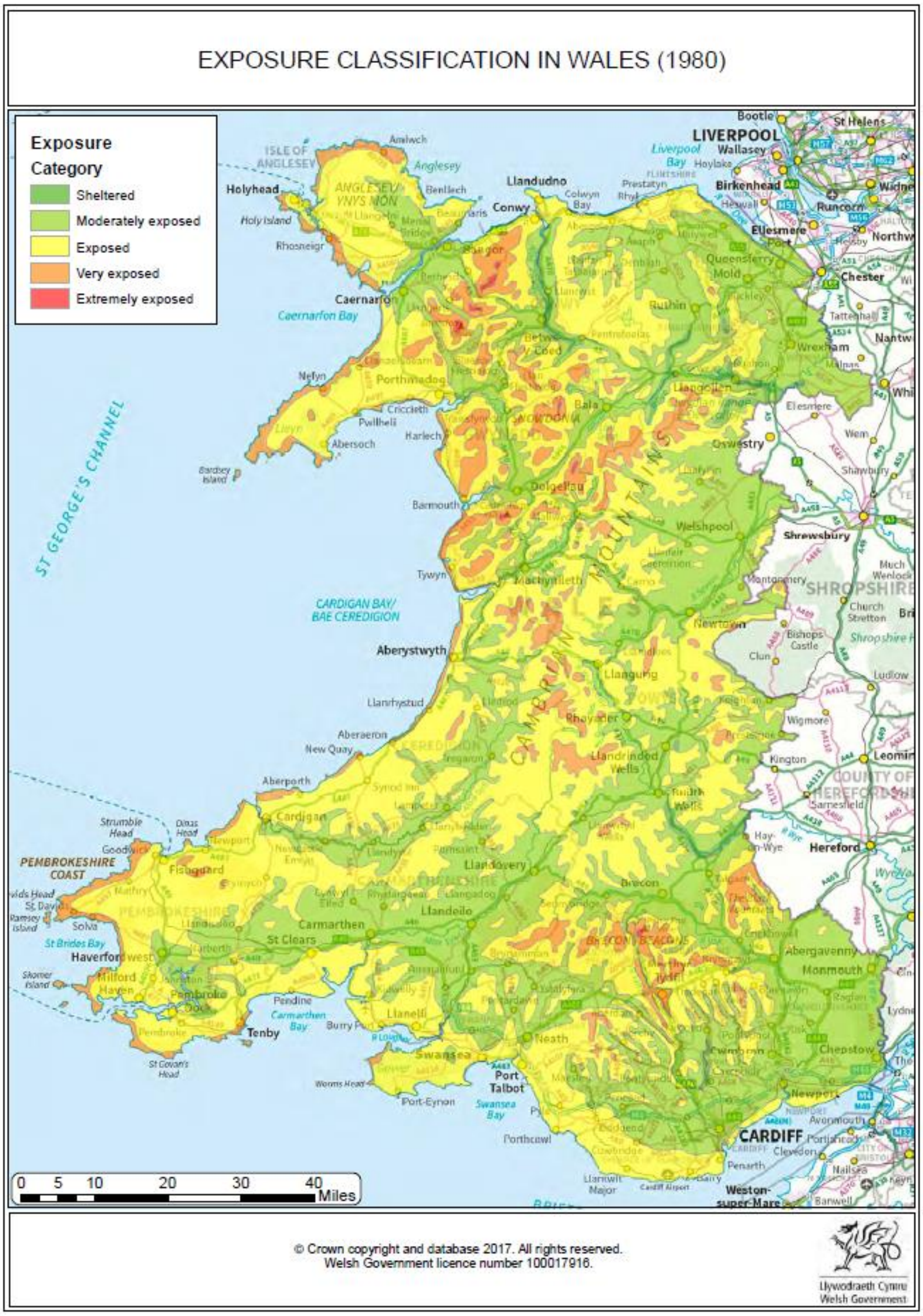


Figure 10. Soil Survey of England and Wales wind exposure map for Wales.

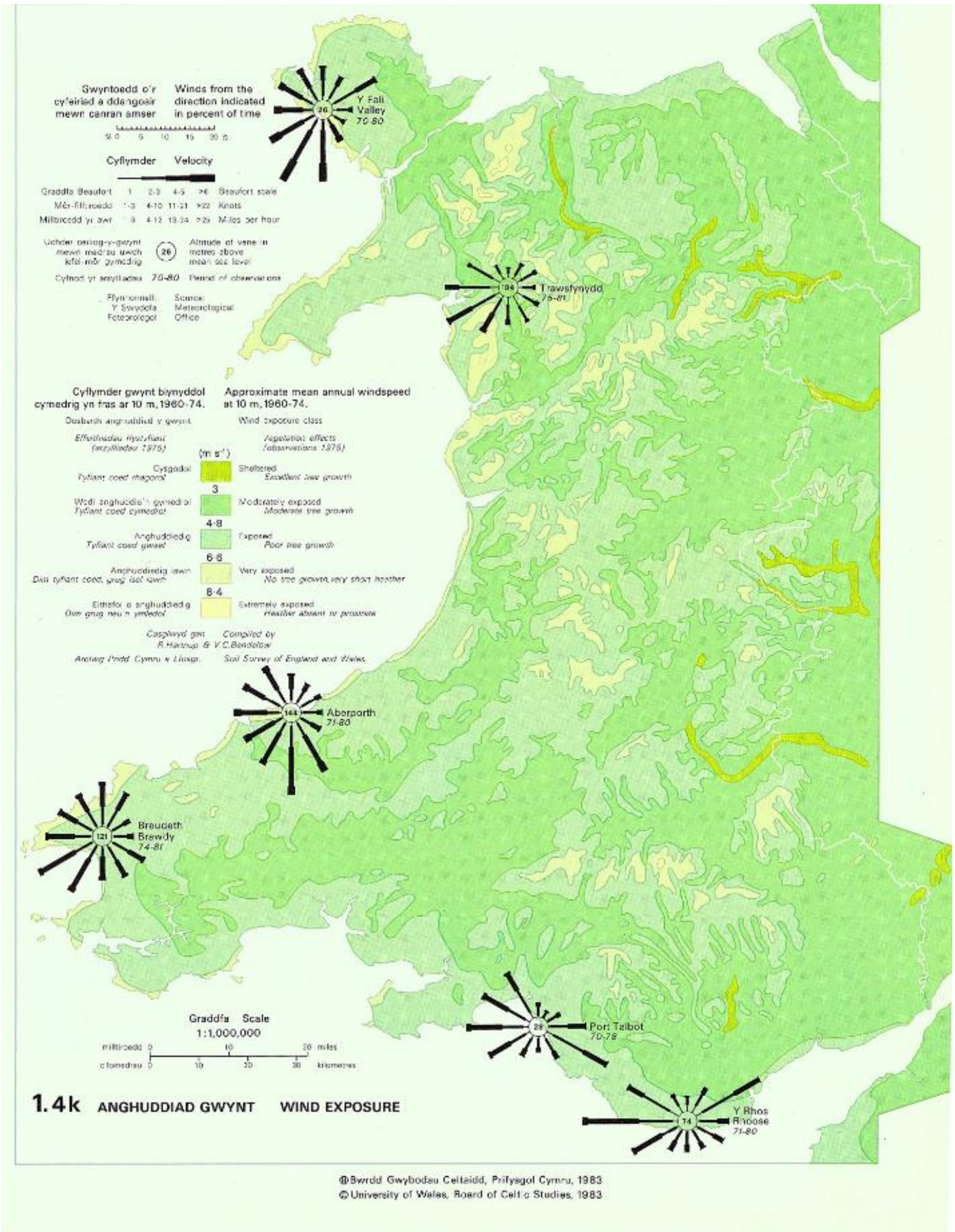


Figure 11. Detailed Soil Survey of England and Wales wind exposure map for Wales with wind roses to indicate the prevailing wind direction and speed.

