Assignment 2: Report – Comparison of Land Capability Assessment and Multi-Criteria Evalutation

Introduction

The aims of this report are to engage with the debate on Land Capability Assessment (LCA) and Multi-Criteria Evaluation (MCE) to provide context for investigating the creation, analysis and presentation of data in these contrasting methods. The resulting information and consideration of the methods will then be used to conclude on the relative advantages and disadvantages of each method in the context of agricultural land use planning.

Broadly, LCA identifies constraining factors within the landscape (Davidson, 1992, 2002) and determines the subsequent suitability of the land. The identification of these factors focusses on a range of biophysical properties concerning the qualities of the soil and topographic features (Davidson, 1992; Brown *et al.,* 2008). The taxonomy for British land capability used is derived from the work of Bibby and Mackney (1969) (cited in Davidson, 1992, p64: table 1) which divides land capability into seven categories from minor through to severe constraints. These are derived from the assessment of five landscape qualities: climate; gradient; soil limitations; wetness; liability to erosion; and climatic conditions, alongside defined criteria (Appendix) (University of Leeds, n.d.). Within a GIS context this facilitates the production of layers displaying each biophysical quality. Typically, an LCA map is created using the overlay function which identifies a maximum operator based upon the assumption that any limitations outweigh all other factors (Van Ranst, 1996). In this sense the LCA method provides a useful overview of land suitability that can be communicated quickly and easily with a range of stakeholders (Davidson, 2002).

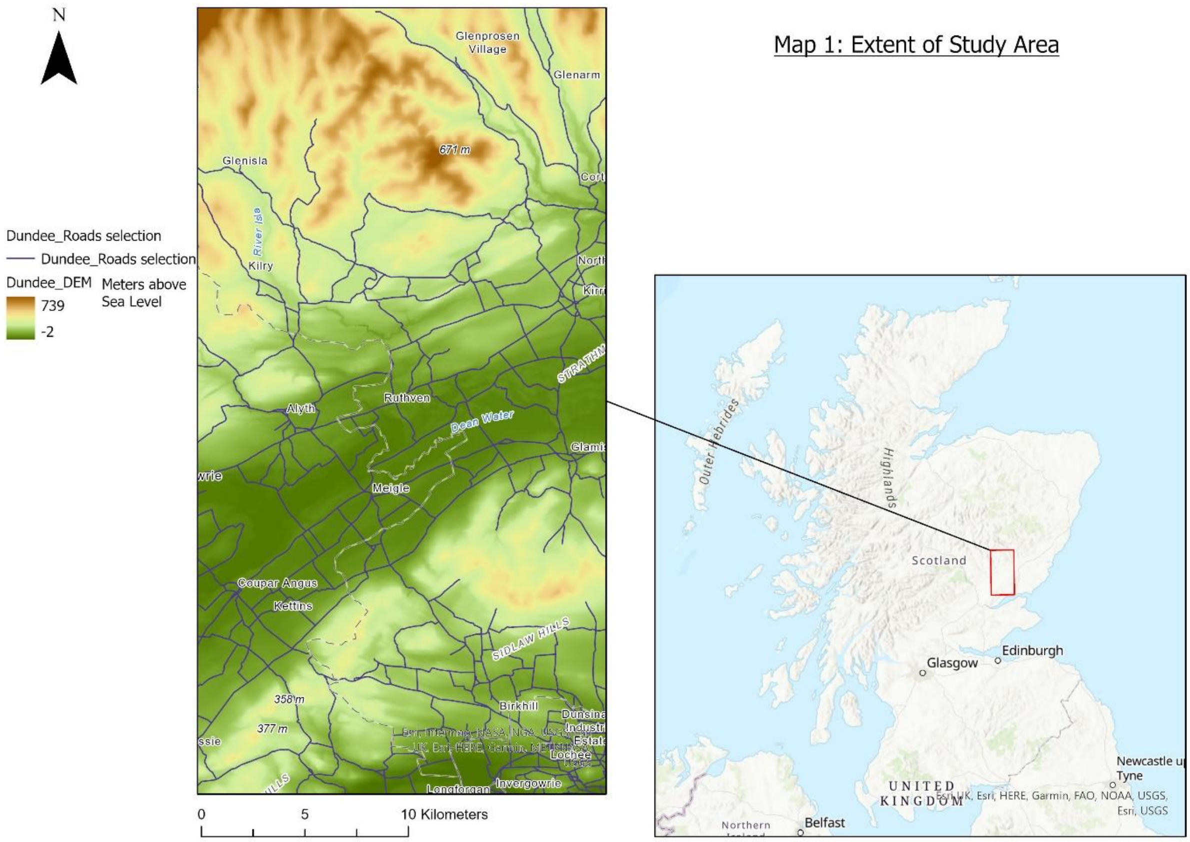
Whilst the LCA method is easily produced and communicated, deterministic methods such as this have been scrutinised (Carver, 1991; VanRanst, 1996; Davidson, 2002; Malczewski, 2004;). It is argued that LCA maps display only one limiting factor and do not take into consideration that multiple factors may affect land capability (VanRanst, 1996; Malczewski, 2004). Through this the Multi-Criteria Evaluation (MCE) has been developed with weighting applied to a range of factors determining the capability of a tract of land (Janssen and Rievelt, 1990; Carver, 1991). The perceived benefit of this being that rather than multiple output maps with different information, a single map is produced which has considered a range of factors deemed pertinent to the issue (Malczewski, 2004; Heywood *et al.* 2011).

Class	Description
1	Very minor or no physical limitation to use
2	Minor limiations that reduce the choice of crops and interfere with cultivation
3	Moderate limitations that restrict the choice of crops and / or demand careful management
4	Moderately severe limitations that reduce the choice of crops and / or demand careful management practices
5	Severe limitations that restrict its use for pasture, forestry and recreation
6	Very severe limitations that restrict use to rough grazing, forestry and recreation
7	Extremely severe limitations that cannot be rectified

Table 1: Soil Classification (Bibby and Mackney 1969, cited in Davidson, 1992, p64)

Data and Study Area

The study area for this report consists of an 80km² region of Eastern Scotland from the outskirts of Blairgowrie in the West to Kirriemuir in the East. South to North the study area encompasses the North-Eastern outskirts of Dundee and the Sidlaw Hills, to the South-Eastern reaches of the Cairngorms. The wide, low-lying valley running from South-West to North-East is the Valley of Strathmore (Map1).



Map 1: Extent of Study Area

Layer	Data Type / Composition	Source
Dundee_DEM	Raster, 50m resolution, mosaic of 8 OS Terrain 50 DTM files - NO23, NO24, NO25, NO26, NO33, NO34, NO35, NO36	EDINA Digimap
Dundeesoils	Raster, 50m resolution - displaying 10 soil classes	James Hutton Institute and Evans (1980) as provided by University of Leeds
VectorMap District	Vector; comprising region 'NO' ($100km^2$) and various data sources. The only data used from this is the 'NO_Roads' element	EDINA Digimap

Table 2: Layer information

The raster data layers used (DTM files, soil map) were converted from ascii to grids using the Copy Raster tool. These were then mosaiced ensuring the spatial reference was set to British National Grid and the resolution remained at the constant of 50m (Table 2). Key figures from the two initial raster layers display that 58% of the study area is comprised of class 2 and 4 soils. The elevation and mountainous nature of the study region is exemplified in both the range and the standard deviation of the DEM layer (Tables 3 and 4).

