Spatial planning of wind turbine developments in Wales

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Summary

A method has been developed for use in identifying the geographical distribution and locations of sites where wind turbines could be installed, taking account of the wind resource and physical, or policy related, constraints on such developments. The aim was to facilitate spatial planning in the strategic assessment of the potential for the provision of wind energy in Wales. In so doing, some of the land-use consequences of selecting alternative scenarios of wind speed thresholds and constraints could be examined.

The strategic appraisal of opportunities for wind energy development used a rule-based model, within which the potential for energy production is represented by wind speed and to compare the spatial distribution of different wind speeds with that of factors that may constrain the development of turbines, for physical or policy reasons. The data within the GIS are interpreted by a set of rules which allocates land to different classes according to the constraints set, the weightings that they are given, and the available wind resource.

The method was based upon a Geographic Information System (GIS), in which map-based data were compiled and analysed to produce maps that show answers to selected 'where' and 'what if' questions relating to the production of wind energy in Wales. The data used included wind resource, using estimates provided by the Department of Trade and Industry (DTI); land use, from the Land Cover of Great Britain 1990; transport infrastructure, from Ordnance Survey digital data; archaeology, landscape and natural heritage designations, from Cadw and the Countryside Council for Wales (CCW). Certain datasets then underwent pre-processing to derive buffer areas around certain features (*e.g.* airfields, transport infrastructure) or, to take account of sensitivities about potential landscape impacts, estimates of the visibility of the landscape from selected designations (*e.g.* National Parks or National Trails).

The method has been designed to enable flexibility in the order, weighting and combination of factors such that alternative options may be explored, and the implications of each evaluated by the user, be they statutory agency, local authority or commercial interests. It provides one facility for discussing options for future development, which may lead to savings for the wind industry, and public funds, in matching the capacity for the provision of wind energy with other land management objectives, and selected physical limitations and environmental issues. Therefore, the different considerations that may influence spatial development of wind energy production can be examined, with new datasets included and rules modified, or re-weighted, according to prevailing policy positions and practicalities.

The rule-base considers the role of natural heritage designations, and the potential importance of each designation with respect to the opportunities for, and the factors that would constrain, wind energy production in Wales. The rule-base has been applied to the data under six scenarios: three different wind speed thresholds of 7 ms^{-1}, 6 ms^{-1} and 5 ms^{-1}; and the presence or absence of coniferous woodland for each.

Seven classes have been used in the outputs datasets produced: Not Available for turbine development; Sensitive to turbine development; Unlikely to be available; Moderate constraints to development; Weak constraints to development; no constraints and wind speed above a selected threshold value; no constraints and wind speed below a selected threshold value.

Inspection of the outputs suggests that certain areas in south and central Wales may provide opportunities for further development onshore at the 7 ms^{-1} threshold, although in relatively small geographical units. However, if it were economic to produce wind power at lower wind speeds, the areal extent of these opportunities is increased. If the 'weak' constraint is relaxed, the scope for development increases further, particularly in the areas of eastern Wales, in the vicinity of the Brecon Beacons, and the Lleyn Peninsula.

There remain several limitations to the method as currently implemented. The most significant is the wind resource data from DTI, which is only available at a resolution of 1 km x 1 km. An alternative wind speed dataset is available from the Forestry Commission at a 50 m x 50 m resolution, which has also been used to compare the outputs from use of the two datasets, the results of which appear promising. In general, there is a need for a wind resource dataset for the United Kingdom that has been derived at higher resolution than 1 km x 1 km, and calculated for a nacelle height of approximately 65 m, to reflect the size of wind turbines currently being planned or installed.

When combining the two low resolutions of data there is a risk of misrepresenting the available resource. For example, if part of a 1 km x 1 km square that has a suitable wind speed, is excluded from consideration for development by the superimposition of data representing a designation constraint, the area left (within the same square) may not include the land that was above the wind speed threshold. Therefore, the outputs from the analyses should be considered to be indicative of where further investigation would be merited and in practice specific anemometer readings would be needed to justify investment.

A second area of future work would be the inclusion the network of 33 kv, and above, electricity lines into which any development would feed. The latter dataset would enable the

limitations of the geographical distribution of the grid to be built into the identification of opportunities for development, and for industry to assess the economic viability of extensions to the grid network with respect to the resources available.

The scenario modelling presented provides an input to a comprehensive evaluation of strategic assessments, in which the characteristics of the land in each strategy class, as triggered by each rule, can be summarized as a proportion of land resources. For example, the area of cultivated agricultural land that may be included within the 'weak constraint' class would also be reported as a proportion of the total area of cultivated land. This would enable the results to be interpreted with respect to the portfolio of the land resources of Wales.

The analysis excluded conditions offshore and, although there is scope for development in this area offshore of the Welsh coastline, there was insufficient data available on the modelling of wind speed. In addition, there has been no comparison with the potential for identifying, at a national level, where electricity may be produced from other renewable sources.

When taken together with existing production by wind turbines and hydro-power generation, an overview of the diversity of options available in Wales could be developed, including integration of strategic assessments both onshore and offshore, for which a similar approach to the analyses of potential and suitability may be undertaken. Therefore, an assessment of the capacity for production versus the potential impacts across different geographical areas could enable a more holistic basis for prioritising options for development.

1. Introduction

The aim of this study was to develop and test a method in which spatial planning could be built in to the strategic assessment of the potential for the provision of wind energy in Wales. In order to meet government targets, wind turbine provision is expected to increase. However, there has been some controversy over the sites chosen by the wind industry, which tend to be in exposed countryside, often used or valued for other, competing, purposes.

The best estimate of the number of turbines that may be needed were published in the British Wind Energy Association's (BWEA's) study 'Planning for Wind Energy: a guide for regional targets' (BWEA, 2000), which suggests that for Wales 193 turbines (using 1.5 MW machines), on 0.15% of the land area, could produce 8% of onshore renewable energy production in the United Kingdom by 2010. A method that accommodates resource data and the potential constraints that could limit scope for development, would enable different scenarios of wind speeds, current and future land use and priorities attached to policy related constraints to be examined. The use of such a method would be to identify the geographical locations where proposed capacity could be installed, and contribute towards the selection of spatial planning strategies for identifying areas of potential development.

Spatial planning requires sufficient geographically referenced data to be available, at appropriate scales or resolutions and level of reliability. By generalizing and simplifying datasets, it is often possible to conduct a study at a small cartographic scale (*e.g.* national level) for broader, more strategically targeted analyses. The application of spatial planning modelling at larger cartographic scales (*e.g.* suitable for local or site specific interpretation) places a higher demand upon the data used. At either scale, the interpretation of the output should take account of the nature of the models used and the assumptions that are made in their implementation. This report describes the data, methods and results of the use of Geographic Information Systems (GIS) to provide one approach to the production of an indicative assessment of the potential areas for wind turbine development in Wales, by synthesizing data from a range of sources and allowing the integration of different stakeholder interests and visions (Birnie *et al.*, 2000). The approach should also enable issues and interests to be represented from across different land use sectors.

The method developed should be applicable a local level, providing that the relevant information can be obtained. This would enable local authorities to derive a locally-based approach to contributing to national government targets of reducing carbon emissions, while taking account of local issues, priorities and concerns. Currently, gaps in the data available include a dataset of probable wind speeds that can be applied at a local level.

The outputs from the study are intended to provide a basis for a strategic overview of the potential for wind energy in Wales, with more detailed information provided at scales suitable for its use as an adjunct to traditional planning techniques. The report provides an outline of the methodologies developed, the data used and a summary of the results obtained from different scenarios of acceptable wind speeds and constraints to development, with discussion of the limitations of the approaches and input data, and possible future alternatives.

2. Data

The approach adopted in the development of a national appraisal of the areas in which wind energy may be most suited was to develop a rule-based model, within which the potential for energy production is represented by wind speed and to compare the spatial distribution of different wind speeds with that of factors that may constrain the development of turbines, for physical or policy reasons. The use of the GIS allows different priorities to be allocated to the factors that may constrain site selection for turbine development.

To enable the mapping of the potential distribution of wind power developments for Wales the scale of most of the datasets is between 1:50 000 and 1:250 000, including data at spatial resolutions of 50 m (land cover) and 1 km (wind speed). However, the range of scales of data used can cause the propagation of cartographic errors through to the final results. Where possible, the sources of such errors have been identified, and comment made of the potential impacts on the results, however the source scales of some datasets were not documented (*e.g.* the boundaries of 'Areas of Outstanding Natural Beauty' (AONBs).

The four broad themes that were considered in the derivation of a dataset that represents the spatial distribution of land where wind turbine development may be focused, are based upon those provided by CCW (Countryside Council for Wales, 1999). Those four themes are:

1. Wind resource data which provides the basis of any assessment of the suitability of an area for the production of wind energy.
2. Physical constraints which are features that will prohibit development, or require significant modifications prior to development.
3. Policy constraints which are factors that result in limiting the spatial extent of the areas subjected to subsequent consideration with respect to the wind regime.
4. Additional factors which may be sensitive to the presence, or geographical distribution, of turbines, or their construction.

2.1 Wind Resource

2.1.1 Wind speed

Models of the distribution of mean annual wind speed in Wales are the basic information on the wind resource. Studies by ETSU Ltd., on behalf of the Department of Trade and Industry have used the NOABL model (Burch and Ravenscroft, 1992; Brocklehurst, 1997), the outputs from which were calculated for a resolution of 1 km x 1 km. The wind speeds have been banded into 1 ms^{-1} intervals, ranging from 4 ms^{-1} to greater than or equal to 7 ms^{-1}, at 10 m above ground level (Figure 1) and 45 m above ground level (Figure 2).

The second source of data on wind speed was a derivation of the DAMS system ('Detailed Aspect method of Scoring'), which is based on location, elevation and exposure and is available at a resolution of 50 m x 50 m (Forestry Commission, 2001a) (Figure 3). This measure is used in the calculation of the risk damage to trees due to wind (Bell *et al.*, 1995) and forms one input to the Forestry Commission ForestGALES model (Forestry Commission, 2001a).

2.1.2 Elevation

The Ordnance Survey 1:50 000 Digital Terrain Model DTM (Ordnance Survey, 2001a) was used as the input to derivation of the modelling of the DAMS dataset, terrain slope and the modelling of visibility of land from selected features, such as national trails, National Parks and AONBs. The DTM is in a raster format with a spatial resolution of 50 m x 50 m and a vertical resolution of 1 m and was also used in the calculation of slope for identifying land of slopes greater than 40^{o} for subsequent use in the rule-base.

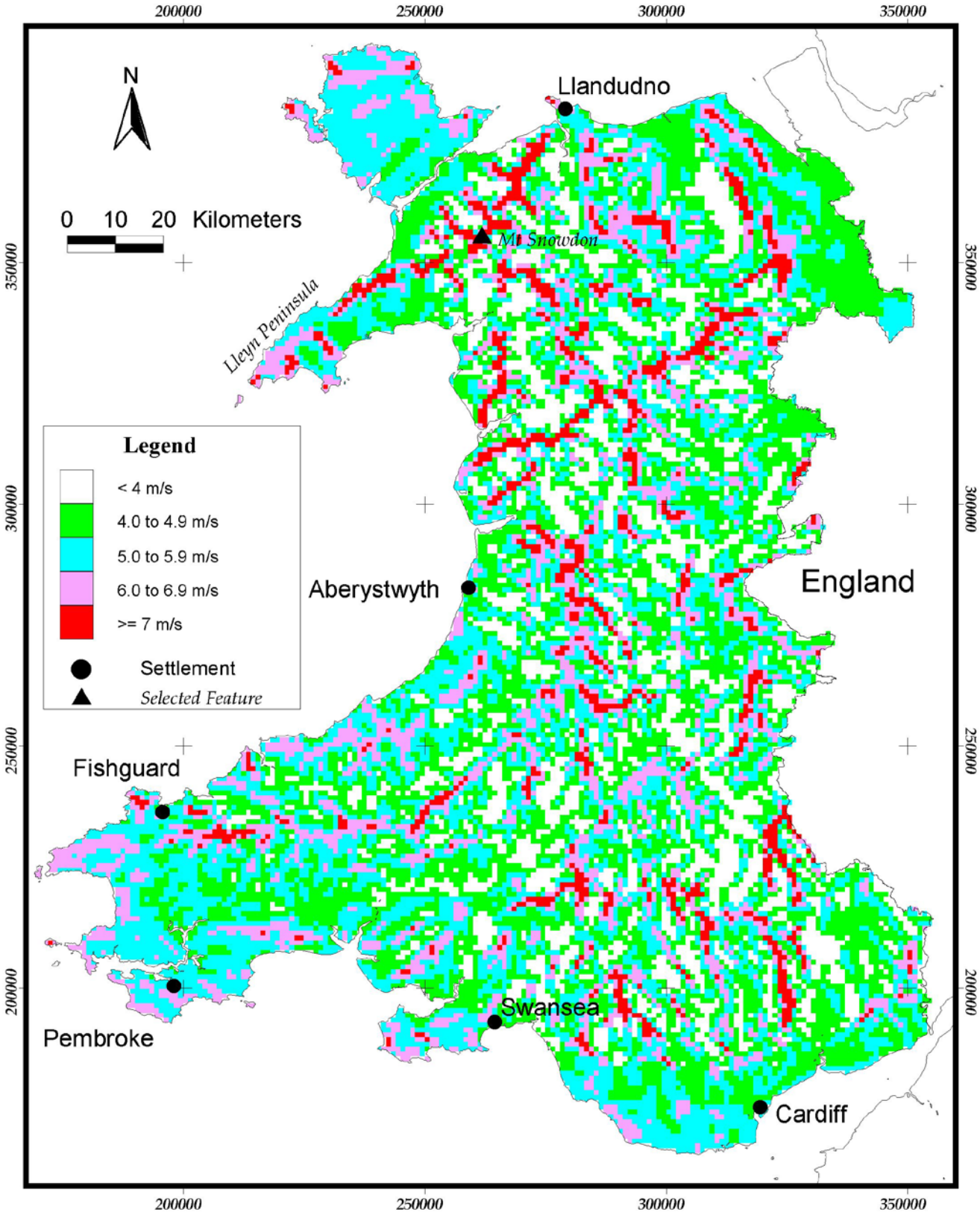

Figure 1. Map of mean annual wind speed: 10 m above ground level (ms^{-1}) (1 km resolution). (Source: wind speed data reproduced courtesy of Department of Trade and Industry).