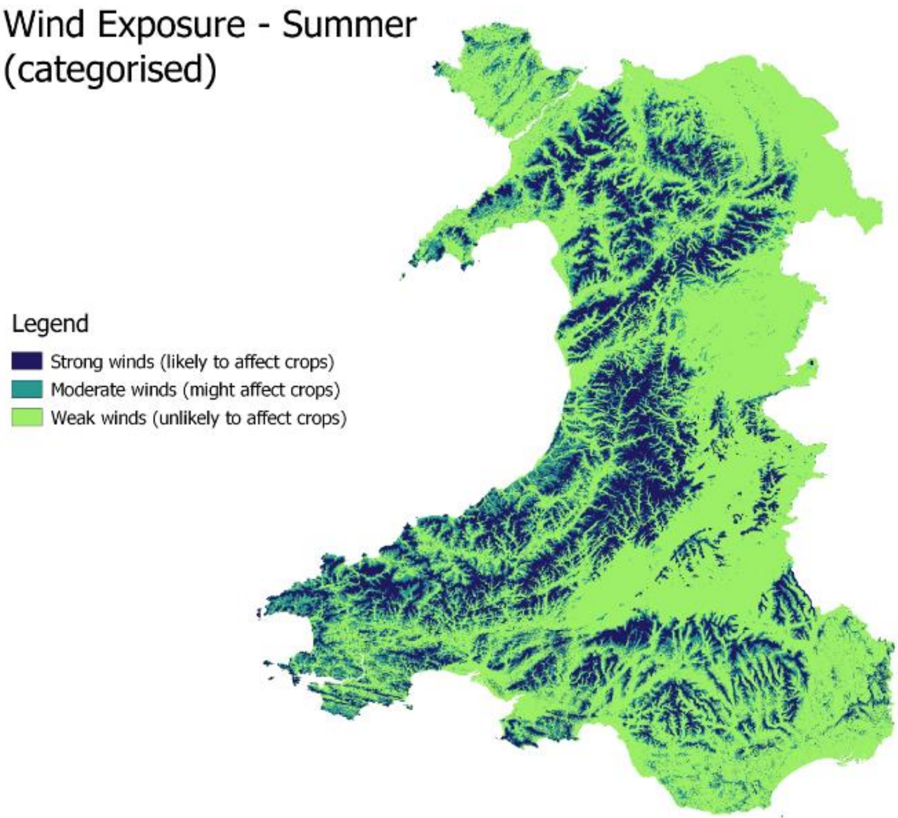


Figure 12. Summer wind exposure (Source: Bell *et al*., 2020a)

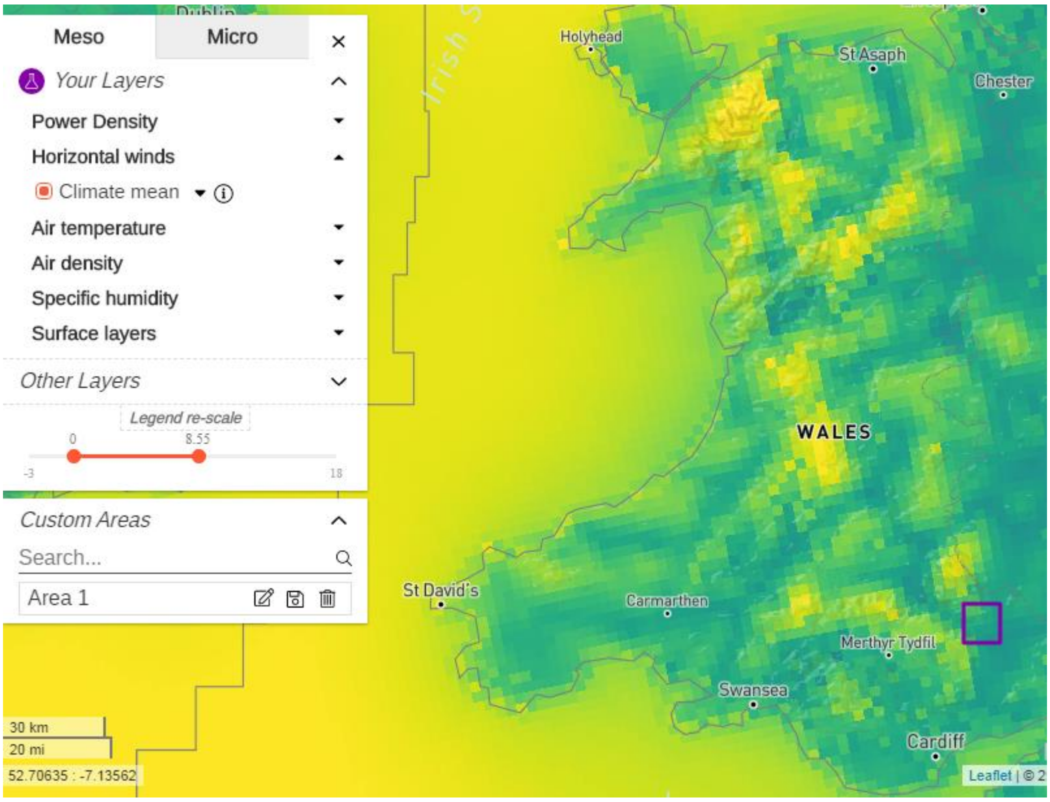


Figure 13. The European wind atlas: an online resource for wind speed data (source: https://map.neweuropeanwindatlas.eu/).

Conclusions for ALC guidance on wind

The Soil Survey of England and Wales (SSEW) produced a wind exposure map in 1980, based on the effect of the wind on vegetation. It is likely that although the wind data (1960-1974) used in the SSEW is dated it is still indicative of the probable wind strength/direction in any area. The SSEW wind map for England and Wales could be made available online to provide an overview of the potential wind exposure for an area, albeit that actual windiness may vary greatly over short distances due to topography, aspect etc. Where a more detailed assessment of wind exposure is required a period of on-site monitoring would be necessary.

- For annual crops, the risk of wind damage is particularly high in summer, when crops tend to be tallest and driest. Consequently, it would be of benefit to identify those areas at high risk of wind damage in summer. Bell *et al*. (2020a) have produced a wind exposure map for Wales which categorises wind as weak, moderate or strong and has the potential to identify sites where crops maybe susceptible to wind damage. Similarly to the SSEW map, large areas of eastern Wales are characterised in the weak wind category (i.e. damage to crops is unlikely). However, as noted above, map categories are only indicative of the wind risk at any site and onsite assessment will be required to take account of more localised wind conditions.

Site limitations

In the ALC, the assessment of site factors (gradient and micro-relief) is primarily concerned with the way in which topography influences the use of agricultural machinery and hence the cropping potential of the land (MAFF, 1988). Flood risk is also regarded as a site limitation as it is usually associated with well-defined topographic features.

Microrelief

Microrelief refers to complex changes of slope angle and direction over short distances, or the presence of boulders or rock outcrops, which even on level ground or gentle slopes, can severely limit the use of agricultural machinery (MAFF, 1988). The degree of limitation depends upon the distribution and severity of changes in slope direction/angle or frequency of rock outcrops. Microrelief is only taken into account in grading when it cannot be removed by normal management; for example it may be possible to remove a boulder but not a rocky outcrop. Only in the latter case, where the limitation cannot be removed should it be taken into account when grading land.

In the current ALC criteria, the effect of microrelief is considered in conjunction with overall gradient. However, detailed guidance on accounting for microrelief is not given and it is stated that 'the degree of limitation should be assessed in relation to the hindrance to mechanical operations'. The current ALC gradient limits are given in Table 1.