Soil Class	Description	% of study area
1	Brown Earths	19
2	Brown earths with gleying	23
3	Mineral alluvial soil	6
4	Humus-iron podzols	35
5	Peaty Podzols	5
6	Sub-alpine Podzols	1
7	Noncalcareous gleys	8
8	Peaty Gleys	1
10	Built up area	2

Table 3: Soil Classes and land coverage

Digital Elevation Model Key Statistics

	Height Above Sea Level (m)
Minimum	-2.00
Maximum	739.00
Mean	214.08
Standard Deviation	138.05

Table 4: DEM Key Statistics

Soil class 9, not listed in table 3, denotes lochs; a water mask layer was applied to the environments setting to ensure that any analysis excluded the cells identified as class 9. The roads vector layer was added and clipped to the extent of the raster layers, with a filter applied to the clipped layer in which private roads, local streets and pedestrianised streets were removed as these were not considered pertinent to the analysis of access to, and exportation of, agricultural goods and farmland.

Methodology and Results – LCA

The procedure for creating a LCA map involves reclassifying data derived from the soils raster layer, the DEM, and a slope model derived from this using geoprocessing tools to convert the DEM cell values into degrees by assessing the values of neighbouring cells. These layers are then reclassified to give five raster layers for gradient (g), climatic limitations (c), liability to erosion (e), soil limitations (s), and wetness (w) outlined in tables 5, 6, 7 below. Results are displayed in figures 1 to 5.

Gradient: Derived from slope

LCA Class	Reclass data range
1	0° - 3°
2	3° - 7°
3	7° - 11°
4	11° - 15°
5	15° - 20°
6	20° - 25°
7	>25°

Table 5: Gradient (g) reclassification values

Climatic Limitations: Derived from DEM

LCA Class	Reclass data range
1	<150m
2	150m - 230m
3	230m - 380m
4	380m - 460m
5	460m - 530m
6	530m - 610m
7	>610m

Table 6: Climatic limitations (c) reclassification values

Soils Raster Layer recode for e, s, w layers

Soils LayerCode	Liability to erosion LCA class	Soil limitations LCA class	Wetness LCA class
1	1	1	2
2	2	2	2
3	5	6	3
4	4	4	2
5	4	5	1
6	3	7	1
7	2	2	2
8	4	5	2

Table 7: Liability to erosion (e), soil limitations (s) and wetness (w) reclassification values.
Source: James Hutton Institute (2021) and Evans (1980) cited by University of Leeds (2021).

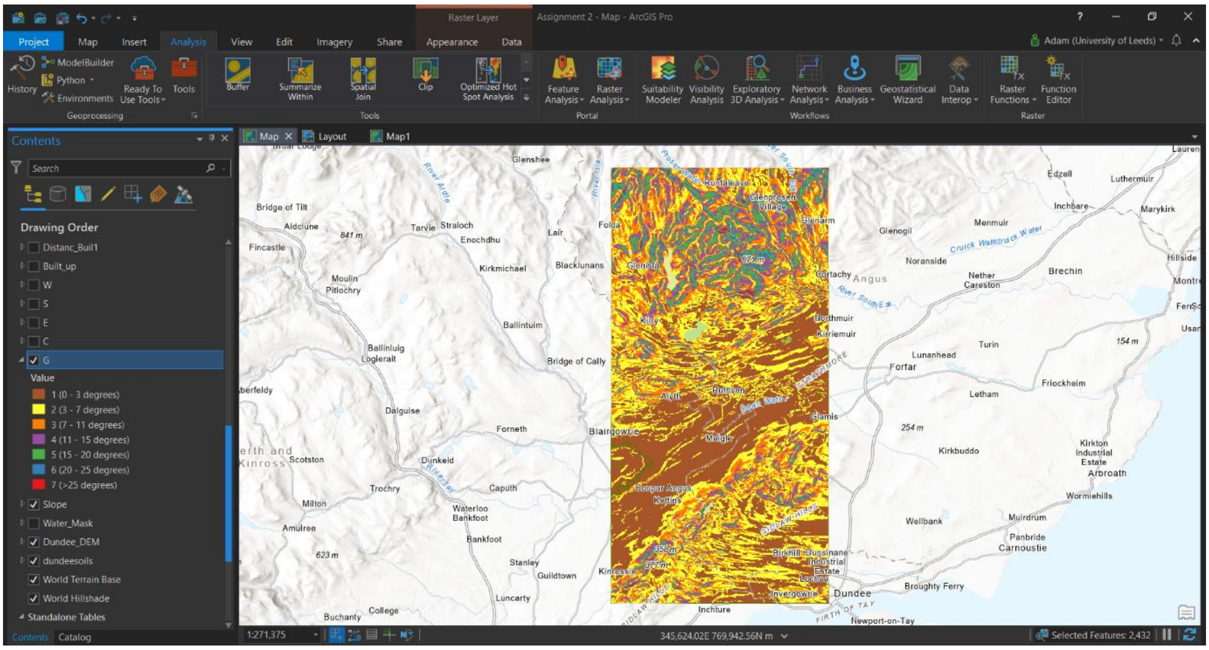


Figure 1: Gradient (g)

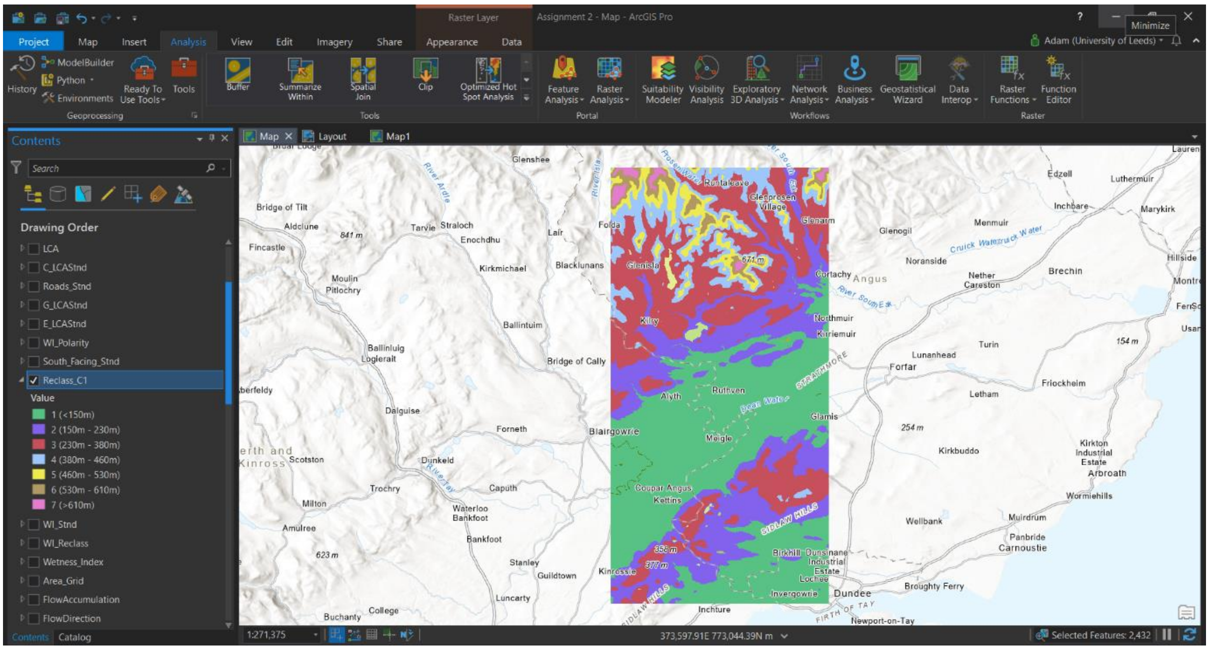


Figure 2: Climatic Limitations (c)

