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Mayo 'Dark and Wild' Amenities – a Multi-Criteria Evaluation

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Document History

Version	Date	Description
2.0	March 6th, 2021	This current version of the report has been reformatted to facilitate online publication. The only material change from Version 1.0 is that for reasons of privacy the names of the individuals who supported this project have been removed. These individuals are instead referred to by their job title and place of work – be it in the Department of Geography or the National Centre for Geocomputation at Maynooth University, in the Western Division of the National Parks and Wildlife Service, or in the School of Physics at Trinity College Dublin. Their support remains very much appreciated by the author.
1.0	March 20th, 2020	The original version of this report was prepared by the author and submitted to academic staff at the Department of Geography, Maynooth University towards fulfilment of requirements for the degree of Masters of Science in Geocomputation at the National Centre for Geocomputation, also in Maynooth University.

Credits

This project makes use of the following datasets:

- Designated Area boundary data as published by the National Parks and Wildlife Service [1]
- Local Authority boundary data as published by the Ordnance Survey Ireland [2]
- Elevation Data as published by NASA's Jet Propulsion Laboratory from their Shuttle Radar Topography Mission [3]
- CORINE Landcover Classification dataset, copyright the European Union, Copernicus Land Monitoring Service 2020, European Environment Agency [4]
- Dark Sky data as provided by the School of Physics, Trinity College Dublin [5]
- OpenStreetMap Data, published under the Open Database License and copyright OpenStreetMap contributors [6]
- ESRI Imagery, copyright ESRI, Maxar and Microsoft [7]

Executive Summary

This document describes a Multi-Criteria Evaluation designed to identify sites that may be most suitable to host amenities related to both the biodiversity of County Mayo, and the Mayo Dark Sky [8] initiative. Such amenities might include low-impact signage suitable for protected sites, as well as more substantial facilities such as boardwalks, bird-hides and interpretive centres that are more appropriate for less sensitive locations.

Data sets used in this analysis include Artificial Sky Brightness data for Ireland as of 2015 [5], details of proposed Natural Heritage Areas [9] as per the National Parks and Wildlife Service (NPWS), and details of places, water bodies, roads, tracks and paths as per OpenStreetMap [6]. The analysis also considers the buffer of land immediately surrounding County Mayo, allowing the impact of features just outside the county boundary to be accounted for.

Among the constraints evaluated in this analysis are the requirement for sites to have minimal slope, to support accessibility by the public, and the need for a view of the sky unobstructed by the terrain. This latter constraint has been fulfilled by calculating hill-shades based on low-lying sources of light.

Among the factors considered is a scoring of all locations based on nearby habitats and the potential for biodiversity of significance. Calculations consider how far from each type of habitat could an amenity be placed, and whether an amenity could be placed within the habitat. For some habitat types an amenity would only be appropriate within a certain range of the outside edge. For example, it would not be recommended to install a bird-hide in the middle of large peat-bog, with the wildlife being disturbed by the public heading to and from the hide. The scoring of habitat and biodiversity potential is based on CORINE Landcover Classification 2018 [4] data, enriched with details of smaller lakes in such a way as to avoid inadvertent double-scoring of the smaller lake sites.

The final site suitability scores have been calculated after appropriate weighting of all factors, and the highest scoring sites extracted as highlight locations. These highlights have been divided into Level 1, 2 and 3, with Level 1 containing the highest scoring sites.

Highlight locations have been further classified into Designated and non-Designated sites. This allows more considered placement of amenities based on their impact: only low-impact amenities should be considered for designated areas. Substantial amenities would be more appropriate in non-designated locations.

It is hoped that this analysis can be of some assistance to stakeholders seeking to increase an awareness of and appreciation for the rich biodiversity of County Mayo, and its valuable Dark Sky.

For the convenience of interested parties the results have been posted on ArcGIS online [10], and at the time of writing are available at the URL https://arcg.is/1SjK0L.

Acknowledgements

The author sincerely thanks

- The academic staff at the Department of Geography, Maynooth University for accommodating this one-off project as part of the M. Sc. in Geocomputation programme at the National Centre for Geocomputation, Maynooth University.
- The Divisional Ecologist of the NPWS, Western Division, for valuable insights and feedback on the project concept, suitability criteria, and relative weightings of the land cover classifications
- Academic staff at the School of Physics of Trinity College Dublin, for the generous provision of the 2015 Artificial Sky Brightness map of Ireland
- District Conservation Officer of the NPWS for kindly sourcing definitions of proposed NHAs.

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Abbreviations

CLC	CORINE Landcover Classification
CRS	Coordinate Reference System
DTM	Digital Terrain Model
GIS	Geographical Information System
NHA	Natural Heritage Area
NPWS	National Parks and Wildlife Service
pNHA	Proposed Natural Heritage Area
SAC	Special Area of Conservation
SPA	Special Protection Area

1. Introduction

Project Scope

This assignment requires a Multi-Criteria Evaluation analysis to be performed to identify the most suitable sites to locate selected infrastructure in County Mayo, Ireland. Numerous national data sets have been made available including details of Irish Roads, Rivers, Lakes, Land-use in 2018 as per the CORINE Land Cover dataset, Geology, Digital Terrain Model (to 90m resolution), 2016 Census data at Small Area resolution, and Protected Areas including Natural Heritage Areas (NHAs), Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). The analysis can be supplemented by additional relevant data sets.

Project Selection

Noting that the United Nations Sustainable Development Goals [11] include Good Health and Well-Being, Quality Education, Climate Action, Life on Land, and Partnership for the Goals, it was initially decided to explore the siting of infrastructure that could contribute to increased wellbeing, education, and awareness of local biodiversity, in partnership with appropriate stakeholders in County Mayo.

Contact was made with the National Parks and Wildlife Service Divisional Ecologist, Western Division, who kindly engaged with colleagues to propose more specific types of infrastructure of particular interest and relevance to County Mayo. These included identifying potential routes for Green Ways through the county, potential sites for Dark Sky camping facilities, and 'Bird hides under Dark Skies'.

It was initially decided to pursue siting of 'Bird hides under Dark Skies', but over the course of the project the scope was broadened to identify sites which had potential to host any type of amenity associated with both the biodiversity of Mayo, and Mayo's Dark Sky. Such amenities could include low-impact infrastructure such as explanatory or way-finding signage, or more significant installations such as bird-hides (with appropriate roofing to view the night sky), boardwalks and interpretive centres.

This scope of identifying sites for wildlife and dark-sky related amenities was selected due to the

- potential usefulness of the analysis to the NPWS, Mayo County Council, Fáilte Ireland, community groups promoting local biodiversity such as local Tidy Towns groups, and related stakeholders
- contribution the project could make to mental well-bring and quality education initiatives, increasing accessibility to and raising awareness of local biodiversity and the night sky
- presence and strength of existing 'Dark Sky' [8] and 'Atlantic Way' [12] initiatives in County Mayo
- potential to integrate additional data sets into the analysis
- challenge of distinguishing between sites that could potentially host significant infrastructure, and those much more sensitive sites where only low-impact amenities would be appropriate
- the author's personal experience and interest in biodiversity, including ongoing participation in citizen science surveys of moths, various species of bats, and 21 years' participation as volunteer surveyor in the national Countryside Bird Survey [13].

Locating Mayo 'Dark and Wild' Amenities

Amenities which are envisioned could be sited under this initiative range from simple way-finding or explanatory signage, to full scale interpretive centres. They include accessible board walks such as at Claggan Mountain Coastal Trail [14], and the construction of hides with suitable roofing that could be used to observe nearby wildlife during the day, and the stars and planets at night.

A typical hide is a wooden cabin-like structure with windows and seating designed to allow nearby habitats such as wetlands to be surveyed using the naked eye, binoculars and telescopes, without disturbing the wildlife. They are often sited carefully so that people approaching the hide are shielded from view to avoid disturbing the wildlife. For the purposes of this project, hides would also have extensive clear sections in their roofs through which the night sky could be observed.

In early 2020 a querying of the data within OpenStreetMap [6] revealed the locations of 7 bird-watching or wildlife-watching hides in Ireland. However, a subsequent review of all Birdwatch Ireland nature reserve site guides [15] revealed that numerous hides were missing, or tagged insufficiently. Missing hides were added and some existing hides updated: at time of writing the details of 20 hides around the country are now within the database.

Reviewing the locations of these existing reference amenities, and with the agreement of the NPWS Divisional Ecologist for County Mayo, the following list of criteria has been developed to help determine site-suitability for wildlife and dark-sky related infrastructure in County Mayo.

It is considered that the most suitable sites should be

- near to wildlife-rich or important habitat, such as open water, wetlands or estuaries
- under dark sky, away from fixed and mobile sources of light pollution
- near to an existing road, track or path for public accessibility and construction purposes
- not located on sloped land – to facilitate ease of public access
- not located near to busy roads (to minimise disturbance and light, noise and exhaust pollution)
- not located where the view of the sky is obstructed by local terrain – e.g. by a nearby mountain

Additionally, sites considered suitable should be distinguishable as sensitive if they are located within a statutory SPA, SAC, NHA, or pNHA.

Document Outline

The remainder of this document describes the analysis in some detail. Chapter 2 introduces the various data sets explored and ultimately selected for the analysis, as well as some pre-processing steps that proved appropriate. The workflows required to generate individual maps for each of six constraints and two factors are detailed in Chapter 3. Chapter 4 explains how these criteria are combined to generate the final site suitability scores. It also describes the selection and classification process for the most suitable sites identified. Conclusions are presented in Chapter 5.

2. Data Collation and Preparation

Data Gathering

An extensive set of geospatial data layers has been made available at the outset of this project. These layers have been reviewed and explored for relevance to this particular project's goals. Additional data layers have been sourced to complement the initial data supplied. All of the key data layers considered for this analysis are introduced below. Some challenges with the data were observed during the course of the project - these are highlighted in the various note sections that follow.

Local Authorities 2016

Description	Polygon definition of all local authorities in Ireland as of 2016
Source	Presupplied
Projection	TM65 Irish Grid - Transverse Mercator
Notes	Visual inspection reveals polygon edges are not shared lines. Dissolving all counties to form the border of Ireland also generates many very narrow gaps within the country, along county boundaries.

Ireland Lakes

Description	Polygon definition of lakes in Ireland
Source	Presupplied
Projection	TM65 Irish Grid - Transverse Mercator
Notes	Superimposing on top of a satellite imagery basemap layer reveals lake edges are relatively coarsely defined and smaller lakes, including many in County Mayo, are not included.

Irish Roads

Description	Vector definition of primary, secondary, unclassified and some other roads in Ireland
Source	Presupplied
Projection	TM65 Irish Grid - Transverse Mercator
Notes	Superimposing on top of a satellite imagery basemap layer reveals many roads including residential area roads and roads built since the 1980s such as the M50 are not included.

Irish Roads – Streets 2

Description	Vector definition of roads in Ireland including residential roads
Source	Presupplied
Projection	TM65 Irish Grid - Transverse Mercator
Notes	Superimposing on top of a satellite imagery basemap layer reveals this is a comprehensive set of roads but does not include some roads opened in recent years e.g. M18 Gort to Tuam motorway, N18 Limerick Tunnel.

Ireland DTM

Description	Raster digital terrain model of Ireland to 90m resolution
Source	Presupplied
Projection	TM65 Irish Grid - Transverse Mercator

CORINE Land Cover 2018

Description	Vector polygon classification of land use in Ireland as per CORINE Land Cover 2018 dataset [4]
Source	Presupplied
Projection	TM65 Irish Grid - Transverse Mercator
Notes	Superimposing on top of a satellite imagery basemap layer reveals this is a comprehensive classification of land cover. Within County Mayo, smaller water bodies are not classified. Documentation reveals CORINE employs a minimum mapping unit of 25 hectares [4].

Protected Areas: NHAs, SAC, SPAs

Description	Polygon definition of all Natural Heritage Areas, Special Areas of Conservation and Special Protection Areas in Ireland
Source	Presupplied
Projection	IRENET95 Irish Transverse Mercator
Notes	The latest version of these files (December 2019) are available online from NPWS [1]

Protected Areas: Proposed NHAs

Description	Polygon definition of all proposed Natural Heritage Areas in Ireland
Source	NPWS [1]
Projection	IRENET95 Irish Transverse Mercator
Notes	These sites are not yet statutorily protected, but are of significance for wildlife or habitats and are candidates for future formal statutory protection.

OpenStreetMap: Places, Roads, Water

Description	Set of vector point and polygon shapefiles including all places, waterways, roads and tracks in Ireland and Northern Ireland as per www.OpenStreetMap.org
Source	Geofabrik OpenStreetMap Download for Ireland and Northern Ireland [16], downloaded Feb 12th 2020 Note that OpenStreetMap data is © OpenStreetMap Contributors.
Projection	GCS WGS 1984
Notes	Superimposing the various shapefiles on top of a satellite imagery basemap layer and exploring the attribute tables reveals • **gis_osm_places_free_1** includes definitions for all counties using polygons with shared borders • **gis_osm_roads_free_1** includes a comprehensive set of paved roads, unpaved tracks and paths of all types • **gis_osm_water_a_free_1** includes a comprehensive set of lakes, ponds, reservoirs and other water features of all sizes These shapefile extracts are updated every 24 hours.

Ireland Artificial Sky Brightness 2015

Description	Raster of artificial sky brightness of Ireland as of 2015 – see Figure 1
Source	Courtesy academic staff of the School of Physics, Trinity College Dublin [5]
Projection	GCS WGS 1984
Notes	The measurements of brightness range from a darkest value of 0 to a brightest value of 8.215 globally calibrated units.