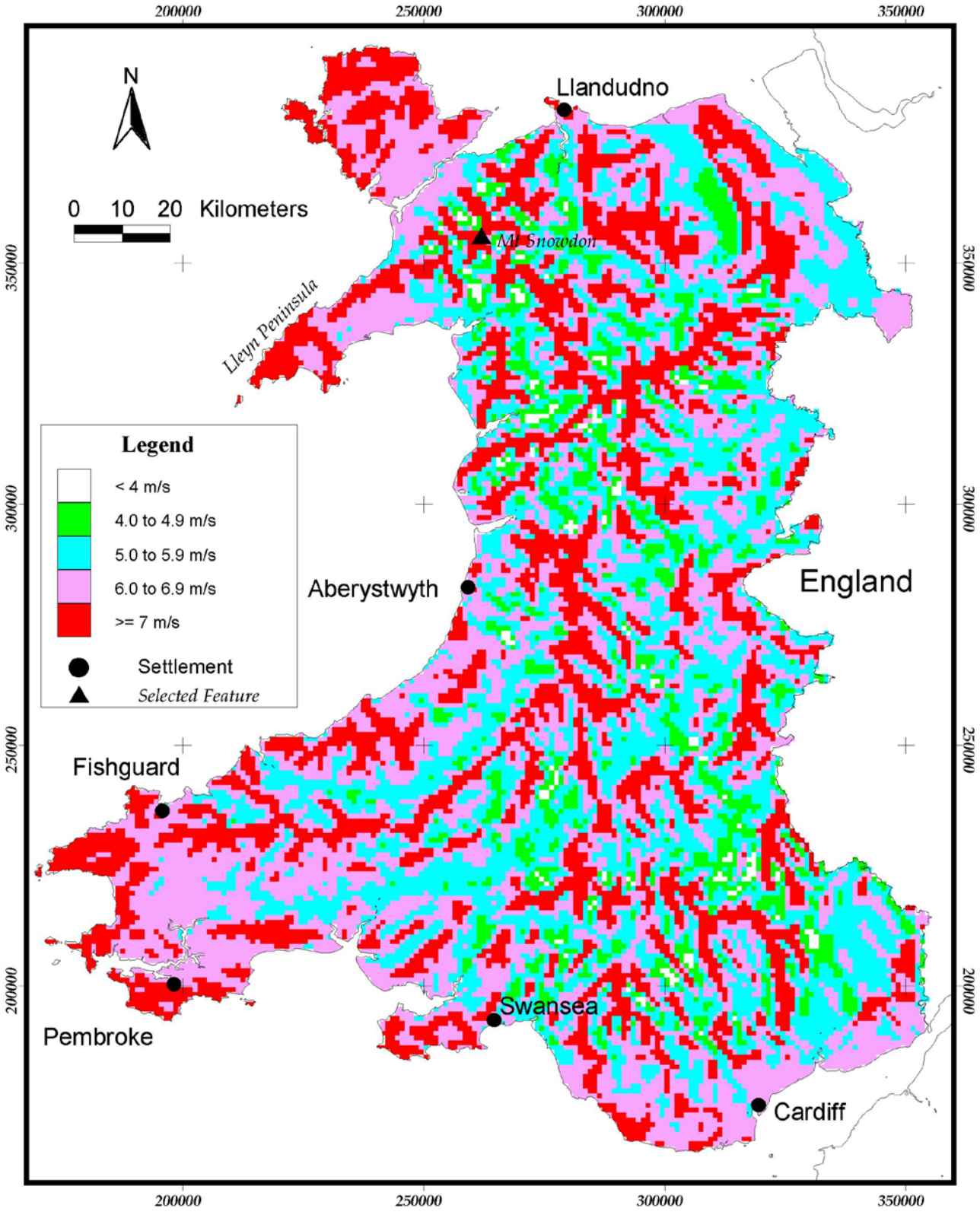

Figure 2. Map of mean annual wind speed: 45 m above ground level (ms^{-1}) (1 km resolution). (Source: wind speed data reproduced courtesy of Department of Trade and Industry).

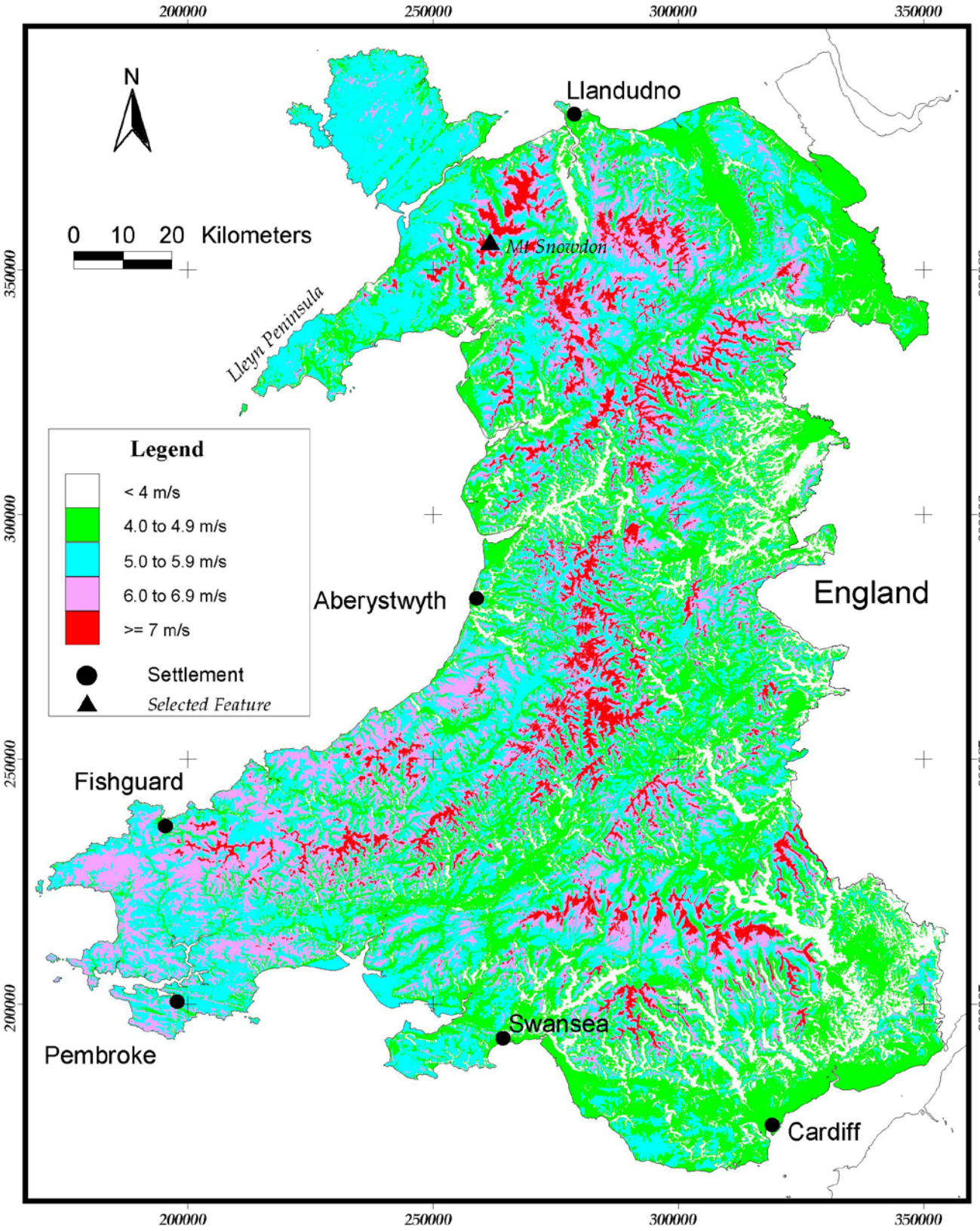

Figure 3. Map of mean annual wind speed: 10 m above ground level (ms^{-1}) (50 m resolution). (Source: Forestry Commission ForestGALES wind risk model; Bell *et al.* 1995).

2.2 Physical Constraints

2.2.1 Land Use

Environmental, economic and social factors associated with different land uses necessitate that consideration be given to those land uses that may be either physical or policy related constraints on the development of wind turbines. Limitations due to the physical environment, onshore, are areas of open water, cliffs and steep ground, most urban land and most woodland, the latter two being discussed in greater detail below.

The source of the land cover data was The Land Cover of Great Britain (LCGB) data (Fuller *et al.*, 1994). The classification has a spatial resolution of 25 m x 25 m and is derived from Landsat Thematic Mapper satellite data, from scenes dated approximately 1990. Some areas remain unclassified due to cloud cover or shadows, and the land cover in other areas will have changed since the date of the satellite overpass. The classification is also subject to errors, some of which are reported in Fuller *et al.* (1998). However the main woodland classes and water are two features that have high classification accuracies and therefore they can be used with some confidence.

2.2.2 Woodland

Woodland areas were obtained from two different sources.

1. A GIS dataset of the ancient replanted, and ancient semi-natural, woodlands in Wales, was obtained from CCW (Figure 4).
2. The LCGB 1990 dataset was used as a source of the remaining woodlands in Wales, which were separated into three classes: coniferous woodland, broadleaf woodland, and scrub/orchard.

There would be a presumption against development where damage may accrue to areas of ancient woodlands, either planted or semi-natural. The current presence of other woodlands may also reduce the scope for turbine development, and only a limited account was taken of the potential for future changes in land use with respect to changing the availability of land for this purpose. Indeed the strategic aims of the Forestry Commission in Wales is to increase the areas of continuous cover forestry, with new woodlands linking and protecting the ancient woodland (Forestry Commission, 2001). However, land which is currently under forestry could become available when the first rotation of tree growth and timber production is complete. The broadest indication of the extent of this area would be obtained by the exclusion of the commercial woodland from the derivation of the constraints to development at different wind speeds.

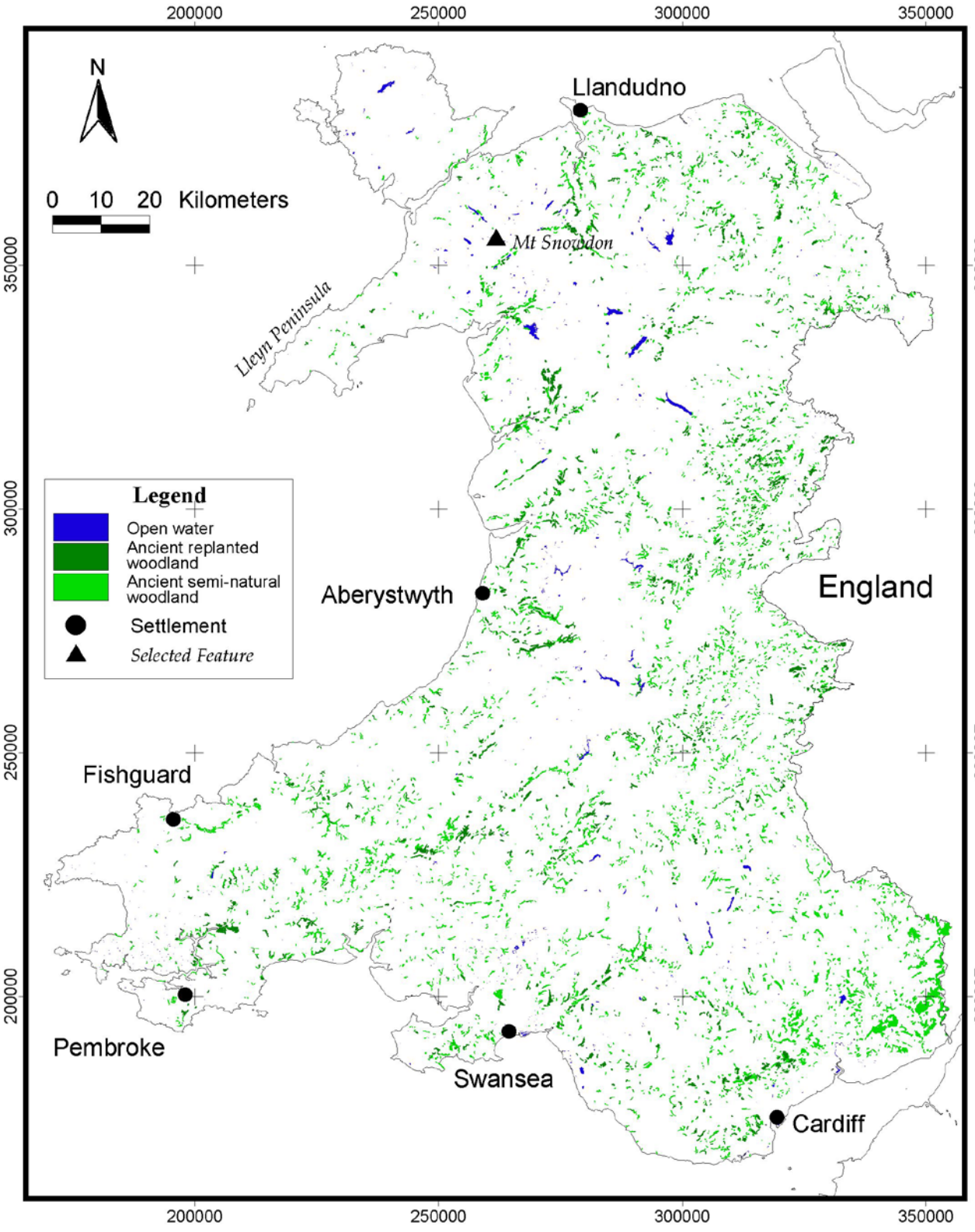

Figure 4. Map of inland open water and ancient woodlands. (Sources: inland open water – Land Cover of Great Britain 1990, ITE; ancient woodlands – Countryside Council for Wales, 2001).

A dataset of the woodlands that are most likely to be felled as part of a commercial management plan was not available. Thus, to illustrate the potential for exploring the consequences of changing the land use on the availability of land for turbine developments, the area mapped as coniferous woodland was identified for inclusions and exclusion as a constraint within the development of the rule-base.

As a consequence of the planting of the 1960s and 1970s, the Forestry Commission anticipate that there is potential for wood production to increase over the next 15 to 20 years (Forestry Commission, 2002). Therefore, if the felling timetable for commercial forestry was to be taken into account, it is possible that additional areas could be evaluated for their suitability and included in any sequencing of wind turbine developments.

2.2.3 Urban land

Urban and built land, and that in the immediate vicinity, are excluded for four reasons, which are listed below:

1. Current use precludes turbine development.
2. The proximity of turbines to buildings may cause turbulence in wind flow.
3. The height of a turbine is recommended as the minimum distance from a built feature, such as a road or building within TAN 8.
4. The potential impact of noise from dwellings.

The LCGB 1990 includes classes of ‘suburban/urban development’ and ‘inland bare ground’. Both of these classes are subject to errors in the classification (*e.g.* due to confusion with areas of shadow), and wide definitions of ‘urban’ land and ‘open ground’. The definition of constraints, based upon impracticality, for wind turbine development suggests a need to distinguish a ‘core’ area of urban development which is centred upon villages, towns and cities, or large industrial complexes. Such areas would exclude individual dwellings and small clusters of houses. It would also seek to exclude those areas that might be classified as parts of the built environment from satellite data.

A reclassification of the land cover map to isolate the urban class demonstrated that there were cells classified in areas remote from the villages and towns. It appeared likely (in the absence of ground information, but referring to large scale maps and a limited number of aerial photographs) that some cells were bare rock, or other sources of misclassification. To limit the classified cells to those that best represented the villages, towns and more extensive built environment two rules were imposed:

1. a minimum area threshold of 2.5 ha (40 cells), which would exclude the smaller groups of cells;

2. an urban area must lie within 750 m of a main road (as mapped by the Ordnance Survey Strategi dataset) on the assumption that an urban area of significance will be connected to, or be in the vicinity of an ‘A’ or ‘B’ class road.

The pre-processing involved the grouping of land cover cells to identify adjacency and filtering the grouped data to isolate the sites that qualified for consideration. These sites were then selected or rejected based upon their proximity to the A or B class roads, with a 750 m buffer. An illustration of the inclusion of the two rules, set against the backdrop of an Ordnance Survey 1:50 000 scale map is shown in Appendix 3. The final map of urban areas is shown in Figure 5.

For inclusion within the rule-base, a buffer of 500 m was derived for each of the derived urban areas (Figure 6). Although the core urban area would be impractical for development, the land that is within the buffer may be considered. Issues of visual intrusion, noise and possibly safety could preclude development within this distance band, but to exclude all such land on the basis of the data available would be inappropriate, as some will include industrial developments.

A further aspect of urban land use which is not directly addressed is the option of turbine development on brownfield sites, which could include areas previously used for open cast mining as well as previously industrial locations. Such locations tend to be relatively small in extent, and at a strategic level not easily represented. Within the analyses presented in this study, the buffered urban areas, where not also within another constraint (*e.g.* a transport buffer), would probably include most such brownfield development sites, from which an overall estimate of the maximum additional area of land that may be considered could be derived. However, as it is not possible to subdivide the types of urban, or built, land from the datasets used in this study, the identification of potential sites would be an example of the value of the future OS Master Map dataset, from which the geographical objects related to relevant land uses could be extracted (Ordnance Survey, 2001b).