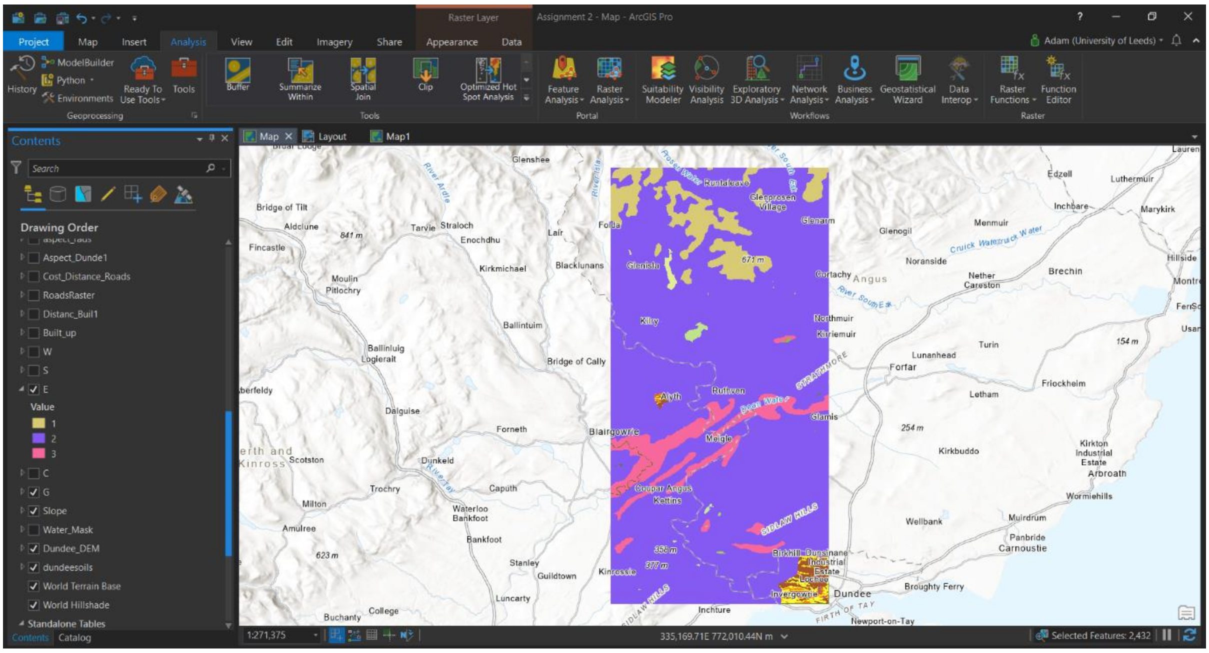


Figure 3: Liability to erosion (e)

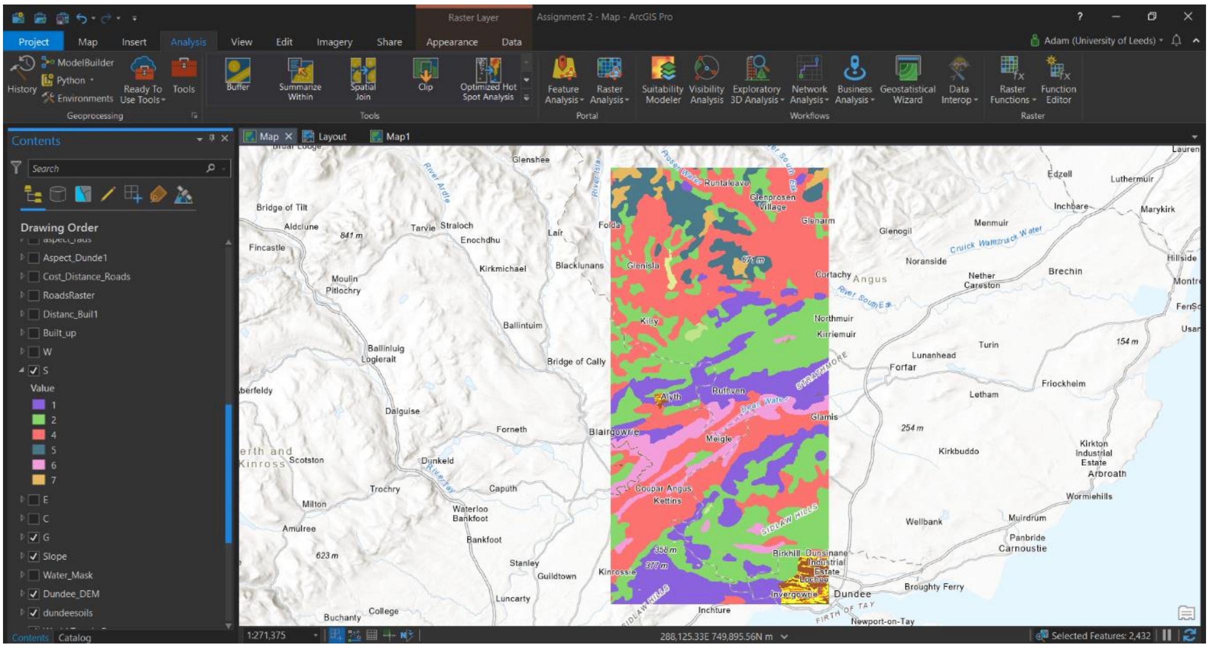


Figure 4: Soil Limitations (s)