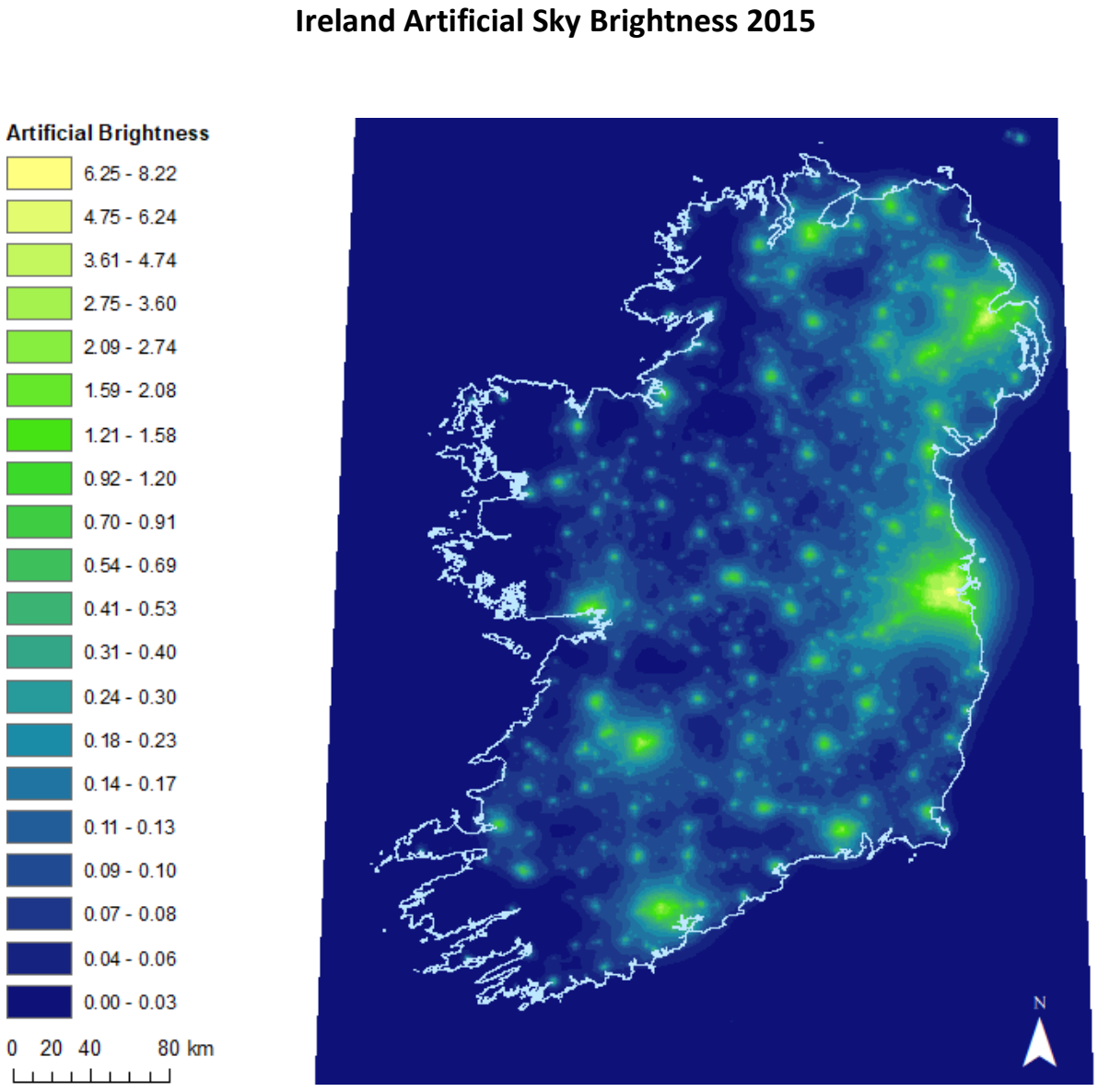


Figure 1: Artificial Sky Brightness of Ireland, 2015

Data Exploration

A number of the candidate data sets were examined for completeness through manual comparison with equivalent data sets, and overlaying on top of recent aerial imagery basemaps.

A sense of the level of detail in the various roadway data sets can be seen in Figure 2. Each map is centred on Main Street, Castlebar. OpenStreetMap proved to be the richest of these data sets, including details of recently constructed roads as well as car park aisles, footpaths, and cycleways.

Figure 2: Main Street Castlebar as per Irish Roads, Streets 2 and OpenStreetMap Road data sets

A comparison of the detail within the lake data sets can be seen in Figure 3. The Ireland Lakes data set does not include any of the water bodies in the north of Achill Island, CORINE Land Cover 2018 only includes lakes of at least 25 hectares in area. OpenStreetMap is the richest of these data sets.

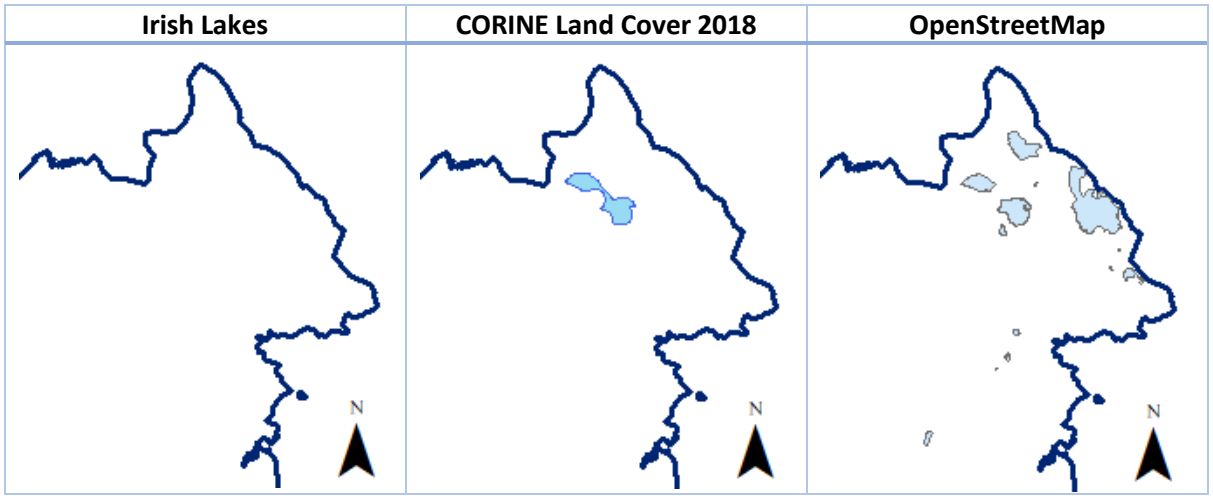


Figure 3: North-East Achill Island as per Irish Lakes, CORINE Land Cover 2018 and OpenStreetMap Water data sets

OpenStreetMap was thus selected as the preferred data source for details of Irish roads, tracks, paths, and lakes.

Data Preparation

Pre-processing was required on the raw data before analysis proper could begin.

To facilitate a reproducible analysis of data, it was decided to make extensive use of the ArcGIS ModelBuilder functionality within ArcMap version 10.6.0.8321, an application within the ESRI ArcGIS Desktop [17] suite. To simplify and streamline data management, specific local folders were created for Raw, Prepared, Analysis and Results data layers.

All raw data layers were stored under a `Data\Raw` folder, and the following pre-processing performed by executing the data models described.

Coordinate Reference System

As the raw data layers to be used were sourced with different coordinate reference systems, it was necessary to re-project several layers so that all shared a common coordinate reference system.

Given the Irish focus of this project and the potential usefulness of the analysis to Irish voluntary and statutory organisations, the TM65 Irish Grid coordinate reference system (CRS) was selected as the CRS of this analysis. This necessitated the SPA, SAC, NHA and pNHA layers be transformed from Irish Transverse Mercator, and the OpenStreetMap data layers from WGS 1984. ArcGIS ModelBuilder was used to define these re-projections as illustrated in Figure 4. The transformed data layers were stored under a folder `Data\Prepared`.

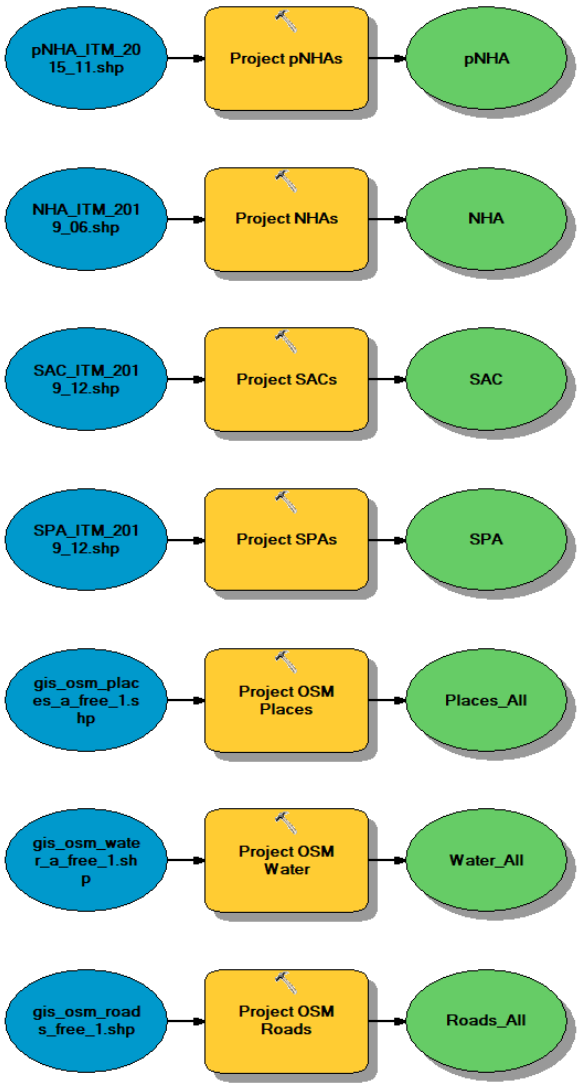


Figure 4: Model employed to reproject raw data

Boundaries

It was considered that several boundaries would be useful to facilitate the clipping of national data sets, the restriction of the analysis to County Mayo, and for visualisation purposes. ArcGIS ModelBuilder was used to extract the definition of County Mayo from the Local Authority 2016 data layer, to create a 15km buffer boundary around this county boundary, and to dissolve all counties with the Local Authority 2016 data layer into the border of Ireland as illustrated in Figure 5.

The 15km buffer around County Mayo was generated to help avoid miscalculations around the county boundary. For example, if a busy motorway ran along the border just outside the county boundary, adjacent stretches of County Mayo would be subject to significant noise, light and exhaust pollution that could be relevant to this analysis.

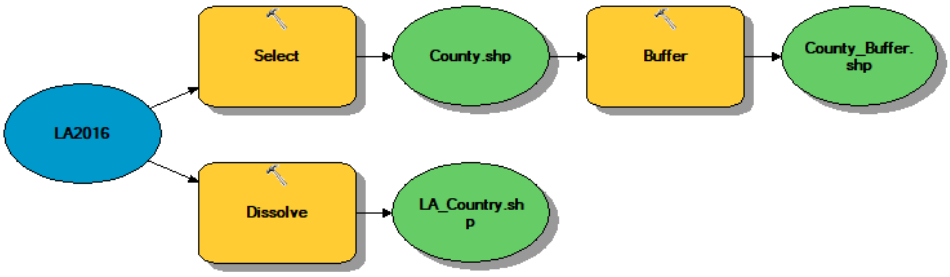


Figure 5: Model employed to extract county, define buffer and dissolve counties into country

It was observed that the Dissolve operation on the Local Authority data set provided more than the expected outline of the country - it also included many narrow pockets of land where the boundaries between adjacent counties were not perfectly aligned with each other. It was thus decided to extract the definition of the coastline of the island of Ireland from the OpenStreetMap Places data layer: all counties on the island were selected using the criteria `"fclass" = 'county'` and these counties were then dissolved to give the coastline of the entire island.

Figure 6: Model employed to construct outline of Ireland

Clipping and Detail Extraction

All supplied data sets included details for either the Republic of Ireland or the island of Ireland. To facilitate efficient analysis it was decided to clip data sets to just the relevant portion of Ireland: the area within the 15km buffer of County Mayo.

The County Buffer layer was used to clip the CORINE Land Cover, OpenStreetMap Roads, OpenStreetMap Water, and Ireland Artificial Sky Brightness layers.

Main Roads were extracted from the OpenStreetMap Roads data layer by applying the selection criteria `"fclass" = 'motorway' OR "fclass" = 'primary' OR "fclass" = 'trunk'`. The reference to trunk was required as some primary roads within County Mayo are tagged as trunk within OpenStreetMap.

Open bodies of fresh water were extracted from the OpenStreetMap Water data layer by applying the selection criteria `("fclass" = 'reservoir') OR ("fclass" = 'water')`. Other classifications of water such as 'wetland' were thus removed.

This clipping and extraction of details was performed using the model illustrated in Figure 7.

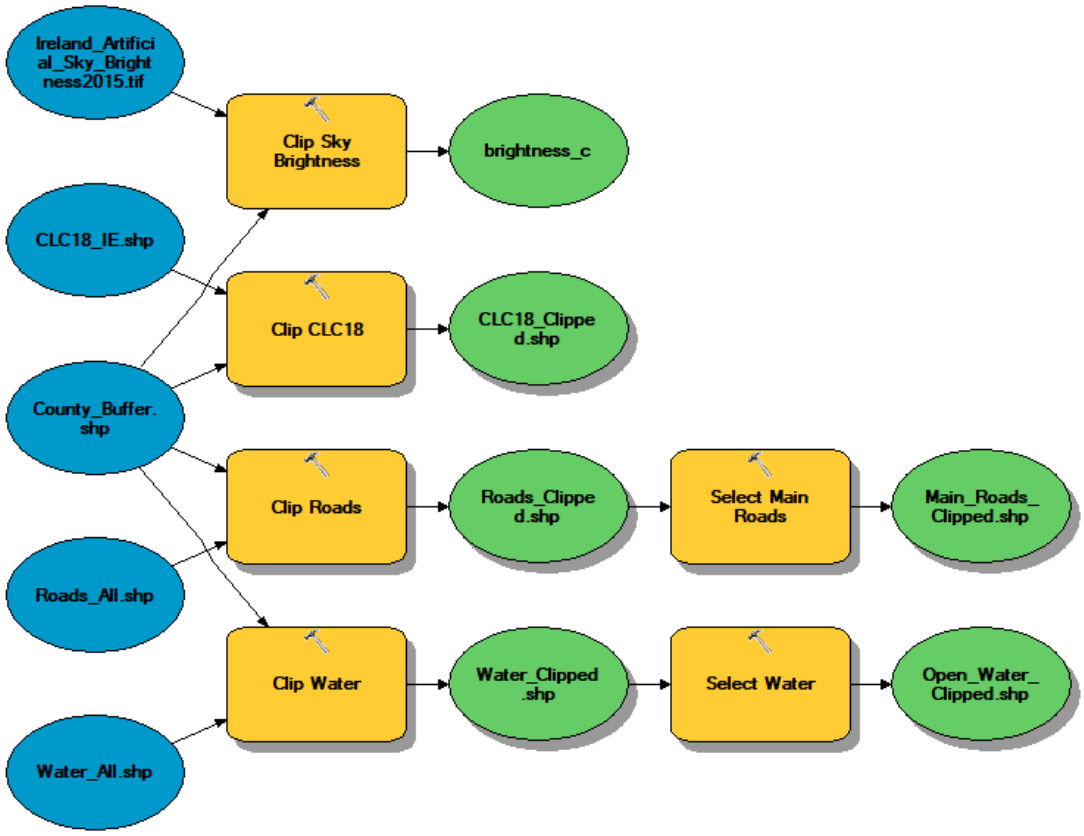


Figure 7: Model employed to clip national data sets, and to extract specific features

The clipped CORINE Land Cover dataset for County Mayo (and the surrounding buffer) included 29 classifications of land cover. To assist in the identification of areas of high wildlife potential, all those classifications of land cover considered to have a reasonable relevance for wildlife amenities were extracted into individual data layers. The individually extracted layers included inland marshes, estuaries, coastal lagoons, intertidal flats, 'land principally occupied by agriculture, with significant areas of natural vegetation', non-irrigated arable land, complex cultivation patterns, coniferous forest, broad-leaved forest, mixed forest, moors and heathland, natural grassland, salt marshes, peat bogs, transitional woodland-shrub, discontinuous urban fabric, pastures, sparsely vegetated areas, 'beaches, dunes, sands', and water bodies.

3. Data Processing

This multi-criteria evaluation was designed such that the site suitability scores could be calculated from a set of geospatial constraints and factors.

Constraints are those criteria resulting in a binary suitability for each location. Unsuitable locations are assigned a value of 0, suitable locations a value of 1. All constraints can be merged using an AND or multiplication operation resulting in a single data set indicating those sites that are entirely unconstrained.

Factors are those criteria where suitability lies somewhere on a scale – some locations are quantifiably better than others based on a criterion. For site suitability scoring purposes, each factor is normalised to contain values from 0 (not suitable at all) to 1 (ideally suited).

The site suitability score for each location can be determined by multiplying the merged constraints by the sum of the factors, weighted appropriately.

For the purposes of this analysis it was decided to use a resolution of 25 metres square for each location (or cell) to be evaluated. This would facilitate a reasonably fine-tuned site suitability analysis. It was considered that the ability to observe nearby wildlife could alter significantly beyond 25 metres.