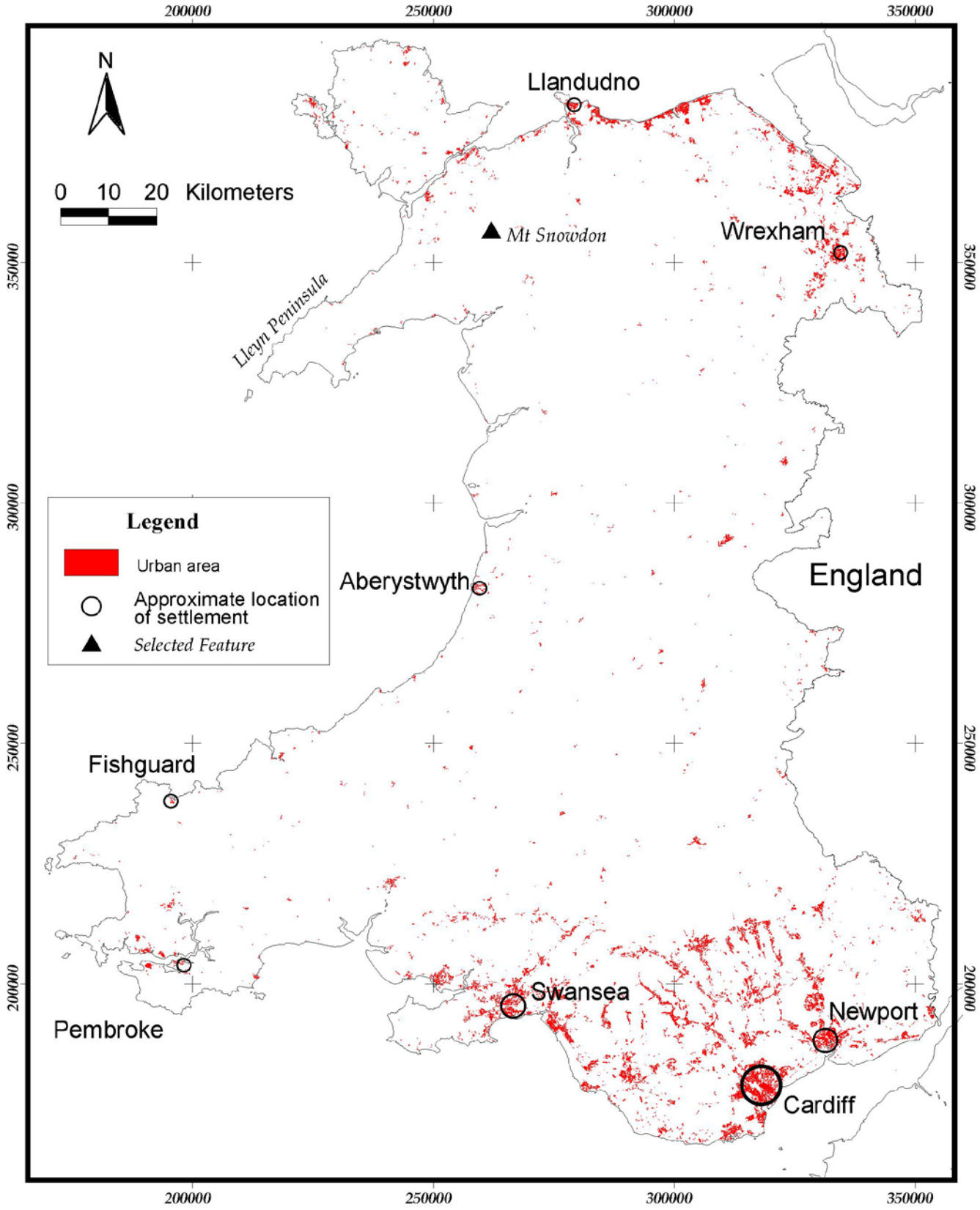

Figure 5. Map of urban areas. (Source: Land Cover of Great Britain 1990, ITE).

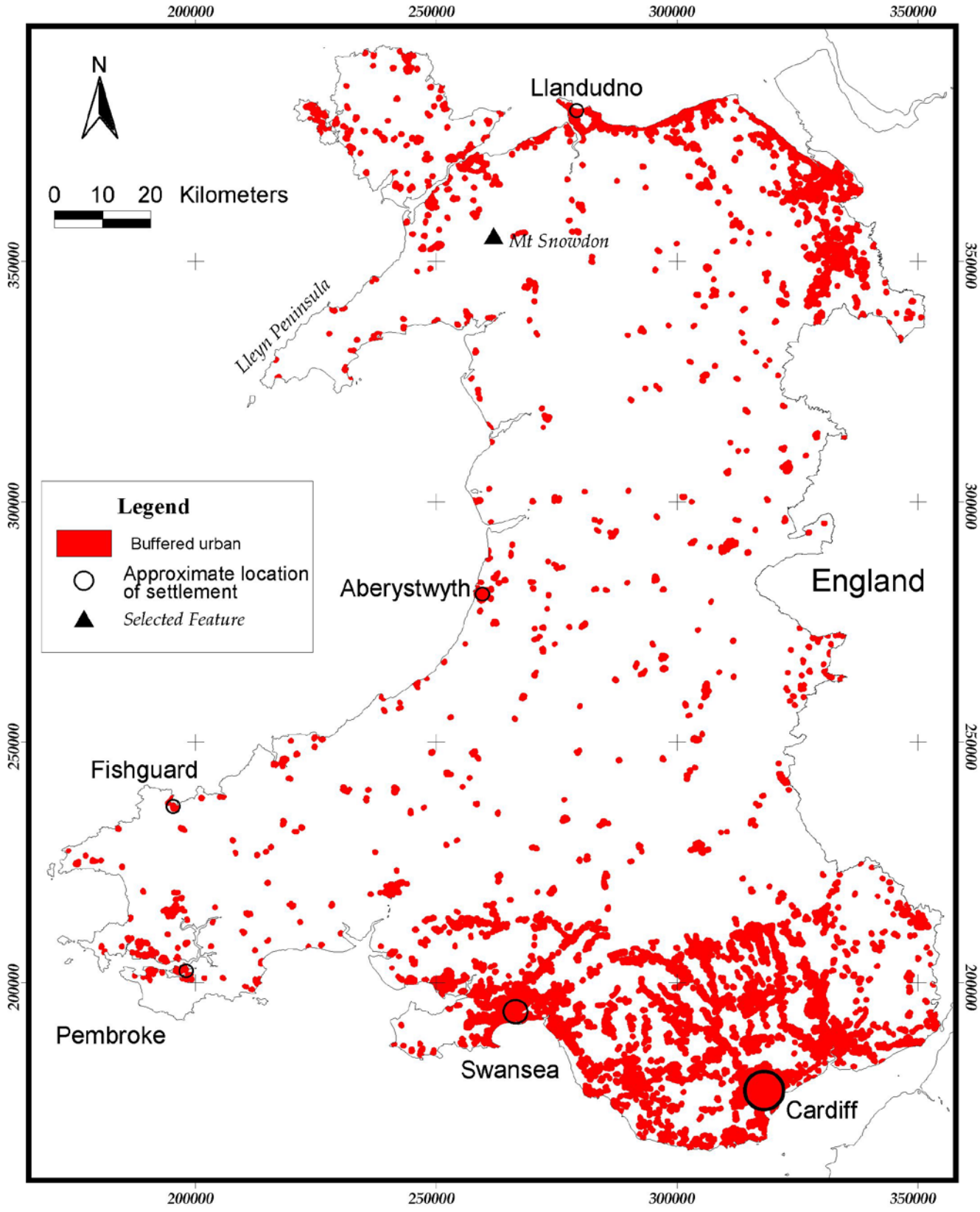

Figure 6. Map of buffered urban areas. (Note: urban areas buffered by 500 m).

2.3 Road, Rail and Canal Transport

Four types of transport, or associated infrastructure, were included within the analyses: roads, railways, airfields and canals. Roads, railways and canals were grouped together and treated in a similar manner, and the data used was the Ordnance Survey Strategi dataset (Ordnance Survey, 2001c) at a scale of 1:250 000. The major roads within this dataset have been edited to match the Ordnance Survey 1:50 000 base maps. However the quality of the minor roads remains limited because of the source scale of the data (Figure 7).

An alternative, more accurate, data source is the Ordnance Survey Landline product, now part of Master Map (Ordnance Survey, 2001b). This dataset is compiled from source scales of 1:1 250, 1:2 500 and 1:10 000 and contains information on the centrelines of roads for all motorways, trunk roads, A and B class roads. However, there is a distinct drawback to the use of this data. There are potentially significant cost implications for the use of the data, the details of which would be dependant upon the users' agreements with Ordnance Survey, specifically, the Service Level Agreement of which CCW are a part.

The matter of resourcing requires to be weighed against the inaccuracy of the Strategi option used in this study. At a national level, the use of the small scale data can be justified as the outputs are small scale plots of Wales, and the principal sources of wind resource data being used are at a spatial resolution of 1 km x 1 km. However, for applications at a local level the larger scale data would be required and is currently available for all local authorities through their agreement with Ordnance Survey.

The derivation of data that represent proximity to the road, railway or canal networks has used datasets that span the border with England so that the influence of such features, although outside Wales, is included within the analyses. The dataset derived for proximity to transport routes was converted into a raster format at 50 m resolution, and subsequently buffered to a distance of 150 m either side of the transport routes. This distance was selected because of the combination of:

1. An estimate of the accuracy of the line features of ±75 m (± half a pixel for the representation of the line and ±50 m for the inaccuracy of the data, approximately 0.2 mm at map scale).
2. The maximum height of a turbine, rounded up to the nearest 50 m.

A map of the buffered transport infrastructure is illustrated in Figure 8.

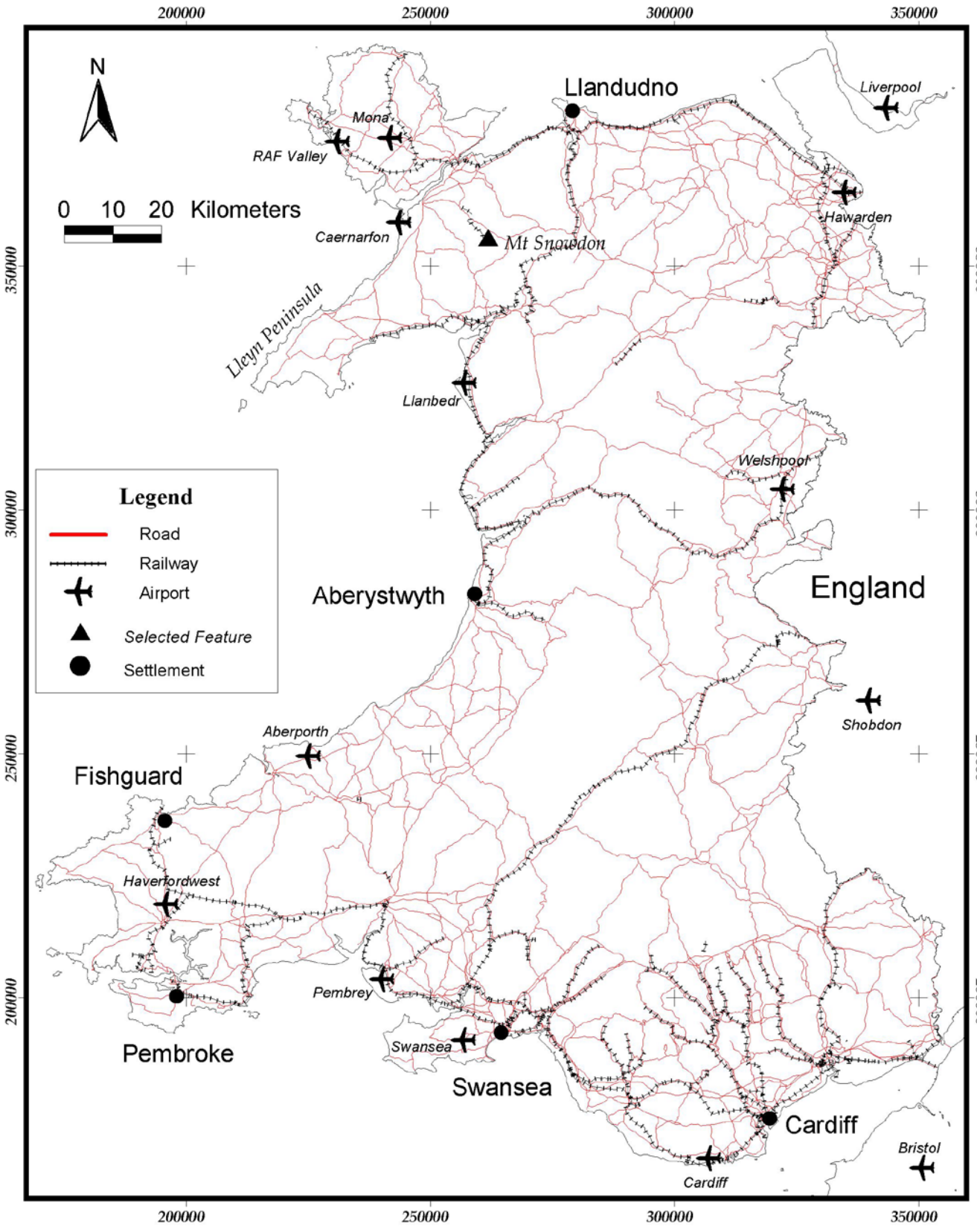

Figure 7. Map of railways, airfields and major roads.

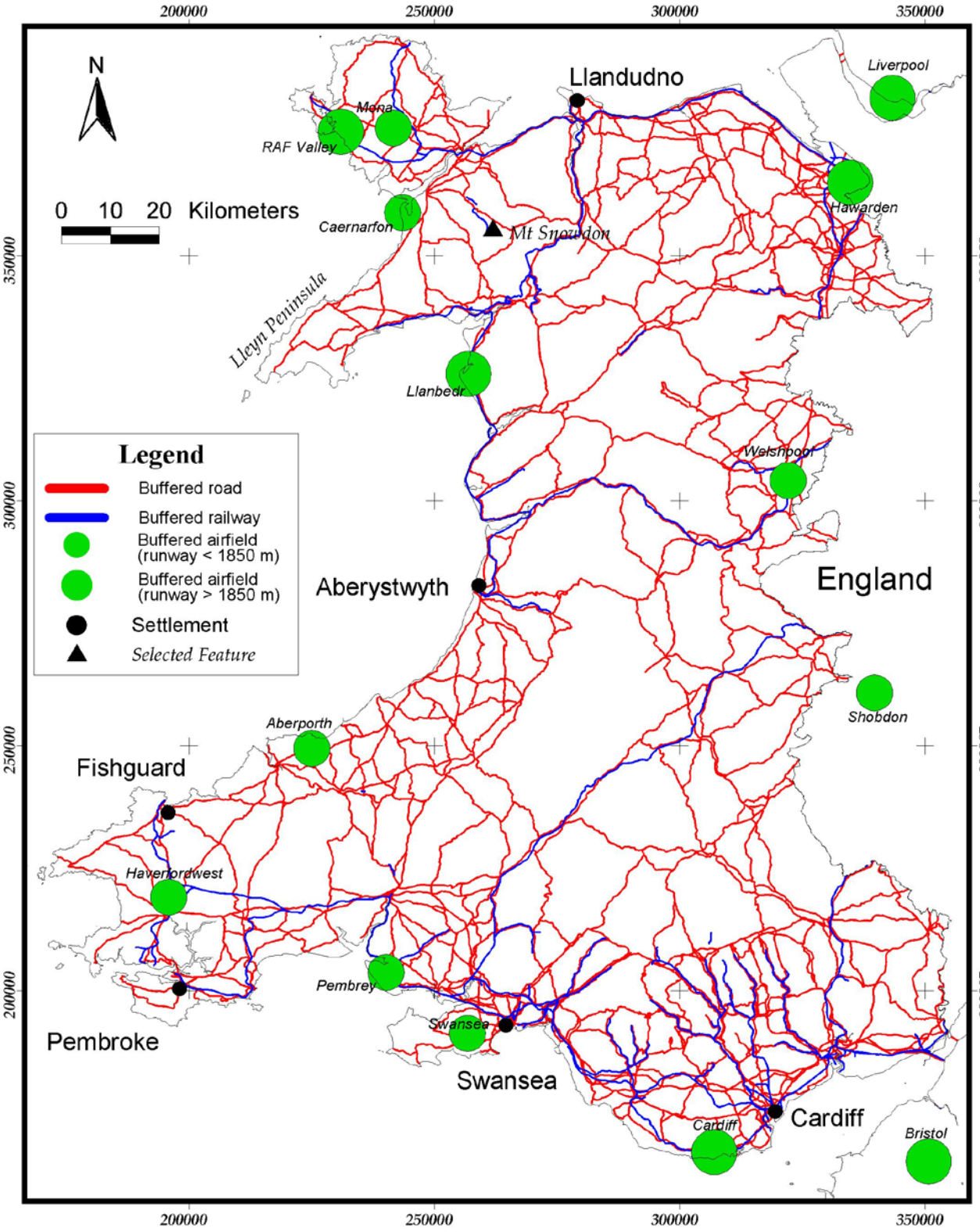

Figure 8. Map of buffered railways, airfields, training areas and major roads.