Table 1. ALC grade/subgrade according to gradient

ALC Grade/subgrade	Gradient limits (degrees)/[%]
1	7 [12.3]
2	
3a	
3b	11 [19.4]
4	18 [32.5]
5	>18 [>32.5]

Slope has a significant effect on mechanised farm operations since most conventional agricultural machinery performs best on level ground and steep slopes are not readily accessible for farm machinery (Baker and Capel, 2011). The safe and efficient use of machinery on sloping land depends on the type and design of the machine and on the nature of the slope being farmed

Changes in microrelief (e.g. ruts, potholes, depressions or rock outcrops) can affect tractor stability and one or more wheels can lose contact with the ground leading to overturning or loss of control (**Figure 14**). Steep, rough, slippery or lose ground and towing implements increase the risk of losing control.

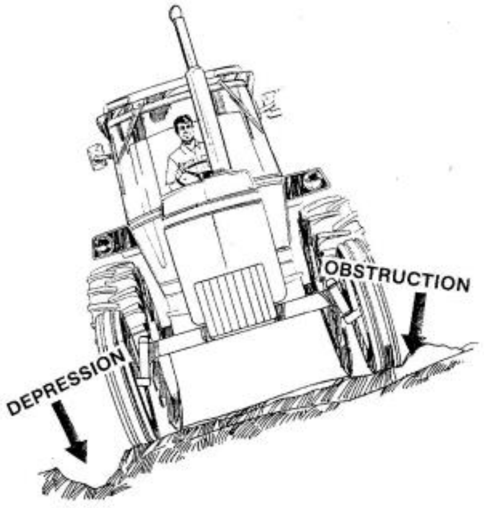


Figure 14. Sloping land with changes in microrelief can lead to loss of control or overturning incidents (Source: Education and Learning for Wales[7]).

ALC notes that the degree of limitation from changes in microrelief depends upon the distribution and severity of such features. For example, relatively few abrupt changes of slope angle on a site with a gentle overall slope may preclude the use of precision sowing or planting equipment. On steep slopes, rock outcrops, or frequent changes of slope direction, may prevent the safe use of a tractor with mounted equipment. Level sites may be impossible to cultivate satisfactorily because of frequent rock outcrops.

Conclusions for ALC guidance on microrelief

Changes in microrelief can increase the effect of slope gradient on the efficiency and safety of machinery operations. In the German Muencheberg SQR system slope is scored according to gradient and is allocated one of five possible scores for arable land from 2 (gradient <2%) to 0 (gradient >12%). If required the score can be modified by one class due to additional limitations as a result of microrelief (Mueller *et al*., 2007). A similar approach could be taken in the ALC.

Appropriate guidance could be included as a footnote to Table 1. 'Grade according to gradient' to detail how microrelief should be used to modify the grading. For example, where the gradient of the land is ≤7° but the land has many depressions or rocky outcrops (that cannot be remedied by normal agricultural operations) then it may be necessary to downgrade the land to ALC grade 3b (from 1, 2 or 3a) to reflect the level of hindrance to mechanical operations. However, where grade according to slope is already ≥4 (i.e. the gradient of the land is >11°) then downgrading according to microrelief is unlikely to be necessary. The footnote to Table 1 could replace the current section on microrelief, which gives no specific guidance on how this limitation should be accounted for. Additional text could be used to clarify (or provide examples) of the types of microrelief that might cause sufficient hindrance to machinery operations to require downgrading.

Flooding

Flooding can have a direct impact on crop vigour and yield by waterlogging (where only the below ground parts are affected) or submergence (where both the above and below ground parts of the plant are under water) (Sasidharan *et al*., 2017). However, the overall effect on plant growth is related to the duration of inundation, waterlogging, soil temperature and the stage of crop development at which waterlogging occurs.

The current ALC flooding limits are given in Tables 2 and 3 below and take account of frequency, duration and timing of flooding and apply to soils of good or moderate permeability. The ALC guidelines also state that 'further downgrading may be justified where flooding affects soils of low permeability', however, there is no explicit guidance on the soil types where this adjustment should be made. In general, clay soils are more susceptible to waterlogging than sandier soils, although the extent and duration of waterlogging depends on a range of factors including climate, soil water regime, topography, cropping and land management.

[7] http://resources.hwb.wales.gov.uk/VTC/ngfl/nvq/agriculture/level_2/e4_using_machinery.pdf

The ALC guidelines recognise that frequency, duration and timing of flooding is key to the impacts on farm practices and crop yields. Grading according to flood risk in summer (defined by the ALC as mid-March to mid-November; the period of active crop growth) is more restrictive than that for winter. For example, rare flooding of short duration would be categorised as ALC grade 2 for the risk in summer and as ALC grade 1 for winter.

Table 2. Grade according to flood risk in summer[1]

Grade/subgrade	Flood limits	
	Frequency[2]	**Duration[3]**
1	Very rare	Short
2	Rare	Short
3a	Very rare Rare Occasional	Medium or long Medium Short
3b	Rare Occasional	Long Medium
4	Occasional Frequent	Long Short or medium
5	Frequent	Long

[1]Summer: mid-March to mid-November.
[2]Frequency, very rare: not more than once in 15 years, rare: once in 10 to once in 14 years, occasional: once in 3 to once in 9 years and frequent: more than once in 3 years.
[3]Duration, short: ≤2 days; medium: >2 and ≤ 4 days and long: >4 days.

Table 3. Grade according to flood risk in winter[1]

Grade/subgrade	Flood limits	
	Frequency[2]	**Duration[3]**
1	Rare	Short
2	Rare Occasional	Medium Short
3a	Rare Occasional Frequent	Long Medium Short
3b	Occasional Frequent	Long Medium
4	Frequent	Long

[1]Winter: mid-November to mid-March.
[2]Frequency, very rare: not more than once in 15 years, rare: once in 10 to once in 14 years, occasional: once in 3 to once in 9 years and frequent: more than once in 3 years.
[3]Duration, short: ≤2 days; medium: >2 and ≤ 4 days and long: >4 days.

Flood risk is used as a criteria to assess capability and suitability of land in other classification systems, including the New Zealand LUC classification, the Canadian LSRS and the German Muencheberg SQR (Lynn *et al*., 2009, AIWG, 1995 and Mueller *et al*., 2007, respectively). For example, in the New Zealand classification LUC classes 2 and 3 can include land that occasionally floods, classes 4-6 land that frequently floods and class 7 and 8 includes land that has very frequent damaging floods; land that floods cannot be graded as LUC class 1 (Table 4). Similarly, to the ALC, the frequency and duration of inundation is used to differentiate between classes.

Table 4. New Zealand Land Use Classification according to flood risk/duration (Source: Lynn *et al*., 2009).

LUC subclass	Frequency	Days of continuous inundation
1w	No flooding	
2w	≤1 in 2 years	1
3w	Annually or 1 in 2 years if lasting 2-3 days	1-2 or 2-3
4w	Annually	2-4
5w	Annually or 2-3 times per year if lasting 1-4 days	4-8
6w	Annually or 3-4 times per year if lasting 4-8 days	8-15
7w	Annually or >1 times per year if lasting 8-15 days	15-30
8w	Annually	>30 days

The Canadian LSRS defines flooding as 'a temporary covering of the soil surface by flowing water from any source' and standing water that forms a permanent covering is not considered (AIWG, 1995). The system is based on the degree of limitation so that the least limited land will have the highest score out of 100. To account for the risk of flooding a deduction is applied as a percentage of the initial landscape rating. Similarly to the ALC the flooding risk is rated according to frequency (rare, occasional, common and frequent) and duration (very brief (< 2 days), brief (2-7 days), long (1-4 weeks) and very long (>4 weeks). Again, for the German Muencheberg SQR system, flood risk is scored based on a combination of the frequency and duration of flooding (Mueller *et al*., 2007). Scoring is further modified depending on when the flooding occurs in the growing period to take account of the fact that damage will be greater later in the season.