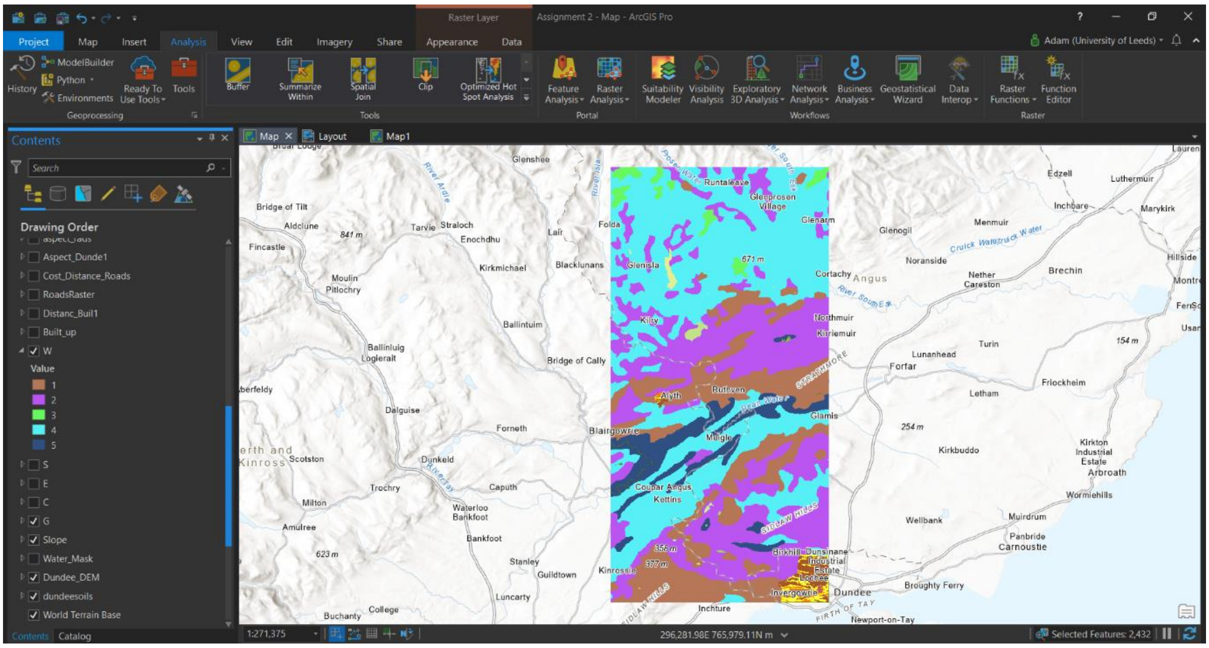
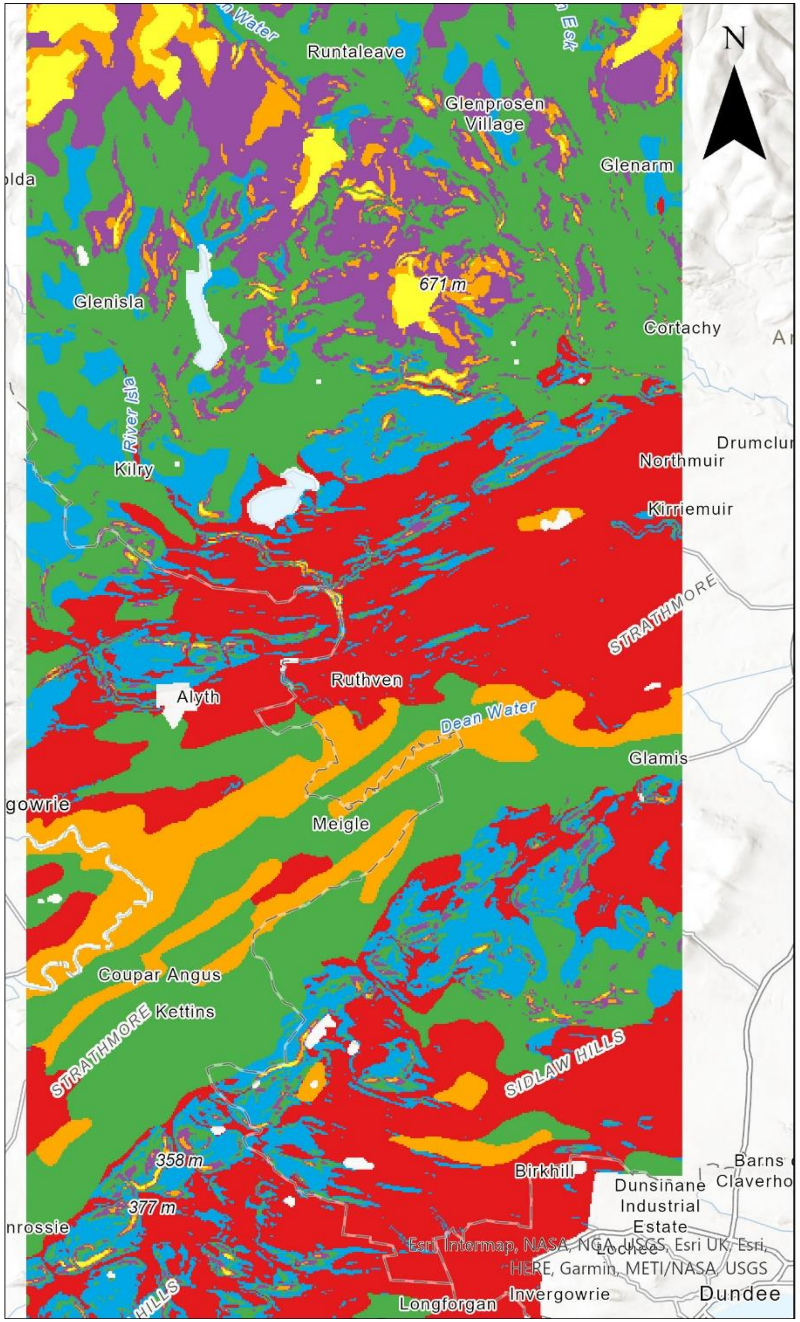


Figure 5: Wetness (w)

Overlap in the definitions of criteria required decisions to be made to ensure that seven sub-classes are consistently applied for direct comparison. With gradient, for example, class 5 specifies a value below 25° but usually less than 20°. Though it is recognised that this could be challenged by various stakeholders, the lower values of 15° to 20° and 20° to 25° are used for classes 5 and 6 respectively.

Cell statistics was used to create the final LCA map, with the 5 raster layers displayed above analysed according to the maximum operator, with the final output map displaying the highest class identified in each cell. Therefore, land is being assessed according to the most limiting factor, be it liability to erosion, soil limitations and so on (Map 2). This allows zones of most suitable land to be identified easily, however, the final LCA map does not specify which of the limiting factors are displayed, requiring further scrutiny of other layers before making a final decision.

Map 2: Land Capability Assessment for Strathmore Valley Region displaying most limiting factor for each area.



LCA Classes
- 2 - Minor limitations that reduce the choice of crops and interfere with cultivations
- 3 - Moderate limitations that restrict the choice of crops and/or demand careful management
- 4 - Moderately severe limitations that restrict the choice of crops and/or require very careful management practices
- 5 - Severe limitations that restrict its use to pasture, forestry and recreation
- 6 - Very severe limitations that restrict use to rough grazing, forestry and rough pasture/recreation
- 7 - Extremely severe limitations that cannot be rectified

Map Projection: Transverse Mercator
Projected Coordinate System: British National Grid

Data Sources:
This Land Capability Assessment Map has been created from raster layers derived from Ordnance Survey Terrain 50 Digital Terrain Models and soil classification data based on The James Hutton Institute (2020) and Evans (1980) as provided by University of Leeds.

0 2.5 5 10 Kilometers

Extent of Study Area

0 110 220 330 Kilometers

Methodology and Results – Extra Factors

In developing the MCE extra factors were considered that may be pertinent in agricultural planning, including distance from built-up areas; distance from roads; degree of 'South-facigness'; and Wetness Index.

To evaluate the distance of each cell from those classified in soil class 10 (built-up areas) the soil raster layer was reclassified to only recognise class 10 cells. Following this the distance accumulation tool was used to create a new layer displaying the distance of each cell from the nearest cell identified as a built-up area (figure 6). In a mountainous region the question of landscape impediment is arguably important, therefore distance from roads was calculated as a separate layer by rasterising the roads vector layer before running the distance accumulation again. The slope layer is added to calculate the cost of traversing the local topography. This layer was then standardised to display a 0 to 1 scale, with 0 denoting closest to a road cell (figure 7), using formula (1).

$$X = \frac{Xk - Xmin}{Xmax - Xmin}$$

(1)

Where *Xk* is the value of an individual raster cell, *Xmin* is the lowest value, and *Xmax* is the highest value. This provides a potentially more accurate representation of distance in the study area, though the conversion of vector data into 50m resolution cells can be questioned in that it may be difficult to determine the extent to which a road is present in any given cell.