(Note: Roads and railways buffered by 150 m either side of mapped line.
Locations of airfields: Ordnance Survey 1:10 000 and 1:50 000 base maps.
Source of airfield and training information:
1:250 000 Topographic Air Chart of the United Kingdom, Civil Aviation Authority, 8th March 2001. Buffering of airfields based upon nominal centre of runway, distance based upon aerodrome traffic zone. Runway < 1 850 m – distance = 3.7 km; runway > 1 850 m – distance = 4.65 km).

2.4 Airfields and Military Training Areas

Issues relating to air transport are principally associated with air safety, navigation and monitoring by radar. Data on specific airfields were compiled from the 1: 250 000 aeronautical charts produced by the Directorate of Airspace Policy at the Civil Aviation Authority (sheets 5 and 7). The locations of military and civilian airfields was identified, and their locations checked by reference to the relevant large scale Ordnance Survey maps, and the location taken as the nominal centre of the runway for each airfield. These data provided one basis of excluding the areas in the vicinity of airfields that may cause concern in relation to potential obstacles or security. Sites used for purposes of military training, such as firing ranges, or parachute training were also identified and excluded (Figure 8).

In addition to the issue of aircraft safety, those of navigation and monitoring require to be addressed. The plane of rotation of the turbine blades with respect to the direction of radar head will determine whether or not turbines will be recorded on such monitoring equipment. Although the turbine is stationary, both the rotation of the turbine blades and the hub may show up on radar in an intermittent fashion ('permanent echoes') and they can sometimes be ignored, or automatically blanked from the screen. To take account of this factor within the planning model, the locations of each radar would be required. Radars are located at all military airfields, at most civil airfields, and at some other locations. Although the locations of some radar sites may not be easily obtained, the locations of all military and civilian airfields can be identified and used as a central point around which there may be restrictions on certain types of development.

2.5 Land and Marine Designations

2.5.1 Role of Designations

Terrestrial and marine areas which are under some forms of designation could be precluded from consideration for the development of wind turbines because of the conflict in objectives for the area that may arise. The nature of the designation may implicitly restrict the construction of features that could be considered intrusive to the landscape (*e.g.* Areas of Outstanding Natural Beauty, or National Parks), or the designation may have significance with respect to wind energy because there may be a fear that the turbines could adversely affect the avifauna such as a Special Protection Area (SPA), where rare and vulnerable birds, are being protected.

However, it should be noted that there is scope for the development of turbines in areas where there are certain designations if it can be demonstrated that they will not conflict with the objectives of the designation citation such as in certain Sites of Special Scientific Interest (SSSIs). Therefore, each site can be treated on a case-by-case basis and the use of the data on designations can be treated as broadly indicative.

Areas protected by conservation-related designations have been used to identify where they may constrain turbine development. The types of designation have been grouped broadly into those of international significance (Figure 9) and national significance (Figure 10).

The designations grouped under the title 'International significance' are:

BIOSPHERE reserves
Special Areas of Conservation (SAC)
Special Protection Areas (SPA)
Wetlands of International Importance (RAMSAR)

The designations grouped under the title 'National significance' are:

Areas of Outstanding Natural Beauty (AONBs)
Heritage coasts
Marine Nature Reserves (MNRs)
National Nature Reserves (NNRs)
National Parks
Sites of Special Scientific Interest (SSSIs)

The broad relevance of these designations to wind turbine development are briefly summarised below, with materials drawn from the guidelines set by CCW (Countryside Council for Wales, 1999).

2.5.2 Areas of Outstanding Natural Beauty (AONBs)

A main purpose of AONBs is to 'conserve and enhance natural beauty, albeit taking into account the needs of different land uses and the economic and social needs of local communities. The designation has no statutory basis but it is expected that the relevant authorities will take account of the 'special character of landscape' which control development. Although 'sustainable forms of social and economic development which in themselves protect and improve the environment' could include renewable wind energy, it is

likely that this would be secondary to issues relating to landscape and potential negative visual impacts of the turbine development of turbines.

2.5.3 Biospheres

The only area currently designated as a Biosphere is the Dovey valley, which is subject to a review and the possibility that it may be expanded to include all of the Dovey catchment. There is an emphasis on sustainable land uses within such an area and that could be argued as a reason for the inclusion of certain parts for the production of renewable energy.

2.5.4 Heritage Coasts

Areas under this designation have no legal protection but should be considered by the relevant planning authorities and, as their designation was in response to perceived concern about development in coastal areas (*e.g.* urban expansion and caravan sites), it is likely that they would be a consideration if a development proposal was close to such a coastal area.

2.5.5 National Parks

National Parks were established to protect the countryside by 'preserving the characteristic beauty of the landscape', amongst other considerations, and this would probably prevent such developments within their boundaries. Their role to '… protect beautiful and relatively wild countryside by: reserving the characteristic beauty of the landscape, …' (Countryside Council for Wales, 2001c), could also mean that potential visual impacts of a development on views from within a National Park may also be considered important, but not necessarily sufficiently significant to inhibit development.

2.5.6 National Nature Reserves (NNRs)

National Nature Reserves protect the best examples of wildlife habitats or geological features, with specific programmes of work for the management of the site's special features. Most sites are owned by CCW, or leased from owners or occupiers under formal agreements under which the land is managed to the benefit of the wildlife and their habitats. It is unlikely, either due to the ownership of the site, or the management agreement that turbine development would be possible within an NNR.

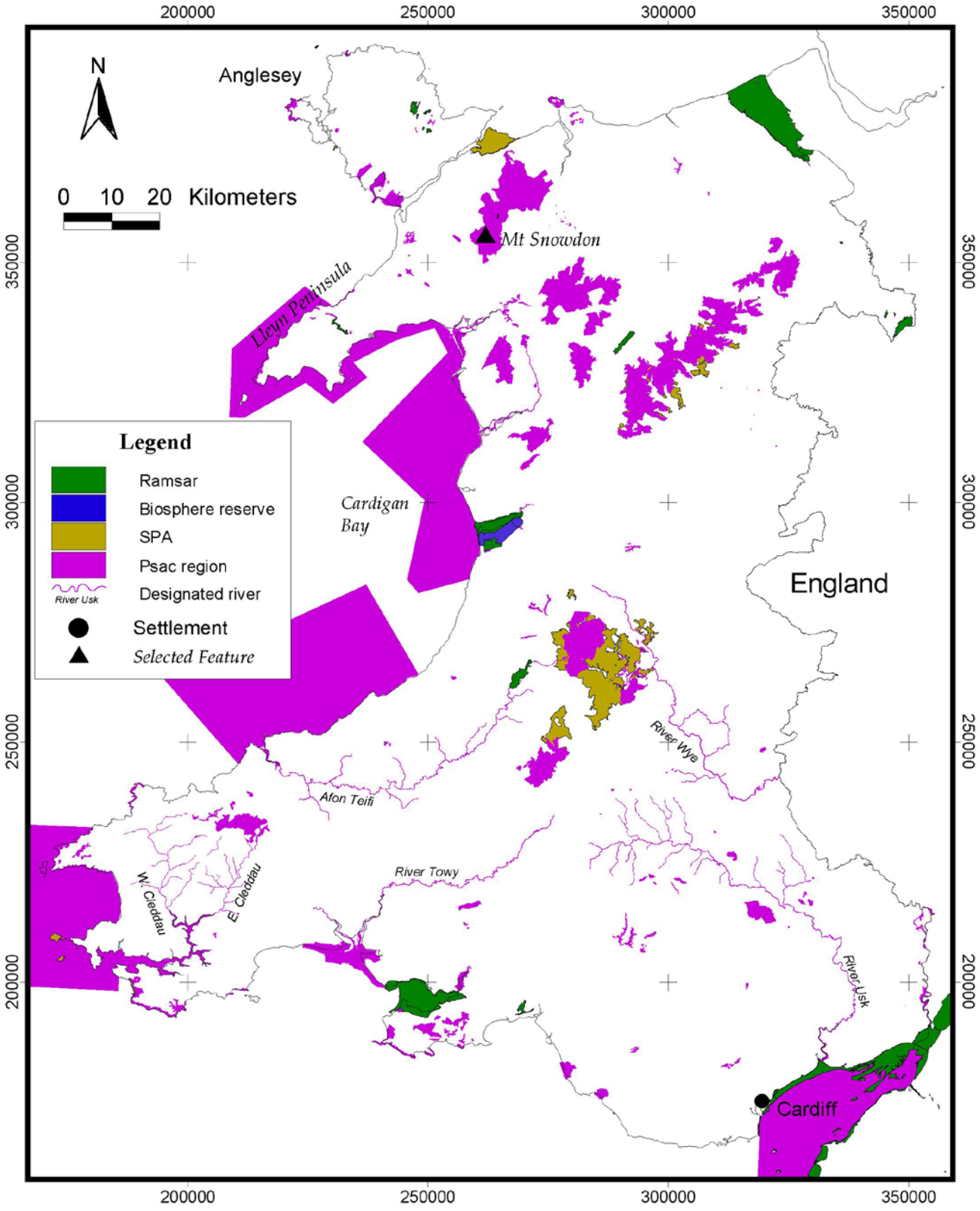

Figure 9. Map of conservation designations of international significance.

(Note: certain riverine features are designated as PSAC regions.
Source: Countryside Council for Wales, 2001).

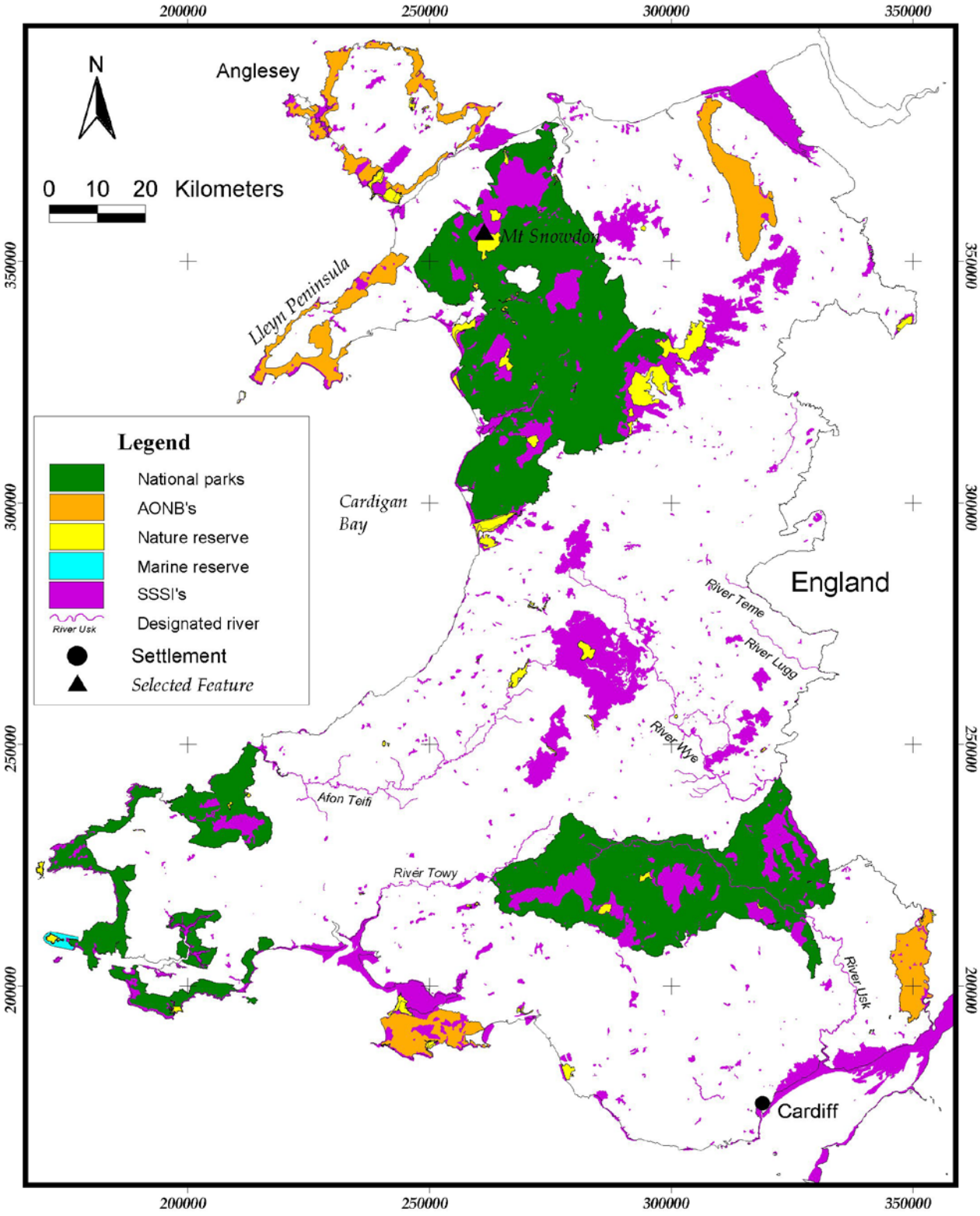

Figure 10. Map of conservation designations of national significance (AONB – Area of Outstanding Natural Beauty; SSSIs - Sites of Special Scientific Interest).

(Note: certain riverine features are designated as SSSIs.
Source: Countryside Council for Wales, 2001).

2.5.7 National Trails

There are currently three national trails: Glyndwr's Way, Offa's Dyke, and the Pembrokeshire Coastal Path. They provide 'commanding views into the mountains and valleys of Wales' (Offa's Dyke Path; Countryside Council for Wales, 2001a), or 'diversity of scenery and wildlife' (Pembrokeshire Coastal Path; Countryside Council for Wales, 2001b). One value of the trails is the views that they offer of the landscape and the description of Offa's Dyke Path notes that 'Where for practical reasons the Dyke cannot be followed, as in the Black Mountains and the Clwydian Hills, the route has been chosen for scenic quality alone' (CCW, 2001c). The extent to which an area of land may be visible from a trail is one measure of the potential sensitivity to change, although this factor alone would not prohibit development.

2.5.8 Sites of Special Scientific Interest (SSSIs)

Sites of Special Scientific Interest are the statutory basis of most areas which are designated as being of particular natural heritage value. In Wales they cover a wide range of habitats, including large areas of uplands, woodlands, bogs and meadows. Most are owned or managed privately, or by wildlife trusts or other voluntary conservation bodies. The factors that lead to the site being notified vary, and a management plan is prepared, in consultation with the owner, to protect or enhance the site's important features. However, layout of turbines and careful design of the associated infrastructure may enable turbines and SSSIs to be closely spatially associated.

2.5.9 Special Areas of Conservation (SAC)

Special Areas of Conservation were established under the European Community Habitat's Directive (European Commission, 1992) and they protect 'vulnerable habitats, and the plants and animals they support' as part of a network of sites, already designated as SSSIs, called 'Natura 2000'. SACs are all SSSIs and thus likely to be excluded from consideration for proposals for turbine development if there is potential damage to the biological value of the site.

2.5.10 Special Protection Areas (SPA)

Special Protection Areas were established under the European Community Habitat's Directive (European Commission, 1992). They protect 'rare and vulnerable birds and the sites used by some migratory species.' In Wales, such species include Merlin, Golden Plover and Red Kite. In general there would probably be a presumption against development within such areas.