Duration of flooding

There is a general consensus in the literature that as the duration of a flood increases so the damage to crops will increase. Waterlogging occurs when the pores within the soil matrix are completely saturated with water and generally results in anoxic (anaerobic) soil conditions. Within 48 hours, plants begin to suffer from oxygen deprivation, which causes a significant reduction in nutrient uptake rates, inhibiting plant growth both above and belowground (Jackson, 2004).

If waterlogged or anaerobic conditions persist, hydrogen sulphide, acetic and butyric acid are produced as the soil redox potential levels reduce (Harvey *et al*., 2019). These compounds can be toxic to plants and can remain even after the soil has dried out again (McKee and McKelvin, 1993). In more extreme cases when soils are subjected to prolonged and complete submergence, the availability of carbon dioxide, light and oxygen decrease, severely reducing photosynthesis and respiration rates and ultimately leading to death in many crop species (Jackson and Colmer, 2005) and a significant monetary loss to farmers (Posthumus *et al*., 2009; Li *et al*., 2016).

Based on the broad literature it is considered that around 15 days is a critical threshold for arable crops in winter, with longer durations for 'improved' grass, and longer still for flood tolerant grass (Morris *et al*, 2008).

Prolonged surface waterlogging can have a serious impact on soil physical and chemical properties and on biological processes. This can profoundly affect the quality of soil as a medium for plant growth, although draining and drying a flooded soil will reverse most of these changes (Ponnamperuma, 1984).

Frequency of flooding

More frequent flooding events increase the likelihood of soil damage, reduce opportunities for working the land and reduce crop yield. Flooded grassland is inaccessible to livestock and reduces opportunities for grazing and/or conserving grass for over winter feed. Where flooding occurs more frequently the range of crops that can be grown is often limited.

Timing of flooding

The timing of flooding is also important in relation to cropping. If waterlogging occurs at the time of planting (autumn or spring according to the crop type), it can be detrimental to plant establishment (Trafford, 1974) because oxygen flow to the seed is restricted, limiting germination (Blake *et al*., 2004), nutrient uptake (Malik *et al*., 2002) and photosynthesis efficiency (Parent *et al*., 2008). Autumn waterlogging can also result in poor rooting in winter cereal and oilseed rape crops leading to overwinter plant loss. Winter waterlogging (in isolation) has minimal impacts.

The spring to summer period is key to determining the degree to which crops can 'recover' from earlier setbacks and ultimate effects on crop yield. Spring waterlogging can delay spring drilling, chemical and fertiliser applications, whilst summer waterlogging can lead to reduced grain fill. More seriously, a flood event in summer can also destroy a crop of grass or cereals ready for harvest.

There is strong evidence from a range of studies that waterlogging can reduce cereal crop yields by 7-24% (e.g. Dickin & Wright, 2008; Dickin *et al*., 2009). A pot trial undertaken by Gutierrez Boem *et al*. (1996) found that winter waterlogging had a larger effect upon both plant growth and yield than spring waterlogging. They suggested that winter waterlogging decreased the number of seeds per plant, whereas spring waterlogging decreased the size of seeds per plant. Consequently, winter waterlogging had a greater impact on seed yield than spring waterlogging, with seed yield almost halved by winter waterlogging but reduced by approximately a third by spring waterlogging.

Other factors

Clay textured soils and slowly permeable soils remain 'wet' for longer periods than other soil types (Morris *et al*. 2010) and have a higher saturated moisture content, a lower percentage of drainage water and a greater available water capacity than light sand soils. In contrast, the best drained light textured soils can be accessible within twenty four hours (or less) of heavy rainfall. Even after the flood waters have receded, clay textured soils will retain the water for longer, extending the period of waterlogging.

Temperature is also a factor with only small impacts reported by Cannell (1980) on oilseed rape yield when crops were waterlogged for between 10-40 days at 1 to 2°C, but when temperature increased to 6°C, seed yields fell by 14% and oil content by 23%.

The pH of a soil usually rises after it becomes waterlogged mainly due to the denitrification of nitrate to gaseous N, which neutralises acidic H+ ions by forming water molecules as part of the bio-chemical reaction (Nicholson *et al*., 2015). The degree to which the pH changes depends on the amount of residual nitrates in the soil, but in the agricultural lowlands of England and Wales most soils when waterlogged for prolonged periods have a pH of 6.7 to 7.2 (Alloway, 1990), compared with an optimum pH of 6.5 and 6.0 for mineral soils under arable cropping and continuous grass, respectively (AHDB, 2017).

Heavy rain and flooding will entrain and transport soil and sediment (particularly where soil structure has been previously damaged by compaction or livestock poaching), and soil loss from sloping or bare fields can be visible and extensive.

Conclusions for ALC guidance on flood risk

An estimated 13% of the 'best and most versatile' agricultural land in England and Wales is at risk of flooding from rivers or the sea, however this includes 56% of the Grade 1 agricultural land; the equivalent figure for Wales is 10% (Roca *et al.*, 2010). Therefore a significant proportion of agricultural production is at risk from flooding.

However, overall the risk of significant flooding is low so that grading according to flood risk will not be relevant for most sites. Data from the National Soil Inventory and Met. Office records (1921-2000) on climate, soil and site parameters (Keay *et al* 2013), suggested that flood was the most limiting factor at only *c*.3% of sites and that >90% of sites would be in Grade 1 for flood risk, **Figure 15**.

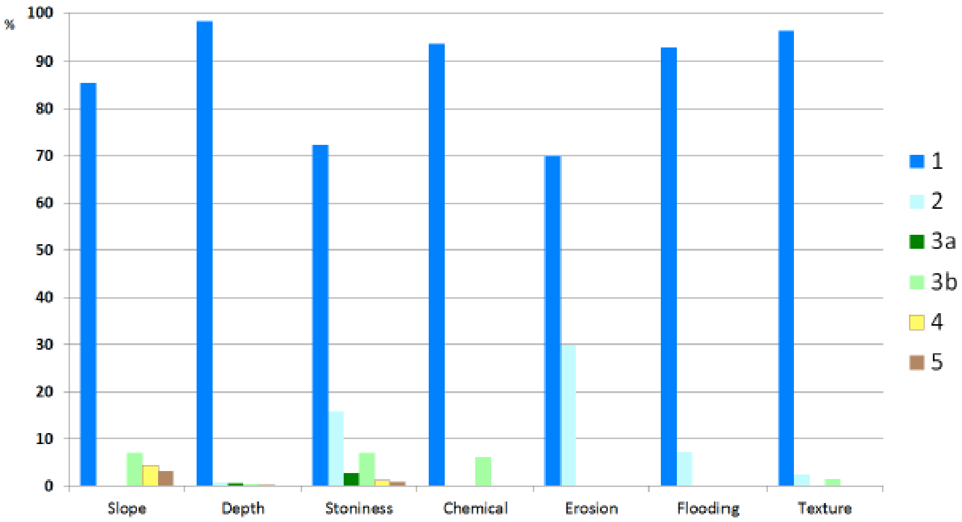


Figure 15. Proportion of land in England and Wales assigned to each ALC grade according to non-climate criteria (1921-2000). Source: Keay *et al.*, 2013.