Thus, before processing, the GIS environment was configured to have a Raster Analysis Cell Size of 25 metres squared. The GIS environment was also configured to have a Processing Extent bounded by the 15km buffer surrounding County Mayo. This allows the impact of features just outside the county boundary to be considered appropriately.

The remainder of this section describes the specific constraints and factors employed in this analysis. The six constraints and two factors evaluated are listed in Table 1.

Table 1: Project Constraints and Factors

Constraints	Factors
• C1: Within County Mayo • C2: Not a lake • C3: Near road or track • C4: Not sloped • C5: Not near primary road • C6: Unobstructed sky	• F1: Sky darkness • F2: Wildlife and habitat potential

C1: Within County Mayo

The analysis is restricted to County Mayo and thus a raster constraint limiting the suitable sites to County Mayo is required.

An integer field '`VALUE`' is added to the attribute table for the county boundary vector layer prepared previously (see page 13). The attribute table row for County Mayo is assigned a `VALUE` of 1. This layer is then converted to a raster using the `Polygon to Raster` function with value field set to `VALUE`. Those areas within the County are thus assigned a value of 1 in the resulting raster file.

Those areas outside the county need to be assigned a value of 0 (rather than `NoData`). This is achieved by using the `IsNull` function to generate a raster of the area outside the county, and then the conditional function `Con` to convert the area outside the county to 0. The area within the county remains 1.

The model generating this constraint is illustrated in Figure 8. A map of the resulting constraint is illustrated in Figure 9.

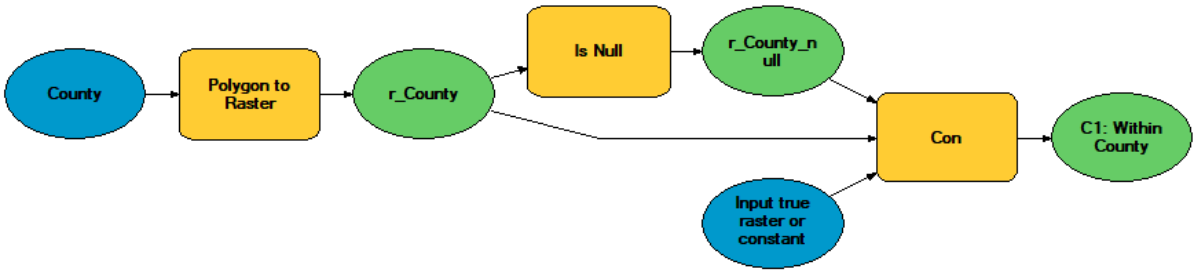


Figure 8: Deriving Constraint 1 - Within County Mayo

Constraint C1: Within County Mayo

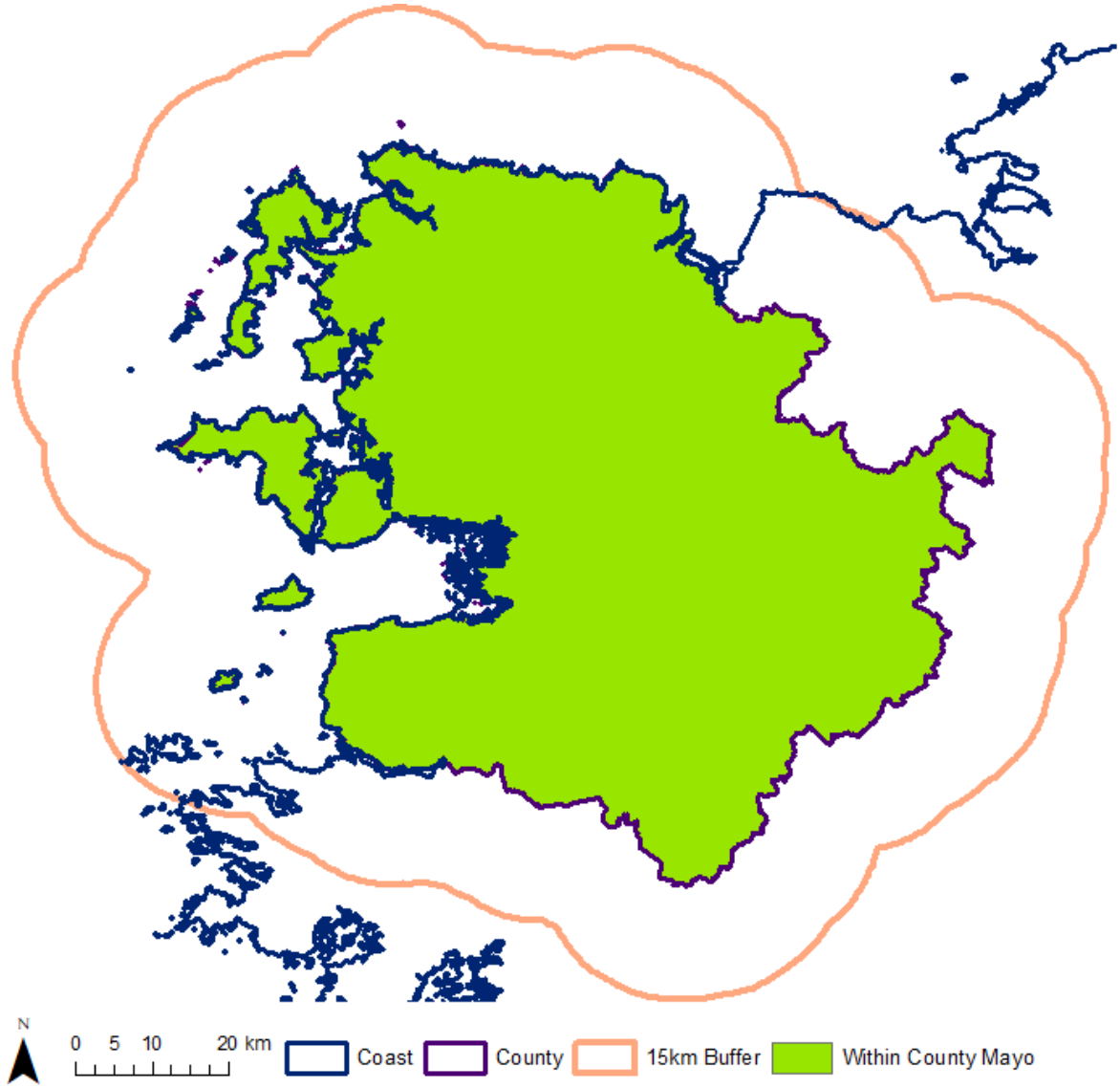


Figure 9: Map of Constraint 1 - Within County Mayo

C2: Not a Lake

The project seeks to identify sites on which infrastructure can be installed or constructed, and so a raster constraint is required that removes areas that are lakes.

There are multiple ways to construct this constraint. In this analysis a raster of distance in metres to the nearest open water – lake or reservoir – is constructed using the `Euclidean Distance` function. OpenStreetMap is used as the data source as the Ireland Lakes data set does not include many of the smaller water bodies within County Mayo. The `Raster Calculator` function is then used to generate a raster of all land other than lake or reservoir using the map algebra expression `"%Dist_Water%" > 0`.

The model generating this constraint is illustrated in Figure 10. A map of the resulting constraint is illustrated in Figure 11.

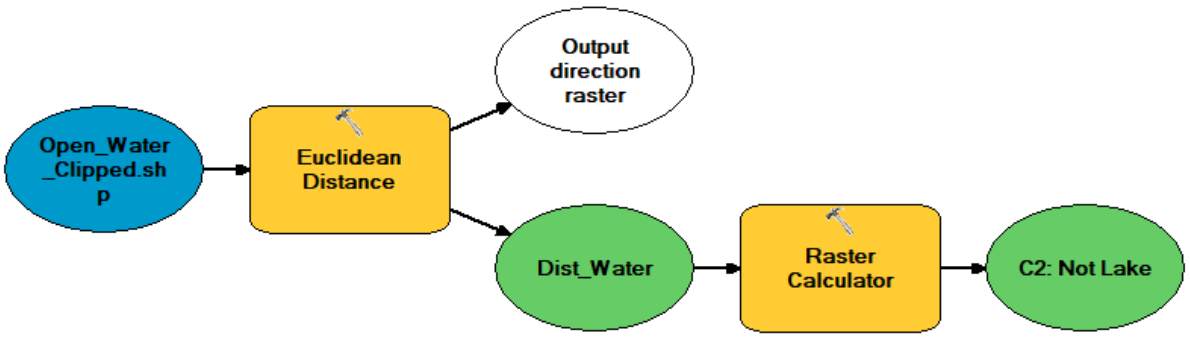


Figure 10: Deriving Constraint 2 - Not a lake

Constraint C2: Not a Lake

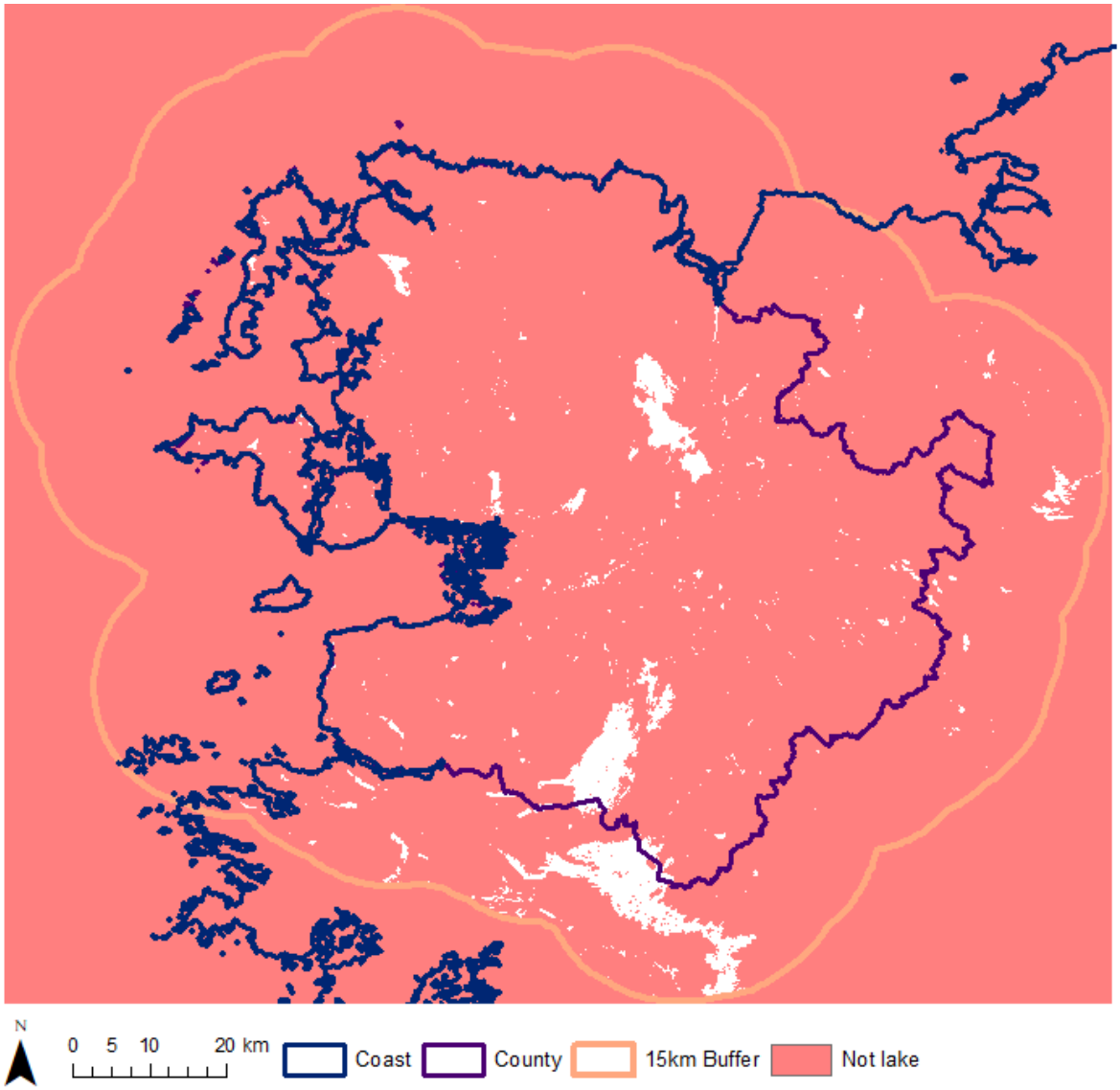


Figure 11: Map of Constraint 2 - Not a lake

C3: Near Road or Track

To facilitate construction of, and subsequent public access to, any new amenity with minimal disruption of existing ground, a raster constraint is required that limits suitable sites to those within 500 metres of an existing road, track or path.

In this analysis a raster of distance in metres to the nearest road, track or path is constructed using the `Euclidean Distance` function. OpenStreetMap is used as the data source as the Ireland Roads and Streets 2 data sets include neither recently constructed roads, nor many of the tracks and paths of County Mayo. The `Raster Calculator` function is used to generate a raster of all locations within 500 metres of a road, track or path using the map algebra expression `"%Dist_Road%" < 500`.

The model generating this constraint is illustrated in Figure 12. A map of the resulting constraint is illustrated in Figure 13.