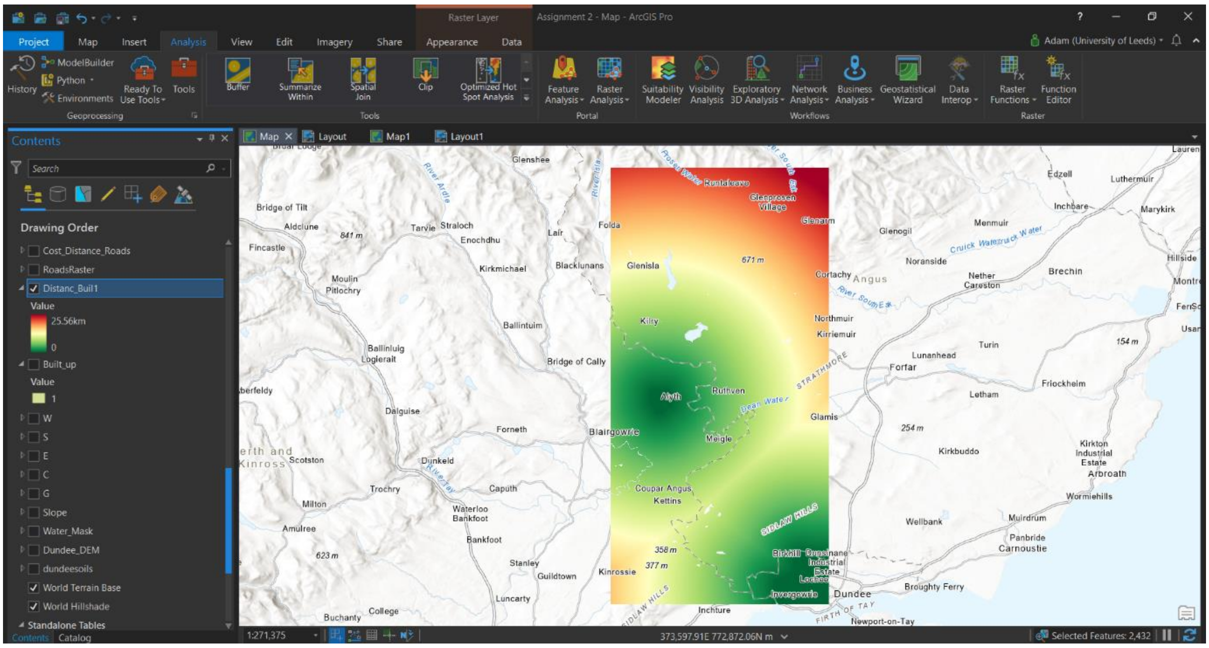


Figure 6: Distance from built-up areas(no cost)

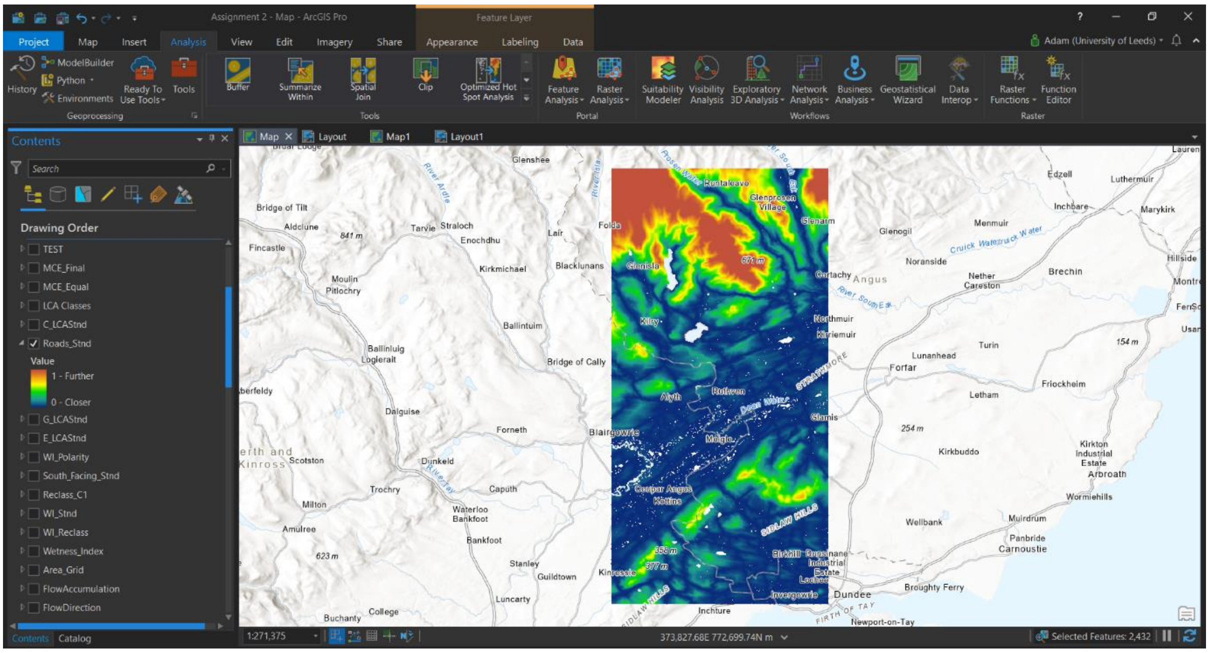


Figure 7: Distance from roads, cost distance

South-facingness was derived from calculating the Aspect of the DEM layer. The aspect layer displays the orientation of the slope in eight-point compass readings. In order to further analyse this in the raster calculator the aspect readings are converted into radians. The cosine of the result is found before applying Formula (1) to the new raster layer to create a standardised south-facingness layer where a value close to zero indicates a south facing slope (Figure 8)

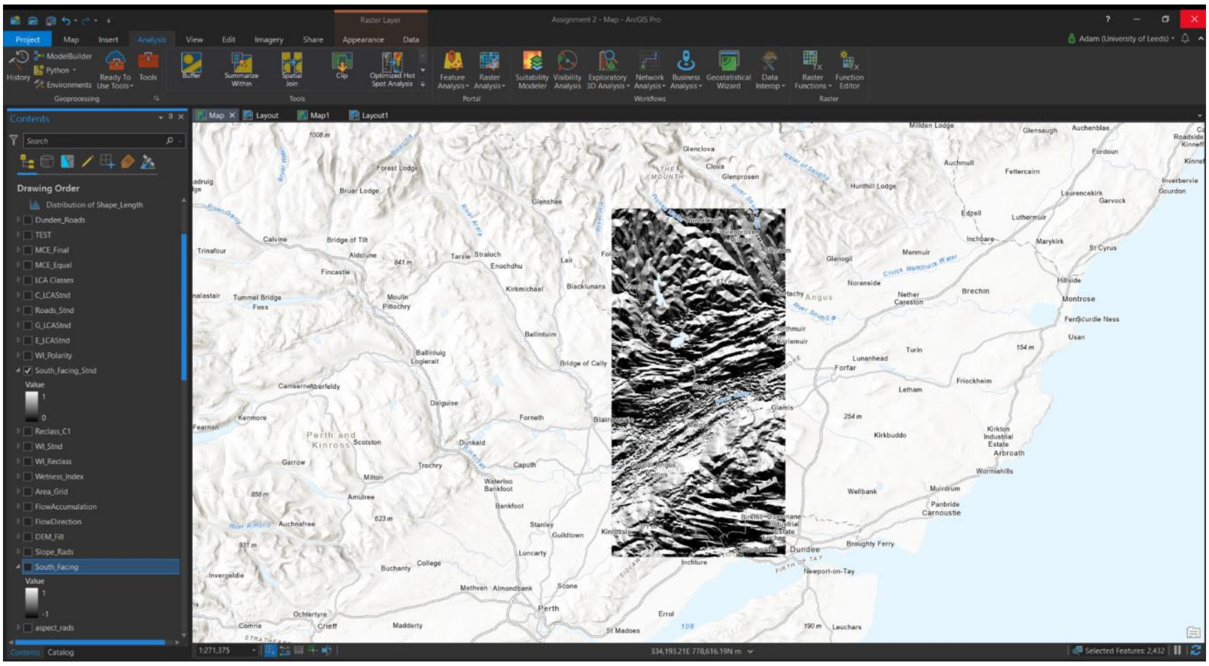


Figure 8: Degree of South-facingness

The Wetness Index (figure 9) is calculated using the DEM, with a ‘fill’ layer created to reduce any imperfections (ESRI, n.d.). The flow direction tool is used to create a layer displaying the direction of water flow in each cell, flow accumulation is derived from this to show the density of flow to a given cell. To calculate the wetness index the slope layer is converted to radians before using formula (2) to calculate the wetness of the soil in each cell:

$$WI = Ln(\frac{a}{tan\beta}) \tag{2}$$

Where *a* is:

$$a = x^2 \text{ x } y \tag{3}$$

x is the resolution of the raster layers (50m) and *y* is the flow accumulation layer. β refers to slope. The resulting layer has a condition applied to it in order to reclassify NODATA into values of zero. This creates a layer with a polarity opposite to that which is beneficial for this report, it is revered so that lower numbers represent ‘best’.