More recently Environment Systems (Bell *et al.*, 2020b) have modelled the risk of flooding by ALC grade for Wales for winter and summer (Figure 16) using Natural Resources Wales flood risk assessment Wales (FRAW) data (NRW, 2019). The FRAW data represents winter flooding (frequency and duration); a corresponding dataset for summer flooding was not available as seasonal differences were reported to be marginal (Bell *et al.*, 2020b). The FRAW flood duration dataset allowed Bell *et al*. (2020b) to match all three ALC flood duration classes (short: ≤ 48 hours, medium: 49-96 hours and long >96 hours). However, the FRAW dataset for frequency did not allow precise modelling of the ALC flood frequency classes (very rare: not more than once in 15 years, rare: once in 10 to once in 14 years, occasional: once in 3 to once in 9 years and frequent: more than once in 3 years); FRAW categorisation of flood frequency was 1 in 10 years, 1 in 30 years and 1 in 100 years. To account for this mismatch between FRAW frequency data and ALC categories Bell *et al*. (2020b) used the following rules: ALC very rare and rare categories were represented by the 1 in 30 FRAW dataset and the ALC occasional category was represented by the 1 in 10 category; the frequent ALC category could not be modelled. As a result some grades could only be partially modelled (i.e. grade 3b in the winter model and grade 4 in the summer model) and some grades were not modelled at all (i.e. grade 4 in winter and grade 5 in summer).

In line with Keay *et al*. (2013), the modelled risk of winter flooding by Bell *et al*. (2020b) was typically low and suggested that most of Wales would be ALC grade 1 for winter flood risk (i.e. no flood risk), followed by grade 2 and small areas of grade 3a and 3b. Similarly, the risk of summer flooding was also low for most of Wales (ALC grade 1), albeit that the risk was higher than for winter flooding with larger areas of land being graded as ALC 3a or 3b (Bell *et al.*, 2020b). This reflects the more restrictive grading for summer flooding (which is generally more harmful to crops) than that for winter flooding For example, rare flooding of short duration would be categorised as ALC grade 2 in summer and as ALC grade 1 for winter. Figure 17, compares the risk of summer and winter flooding for the Welshpool area and illustrates the lower ALC grading allocated as a result of summer flooding (ALC 3a/3b) compared with winter flooding (ALC 2/3a).

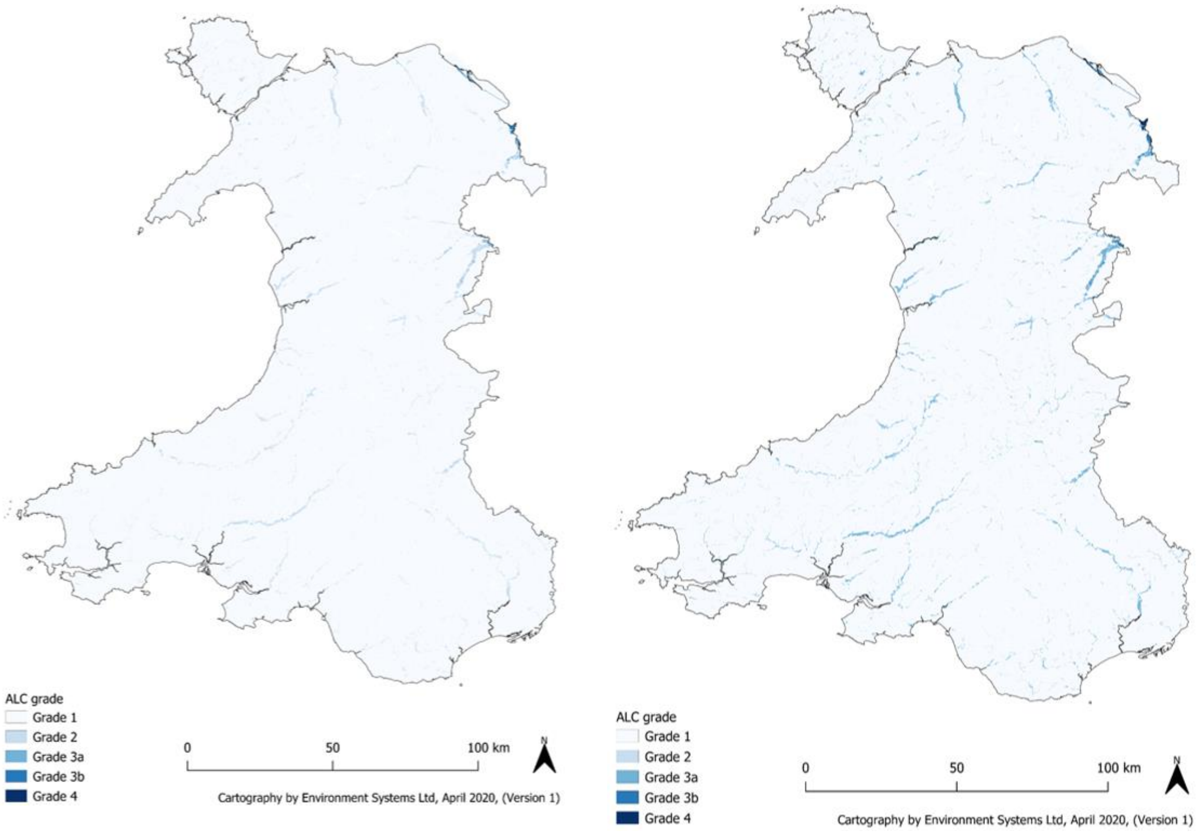


Figure 16. ALC Grade according to flood risk for Wales for a) winter and b) summer. (Source: Environment Systems).

In England the Environment Agency has an interactive online flood risk map which can be used to assess the extent and risk of flooding for any location (by entering a location or postcode[8]). The map shows flood risk from rivers or the sea, surface water (categorised into four risk levels according to the chance of flooding in any year, i.e. high: ≥3.3%, medium: 1-3.3%, low: 0.1-1% and very low: ≤0.1%), or reservoirs (Figure 18). However, note that the risk categories are a poor match to the ALC flood frequency categories, i.e. the EA very low risk category suggests an annual chance of flooding of <0.1% (or once in 1000 years), whereas the lowest category in the ALC, very rare suggests an annual change of flooding of ≤6.6% (not more than one in 15 years). This is a reflection of the different risk that is being assessed, i.e. the risk to property is assessed by the EA v the risk to crops that is assessed by the ALC system.

Similarly, the Environment Agency has produced a flood risk map to inform planning decisions that indicates the flood zone of any location, i.e. flood zone 1 (<0.1% annual chance of river or sea flooding,) zone 2 (0.1-1% annual chance of river flooding and 0.5-0.1% chance of sea flooding and zone 3 (≥1% annual chance of river flooding and ≥0.5% chance of sea flooding) (**Figure 19**). Many of the Environment Agency datasets related to flooding are available under an Open Government Licence to download from data.gov.uk[9]. However, there is no easily accessible data source on the duration of flood events in England.

[8] https://flood-warning-information.service.gov.uk/long-term-flood-risk/map

[9] https://data.gov.uk/search?q=flood&filters%5Bpublisher%5D=Environment+Agency&filters%5Btopic%5D=&filters%5Bformat%5D=&sort=best