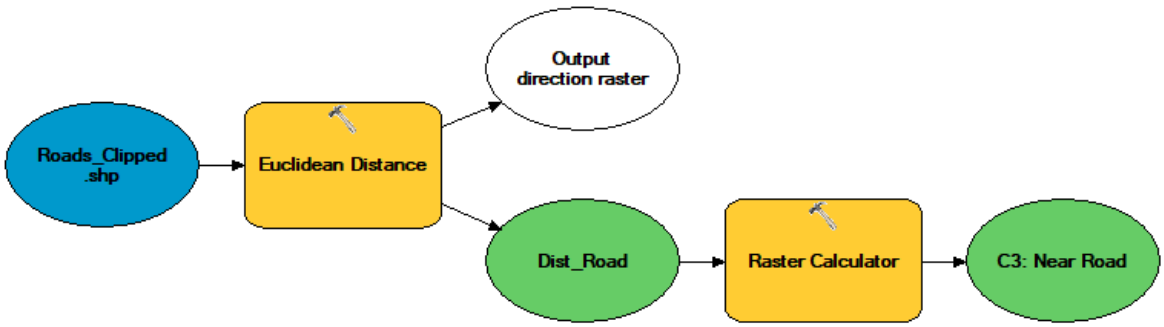


Figure 12: Deriving Constraint 3 - Near Road or Track

Constraint C3: Near Road or Track

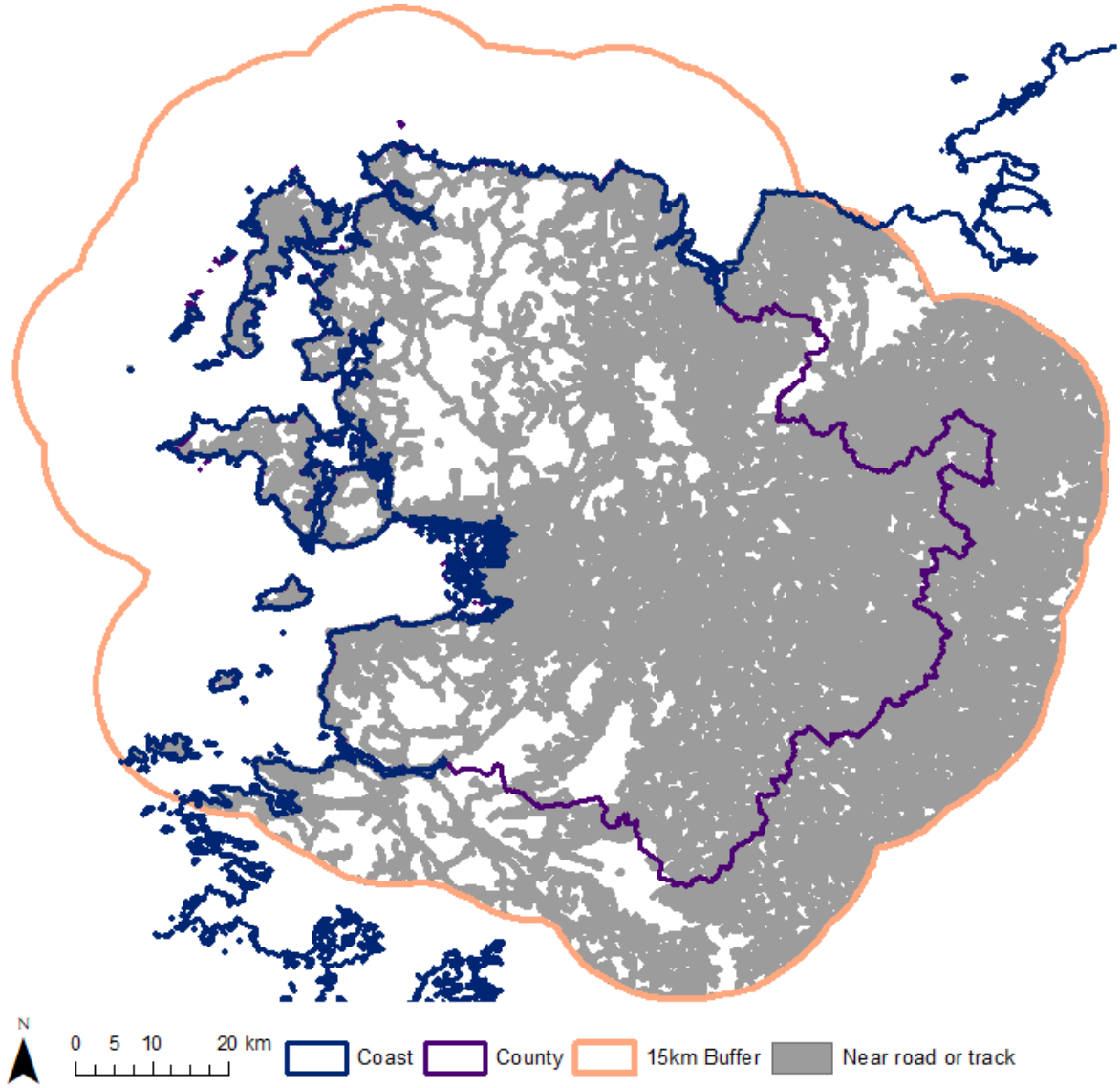


Figure 13: Map of Constraint 3 - Near Road or Track

C4: Not Sloped

To facilitate wheelchair and buggy access to any amenity to be constructed, a raster constraint is required that limits suitable sites to those with a slope of less than 1 in 20, as per the Irish Wheelchair Association Access Guidelines [18].

In this analysis a raster of slope in degrees is constructed using the `Slope` function. The `Raster Calculator` function is then used to generate a raster of all areas sloped less than 1 in 20 using the map algebra expression `"%level%"<= 4.76`, as a slope of 1 in 20 corresponds to 4.76 degrees. Although the Ireland DTM data is at 90m resolution, it is assumed that any significant undulations within the 90m resolution can be graded out during amenity construction. The model generating this constraint is illustrated in Figure 14. A map of the resulting constraint is illustrated in Figure 15.

Figure 14: Deriving Constraint 4 - Not Sloped

Constraint C4: Not Sloped

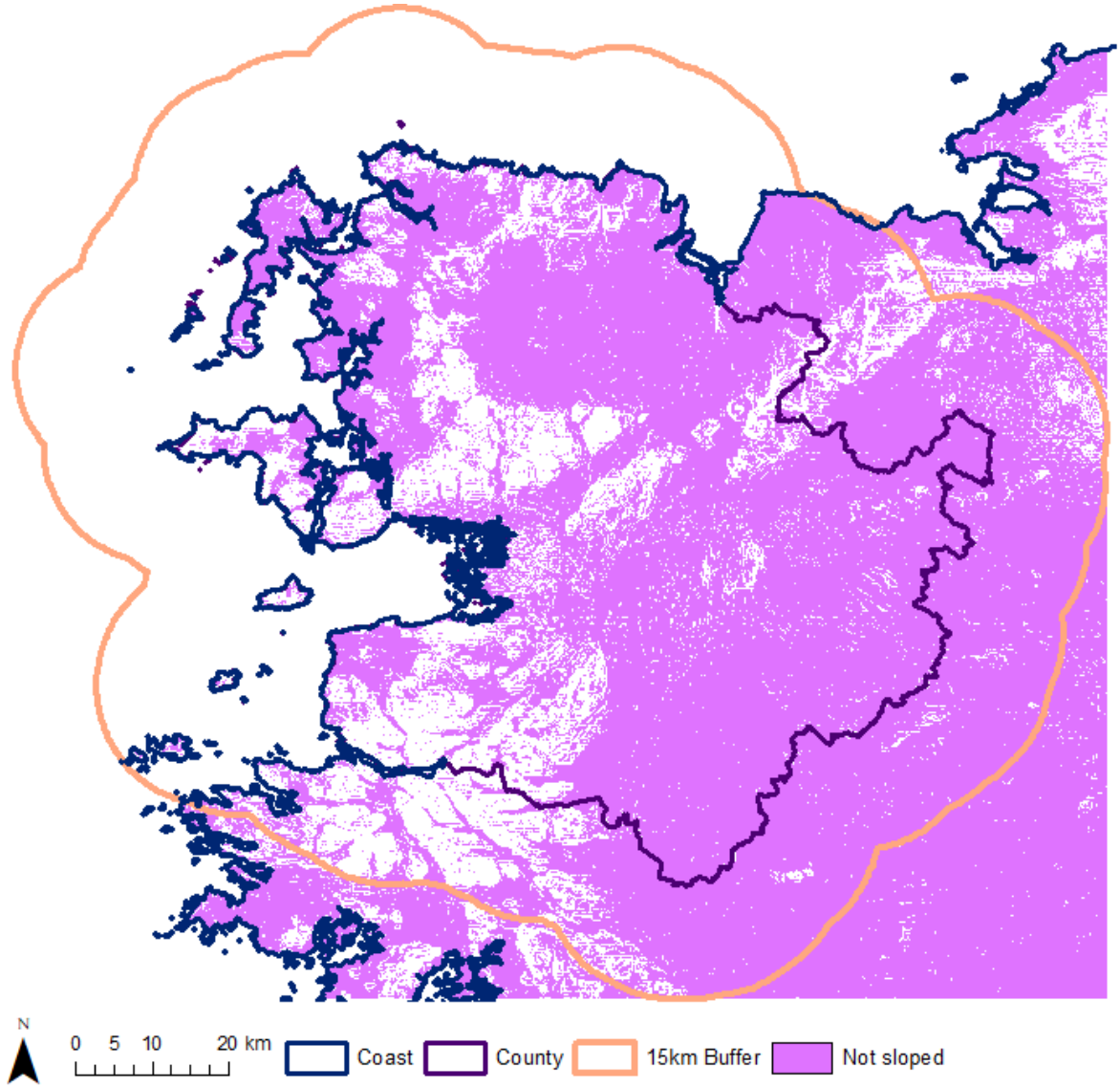


Figure 15: Map of Constraint 4 - Not Sloped

C5: Not Near Primary Road

To minimise impact of light, noise and exhaust pollution from busy traffic, a raster constraint is required to avoid amenities being constructed within 500 metres of a primary road.

In this analysis a raster of distance in metres to the nearest Primary Road is constructed using the `Euclidean Distance` function. The `Raster Calculator` function is then used to generate a raster of locations at least 500 metres from the nearest primary road using the map algebra expression `"%Dist_M_Road%" > 500`. OpenStreetMap is used as the data source as the Ireland Roads and Streets 2 data sets do not include recently constructed primary roads e.g. the M18 Gort to Tuam motorway.

The model generating this constraint is illustrated in Figure 16. A map of the resulting constraint is illustrated in Figure 17.

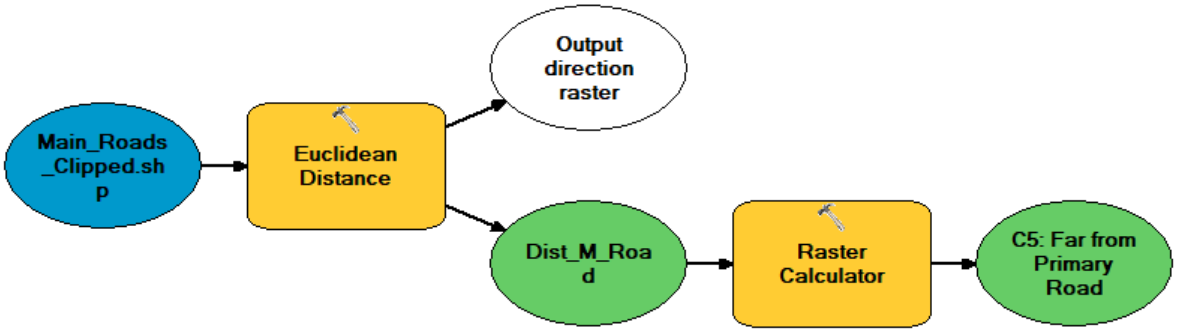


Figure 16: Deriving Constraint 5 - Not near Primary Road

Constraint C5: Not Near Primary Road

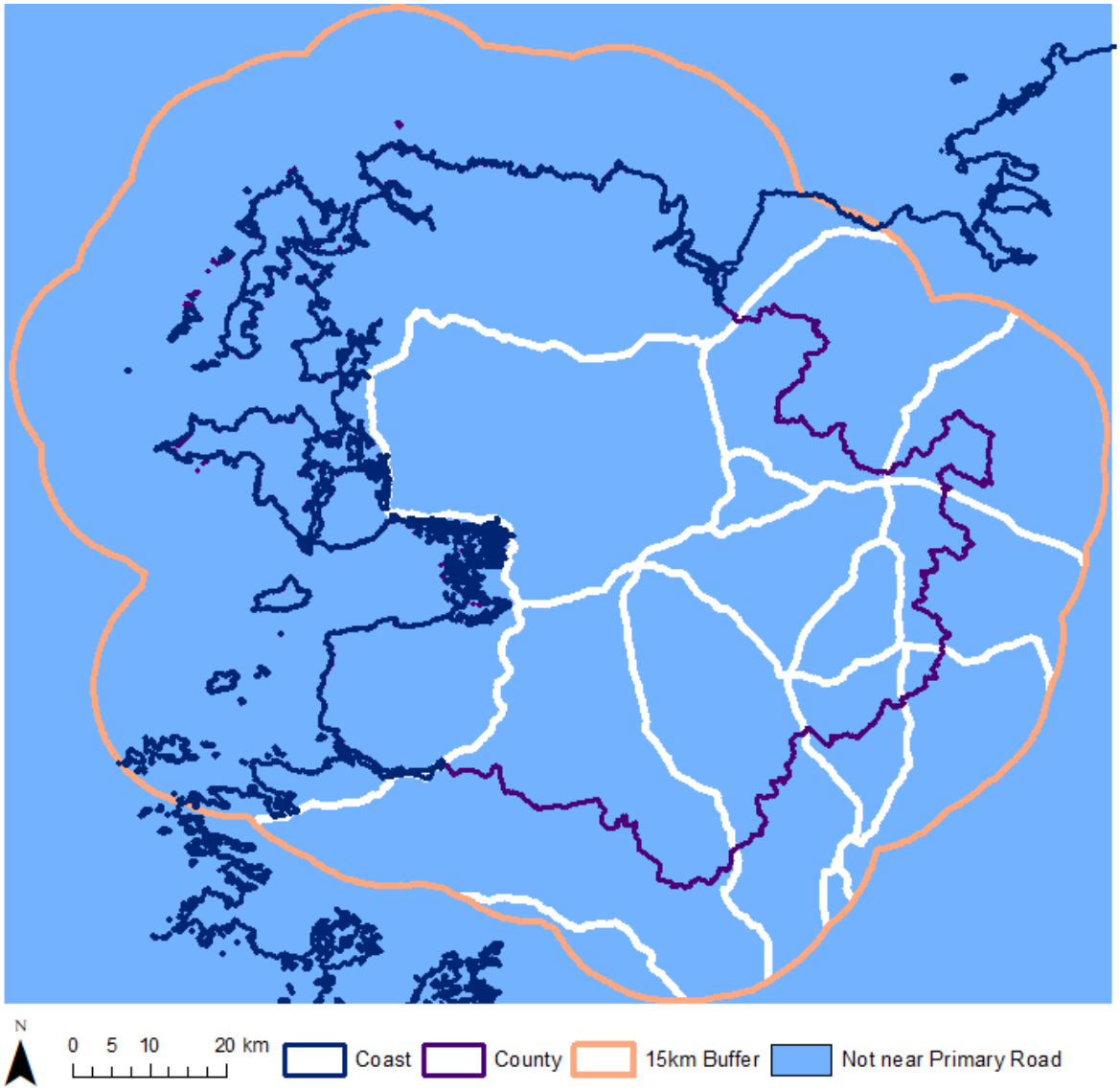


Figure 17: Map of Constraint 5 - Not near Primary Road

C6: Unobstructed Sky

To maximise the benefits of any installation that explains or facilitates showcasing the night sky, a raster constraint is required to avoid siting an amenity near terrain that obstructs a significant amount of the night sky.

In this analysis the `Hillshade` function is used on the 90m resolution Ireland DTM data to identify land that would be shaded by a light source at 15 degrees altitude at every 45 degrees azimuth. Land that is in shade for any of these eight light source positions is considered a site whose view of the sky is obstructed by nearby terrain. As a value of 0 indicates shade, the `Raster Calculator` function is used to identify sites that are not obstructed using the map algebra expression `("%shade0%" > 0) | ("%shade45%" > 0) | ("%shade90%" > 0) | ("%shade135%" > 0) | ("%shade180%" > 0) | ("%shade225%" > 0) | ("%shade270%" > 0) | ("%shade315%" > 0).`

The model generating this constraint is illustrated in Figure 18. A map of the resulting constraint is illustrated in Figure 19. It can be seen, for example, that views of the sky are obscured in the area surrounding Croagh Patrick.