$$X = 1 - \frac{Xk - Xmin}{Xmax - Xmin} \tag{4}$$

With symbology as denoted in formula (1).

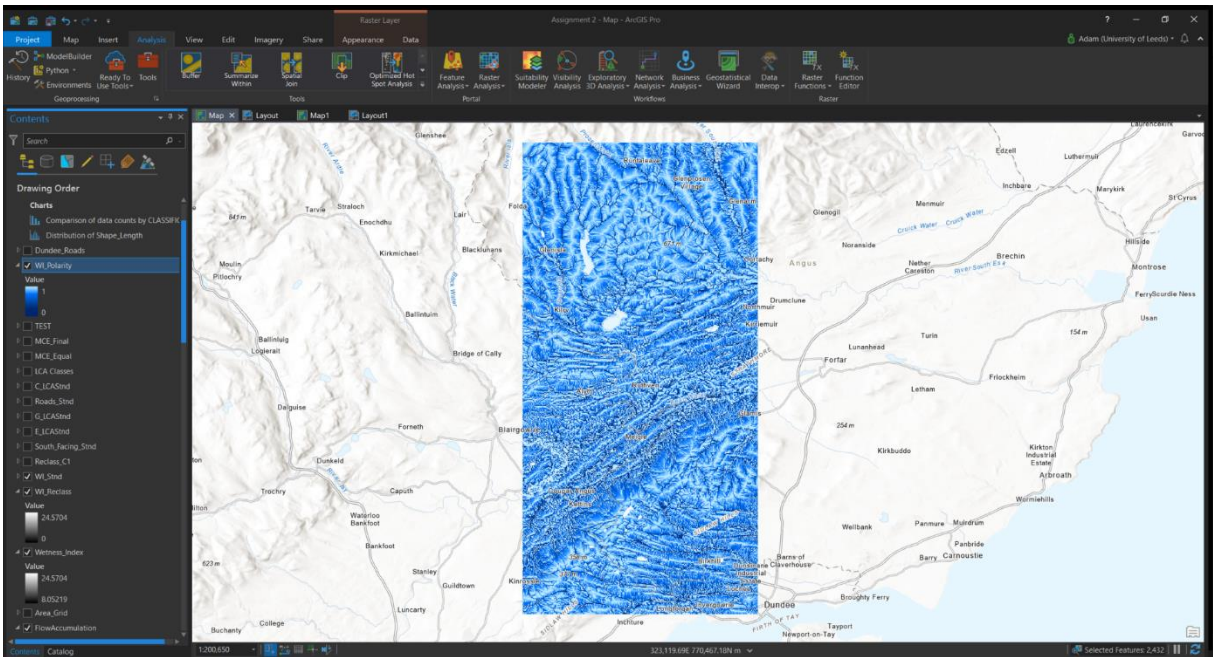


Figure 9: Wetness Index raster layer

Methodology and Results – MCE

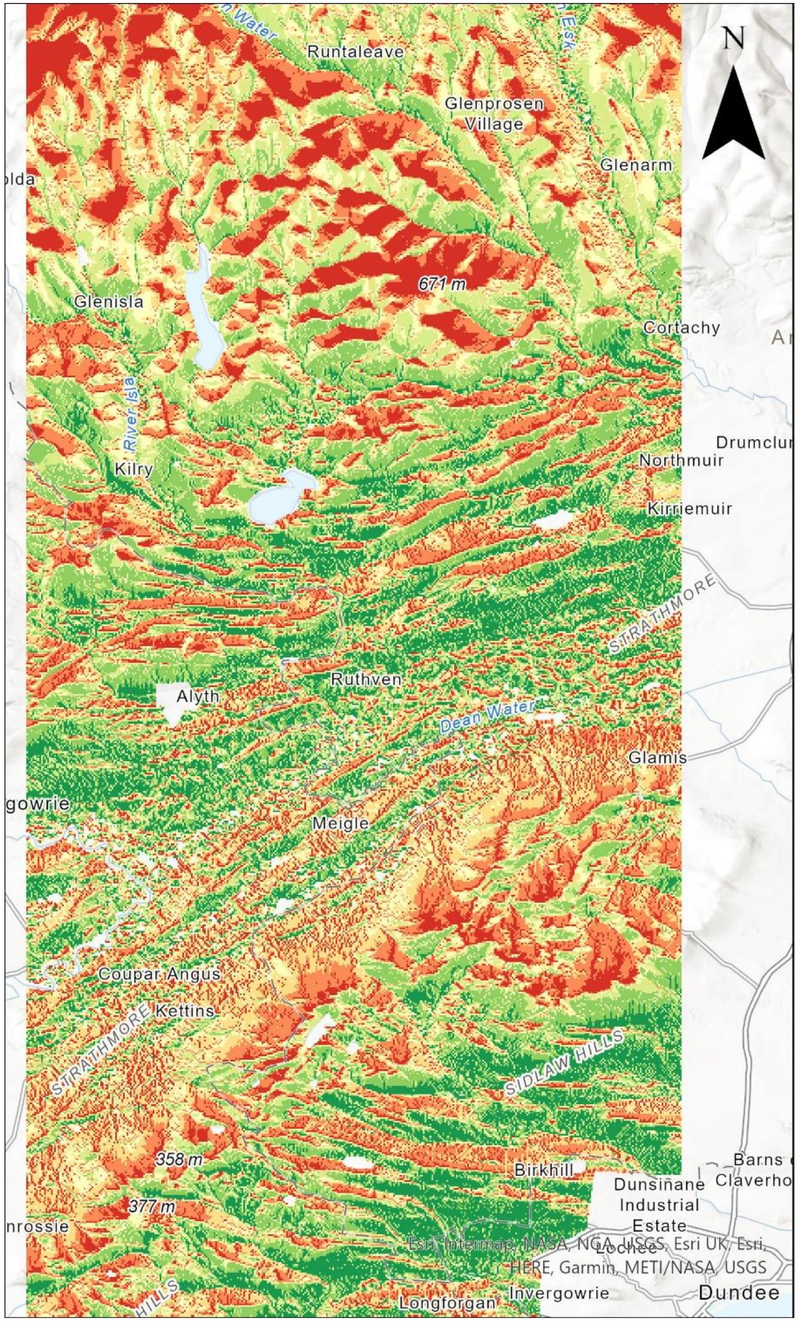
The MCE was created by giving weightings to each chosen layer in the raster calculator to produce a final map (table 8, formula 5).