2.5.11 Wetlands of International Importance (RAMSAR)

Wetlands of International Importance represent habitats of key importance to certain flora and fauna, particularly ducks and waders which may be vulnerable to turbine strikes. Therefore, such sites are unlikely to be suitable for the development of turbines.

2.5.12 Other Designations

Offshore development has not been explicitly incorporated into the strategies developed. However, the methodology being followed would provide for the inclusion of relevant datasets and the incorporation of rules which reflect the importance of areas for wildlife, industry and commerce or landscape value. The marine designations are included within Figures 9 and 10 to indicate their extent and location around the Welsh coastline.

Other designations which have not been considered but would be included in deliberations would include Biogenetic Reserves, Local Nature Reserves, Country Parks and County Wildlife Sites and local authority designations such as the Sensitive Landscape Areas of Powys County Council.

2.6 Archaeology

Sites of archaeological or historic interest, covered by The Ancient Monuments and Archaeological Areas Act 1979, which may be affected by wind turbine development require consent from the National Assembly of Wales, through 'Cadw: Welsh Historic Monuments Executive Agency'. Such sites comprise Caves, Prehistoric funerary and ritual sites, Prehistoric domestic and defensive sites, Roman sites, Linear earthworks, Crosses and inscribed stones, Ecclesiastical sites and wells, Medieval and post-medieval secular sites, Bridges and Industrial sites (Cadw, 2002).

Proposed developments have to take these into consideration when submitting an Environmental Statement and Impact Assessment. Generally, such sites are sufficiently small in geographic extent that at a strategic level their presence will not be evident. However at a local level this is not appropriate because the spatial arrangement of such features may be of significance and thus exclude areas greater than that in the immediate vicinity of the site.

Account has been taken of the distribution of scheduled ancient monuments using data provided by CCW, with a point representing each of the 2 907 sites. Their incorporation into the spatial database used a point dataset, which was then buffered at a distance of 50 m, recognizing that these features occupy an area, and are not 'points' (Figure 13). However, it should be noted that this approach to their representation assumes that each feature is circular, with a 100 m diameter, which is clearly not the case.

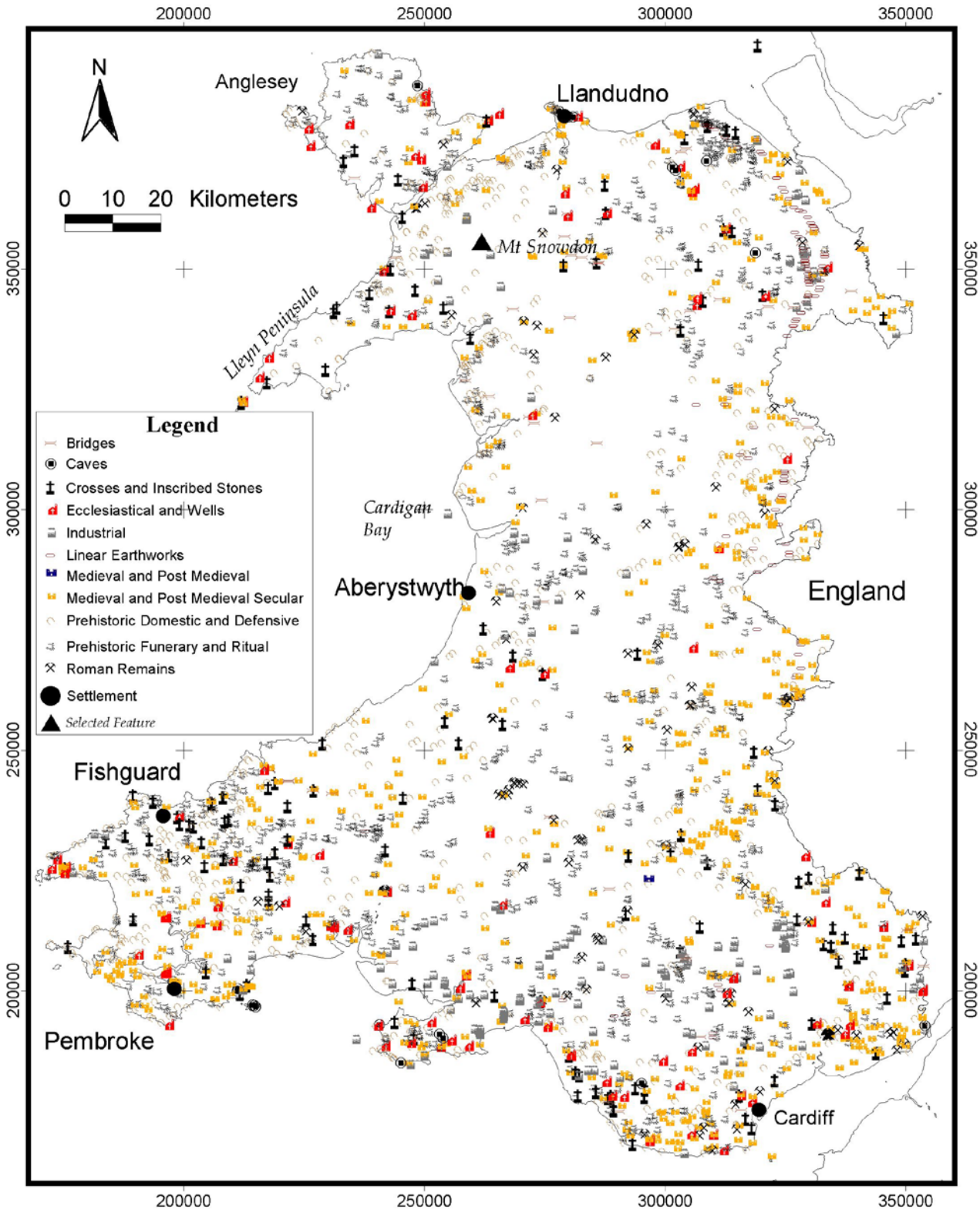

Figure 11. Registered archaeological sites.

An alternative means of approximating the extent of the archaeological features would be to calculate the radius of a circle that would be equivalent in area to that recorded for the feature. For example, a feature of area 213 ha (the largest documented) would be the equivalent of a circle with radius 804 m; whereas the mean size of site is 1.54 ha (equivalent to a radius of 70 m) and the median 0.3 ha (equivalent to a radius of 30 m). In total, 68% of all points are less than or equal to the area used. For use at a more detailed level of operation, the dataset should include the outline of the extent of the feature where possible, otherwise, a circle equivalent to the area may be valid, but risks excluding areas inappropriately.

2.7 Major Rivers

The significance of a potential development proposal with respect to river systems and reservoirs due to any impacts that the construction (or decommissioning) phase had on water quality are dealt with within an Environmental Assessment. There are no specific constraints imposed on development and thus none explicitly incorporated into the modelling used in deriving strategic plans. However, some rivers are included where they are part of designations as SPAs, such as the Rivers Wye, Towy, Teifi, and Cleddau (Figure 9).

The Water Resources Act 1991 (as amended), which was drawn up by the River Authority but amended due to creation of Environment Agency (EA). The EA Wales has responsibility to the Welsh Assembly, and thus on the topic of water, and conservation issues beyond riverine flora and fauna, would consult closely with CCW. Therefore, the use of the rule-based procedure at larger scales than those described in this report could enable accommodation of concerns relating to hydrology and the topics that come within the remit of the EA.

Generally, the issues pertinent to hydrology are likely to be site specific, but as wind turbine developments are predominantly situated at the top of hills, their exact location may influence impacts on more than one watershed. If the runoff from a site drains into different river systems, the impacts could be widely distributed downstream. Issues may include potential problems of small levels of pollution due to the leakage of oil into the water supply causing discolouration, silt deposition, or alterations to a water course. The construction and use of access roads may offer the greatest problem as the layout of the road(s) may alter the area of a catchment of a stream, interrupt riparian rights and alter springs or water features that supply drinking water.

2.8 Co-registration

The data have been obtained from different sources and at different resolutions and scales. The data were represented in a raster format for processing but as they originate from different sources, scales and resolutions, a single dataset was selected as a base to which the others were co-registered for consistency. The dataset used was the DTM, at resolution 50 m x 50 m. All other datasets were then transformed to a similar resolution and position, and the National Grid co-ordinates of the top left corner of the cell set to match. However, the 1 km x 1 km resolution was retained for the wind speed data obtained from ETSU Ltd. (Figure 1 and Figure 2).

3. Methodology

3.1 Pre-processing

3.1.1 National Trails

The data on the Pembrokeshire coastal path and Offa's Dyke have been processed to produce a set of points at approximately 50 m intervals along the line of the trail (the actual distance will vary be between 50 m and 71 m). Each 50 m x 50 m cell of the DTM has been analysed to calculate the number of points along the path from which it may be visible, providing a score for each cell.

The results for the Pembrokeshire Coastal path (Figure 12) show that there are potentially a number of locations that may be visible from extensive stretches of the path, but that the highest visibility would be of the coastal waters. However, coastal land east and west of Fishguard are among the locations that may be most visible from numerous points along the path.

The data for Offa's Dyke (Figure 12) indicates that there are fewer areas which may be visible from extensive stretches of the path compared to those of the Pembrokeshire Coastal Path. The land from which the path offers most views is that to the north end, to the north of Ruthin.

It should be noted that only the data for the Pembrokeshire Coastal Path and Offa's Dyke Path trails were available. Therefore, other trails of significance (such as Glyndwr's Way) and, perhaps, some Public Rights of Way, require to be included in future analyses.

3.1.2 National Parks and AONBs

The land in the vicinity of the three National Parks and five AONBs has also been analysed to identify those areas from which there are the most extensive views of the landscape protected areas. Points have been created at intervals of 1 km x 1 km for each of the eight areas and their visibility analysed from each 50 m x 50 m cell of the DTM, up to a distance of 10 km from the boundary of the area. This provides an estimate of the spatial pattern of the land from which there are views of these designated areas (Figure 13).

The visibility data may be analysed in combination with other datasets in the assessment of the potential importance of being able to 'see' land that lies within the designated areas with regard to development on that site. A value of '1' means that a single 1 km x 1 km location may be visible but provides no information on the extent to which the view of the land within the designated area is significant to all views from the observer's location.

The locations which offer the greatest potential visibility of the NPs and AONBs from beyond their boundaries, but within a 10 km radius of view, include the coastal areas west of Snowdonia and either end of the Menai Straits, the Vale of Clwyd west of the Clwydian Range, and immediately north of the Gower AONB. The close proximity of the Snowdonia National Park to both the Anglesey and Lleyn AONBs means that there are areas in the vicinity of Caernarfon from which all three designated sites may be visible from the same location.

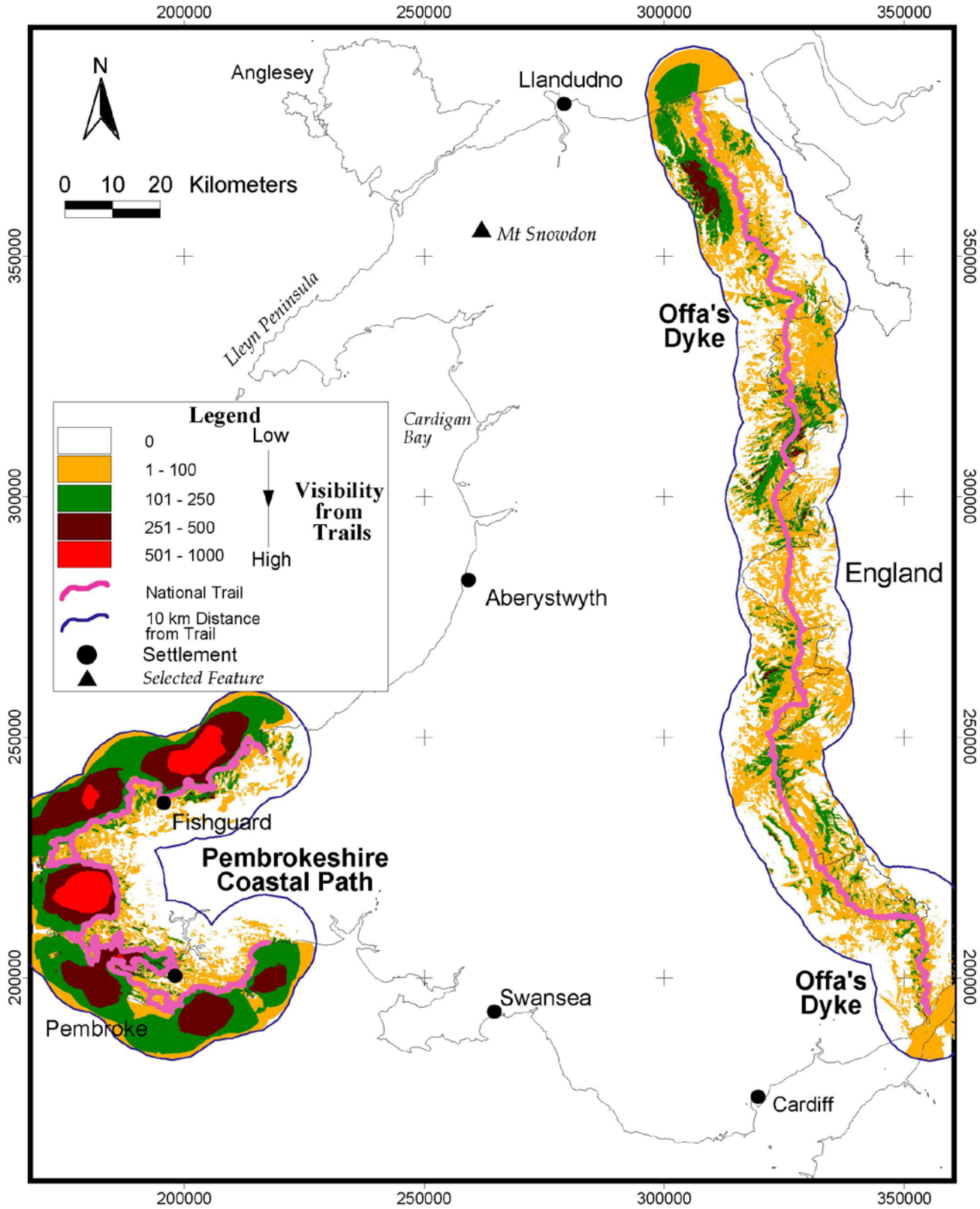

Figure 12. Visibility from National Trails, up to a distance of 10 km.