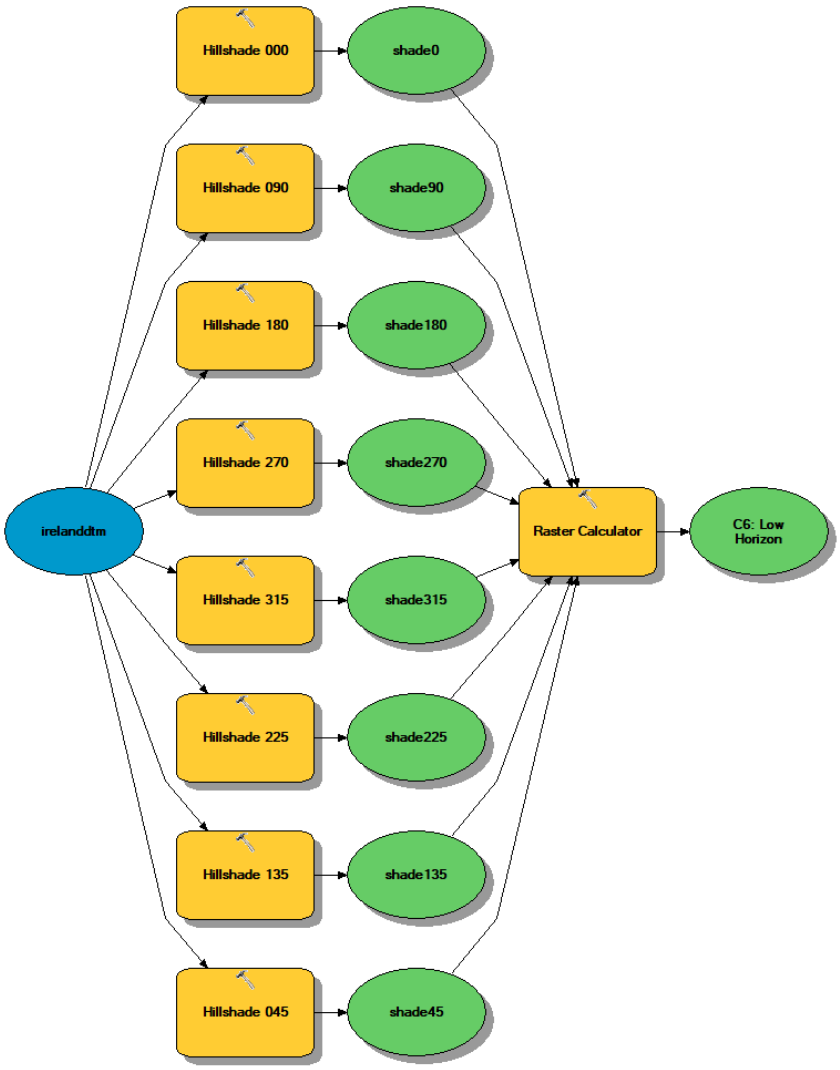


Figure 18: Deriving Constraint 6 - Unobstructed Sky

Constraint C6: Unobstructed Sky

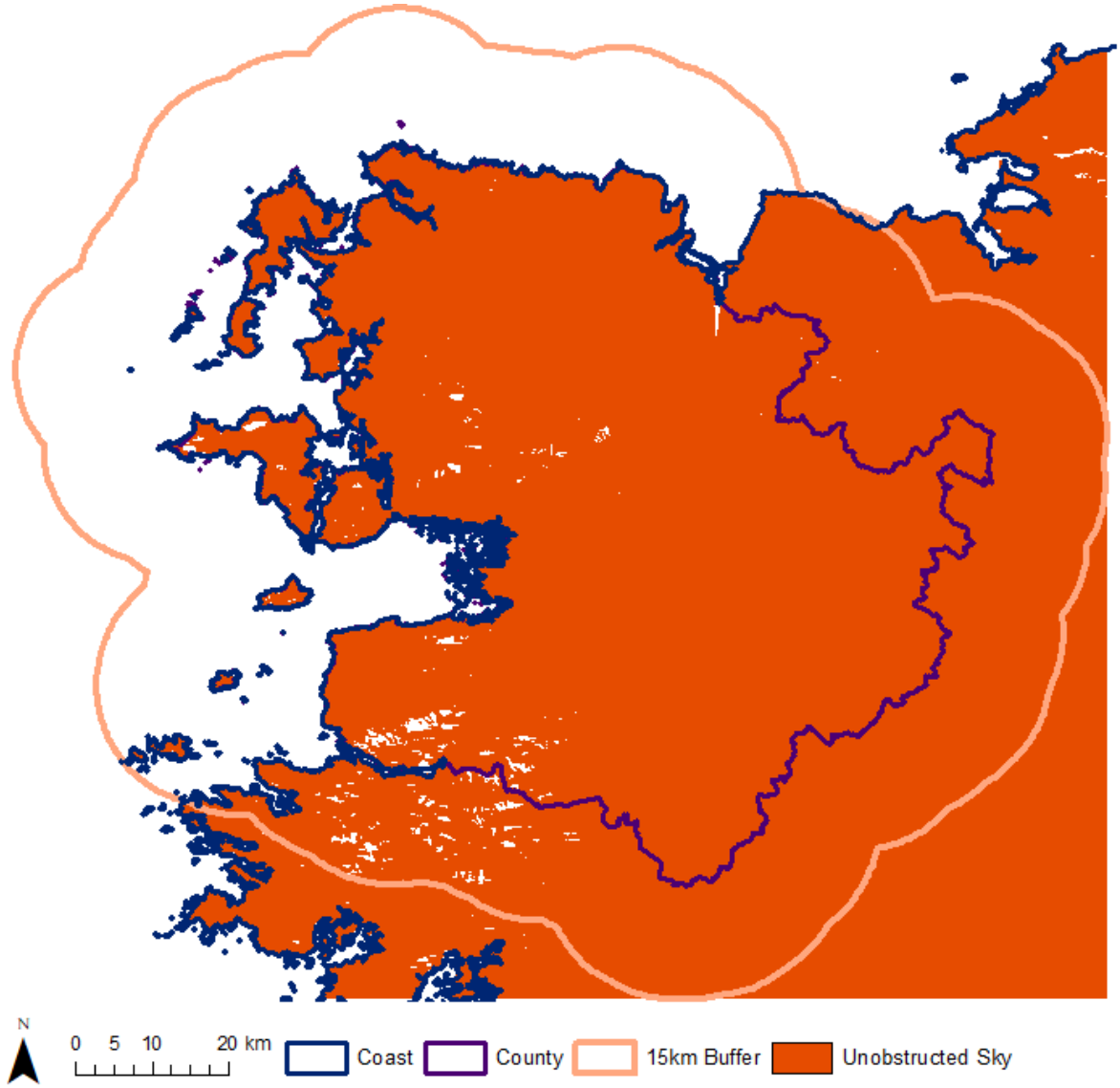


Figure 19: Map of Constraint 6 - Unobstructed Sky

Merging Constraints

All six constraints previously described can be merged to generate a map highlighting sites that are not subject to any of the six constraints.

As all constraints assign a value of 0 to a constrained location and 1 to an unconstrained site, the `Raster Calculator` function can be used to calculate a raster of locations not subject to any constraint using the map algebra expression `"%C1: Within County%" * "%C2: Not Lake%" * "%C3: Near Road%" * "%C4: Not Slope%" * "%C5: Far from Primary Road%" * "%C6: Low Horizon%"`.

The model combining all constraints is illustrated in Figure 20. A map highlighting the resultant unconstrained locations is illustrated in Figure 21. It is these sites that will be scored for suitability based on appropriate additional factors.

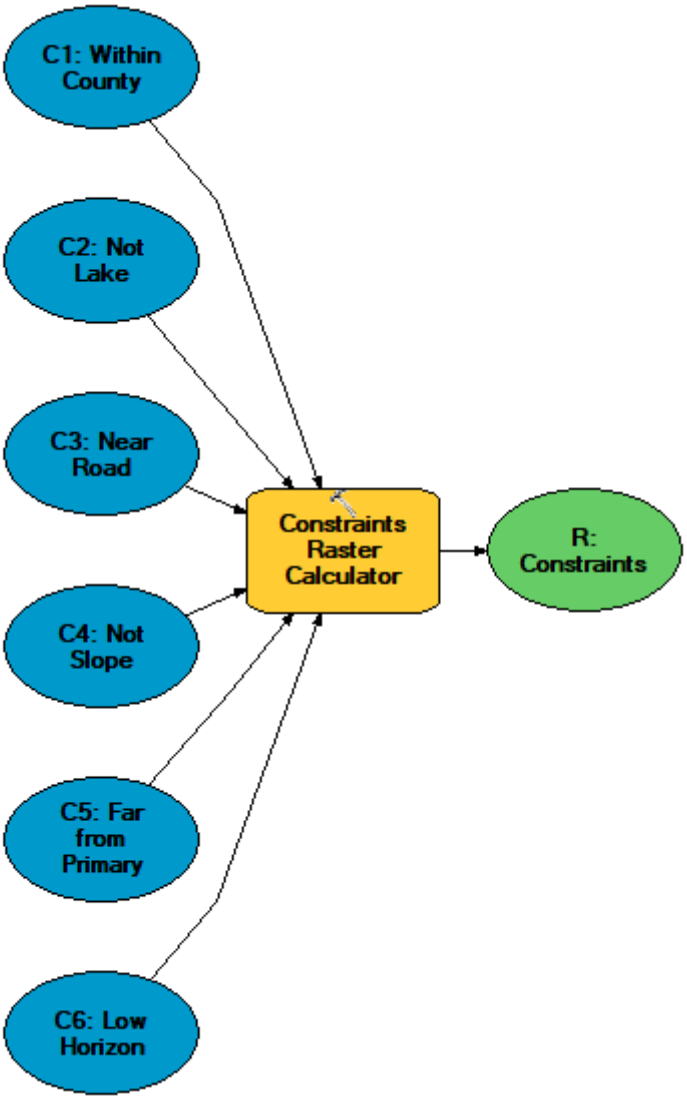


Figure 20: Merging all Constraints

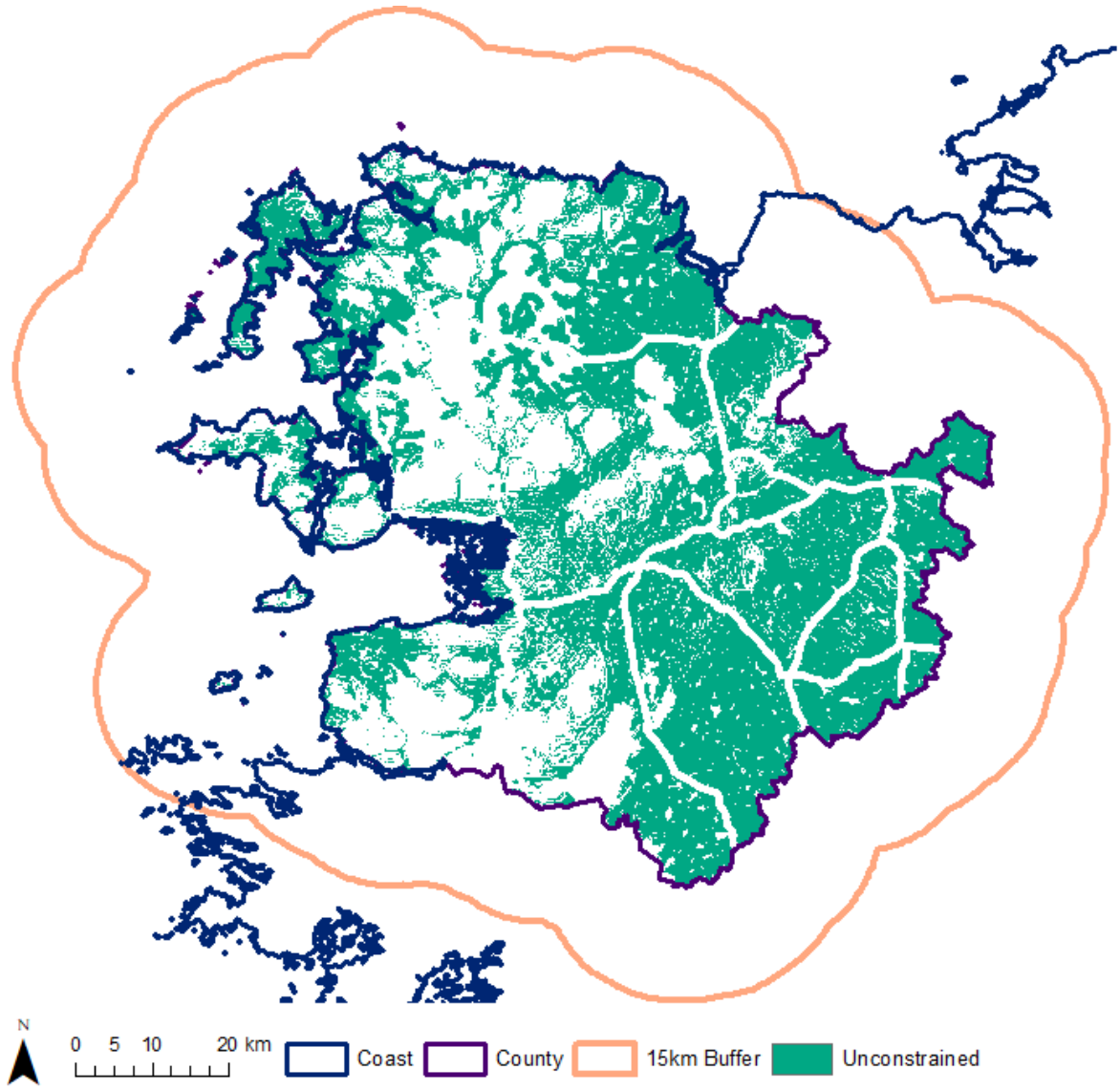


Figure 21: Map of Unconstrained Locations

F1: Sky Darkness

One factor to consider when placing amenities that showcase both wildlife and the sky at night, is to choose locations with the lowest readings for artificial sky brightness. These locations will reveal the most detail in the sky to observers on the ground.

An analysis of the Artificial Sky Brightness of Ireland for 2015 [5], provided courtesy of staff at the School of Physics, Trinity College Dublin, reveals that brightness values for Ireland range from 0 for the darkest regions to 8.215 globally calibrated units in the area with the most artificial brightness in the sky. After clipping to the buffer surrounding County Mayo, the highest reading of artificial brightness for the region under analysis is 1.326 globally calibrated units. To ensure that amenities would only be placed in areas with particularly dark skies, it was decided that only sites whose brightness values are lower than 5% of the maximum Mayo brightness (i.e. lower than 0.0664 calibrated units) be considered. Of those sites within this range of darkness, the sites should have their brightness normalised to a score between the values of 0 (denoting brightest sky) and 1 (denoting darkest sky).

Assuming a linear relationship, this translates to a normalised score being equal to -15.08395 times the brightness value, plus 1. Thus the `Raster Calculator` function can be used to create a raster of normalised scores using the map algebra expression `(1 - "%brightness_c%" * 15.08395 ) * ("%brightness_c%" < 0.0664)`.

The model to generate these normalised scores for darkness is illustrated in Figure 22. A map of the resultant scores is illustrated in Figure 23.