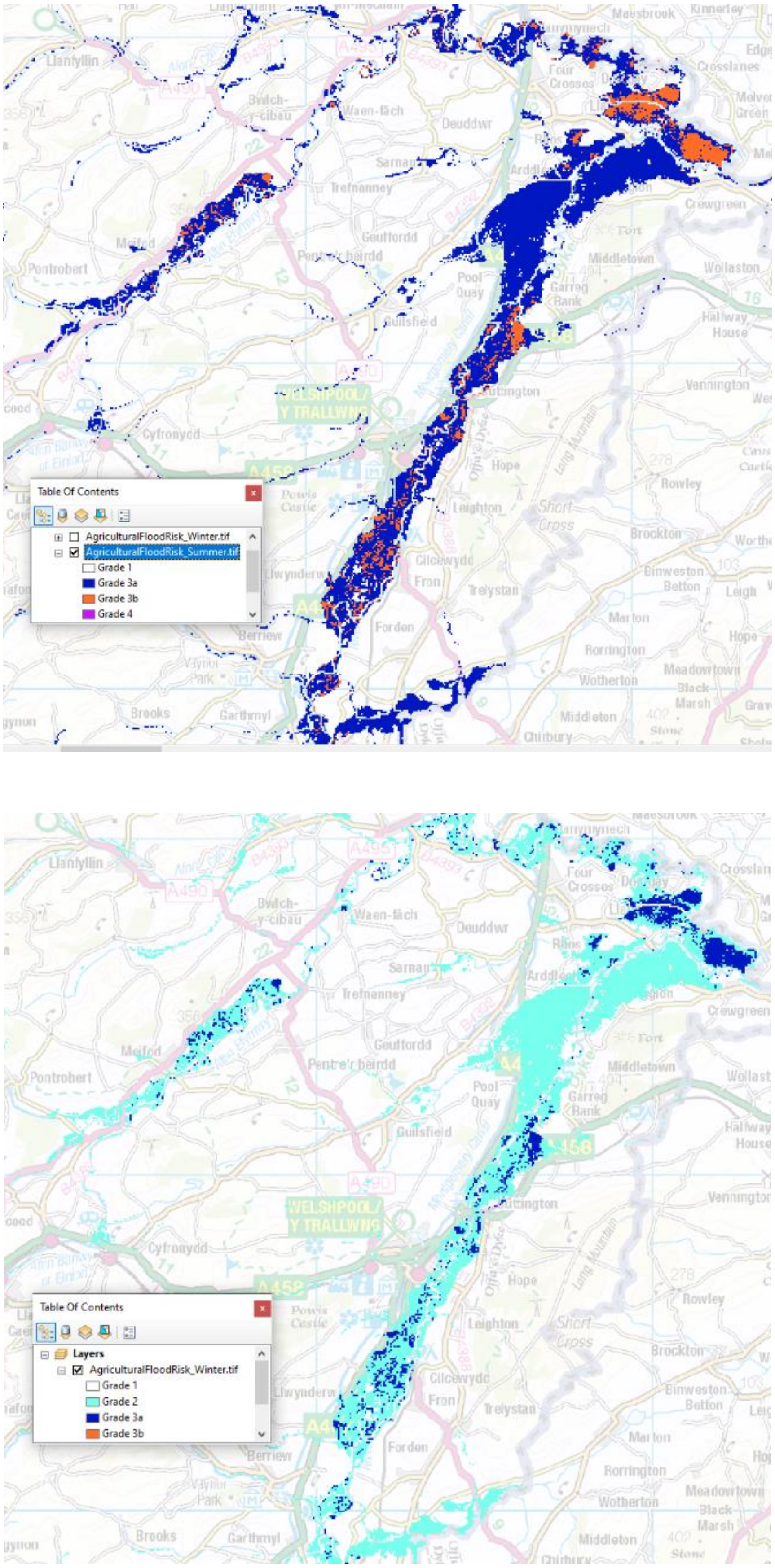
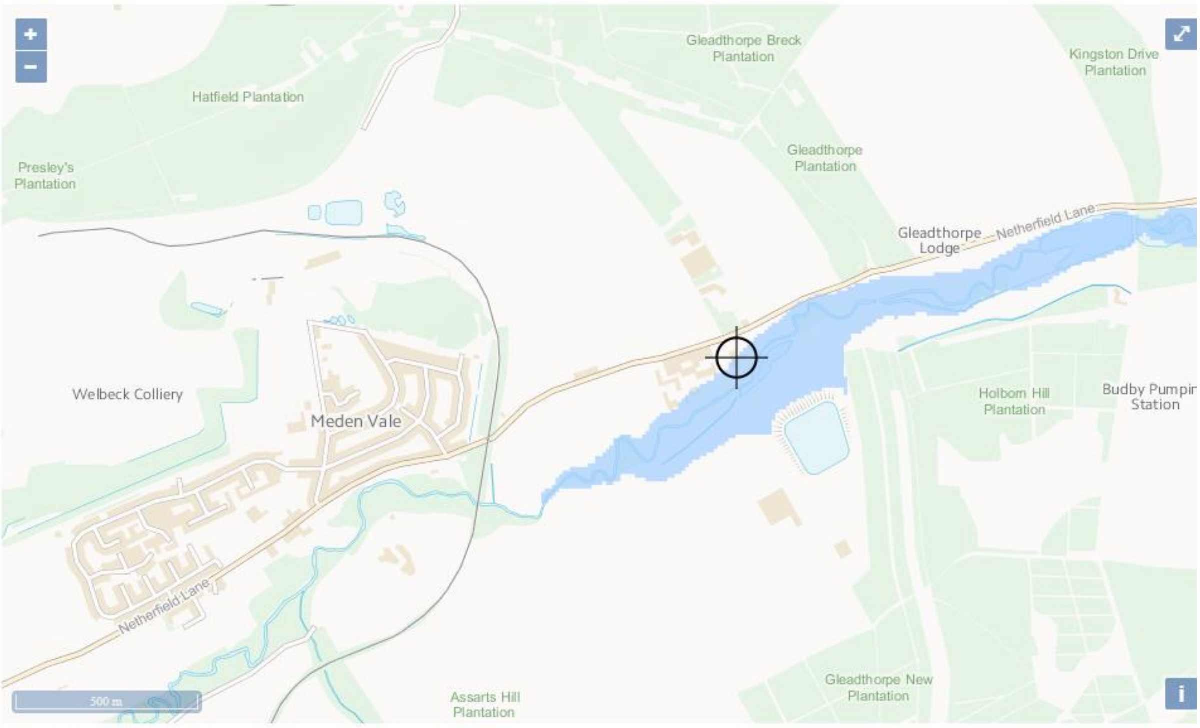


Figure 17. Section of flood risk map: ALC Grade according to flood risk for Welshpool for a) summer and b) winter. (Source: Environment Systems).

Extent of flooding from rivers or the sea

High Medium Low Very low



Extent of flooding from reservoirs

Maximum extent of flooding   Location you selected

Figure 18. Example Environment Agency interactive flood risk maps

Figure 19. Example Environment Agency interactive flood map for planning

The ALC categories for short (<48 hours) and medium (>2 days and <4 days) flood duration broadly align with literature values which suggest that 48 hours is the critical period after which plants begin to suffer from oxygen deprivation. The long duration category (>4 days) would seem precautionary but recognises the wide ranging effects of flooding, not just on plants but on workability and access. Also, note that coastal (saline) flooding may be more damaging to crops due to damaging salt concentrations (Roca *et al*., 2010) and impacts on soil stability.

The ALC grades suggest that summer flooding (defined as mid-March to mid-November) is more damaging than winter floods because the crop root systems are active and more likely to be affected by waterlogging. In addition, whole crops may be lost by summer floods that occur just prior to harvest. However, some research has suggested that winter waterlogging can have a more significant effect on crop yield for crops that are in the ground over winter, such as winter cereals or oilseed rape. In addition, climate predictions suggest that winter rainfall is expected to increase so that there may be merit in a more in depth review of the risks related to flood risk at different times of the year.

For simplicity, it is suggested that there could be a single grade relating to flood risk based on the stricter limits in the current grading according to summer flood risk. In addition, the current additional recommendation for downgrading where soils of low permeability are present should be made more explicit as a footnote to the flood risk table.

Data on flood duration is not easy to access making it difficult to grade land according to the current ALC flood risk guidance, which is based on flood frequency and duration data. However, as data on flooding frequency is more accessible it may be possible to grade land on the risk of flooding in any one year, although further investigation would be required to identify the most suitable data sources. For the estimated 10% of land that would not be ALC grade 1 for flood risk more detailed data/information on localised flood risk may be required.

Interactive limitations

The physical limitations which arise from interactions between climate, site and soil are soil wetness, droughtiness and erosion.