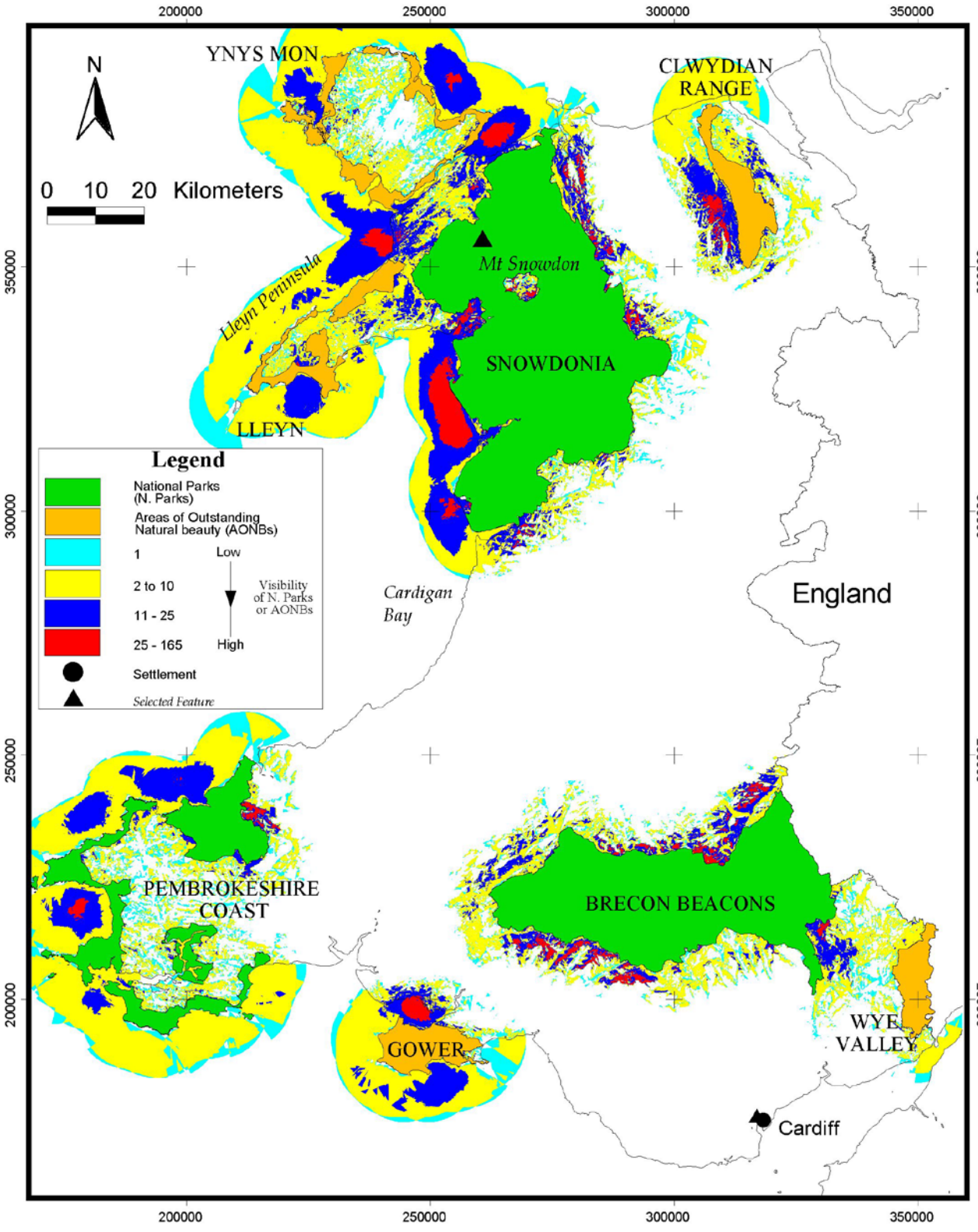

Figure 13. Visibility of National Parks or Areas of Outstanding Natural Beauty, within a 10 km radius of view.

3.2 Rule-base

3.2.1 Background

Based upon the guidelines set out by CCW (CCW, 1999), the descriptions of the relevant datasets and the data derived from them, a set of rules have been devised to classify Wales according to the opportunities for turbine development, and factors that may act as constraints. The method used has been designed to enable flexibility in the order, weighting and combination of factors such that alternative options may be explored, and the implications of each evaluated by the user.

The approach adopted allows for alternative physical constraints, policy options and impact considerations to be accommodated by the modification of the rules associated with the combinations of the datasets. The outputs of the analyses were datasets in which three different wind speed thresholds have been used, each with the inclusion and exclusion of coniferous woodland (which is predominantly owned by the Forestry Commission) (Table 1).

Table 1. Summary of scenario options used.

	Coniferous woodland	
Wind speed	**Included**	**Excluded**
7 ms^{-1}	Scenario 1	Scenario 2
6 ms^{-1}	Scenario 3	Scenario 4
5 ms^{-1}	Scenario 5	Scenario 6

The spatial distribution of the output of each individual rule are shown in Figures 14 to 18 overlaid upon the 1 km resolution wind speed data. The locations of the existing wind turbine developments are also shown for reference.

3.2.2 Not available

Figure 14 shows the area which comes into the class ‘Not Available’. This dataset comprises land that comes into any of the following categories:

existing urban land (as described in section 2.2.3),

OR

ancient woodlands,

OR

steep slopes (greater than 40^{o}),

OR

lakes and reservoirs.

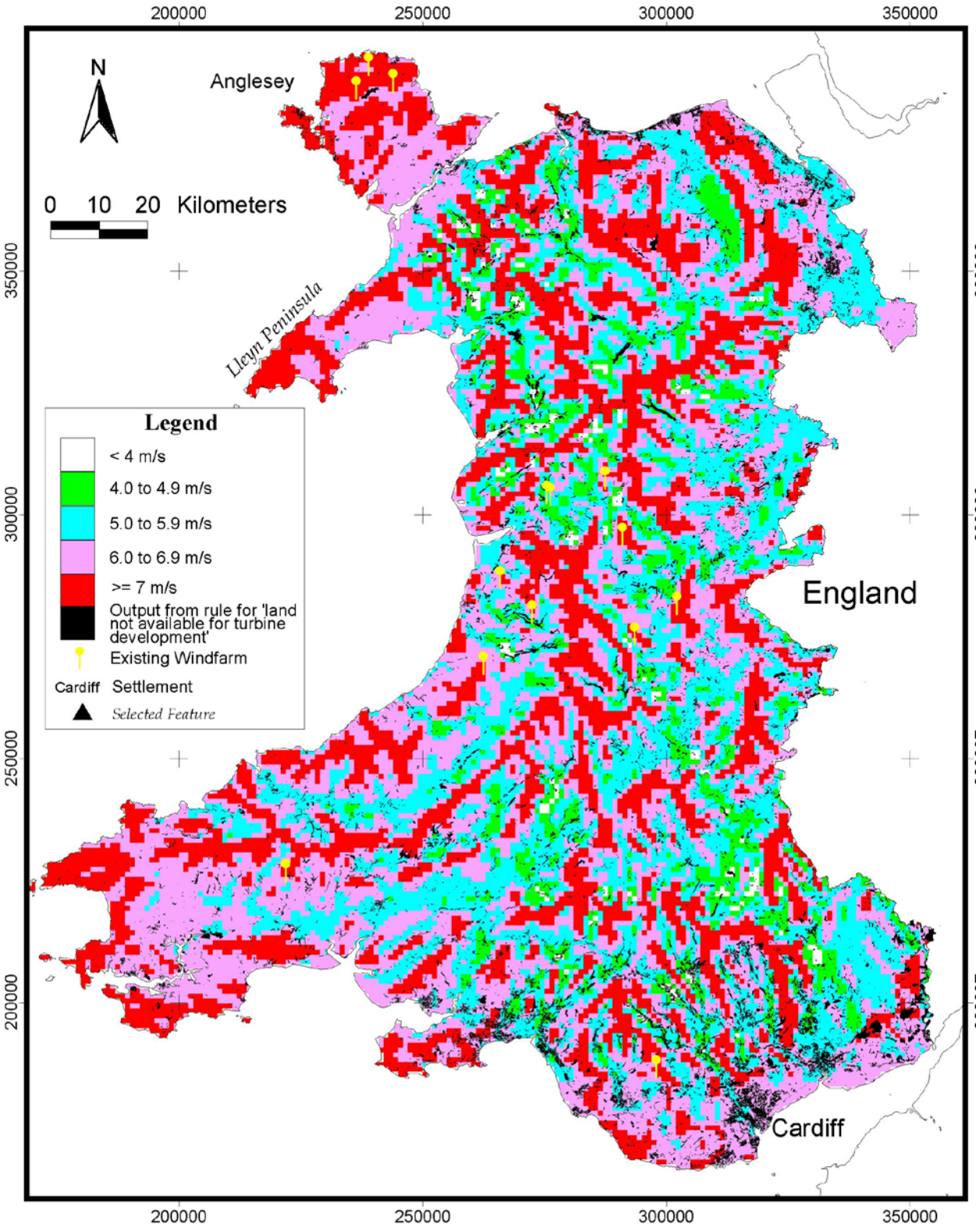

Figure 14. Map of output from rule for 'not available for turbine development', superimposed upon the mean annual wind speed modelled for 45 m above ground level, 1 km resolution (ms^{-1}).

The distribution of this class has concentrations around the urban areas of south and south-east Wales (*e.g.* Cardiff), north-east Wales and the north coast, with the remainder of the smaller towns, ancient woodlands and lakes spread across the country. This rule does not exclude many areas where the wind speed is likely to be 7 ms^{-1} or greater as little of this class occupies higher land, or the windier areas of coastline.

3.2.3 Sensitive

Figure 15 shows the area which comes into the class 'Sensitive to turbine development'. This dataset comprises land that comes into any of the following categories:

land inside a landscape related designation (*e.g.* National Park or AONB),
OR
land inside a RAMSAR,
OR
land inside a Biosphere,
OR
land in close proximity to a registered archaeological site,
OR
land inside a National Nature Reserve,
OR
land that is within both a PSAC AND a SPA,
OR
land that is within both a SSSI AND a SPA.

The requirements imposed, that to be included within the 'Sensitive' class land must be in a PSAC *and* a SPA, or an SSSI *and* a SPA, reflect the importance of areas that are of importance for vegetation and wildlife. However, it is recognised the approach taken to the derivation of a strategic plan lacks subtlety in its treatment of sites where site specific planning may not conflict with the objective or detail of the designation citation. A more sophisticated approach could be built in to both the coding and use of the data, as well as the specification of the rule-base. Recognition of the opportunities offered by a site specific level study is represented by the inclusion of land within an SSSI (but not also a SPA) in the 'Unlikely to be available' class rather than the 'Sensitive'class.

The class is dominated by the areas excluded due to being a part of a National Park or AONB, particularly evident in the north-west (Snowdonia) and south-east (Brecon Beacons). The constraints applied via other designations, the principal roles of which are the protection of vegetation, wildlife or avifauna habitats, are also evident in central and north-east Wales.

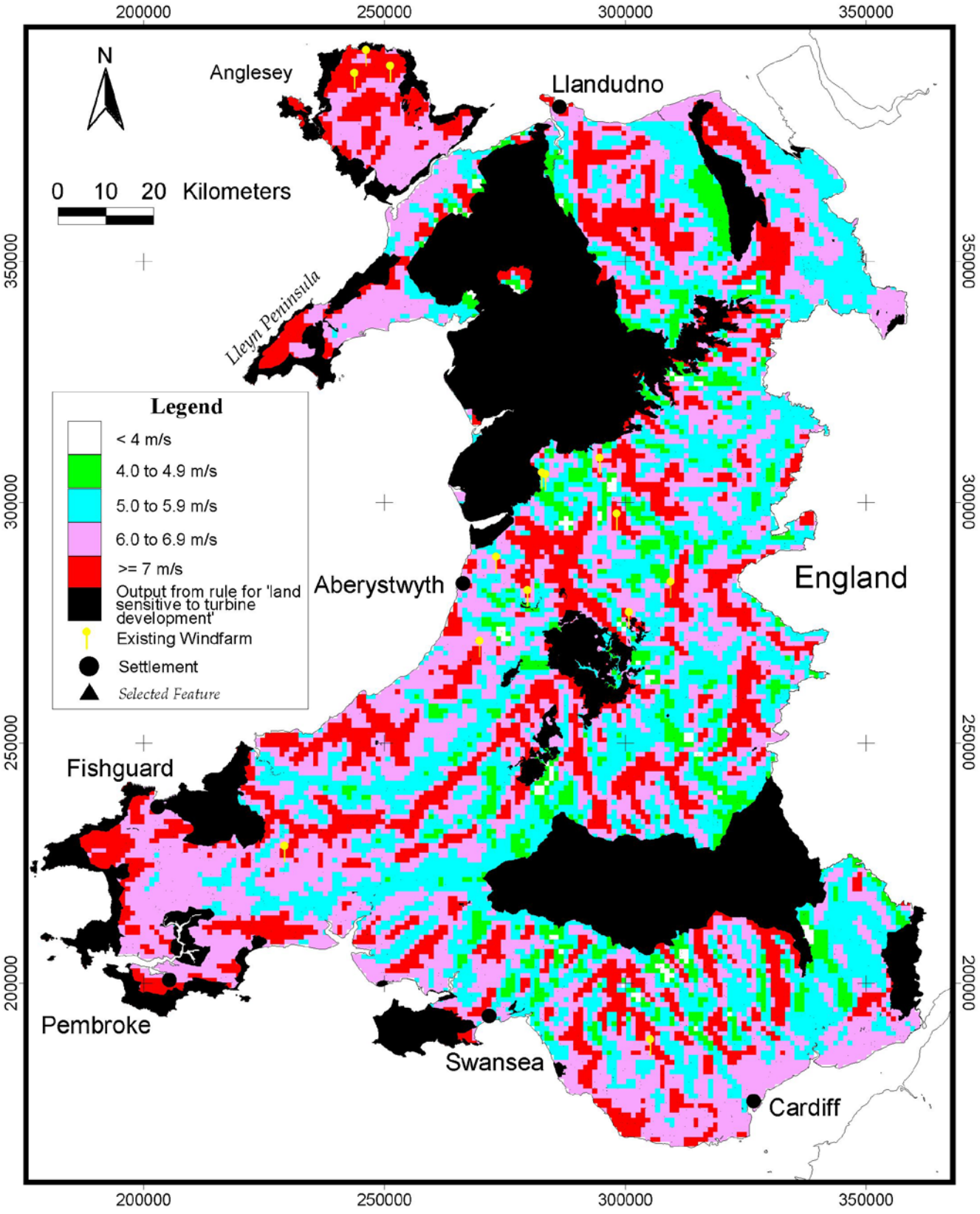

Figure 15. Map of output from rule for 'land sensitive to turbine development', superimposed upon the mean annual wind speed modelled for 45m above ground level, 1km resolution (ms^{-1}).

Alternative options for the derivation of the Sensitive class could include a greater restriction of development within SSSIs or SACs and SPAs, reflecting a higher level of importance of all these designations than that represented within the current rule-base.

3.2.4 Unlikely

Figure 16 shows the area which comes into the class 'Unlikely to be available for turbine development'. This dataset comprises land that comes into any of the following categories:

broadleaf woodland,
OR
coniferous woodland,
OR
land in a scrub/orchard,
OR
in close proximity to an airfield or military training area,
OR
within 150 m of a main road,
OR
within 150 m of a railway,
OR
within 500 m of an urban area (as described in Section 2.2.3),
OR
land within an SSSI but not an SPA
OR
land within an PSAC but NOT in a NNR.

This class considers the presence of woodland land cover types, major transport routes and selected designations. In the case of woodlands (but not the 'ancient woodlands' used in the derivation of the Sensitive class), there may be periodic opportunities to change the land use. This will most likely be due to the cycle of production (*e.g.* with regard to plantation coniferous woodlands), which also occupy some of the higher, and windier land. Much of the coniferous plantation woodland may also preclude the inclusion of areas within designations such as PSAC, SAC or SSSI, and occupy locations that are distant from human inhabitation.

The two parts of the rule that relate to designations are a representation of land that is under some form of protection, but with potentially fewer restrictions than the combinations used within the Sensitive class. However, as with the Sensitive class, details about individually designated sites could be incorporated within the rule-base to strengthen, or weaken, the possible level of constraint that it may represent.