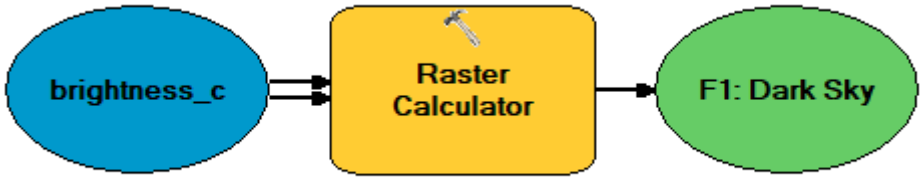


Figure 22: Deriving Factor 1 – Sky Darkness

Factor F1: Sky Darkness

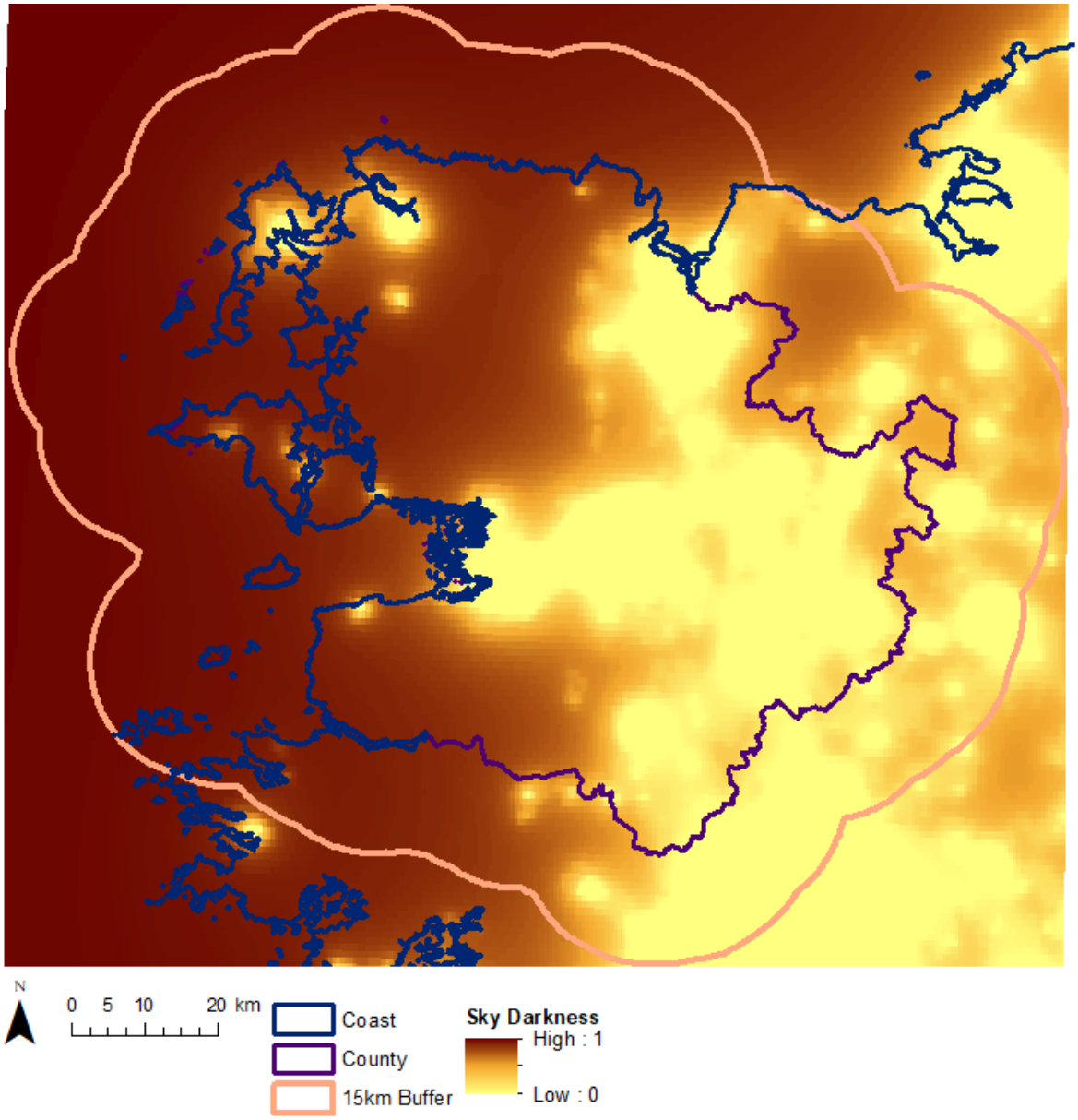


Figure 23: Map of Factor 1 – Sky Darkness

F2: Wildlife and Habitat Potential

A second factor to consider when placing amenities that showcase both wildlife and the sky at night, is to choose locations with the highest potential for interesting biodiversity or habitat.

AIRO's Environmental Sensitivity Mapping Tool [19] reveals interesting layers of data in the Biodiversity Flora Fauna category that included Annex 1 Habitats (as per the European Union's Habitats Directive), and Birdwatch Sensitivity (as per Birdwatch Ireland's Bird Sensitivity Mapping for Wind Energy Developments and Associated Infrastructure). Additionally, the National Biodiversity Data Centre maintains extensive digital records of all biodiversity observations in Ireland.

However, access to raw versions of these data sets could not be secured within the time-constraints of this project, and so an estimation of wildlife richness of sites within County Mayo has been performed based on the most recent landcover classification information available – CORINE Land Cover 2018 [4].

Overlaying the CORINE 2018 dataset above aerial imagery of County Mayo reveals that many small lakes within County Mayo are not captured by the CORINE analysis – this potentially biodiversity rich habitat is subsumed into the surrounding land cover classification(s), which in many locations in County Mayo are peat bog or coniferous forest. To more accurately reflect the biodiversity potential of these smaller lakes, the CORINE 2018 dataset has been refined for this analysis: it was overlaid with lakes and reservoirs of all sizes as defined in OpenSteetMap, and the layers flattened by employing the `Erase`, `Append`, `Field Update`, and `Dissolve` functionality to enrich CORINE with these smaller features. The dissolve operation was necessary to deal with the minor water body polygons that existed around the edges of the lakes, post merge.

It may be of interest to note that during an early iteration of this analysis, the lakes as per the OpenStreetMap layer were scored separately to the CORINE land cover data, but this resulted in scoring errors: smaller lakes received both a score from the OpenStreetMap Lakes layer and a score based on their CORINE land cover classification. Thus higher scores than appropriate were arising near small lakes in particular. Integrating the smaller lakes into the CORINE dataset before scoring avoided this issue.

This refined CORINE 2018 dataset for County Mayo and environs classifies all land cover into one of twenty-nine classifications. A score from 0 (for habitat of no amenity potential) to 5 (for maximum amenity potential) was assigned to each of these classifications based on the authors experience in surveying native biodiversity (e.g. 21 years participation in the national Countryside Bird Survey [13]).

In addition, a distance outside and a distance inside each habitat type was assigned to each classification of land cover. These distances denoted how far away from - and how far inside - each type of habitat would be appropriate to observe wildlife, and thus locate an amenity such as signage, a boardwalk or a bird-hide. For example, facilities such as a bird-hide could be reasonably sited within 50m of the outside of a broad-leaved forest, or anywhere within such a forest. A water body would be a different proposition: whilst up to 50m away from the edge of a lake would be reasonable it would not be practical to install a bird-hide within the habitat - on top of the water. For some habitats such as peat bogs or marshes, construction of light infrastructure such as a boardwalk may be possible, but only within a zone of perhaps 100m inside the outer edge of the habitat. Additionally, requiring the public to walk hundreds of metres across an open habitat such as a peat bog would likely disturb any wildlife that happened to be within viewing distance.

In this analysis the appropriate habitat score is assigned to the appropriate area within and beyond each habitat type, as illustrated in Figure 24.

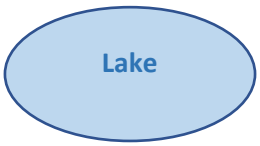
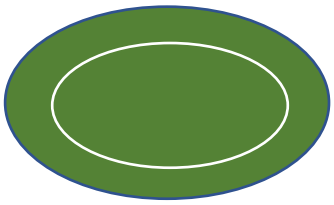
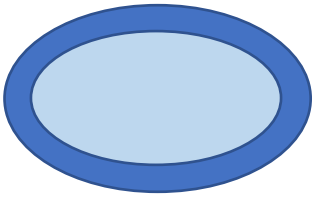
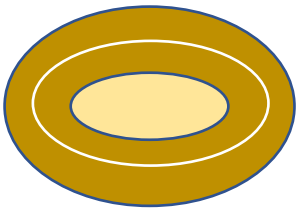
Broad-leaved Forest	Water Body	Peat Bog
		
		
Amenities can be sited just outside (near the edge of the habitat), or anywhere within. The dark-green area receives a score for this habitat type.	Amenities can be sited only just outside (near the edge of the habitat). They cannot be sited within. The dark-blue area receives a score for this habitat type.	Amenities can be sited just outside (near the edge of the habitat). They can also be sited just inside the edge of the habitat. The dark-brown area receives a score for this habitat type.

Figure 24: Amenity siting for various habitats

The scores and siting distances for each habitat type have been reviewed and refined by the NPWS Divisional Ecologist with responsibility for County Mayo. The final scores seek to reflect not just the variety and richness of biodiversity possible in each habitat, but also the importance of that habitat from a European and global perspective. Finally, although habitats such as land associated with railways often hold interesting flora and fauna, it was considered inappropriate to encourage visitors and wildlife viewing in these areas and so such classifications of land cover were assigned a score of 0.

These final siting distances and scores are listed in Table 2.

Table 2: Land Cover Classification Scoring Scheme

Land Cover Classification	Notes	Siting outside (m)	Siting within (m)	Wildlife/ Habitat Score
Estuaries	Waterlogged habitat	50	0	5
Intertidal flats				
Water bodies				
Coastal lagoons	Waterlogged habitat	50	0	4
Inland marshes				
Broad-leaved forest			(anywhere)	
Beaches, dunes , sands	Sensitive habitat	50	0	3
Salt marshes	Waterlogged habitat			
Peat bogs	Amenities only appropriate near habitat edge		100	
Moors and heathland				
Natural grasslands			(anywhere)	
Land principally occupied by agriculture with significant areas of natural vegetation				
Mixed forest				
Bare Rocks		50	(anywhere)	2
Non-irrigated arable land				
Coniferous forest	Overwhelmingly non-native, biodiversity poor	50	50	1
Complex cultivation patterns			(anywhere)	
Discontinuous urban fabric				
Pastures				
Sparsely vegetated areas				
Transitional woodland-shrub	Overwhelmingly non-native, biodiversity poor			
Airports	Public not to be encouraged irrespective of biodiversity	0	0	0
Burnt areas				
Continuous urban fabric				
Industrial or commercial units				
Mineral extraction sites				
Road and rail networks and associated land				
Sport and leisure facilities				

The model illustrated in Figure 25 is used to calculate the raster of wildlife and habitat potential for all locations in the area under analysis. This model employs the following steps:

- Generate a vector shapefile for each of the land cover classifications
- Generate a separate raster for each classification, generally by using the `Euclidean Distance` function and then `Raster Calculator`. The `Raster Calculator` should take into account the relevant values for "Siting outside" and "Siting within" as per Table 2. A value of 1 indicates the presence of the habitat, a value of 0 indicates the absence.
- For those classifications where siting within is possible only within a certain range of the edge of the habitat, such as "Moors and heathland", a workflow of `Buffer` (with negative distance), `Polygon to Raster`, `IsNull` and `Con` functions are necessary to construct the appropriate raster.
- A `Weighted Sum` function is used to calculate a weighted some of all individual habitat rasters, using the scores as indicated in Table 2.
- For County Mayo, this resulted in a raster of habitat scores ranging from 0 to 15. These scores were normalised to values between 0 and 1 by using a `Raster Calculator` function to divide by 15.

This analysis results in the map of 'wildlife and habitat potential' scores illustrated in Figure 26.