Layer	Weighting
(a) Distance from roads	0.30
(b) South-Facingness	0.30
(c) Wetness Index	0.25
(d) Climatic Limitations	0.10
(e) Liability to Erosion	0.05

Table 8: MCE Weightings

$$MCE = (0.3 * a) + (0.3 * b) + (0.25 * c) + (0.1 * d) + (0.05 * e) \tag{5}$$

Weightings are based on Scottish Government (2020a, 2020b) proposals discussing future land use strategy. These are focussed on the development of sustainable agriculture which maximises yields, while limiting environmental impacts through developing a green economy based on shorter supply chains (Scottish Government, 2020b). Therefore, distance from roads was given an increased weighting since it considers physical landscape in the distance calculation. South-facing slopes and wetness are important factors in increasing yields, whilst climatic limitations and liability to erosion also need to be considered for sustainability. This range of layers also gives data that are derived from DEM, slope, aspect whilst also considering socio-economic elements in the accessibility of land, ensuring that redundancy in the data is limited. The final output (Map 3) displays the MCE findings with a score of 0 denoting most suitable location.



Map 3: Weighted Multi-Criteria Evaluation of Agricultural Land Suitability for the Strathmore Valley Region, Scotland

MCE

Value

- 0.046 - 0.196
- 0.196 - 0.282
- 0.282 - 0.343
- 0.343 - 0.408
- 0.408 - 0.456
- 0.456 - 0.524
- 0.524 - 0.917

Map Projection: Transverse Mercator
Projected Coordinate System: British National Grid

Data Sources:
This Multi-Criteria Evaluation Map has been created from raster layers derived from Ordnance Survey Terrain 50 Digital Terrain Models, VectorMap District data and soil classification data based on The James Hutton Institute (2020) and Evans (1980) as provided by University of Leeds.

0 2.5 5 10 Kilometers

Extent of Study Area

0 110 220 330 Kilometers

Discussion

Comparing the results of the LCA and MCE methods (figure 10) reveals that the LCA method gives a more 'zonal' set of results. The most suitable land in the study area is identified as the central region and the South-Eastern corner. This is useful for agricultural planning as this allows broad areas of potential development to be considered, however, it is worth stating that the maximum operator approach applied to this is limiting the strength of any conclusions. Note that no areas conform to LCA class 1 as this would require each of the 5 components analysed to identify as such, which may invalidly suggest that agricultural productivity is controlled by the most limiting factor present (VanRanst *et al.*, 1996; Malczewski, 2004).

The MCE method broadly identifies similar zones as the LCA, however, due to the weightings used land within these zones with less-desirable outcomes are given; the opposite is also true in that areas identified as class 4 and 5 in the LCA contain suitable land, particularly in the lower-lying, south facing valley floors in the north. The utility of the MCE is that all factors have been given a known weighting and thus further limiting factors would not need to be explored in other data sets. The use of the MCE approach is widely advocated in the literature as providing greater flexibility (Janssen and Rievelt, 1990; Davidson, 2002) and acknowledging the multi-dimensional approach needed in policy making (Carver, 1991).

The MCE can be critiqued regarding the selection of factors and the associated weighting as it is based on an interpretation of policy direction in a weighted linear combination (WLC) (Malczewski, 2000). This arbitrary selection of weightings could arguably be enhanced through using decision-making frameworks such as the Analytical Hierarchy Process (AHP) (Melczewski, 2004). This allows for the views of all parties to be assessed in determining weightings of input factors, therefore developing weights based on a range of expert contributions (Chaudhary *et al.*, 2016) resulting in a more holistic outcome that can be assessed equally by all parties.

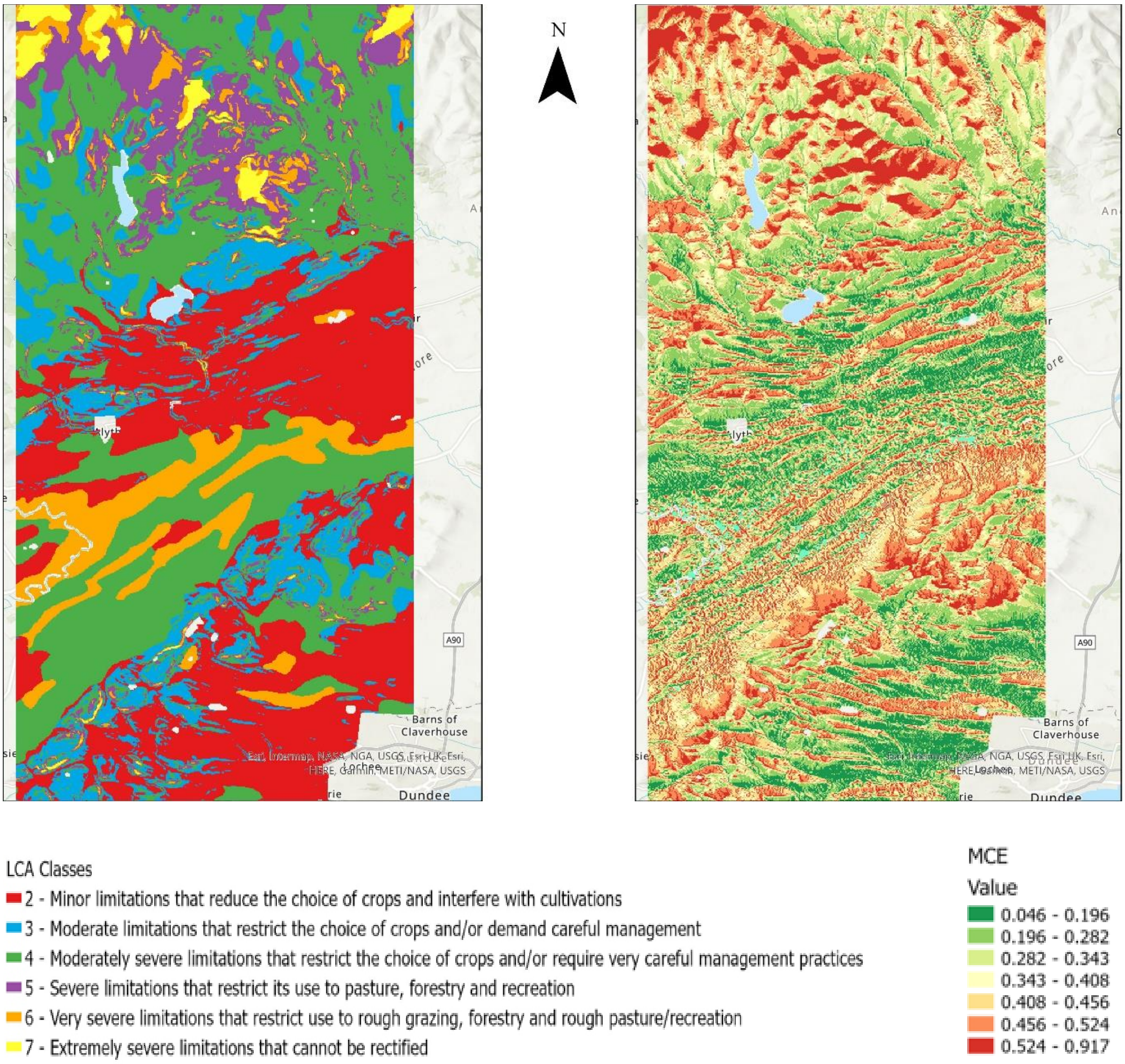


Figure 10: LCA(left) and MCE(right)

Within this methodology areas of Dundee and Alyth are not evaluated as they are classified as built-up areas in the soil raster (class 10) despite other known urban areas being included with a soil classification. In order to rectify this the buildings layer included in the Vector District file could be utilised to further identify built-up areas and remove from the analysis. This data could be rasterised in the same way the roads data was and reclassified as a value of 10, matching soil classification. A maximum operator layer using cell statistics could then be created, effectively overriding the previously identified soil subclasses, and class 10 cells could then be reclassified as NODATA as in the original methodology. Potentially providing more valid consideration of agricultural policy by removing built-up areas from the analysis.