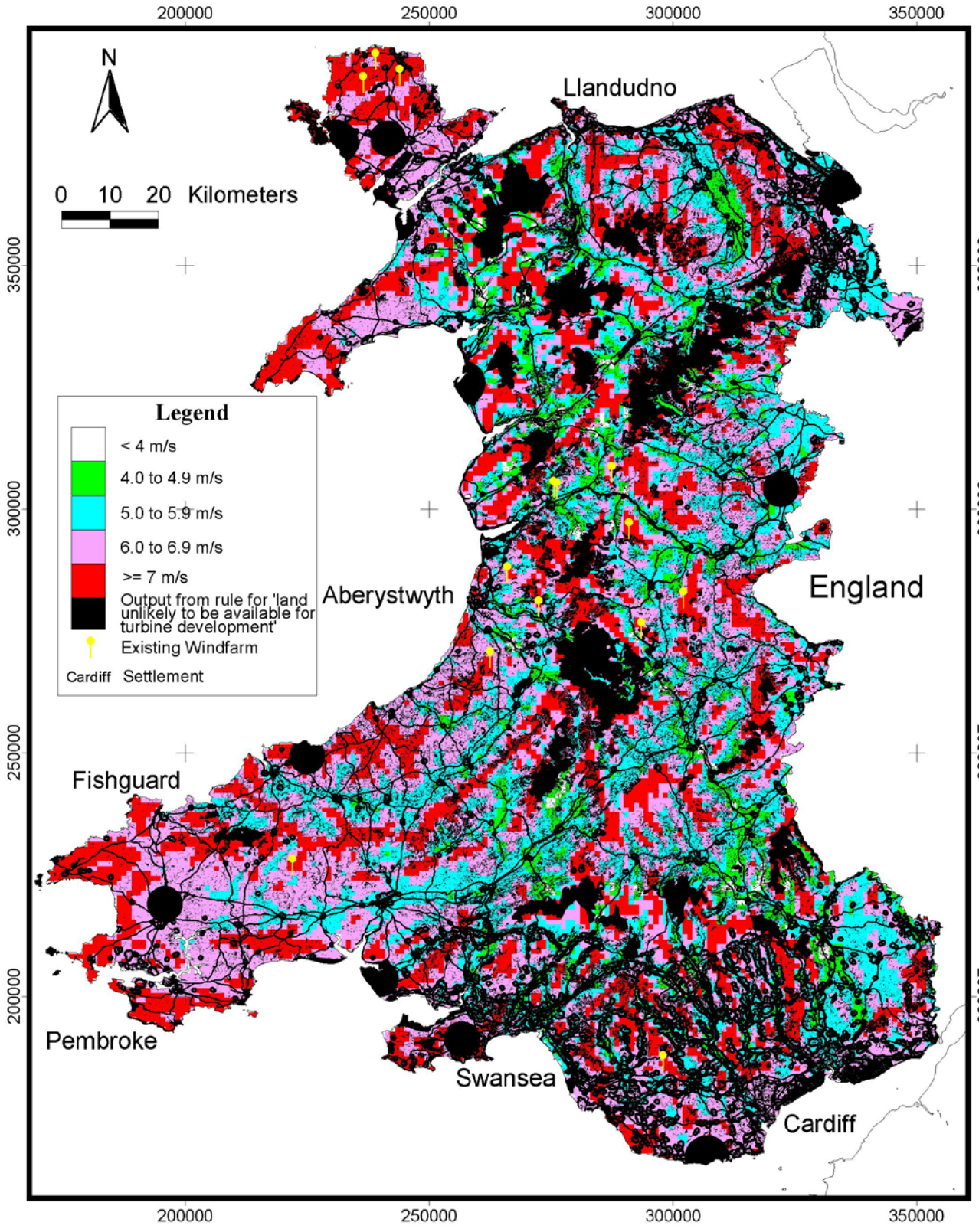

Figure 16. Map of output from rule for 'unlikely to be available for turbine development', superimposed upon the mean annual wind speed modelled for 45 m above ground level, 1 km resolution (ms^{-1}).

The spatial distribution of the class is spread across the country, with particular concentrations in the south and south-east, mainly due to the inclusion of data on the proximity to urban areas, main roads and railways. By comparison, in central and north Wales, the role of natural heritage designations is more significant, and the presence of woodland excludes parcels across much of the country.

Some of the modifications that may be considered would be changes to the distance thresholds from the main roads and railways; the introduction of a threshold around selected river courses; and, an increase in the threshold distance around an urban area.

3.2.5 Moderate

Figure 17 shows the area which comes into the class 'Moderate constraints to turbine development'. This dataset comprises land that comes into any of the following categories:

wind speed >= selected threshold value (*e.g.* 7 ms^{-1}, 6 ms^{-1}or 5 ms^{-1}),
AND
high visibility from National Parks AND AONBs,
OR
visible from a national trail (only data for Offa's Dyke and the Pembrokeshire Coastal Path are available for inclusion).

The emphasis within this class is on incorporation of areas in which development may cause high visual impacts on resources for which landscape is one important factor. However, with respect to the designated areas, the level of visibility was required to be 'high', *i.e.* not 'only just visible'. To reduce the sensitivity of locations being included in which the view of land within a designated area may be very limited, and the potential significance of error in the DTM (Fisher, 1996), a threshold score of '2' has been used within the rule base.

As a consequence of the use of data on the national trails, the distribution of the 'Moderate constraint' class is concentrated in the south-west (around the Pembrokeshire Coastal Path) and sections along the border with England. However, there are also areas that come into this class within, or in the vicinity of the National Park or AONBs reflecting the highest areas of landscape visibility. This also reinforces the distribution of the class in the south-west (the Pembrokeshire Coast National Park) and the north-east (the Clwydian Range) (Figures 11 and 12).

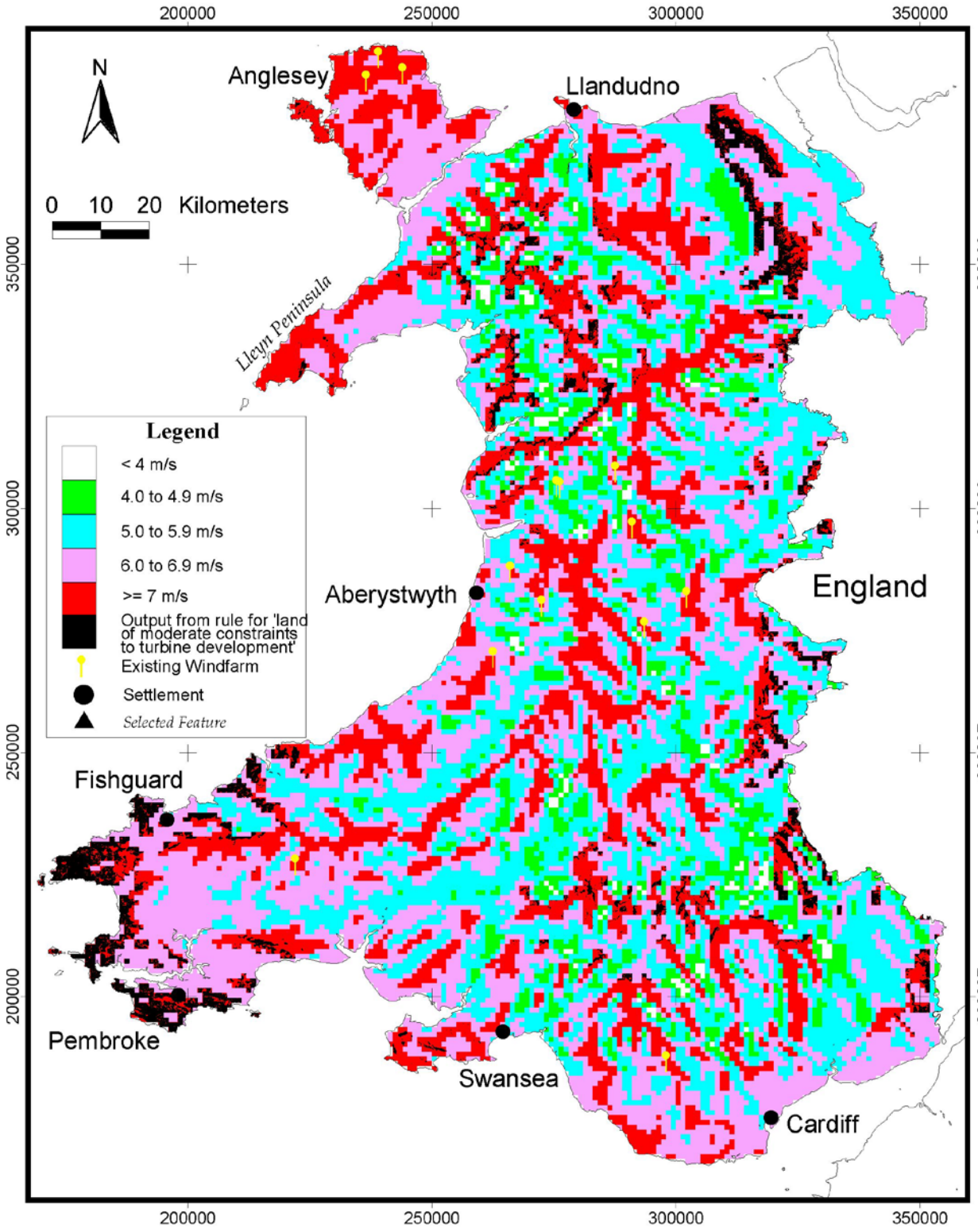

Figure 17. Map of output from rule for 'moderate constraints on turbine development' when applied using a 7 ms^{-1} wind speed threshold, superimposed upon the mean annual wind speed modelled for 45 m above ground level, 1 km resolution (ms^{-1}).

Modifications that may be considered would be to include consideration of development on common land; changes in the threshold between 'high' and 'low' levels of visibility; the inclusion of a rule that takes account of the number of designated areas from which land may be visible (*e.g.* weighting constraints on land visible from three such areas higher than those visible from only one site).

3.2.6 Weak

Figure 18 shows the area which comes into the class 'Weak constraints to turbine development'. This dataset comprises land that comes into any of the following categories:

wind speed >= selected threshold value (*e.g.* 7 ms^{-1}, 6 ms^{-1} or 5 ms^{-1}),
AND
low visibility from National Parks AND AONBs,
OR
agricultural grasslands/tilled land.

These areas comprise low levels of visibility of either National Parks or AONBs and therefore may be considered to have a lesser potential visual impact from such designated areas compared to the land included within the 'Moderate' class. The areas also include any of the higher quality agricultural land that may be found within areas greater than the selected threshold wind speed.

The distribution of the 'Weak constraint' class is concentrated in the vicinity of the National Parks and AONBs (see Figures 10 and 13), with a small area on the coast to the south-west of Cardiff, probably representing cultivated land. An additional consideration for this class may be the inclusion of visibility from main roads; the reallocation of cultivated land from the 'Weak constraint' class to the 'Moderate constraint' class to reflect a higher level of importance.

3.2.6 No constraints

The land which is not classified by any of the preceding rules, which reflect constraints to development, is allocated to one of two classes based upon the threshold wind speed that was specified: *i.e.* above or below that threshold. Of these two classes, 'No constraints: wind speed >= threshold wind speed' is interpreted as being the most suitable for development, and subject to no restrictions (as represented within the rule-base). Therefore, such areas would represent the core areas, or priorities for further inspection and analyses.

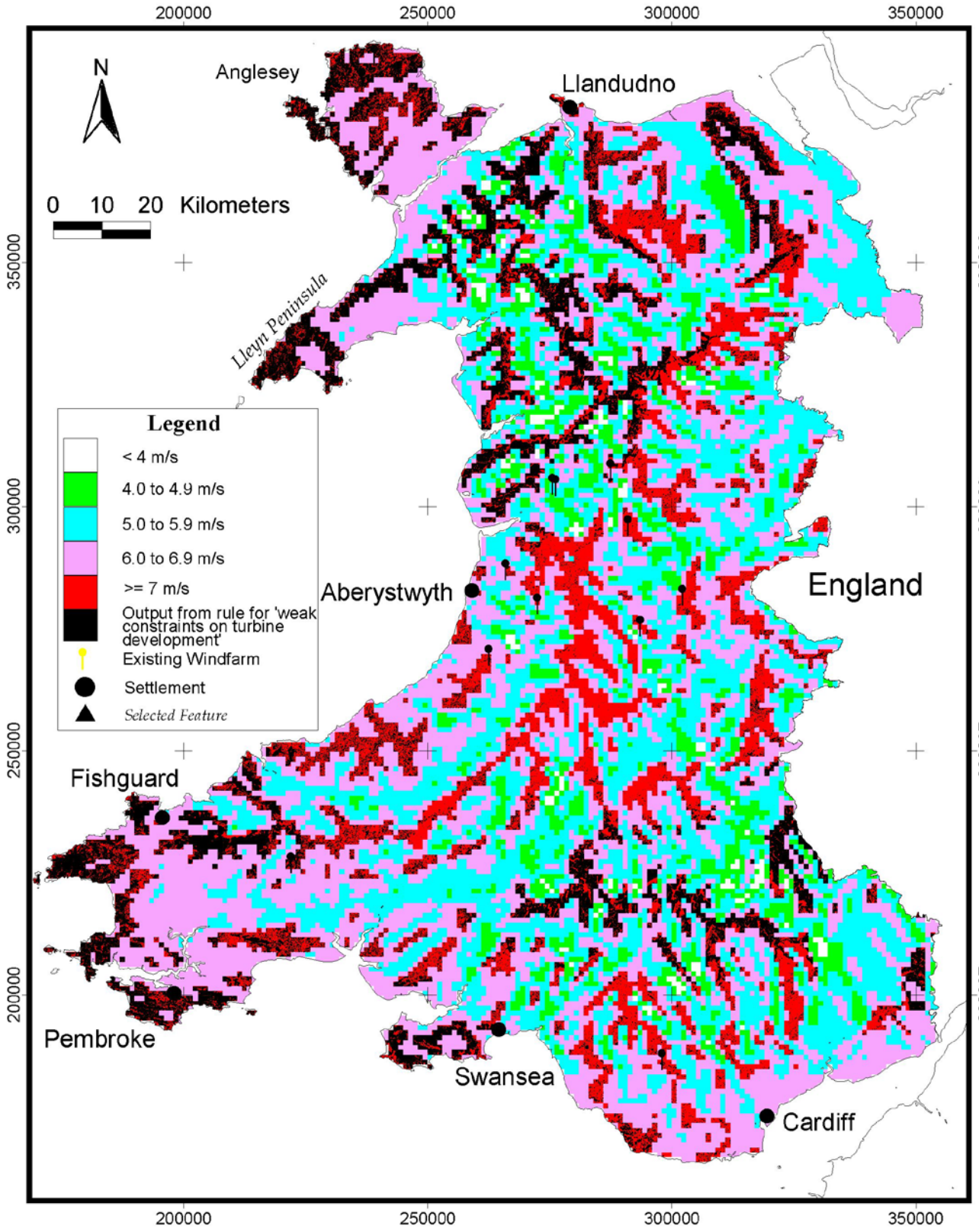

Figure 18. Map of output from rule for 'weak constraints on turbine development' when applied using a 7 ms^{-1} wind speed threshold, superimposed upon the mean annual wind speed modelled for 45 m above ground level, 1 km resolution (ms^{-1}).

3.3 Rule-base scenarios

To indicate the potential increase in opportunity for renewable energy production from wind, provided technology and economic conditions were to enable operation at lower wind speeds, thresholds of 6 ms^{-1} and 5 ms^{-1} have also been used. Each of the three wind speeds have been run with and without coniferous plantation forestry being included to indicate the range of options that may become available under each combination.

The data are all represented within formats compatible with the ERDAS IMAGINE (ERDAS 1999) or ArcView (ESRI, 2002) software packages, with the rule-base currently implemented within the 'Expert Classifier' module of ERDAS IMAGINE 8.4. This package combines the datasets according to a set of rules, such as those illustrated in Appendix 2 (a), and enables classification to be traced back to the rule that triggered the allocation of the class, examples of which are shown in Appendix 2 (b), (c) and (d).

Figures 19 to 24 show the outputs from each run of the model, and Table 2 summarises the outputs from each rule that apply in the vicinity of each of the current wind turbine developments.

However, there are a number of caveats that apply to such a summary which are listed below.

1. The wind speed data used are at a low resolution and thus can only be taken as indicative of the actual values for each development.
2. The location of each development has been represented by one only point and therefore, values that may apply at the level of an individual turbine (*e.g.* visibility from within a National Park) will vary from those summarised.
3. The accuracy of the boundaries of some designations, and the classification of land cover has not been incorporated into the mapping. Therefore, error in the classification of land cover could result in the reallocation of coniferous woodland for broadleaved woodland, potentially excluding a site from further consideration.

Table 2. Summary of classes within 500 m radius of nominal centre point of existing wind turbine developments (Percentage of circle, 500 m radius).