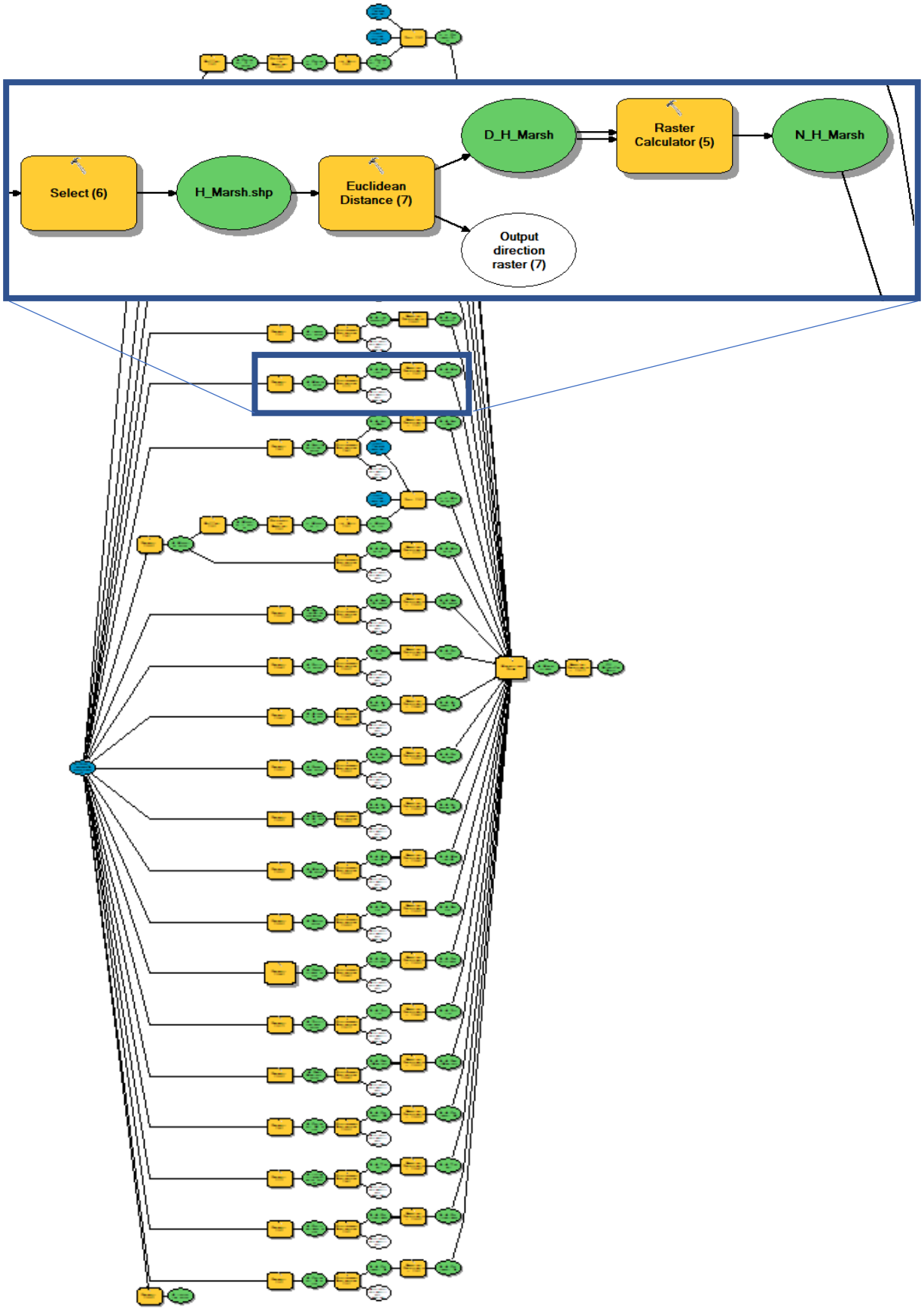


Figure 25: Deriving Factor 2 - Wildlife and Habitat Potential

Factor F2: Wildlife and Habitat Potential

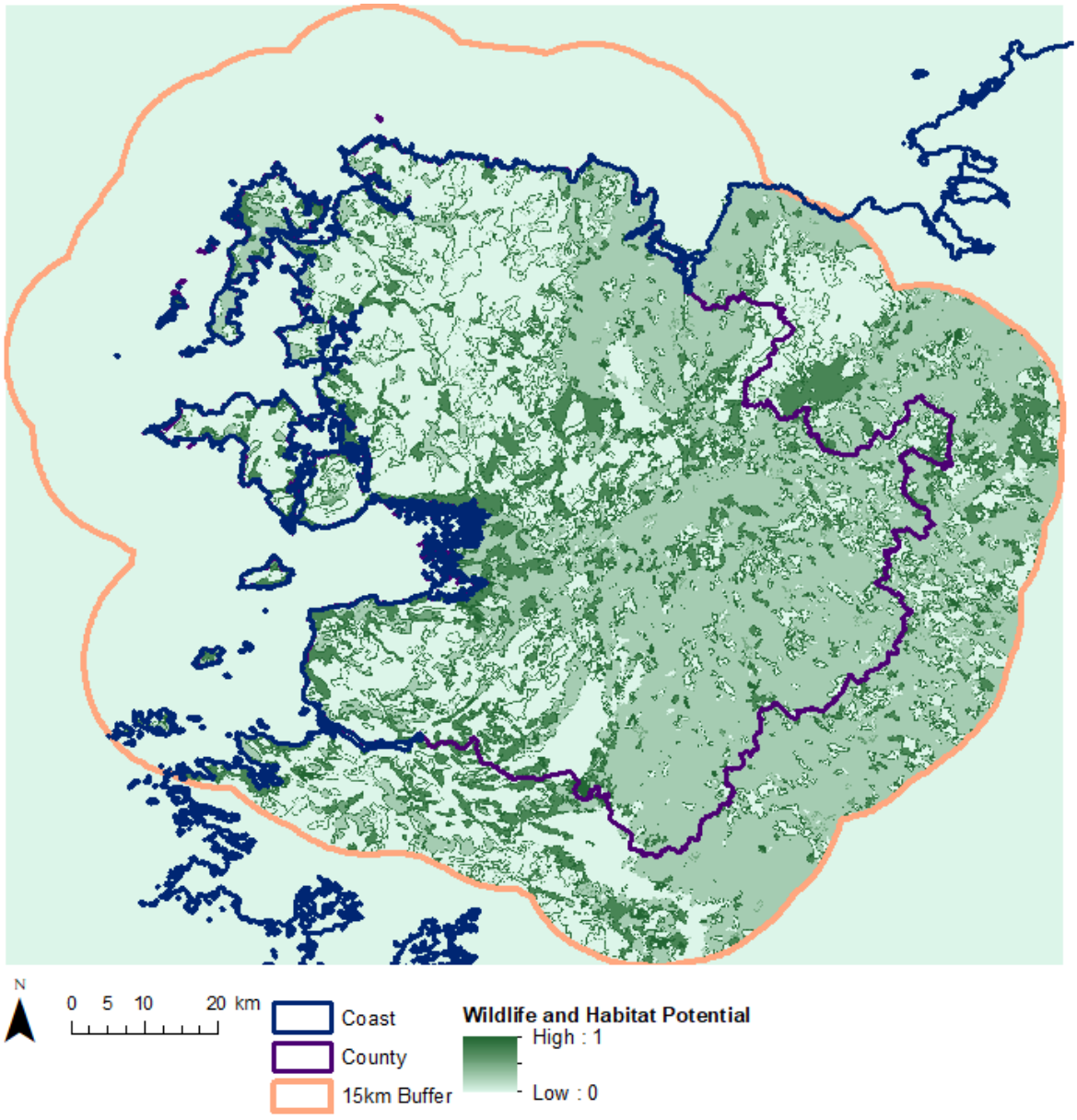


Figure 26: Map of Factor 2 - Wildlife and Habitat Potential

4. Results

Site Suitability Scoring

Given all the criteria described in Section 3, the overall suitability index for each location (i.e. 25 metre-squared cell) in the area under analysis can be calculated as follows:

```
Suitability = C1 * C2 * C3 * C4 * C5 * C6 * ((F1 * w1) + (F2 * w2))
```

In this equation, C1 through C6 are the normalised individual constraints and F1 and F2 are the normalised factors. w1 and w2 are relative weights assigned to factors F1 and F2. For the purposes of this analysis, it was deemed that both the factors F1 (darkest sky) and F2 (wildlife and habitat richness) should have equal importance, and so both w1 and w2 are assigned a value of 0.5. It could be argued that due to frequent cloud cover the darkest sky factor should have a lower importance, but in consultation with the NPWS Divisional Ecologist it was deemed that the novelty of having such dark sky justifies it being assigned an equal importance to wildlife and habitat richness. Indeed, some artificial sky brightness values recorded in County Mayo were so unusually dark that they helped calibrate the values observed from across the European continent.

Additionally, as all the normalised individual constraints have already been merged as described on page 29, the suitability calculation can be simplified to:

```
Suitability = [Merged Constraints] * ((F1 * 0.5) + (F2 * 0.5))
```

This calculation has been implemented using the model illustrated in Figure 27. The `Raster Calculator` function implements the map algebra expression `"%R: Constraints%" * ((0.5 *"%F1: Dark Sky%") + (0.5* "%F2: Wildlife Rich%"))`.

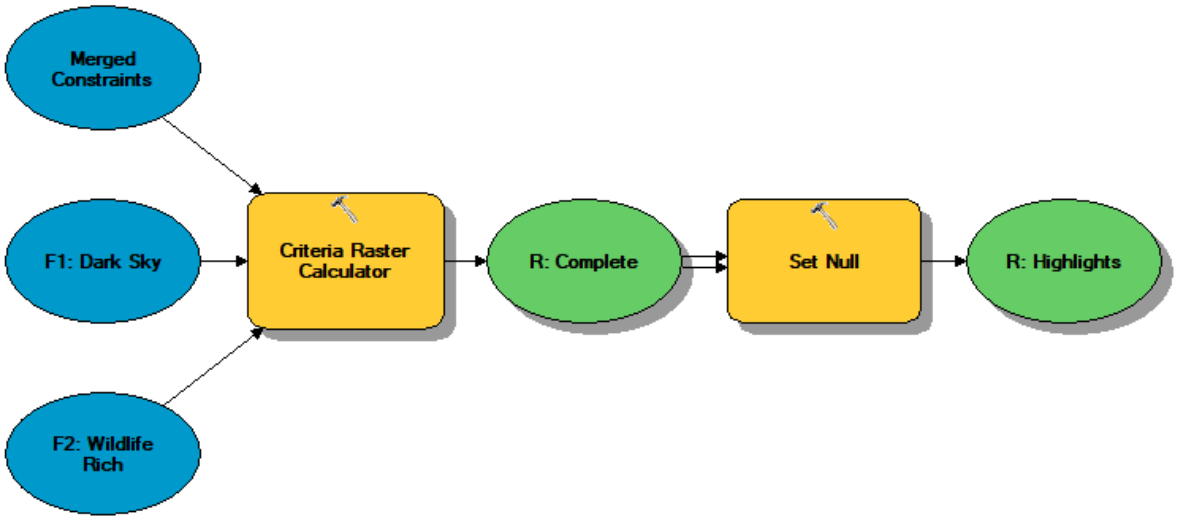


Figure 27: Deriving the final site suitability scores

The resultant site suitability scores are illustrated in Figure 28.

Complete Site Suitability Scores

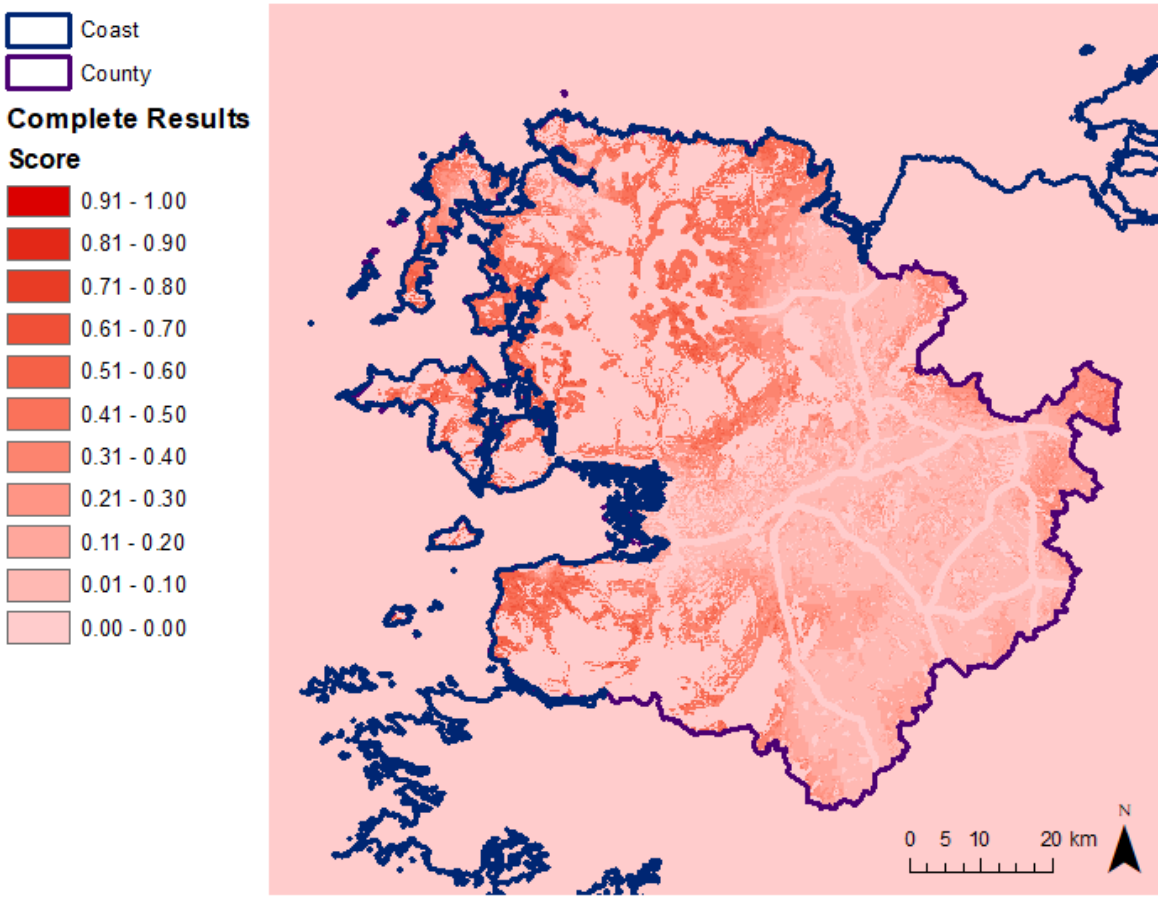


Figure 28: Complete site suitability map

Highlight Sites

For legibility, the sites with highest suitability (a score of 0.5 or higher) are extracted using a `SetNull` function with the expression `VALUE < 0.5` as illustrated previously in Figure 27. These highlight sites are illustrated in Figure 29.

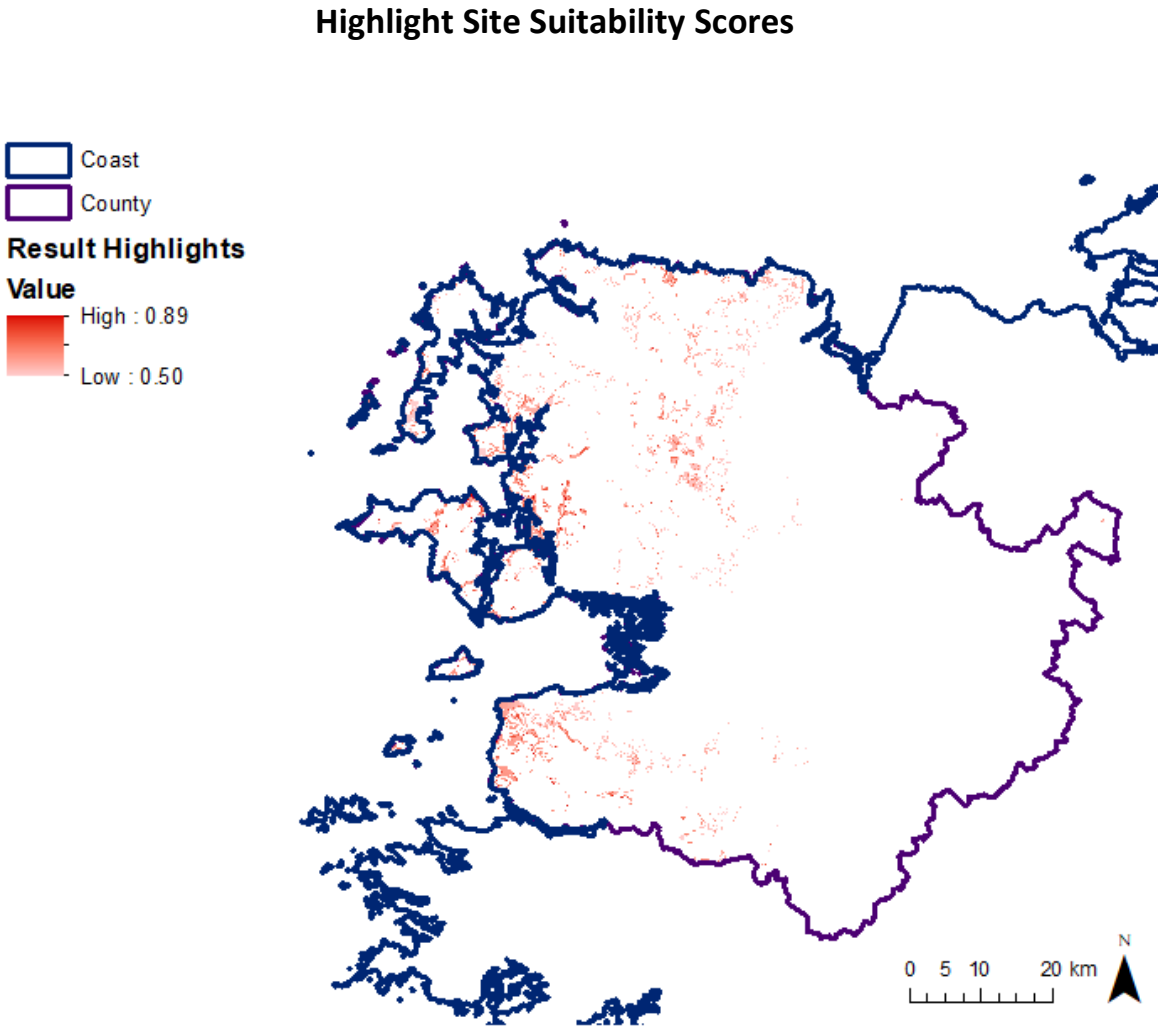


Figure 29: Highest scoring sites

Highlight Site Classification

As a final step it was decided to differentiate between sensitive sites on which only low-impact amenities such as signage would be preferable, and less sensitive sites on which more substantial works such as the construction of board walks, hides or interpretive centres may be acceptable.

The SAC, SPA, NHA and proposed NHA layers were merged into one shapefile named `Designated_all`. It was decided to highlight the most suitable sites as Level 1, these having a score of greater than 0.7. Sites scoring between 0.6 and 0.7 would be deemed Level 2, and those between 0.5 and 0.6, Level 3.

A model was constructed to extract Level 1, Level 2 and Level 3 sites into individual raster files using the `Raster Calculator` function. These three rasters were converted to three vector shapefiles using the `Raster to Polygon` function. The sites within each vector had to be selected using the `Select` function with an expression of `"GRIDCODE" = 1`. Then for each Level the sites in Designated areas are extracted using the `Clip` function and the sites in non-Designated areas are extracted using the `Erase` function.

The model used to classify the results is illustrated in Figure 30, and the resulting map as rendered in ArcMap Desktop in Figure 31.