Conclusion

Overall, it is evident that LCA and MCE allow for an in-depth consideration of the constraints placed on land-use planning, however, the MCE method permits a more holistic approach in evaluating factors with a given weighting. In order to reach a full conclusion, however, it would be useful to add further to this by addressing shortcomings in the data, such as including precipitation in climatic limitations, or through the inclusion of more stringent methods for evaluating weightings in MCE through the introduction of a decision matrix method in order to realise the full potential of these contrasting approaches.

References

Brown, I., Towers, W., Rivington, M. and Black, H. I. J. (2008) Influence of climate change on agricultural land-use potential: Adapting and updating the land capability system for Scotland, *Climate Research* **37**, pp43-57

Carver, S. J. (1991) Integrating multi-criteria evaluation with geographical information systems, *International Journal of Geographical Information Systems* **5**(3), pp321-339

Chaudhary, P., Chhetri S. K., Joshi K. M., Shrestha B. M. and Kayastha, P. (2016) Application of an Analytic Hierarchy Process (AHP) in the GIS interface for suitable fire site selection: A case study from Kathmandu Metropolitan City, Nepal, *Socio-Economic Planning Sciences* **53**, pp60-71

Davidson, D. (1992) *The Evaluation of Land Resources,* Longman

Davidson, D. (2002) The Assessment of Land Resources: Achievements and New Challenges, *Australian Geographical Studies* **40**(2), pp109-128

ESRI (No Date) *How Fill Works*, [Online]. [Accessed 09 March 2021]. Available from https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-fill-works.htm

Heywood, C., Cornelius, S. and Carver, S. (2011) *Introduction to Geographical Information Systems. In Introduction to Geographical Information Systems,* Pearson Prentice Hall, UK

Janssen, R. and Rievelt, P (1990) Multicriteria analysis and GIS: an application to agricultural land use in the Netherlands, in: Scholten, H. J. and Stillwell, J. C. H. (eds), *Geographical Information Systems for Urban and Regional Planning,* Kluwer Academic, Dordrecht

Malczewski, J. (2000) On the Use of Weighted Linear Combination Method in GIS: Common and Best Practice Approaches, *Transactions in GIS* **4**(1), pp5-22

Malczewski, J. (2004) GIS-based land-use suitability analysis: a critical overview, *Progress in Planning*, 62(1), pp 3-65

Scottish Government (2020a) *Getting the best from our land – a land use strategy 2016 to 2021: first annual progress report* [Online]. [Accessed 06 March 2021] Available from: https://www.gov.scot/publications/first-annual-progress-report-getting-best-land-land-use-strategy-scotland-2016-2021/pages/3/

Scottish Government (2020b) *Farming and Food Production Future Policy Group update: March 2020* [Online]. [Accessed 06 March 2021] Available from: https://www.gov.scot/publications/farming-and-food-production-future-policy-group-update-march-2020/

University of Leeds (No Date) *Land Capability Assessment (LCA)*, University of Leeds, Leeds

Van Ranst, E., Tang, H., Groenemam, R. and Sinthurahat, S. (1996) Application of fuzzy logic to land suitability for rubber production in peninsular Thailand, *Geoderma* **70**(1), pp1-19,

Appendix

Guidelines for the recognition of capability classes:

Class 1	Land with very minor or no physical limitations to use. Soils are usually well drained, deep (more than 75cm) loams, sandy loams or silty loams, related humic variants or peat, with good reserves of moisture or with suitable access for roots to moisture; they are either well supplied with nutrients or responsive to application of fertilisers. The land is level or gently sloping (usually less than 3°) and climate favourable; altitude below 150m.
Comment:	A wide range of crops can be grown and yields are good with moderate inputs of fertiliser.

Class 2	Land with minor limitations that reduce the choice of crops and interfere with cultivations.
Subclass	Limitations may include, singly or in combination, the effects of:
w	moderate or imperfect drainage
s	less than ideal rooting depth (not less than 50cm) and/or slightly unfavourable soil structure and texture
g	moderate slopes (not greater than 7°)
e	slight erosion
c	slightly unfavourable climate (altitude usually below 230m)
Comment:	A wide range of crops can be grown though some root crops and winter harvested crops may not be ideal choices because of harvesting difficulties.

Class 3	Land with moderate limitations that restrict the choice of crops and/or demand careful management.
Subclass	Limitations may result from the effects of one or more of the following:
w	imperfect or poor drainage
s	restriction in rooting depth (not less than 25cm) and/or unfavourable structure and texture
g	strongly sloping ground (not greater than 11°)
e	slight erosion
c	moderately unfavourable to moderately severe climate (more than 1000mm annual rainfall and altitudes usually below 380m)
Comment:	The limitations affect the timing of cultivation and range of crops which are restricted mainly to grass, cereal and forage crops. Whilst good yields are possible, limitations are more difficult to correct.

Class 4	Land with moderately severe limitations that restrict the choice of crops and/or require very careful management practices.
Subclass	Limitations are due to the effects of one or more of the following:
w	poor drainage difficult to remedy and/or occasionally damaging floods
s	shallow and/or very stony soils but capable of being ploughed
g	moderately steep gradients (not greater than 15°)
e	slight erosion, especially loose or sandy soils in exposed areas
c	moderately severe climate (more than 1270mm annual rainfall and altitudes usually below 460m)
Comment:	Climatic disadvantages combine with other limitations to restrict the choice and yield of crops and increase risks. The main crop is grass, with cereals and forage crops as possible alternatives where the increased hazards can be accepted.

Class 5	Land with severe limitations that restrict its use to pasture, forestry and recreation.
Subclass	Limitations are due to one or more of the following defects which cannot be corrected:
w	poor or very poor drainage and/or frequent damaging floods
s	soils too shallow or stony to plough satisfactorily
g	steep slopes (not greater than 25° and usually less than 20°)
e	severe risk of erosion
c	severe climate (altitude usually below 530m)
Comment:	High rainfall, exposure and a restricted growing season prohibit arable cropping although mechanised pasture improvements are feasible. The land has a wide range of capability for forestry and recreation.

Class 6	Land with very severe limitations that restrict use to rough grazing, forestry and recreation.
Subclass	Of the following limitations one or more cannot be corrected:
w	very poor drainage and/or liable to frequent damaging floods
s	shallow soil, extremely stony or boulder strewn
g	very steep slopes (greater than 20°)
e	severe erosion
c	very severe climate (usually below 610m)
Comment:	The land has limitations which are sufficiently severe to prevent the use of machinery for pasture improvement. Very steep ground which has some sustained grazing value is included. On level or gently sloping upland sites wetness is closely correlated with peat or humose flush soils.

Class 7	Land with extremely severe limitations that cannot be rectified.
Subclass	Limitations result from one of more of the following defects:
w	very poor drainage; boggy soils
s	extremely stony, rocky or boulder strewn soils, bare rock, scree or beach sands and gravels; untreated waste tips
g	very steep gradients (generally greater than 25°)
e	severe erosion
c	extremely severe climate (altitude over 610m)
Comment:	Exposed situations, protracted snow cover and a short growing season preclude forestry though a poor type of rough grazing may be available for a few months.

Source: University of Leeds (n.d.) p2-3