Irrigation

Irrigation provides a way of regulating the local amount and seasonal availability of water to match agricultural needs. Over the last 25 years there has been a marked increase in the irrigation of high value crops, particularly potatoes and field vegetables, driven by the supermarket demands for quality, consistency and continuity of supply (Knox *et al*., 2013).

Droughtiness limits for ALC grades/subgrades are defined in terms of moisture balance for wheat and potatoes; only land with a positive moisture balance for both crops is graded as ALC 1. The use of irrigation can potentially 'correct' any moisture deficit and enhance the potential of agricultural land especially in drier areas. As a consequence, current ALC guidance states that irrigation 'should therefore be taken into account in ALC grading when it is current or recent practice'. However, because irrigation is likely to benefit only part of the full range of crops which could be grown, it will usually upgrade land by no more than one grade or subgrade.

Current ALC guidance in relation to irrigation is not specific, i.e. there is no table of values that indicate the effect of irrigation on grading. It assumes that potatoes, field vegetable, fruit crops and sugar beet (in drier areas) would receive irrigation water and recognises that irrigation will be of less benefit in wetter areas or where crops are grown on soils with high available water capacities (e.g. silts). Guidance suggests that to determine the effect of irrigation the following factors should be taken into account:

- The adequacy of irrigation water supply
- The range of crops to which water is usually applied
- Climate and soil factors.

Other land classification schemes take a similar approach to the ALC, for example, the New Zealand LUC recommends that 'where it is feasible to either remove or significantly reduce the physical limitation (e.g. through irrigation) then the land is assessed as if the limitation has already been removed or managed'. Likewise, the German Muencheberg SQR system recognises that irrigation can alleviate drought risk and where irrigation exists states that 'the land should be scored recognising the benefits of irrigation' (Mueller *et al*., 2007). However, the German guidance also states that the SQR without irrigation should also be scored.

The demand for irrigation varies significantly from year to year depending on the weather and summer rainfall. However, compared with total national freshwater abstractions, including those for public water supply, industry and electrical generation agricultural irrigation constitutes only a minor use (1 to 2% of total water use). Most agricultural cropping in England and Wales is rain-fed and, even in a dry year, only a very small proportion of cropped land (<0.5%) is typically irrigated. Irrigation demand is generally low in Wales because rainfall amounts during the growing season are usually adequate to meet most crop requirements. However, large areas of Wales have no or little scope for further summer surface water abstractions (EA 2001).

Future government policy may implement major legislative reforms to the abstraction licensing regime to reduce levels of over-abstraction and restore environmental flows. This will introduce additional costs associated with licensing and may make it more difficult to obtain permission to irrigate land. However, because the cost of the irrigated water accounts for only 5-7% of total irrigation costs, demand for water is currently not responsive to price (Morris *et al.* 2004).

Irrigation is a consumptive use (that is, the water is not returned to the environment in the short term) and is concentrated in the driest areas in the driest years and driest months when resources are most constrained (Knox *et al*., 2010). As a consequence, irrigation can be the largest abstractor in some catchments in dry summers (Watts *et al*., 2015). This creates conflict with other water demands, most notably those for public water supply and environmental protection.

Summer abstraction is increasingly unreliable for many existing abstraction licence holders, and new summer licences are unobtainable in many catchments (Weatherhead *et al*., 2014) However, abstraction during the winter and/or at high flows into reservoirs is usually possible, and can provide a more reliable resource. Reservoir construction requires planning permission and compliance with the Reservoirs Act 1975 and large raised reservoirs (≥25,000 m^3) must be designed by a qualified engineer and registered with the environmental regulator. Currently there are no restrictions on the use of reservoir water however, future legislation is expected to bring in the need for reservoir abstraction licences in some circumstances (AHDB, 2019). Due to the substantial capital investment required, on-farm reservoirs are most suited to the irrigation of high value crops and/or where reliability of supply is important (e.g. supermarket contracts).

Conclusions for ALC guidance on irrigation

ALC guidance for irrigation is only applicable to a small area of land growing a small range of crops, where the application of water can increase the grading of land. Since over half of UK irrigated production is currently cropped in catchments defined as being 'over-abstracted' or 'over-licensed', there are understandably concerns regarding the environmental impact that any future increases in water demand might have on water resources (Knox *et al*., 2013).

Overall, it is suggested that irrigation should not be taken into account in ALC grading given the negative impacts that abstraction can have on local water resources in areas where water is scarce. Taking irrigation out of ALC would help ensure that cropping is appropriate to local conditions.

Soil erosion

The incidence of erosion is determined by interactions between weather, soil type/condition, topography and the amount and type of vegetative cover. It is strongly influenced by agricultural management practices. There is no specific guidance in the ALC Guidelines in relation to erosion and it is acknowledged that a number of the risk factors for erosion (i.e. soil depth or gradient) are taken into account by other parts of the ALC grading process.

The factors that influence the vulnerability of land to soil erosion have been reviewed extensively in the literature. Risk factors include the intensity, duration and timing of rainfall events; the physical, biological and chemical properties of soils; the length, gradient and form of slope; the type of vegetation/crop on the land and its stage of development; and the type and timing of land management practices (Knox *et al*., 2015).

Evans (1990) suggested that soils with an organic carbon content of less than 2% (*c.*3.5 % organic matter content) can be considered erodible. However, it should be noted that some soils with very high organic contents, particularly peats, are highly susceptible to wind and water erosion. Furthermore, the role played by organic matter depends on its origin. For example, organic matter from farmyard manure contributes to aggregate stability, while peat has very low aggregate stability.

Erosion can occur as a result of water runoff, wind blow, tillage, co-extraction with root vegetables and farm machinery, and human and animal impact (from recreation and grazing) (Knox *et al*., 2015). In general, water-induced erosion is more widespread than wind erosion (Owens *et al*., 2006). It occurs most frequently on sloping land with bare soil or sparse crop cover where the soil is weakly structured and has a fine sandy or coarse silty texture. Rills and gullies may be formed which, where these are deep and wide, may hinder farm machinery operations.

Steeper slopes are often associated with shallower soils, with less water retention capacity due to gravity and with a higher risk for soil degradation and landslides (Van Orshoven *et al*., 2014). Steepness of slope in combination with soil texture affects the level of risk of soil erosion by overland flow (Defra, 2005). In general, sandy and light soils are at most risk of erosion even on gentle slopes (2-3°) where rills may develop in some seasons during very wet periods (**Table 5**). In comparison, the risk of erosion on heavy soils is lower because of their greater inherent stability, even when the slope is steep (>7°). In addition, slope gradient, form and length affect the volume and velocity of overland flow which influences the rate/amount of eroded and transported material (Knox *et al*., 2015).

Table 5. Risk of erosion in relation to slope steepness and soil texture (Defra, 2005).

Soil	**Steep slope >7°**	**Moderate slope 3-7°**	**Gentle slope 2-3°**	**Level ground <2°**
Sand	Very high[1]	High[2]	Moderate[3]	Lower[4]
Loamy sand	Very high	High	Moderate	Lower
Sandy loam	Very high	High	Moderate	Lower
Sandy silt loam	Very high	High	Moderate	Lower

Silt loam	Very high	High	Moderate	Lower
Silty clay loam	High	Moderate	Lower	Slight
Other mineral soils	Lower	Lower	Slight	Slight

[1]Very high risk: rills are likely to form in most years and gullies may develop in very wet periods. [2]High risk: Rills are likely to develop in most seasons during wet periods. [3]Moderate risk: Sediment may be seen running to roads, ditches or watercourses and rills may develop in some seasons during very wet periods. [4]Low risk: Sediment rarely seen to move but polluting runoff may enter ditches or water courses. Slight risk: any water running off the site is unlikely to be discoloured.