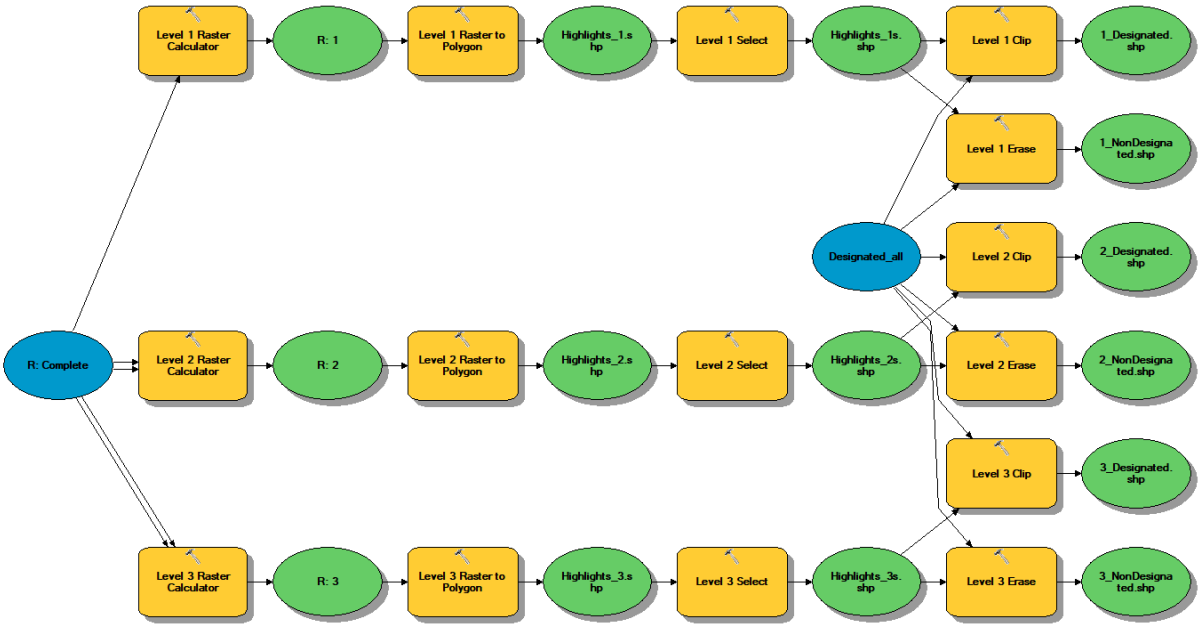


Figure 30: Classifying Level 1, 2 and 3 sites into those Designated and non-Designated

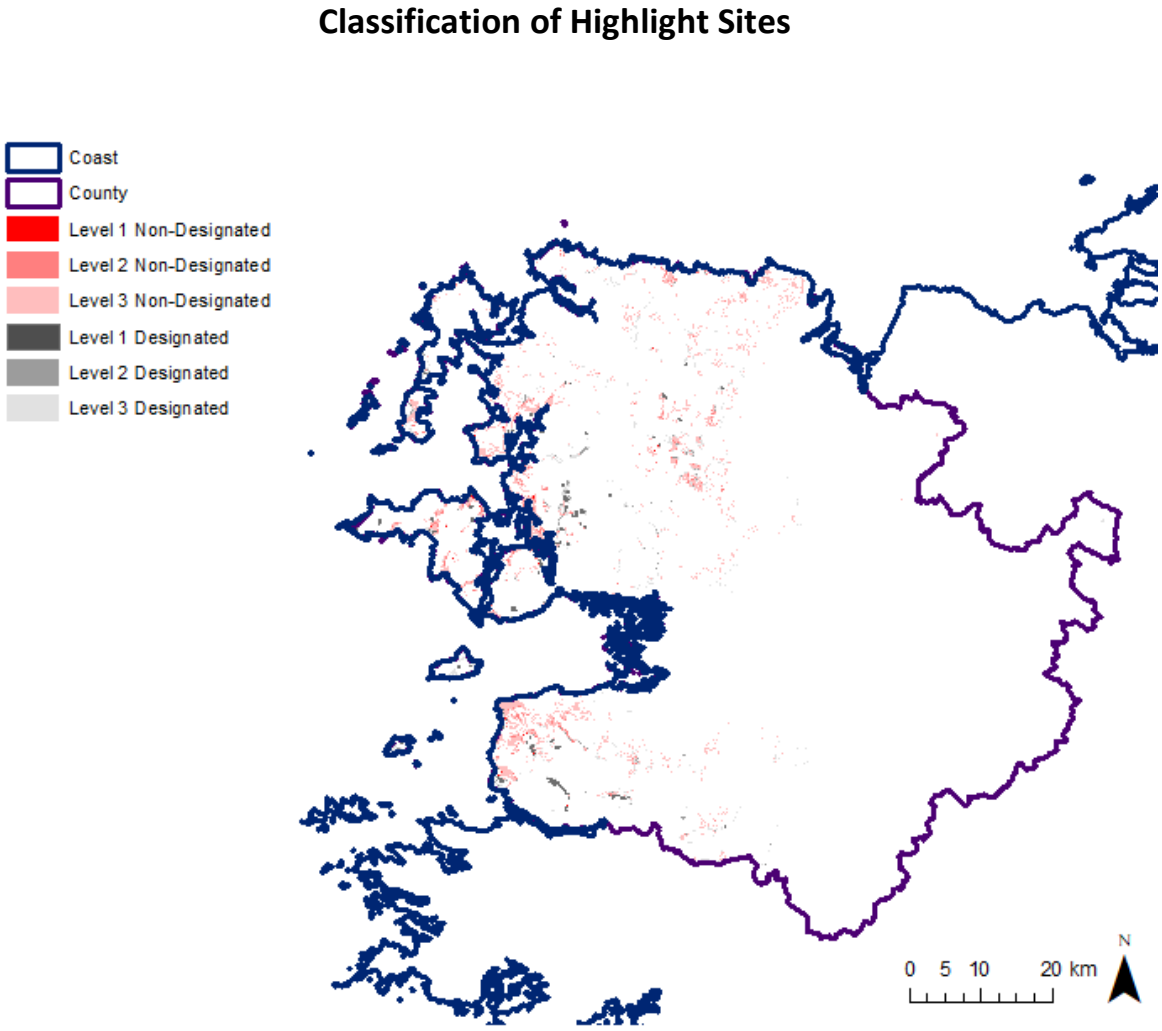


Figure 31: Level 1, 2 and 3 sites, both Non-Designated and Designated

Hosting Online

To facilitate the browsing of the results of this analysis, details of the highlighted sites were uploaded to a new Web Map created on the ArcGIS Online portal [10]. This system does not appear to support the integration of raster files at the time of writing, hence the classification of highlighted sites was generated in the form of vector files.

Each of the final vector layer shapefiles were compressed into a zip file, uploaded and configured. The style and names of layers were adjusted to facilitate legibility, meta-data was added, and a basemap of ESRI imagery assigned.

At the time of writing this online map is accessible at the URL https://arcg.is/1SjK0L.

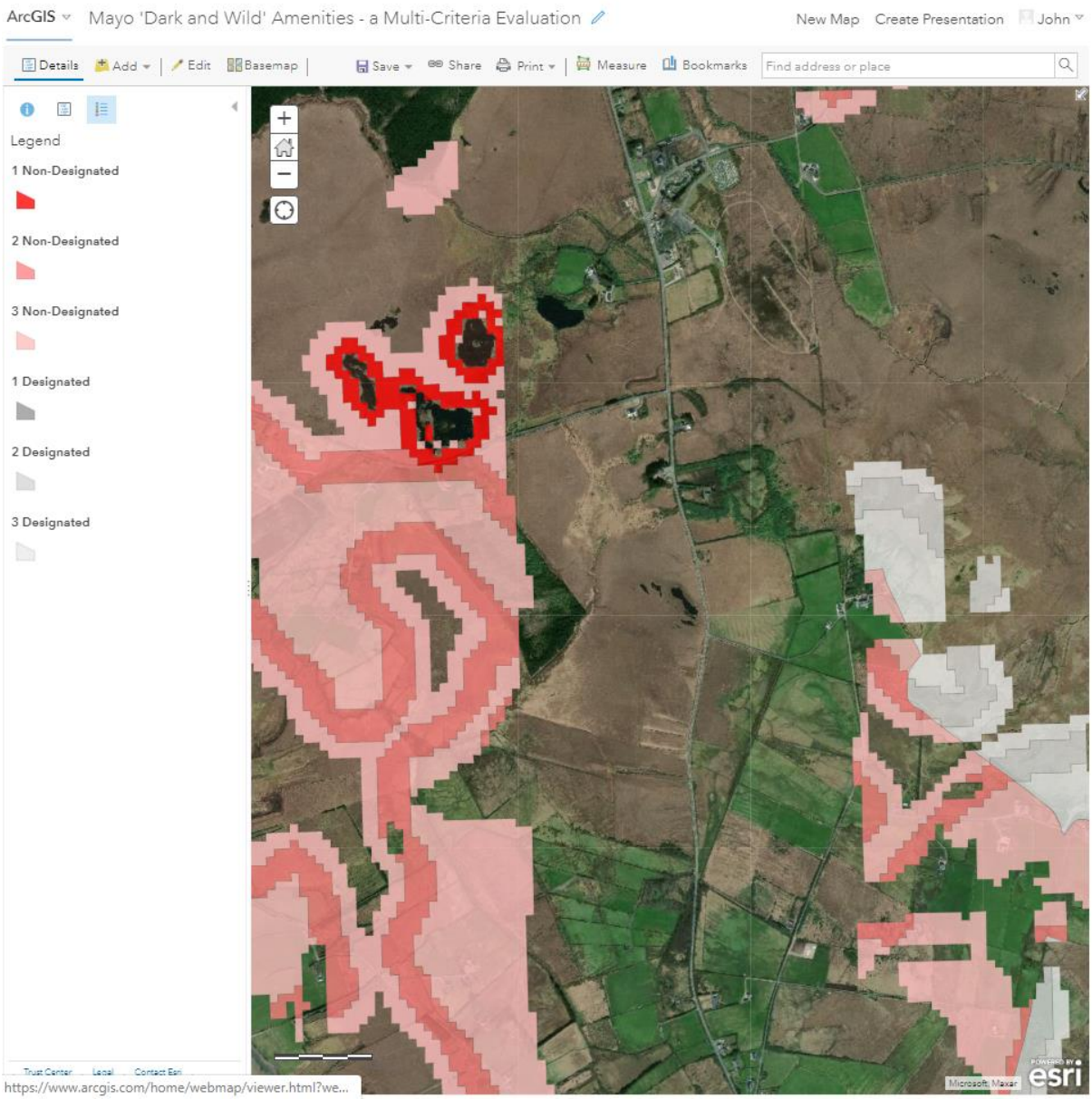


Figure 32: Results hosted on ArcGIS Online, zoomed in to Ballycroy National Park Visitor Centre

Observations

It is observed from this analysis that almost no sites in the east of County Mayo emerge as being suitable for Mayo 'Dark and Wild' Amenities. This is largely due to the relatively high amount of light pollution in this area. To the west of the county, an absence of nearby roads and the sloped aspect of the mountains are significant constraints. The constraint of not selecting any sites within 500m of primary roads is also noteworthy, as this rules out the corridor along the N59 which runs through otherwise suitable locations. From a biodiversity perspective, due to their increased potential for wildlife sightings, sites bordering two or more habitat types score highest, with land adjacent to lakes, estuaries and intertidal flats scoring particularly high.

Many of these features can be observed in Figure 32. It shows an area along the N59 primary road that includes the Ballycroy National Park Visitor Centre located in the upper third of the picture. Note the absence of Level 1, 2 or 3 sites in the strip within 500m of the N59 running from North to South in the map. The more suitable sites, Level 1 and Level 2, can be seen to occur along the edges of habitats - locations from where there is a chance of at least two interesting habitats being observed. The highest scoring sites indicated are Level 1 (coloured in bright red), occurring along the edges of small freshwater lakes. Some of the Level 2 and Level 3 sites to the east of the figure are on land designated as SAC, SPA, NHA or proposed NHA, as denoted by their grey colour. Only amenities of low impact such as signage should be considered for these sensitive areas.

It is gratifying to note that this analysis highlights some areas of County Mayo that are known to host important populations of birds such as migratory geese, Twite, Chough and Corncrake. These include Termoncarragh Lake to the west of Bellmullet, sites on the north-east of Achill Island, and significant swathes of land to the west of Louisburgh. Site suitability scores in these locations are illustrated in Figure 33, Figure 34 and Figure 35 respectively. The legends in these maps are not displayed to maximise the viewable area - they share the same legend as in Figure 32.

Figure 33: Sites highlighted near Termoncarragh Lake, west of Bellmullet

Figure 34: Sites highlighted on north-east Achill Island

Figure 35: Sites highlighted to the south-west of Louisburgh

5. Conclusions

A multi-criteria evaluation has been successfully performed for County Mayo, identifying and classifying sites that may be suitable for hosting amenities appropriate to both the biodiversity of County Mayo and the Mayo Dark Sky initiative. Such amenities could include low-impact signage appropriate for protected sites, or more significant infrastructure such as bird-hides, sky-observation platforms and interpretative centres that would be more appropriate for less sensitive, non-designated locations. This analysis distinguishes between both of these scenarios. The analysis is to a low-level of granularity – 25 metres squared – and leverages a wide variety of data sets.

Some difficulties were encountered during the execution of this project. Challenges included the presence of unwanted artefacts such as narrow gaps between the borders of counties in the Local Authority 2016 data set, and the absence of some low-level detail such as smaller lakes and recent roads from the Ireland Lakes, Ireland Roads and Streets 2 data sets. These issues were addressed with the importation of the latest openstreetmap data via geofabric facilities. Visual inspection of the imports for errors or omissions was performed before the data was employed in the analysis.

Extensive use of the modelling facilities within ArcMap were made to ensure the reproducibility of the analysis. Initial models proved too big or temperamental to be rerun consistently without crashing. More reliable models were constructed by splitting the models into smaller pieces of workflow, as documented in Sections 2 and 3.

The implementation of models proved valuable when it was realised that smaller lakes were being scored twice in an early iteration of this analysis. They received a score based on their CORINE classification (e.g. as a Peat Bog) and based on their presence as a lake in OpenStreetMap. After correcting this issue by merging and dissolving the OpenStreetMap Lakes layer into the CORINE layer, all subsequent GIS processes could be re-executed with ease.

The uploading of the results to ArcGIS Online proved convenient for sharing interim and final results with other stakeholders, in particular with the NPWS. At the time of writing this online map is accessible at the URL https://arcg.is/1SjK0L.

This current analysis scores sites that could be suitable for arbitrary infrastructure that highlights wildlife during the day and the dark sky at night. This analysis may allow interested parties to identify a particular site for a targeted piece of infrastructure, or a set of sites for a broader set of infrastructure such as a wildlife and dark sky trail. Once a particular form of infrastructure is selected, the results of this project could be fine-tuned by refining the criteria, scoring and weighting as appropriate.

A particular area for potential fine tuning is Factor 2 – Wildlife and Habitat Potential. The CORINE Land Cover data set is relatively coarse in its classification. A more detailed classification would be able to differentiate between biodiversity-poor young coniferous forestry, and biodiversity-rich native woodland scrub. Perhaps the Annex 1 data sets associated with the EU Habitats Directive could provide this level of data. The Birdwatch Sensitivity detail included in the AIRO Environmental Sensitivity Mapping tool could also help to identify those areas of particular importance from an avi-fauna point of view. Additionally, whilst all freshwater lakes are scored highly in the existing analysis, in reality some lakes are better than others from a biodiversity perspective due to their depth, gradient, and surrounding habitat.

In closing, it is hoped that the current analysis can support the identification of initiatives to promote and showcase both the wildlife and the Dark Sky of County Mayo. In these challenging times for biodiversity as well as the population at large, perhaps both could benefit from the provision of additional Mayo 'Dark and Wild' amenities.

6. References

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