Conclusions for ALC guidance on erosion

The effects of soil erosion on land quality are typically associated with rill/gully formation or loss of soil depth, particularly on sloping land. This may reduce the range of crops that can be grown or markedly increase production costs. These factors are taken into account in the ALC grades for gradient, microrelief and soil depth and only on rare occasions will erosion not be quantified by these other assessments of limitation. As a result, it is suggested that the text on erosion could be reviewed to include more detailed guidance on the factors that are likely to increase erosion risk (i.e. slope, soil texture/depth, climate and ground cover), as well as high intensity, episodic events.

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Appendix 1: Examples of other land classification systems

New Zealand Land Use Capability-LUC (Lynn et al., 2009).

The LUC has three components: LUC class (assessment of the land's capability for use while taking into account its physical limitations, i.e. rock type, soil, slope angle, erosion type/severity and vegetation cover), LUC subclass (identifies the main kind of limit or hazard, i.e. erodibility, wetness, soil or climate) and LUC Unit (groups together land which requires the same kind of management). Similarly to the ALC, the grade is allocated according to the most limiting factor.

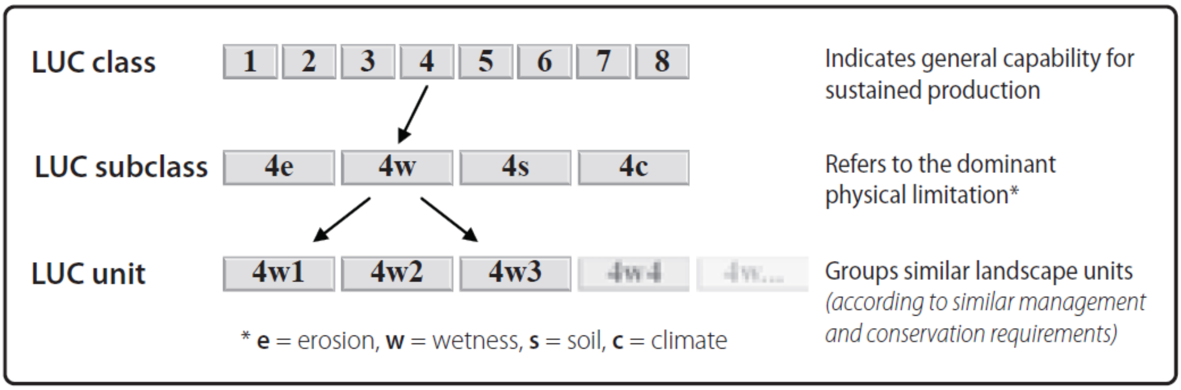

Figure A1. Schematic of the New Zealand Land Use Capability classifications

Canada: Land Suitability Rating System (LSRS) for Agricultural Crops (AIWG, 1995)

A system for rating the suitability of land for production of spring-seeded small grains (and hardy oilseeds) in Canada.

The system has two categories: Classes based on the degree of limitation of land for production of the specified crop or crops and subclasses based on the kind of limitation (i.e. climate, soil or landscape related). It is based on a scoring system out of 100, where Class 1 land scores 80-100 and limitations are classed as none to slight to Class 7 land which scores 0-9 (unsuitable). Note that the system is based on suitability for a particular crop type where land is Class 7 this does not imply that the land could not be developed for other crops. More recently, further work has expanded the LSRS to include crop modules for maize, soybeans, forages (alfalfa, grasses) and canola (Bock *et al*., 2018). The current version of the rating system utilises web-based technologies that optimise data handling and storage and facilitates user access to the tools and calculators that make up the system

The Muencheberg Soil Quality Rating (SQR) (Mueller et al., 2007).

The SQR rating is based on a 100 point scale; a series of indicators are ranked from 2 (best condition) to 0 (worst), with possible increments of 0.25 or, more typically 0.5. The final basic score ranges from 0 (theoretical minimum, practical is about 15) to 34. It is a measure of soil quality for farming. Values less than 20 indicate poor soils, values greater than 27 are typical of good soils. A series of hazard indicators are then considered as multipliers for the basic soil score ranging from 0.01 (hazard properties do not allow farming) to 3 (no hazard properties). The lowest multiplier is the valid one (i.e. the most limiting factor).

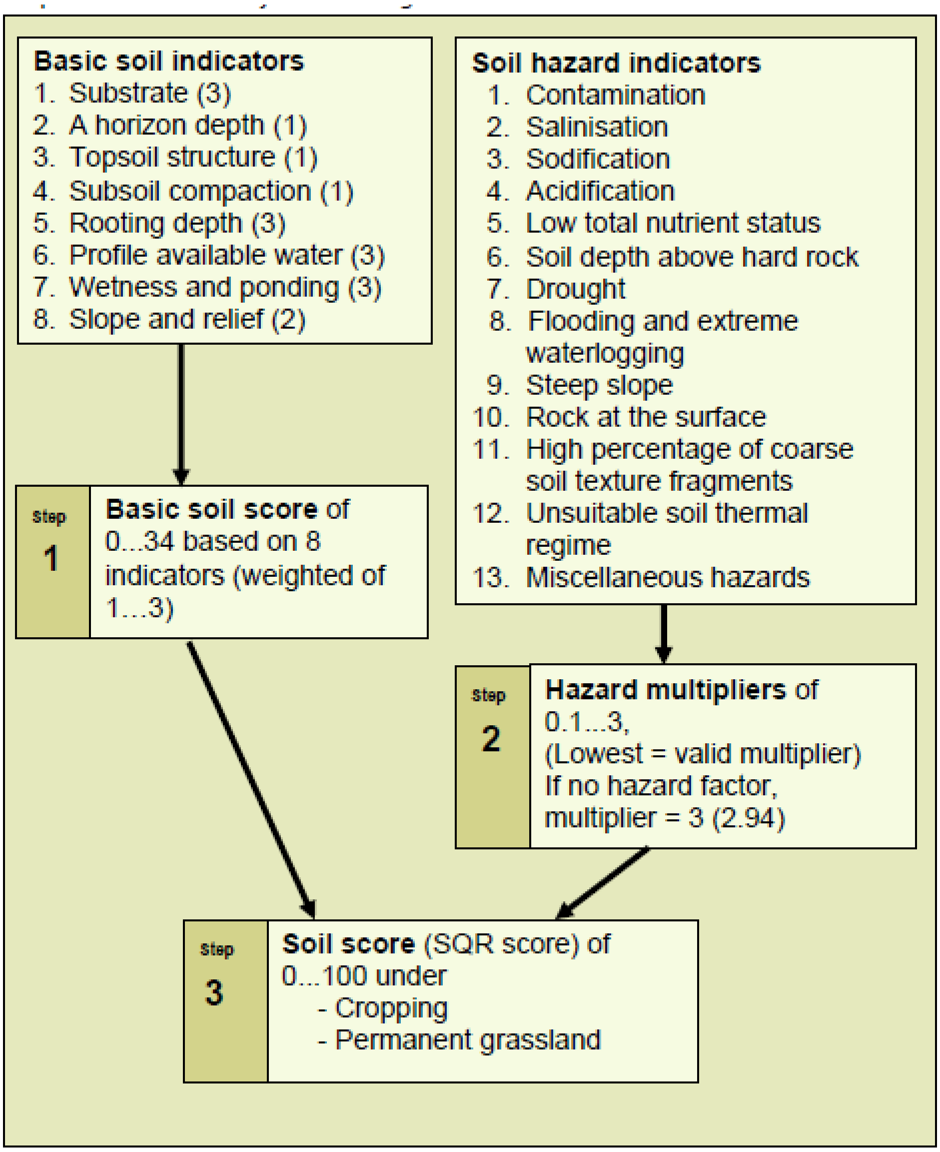

Figure A2. Schematic of the Muencheberg SQR