Wind speed 5 ms^{-1}	Mynydd Gorddu	Cwm Rheidol	Rhyd-y-groes	Trysglwyn	Llangwyryfon	Machynlleth	Bryn Titli	Carno	Llandinam	Gilfach Goch	Cemmaes	Dyffryn Brodyn	Llyn Alaw
Unsuitable	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Suitable	42.2	76.7	32.1	35.7	72.2	11.5	96.6	100.0	99.4	72.0	45.7	27.1	14.2
Not available	0.0	2.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Sensitive	0.0	0.6	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.6	0.0	0.0	0.0
Unlikely	11.3	8.1	16.8	1.1	3.0	13.4	0.6	0.0	0.2	3.8	48.0	6.0	0.6
Weak constraint	46.5	12.6	51.0	63.1	24.8	71.3	2.4	0.0	0.0	23.6	6.0	66.9	85.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Wind speed 6 ms^{-1}	Mynydd Gorddu	Cwm Rheidol	Rhyd-y-groes	Trysglwyn	Llangwyryfon	Machynlleth	Bryn Titli	Carno	Llandinam	Gilfach Goch	Cemmaes	Dyffryn Brodyn	Llyn Alaw
Unsuitable	0.0	0.0	0.0	0.0	0.0	31.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Suitable	42.2	76.7	32.1	35.7	72.2	11.0	96.6	100.0	99.4	72.0	45.7	27.1	14.2
Not available	0.0	2.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Sensitive	0.0	0.6	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.6	0.0	0.0	0.0
Unlikely	11.3	8.1	16.8	1.1	3.0	13.4	0.6	0.0	0.2	3.8	48.0	6.0	0.6
Weak constraint	46.5	12.6	51.0	63.1	24.8	44.2	2.4	0.0	0.0	23.6	6.0	66.9	85.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Wind speed 7 ms^{-1}	Mynydd Gorddu	Cwm Rheidol	Rhyd-y-groes	Trysglwyn	Llangwyryfon	Machynlleth	Bryn Titli	Carno	Llandinam	Gilfach Goch	Cemmaes	Dyffryn Brodyn	Llyn Alaw
Unsuitable	38.8	79.4	60.3	0.0	27.2	86.4	3.6	0.0	4.2	7.2	16.6	0.0	0.0
Suitable	24.2	9.7	6.4	35.7	55.4	0.0	93.1	100.0	95.3	64.8	29.9	27.1	14.2
Not available	0.0	2.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Sensitive	0.0	0.6	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.6	0.0	0.0	0.0
Unlikely	11.3	8.1	16.8	1.1	3.0	13.4	0.6	0.0	0.2	3.8	48.0	6.0	0.6
Weak constraint	25.7	0.2	16.4	63.1	14.4	0.0	2.4	0.0	0.0	23.6	5.3	66.9	85.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

3.4 Rule-ordering

The ordering of the rules ensures that land (or water) which is not going to be available for turbine development (*e.g.* lakes) will be triggered first and be displayed in the maps in preference to any other class. Rules determining the 'Sensitive' class (*e.g.* within National Parks) has the second priority, and land 'unlikely to be available' has the third priority. These three classes are set irrespective of the wind speed levels.

The 'moderate constraint' and 'weak constraint' are both only triggered when the wind speed is greater than the threshold value. The wind speed threshold determines the split in classes for the remaining land which is not within any constraint.

Scenario 1 in Figure 19 shows the output of the rule-base using a 7 ms^{-1} wind speed threshold and the locations of the existing wind turbine developments. The urban land, which is not available for development, is evident in the south-eastern valleys, and the larger towns in south and north-east Wales. The presence of lakes is more evident in the centre and north-west of the country, but the areas excluded by ancient woodlands are less distinct due to their relatively small size.

The dominance of the national parks and AONBs that comprise the largest proportion of the Sensitive class are evident in the north-west, south and south-west. Land that is within the Unlikely class, which is only classified where land is not already identified as being Not Available, or Sensitive, is visible on the periphery of most urban areas and airfields (particularly significant in Anglesey), and areas of SSSIs in central and north Wales.

The Not Available, Sensitive and Unlikely classes remain unaltered in the final classification by alterations in the threshold wind speed (Figures 19, 21 and 23). However, for each of the three wind speed thresholds used, the core of the areas identified as having no constraints are on the hill ridges in south-east Wales, and in areas of central Wales (*e.g.* Mynydd Llanllwni, Mynydd Eppynt, Glan Fedwen and Esgair Ambor). No coastal sites have been identified using the set of rules applied.

A comparison of Figures 19, 21 and 23 shows an increase in the areas identified as having No Constraints and wind speeds greater than the threshold, although these are predominantly increases in the extent of the core areas. A number of additional smaller sites has also been identified particularly in west Wales.

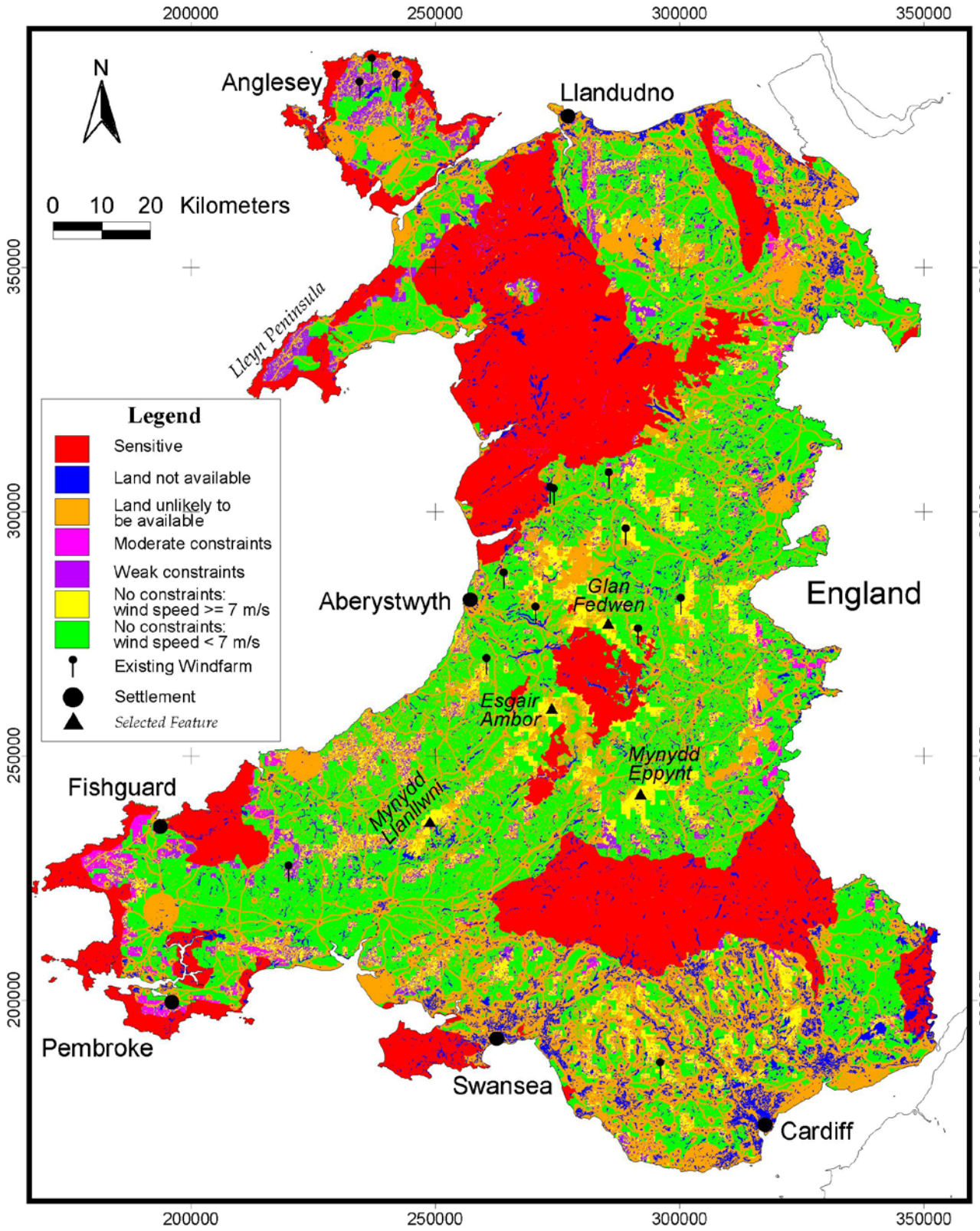

Figure 19. Output of scenario 1: wind speed threshold = 7 ms^{-1}.

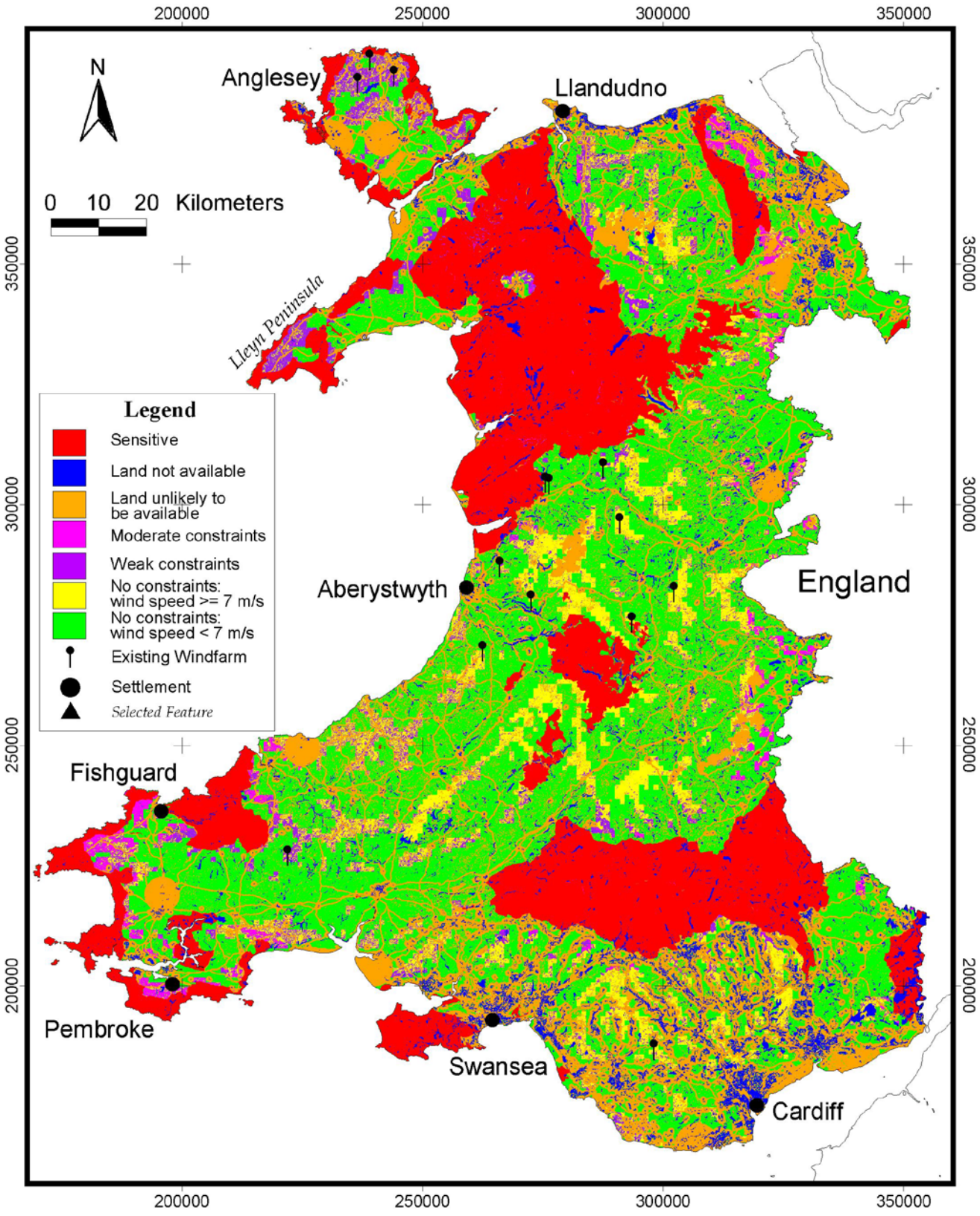

Figure 20 .Output of scenario 2: wind speed threshold = 7 ms^{-1}. (Coniferous woodland excluded).

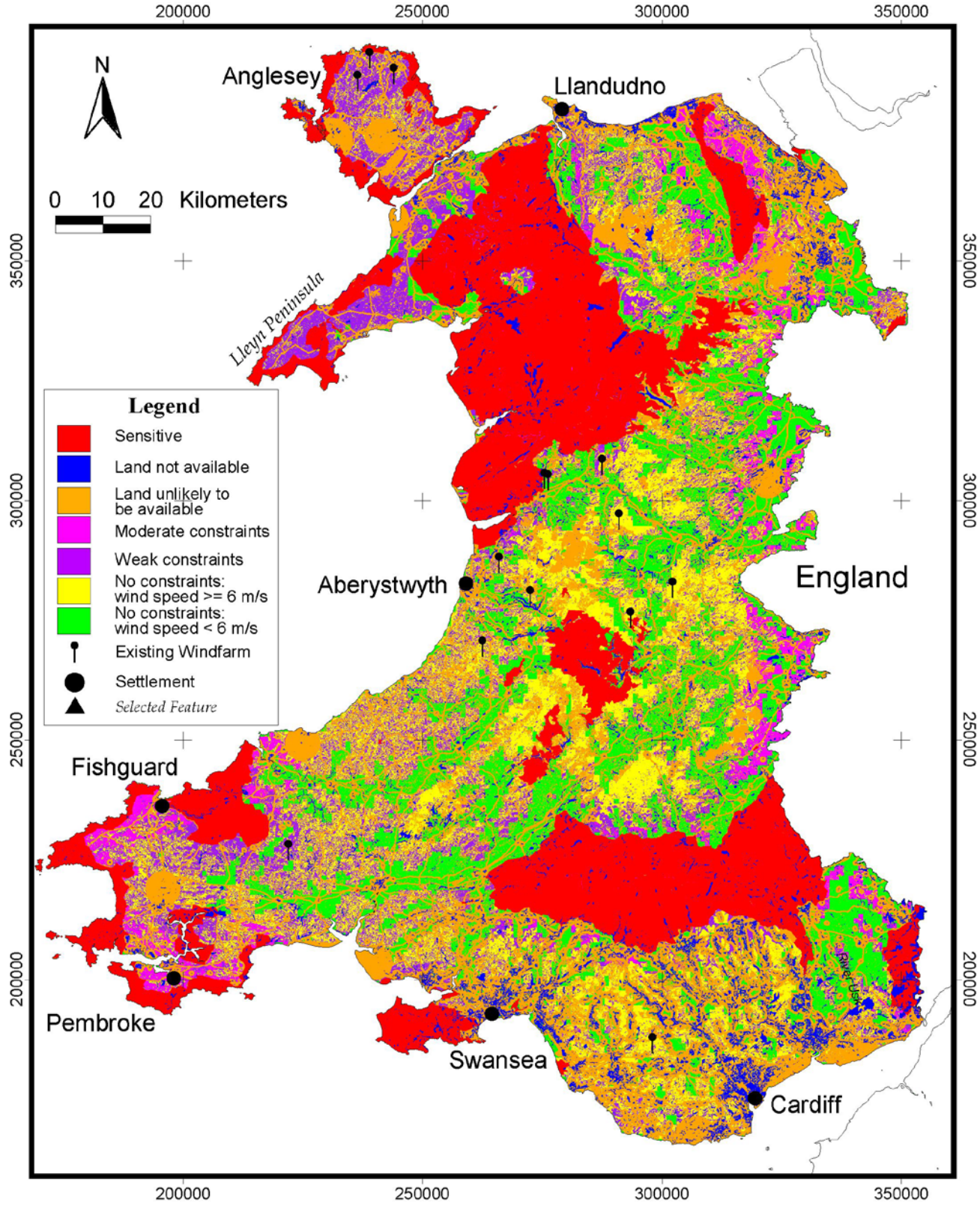

Figure 21. Output of scenario 3: wind speed threshold = 6 ms^{-1}.

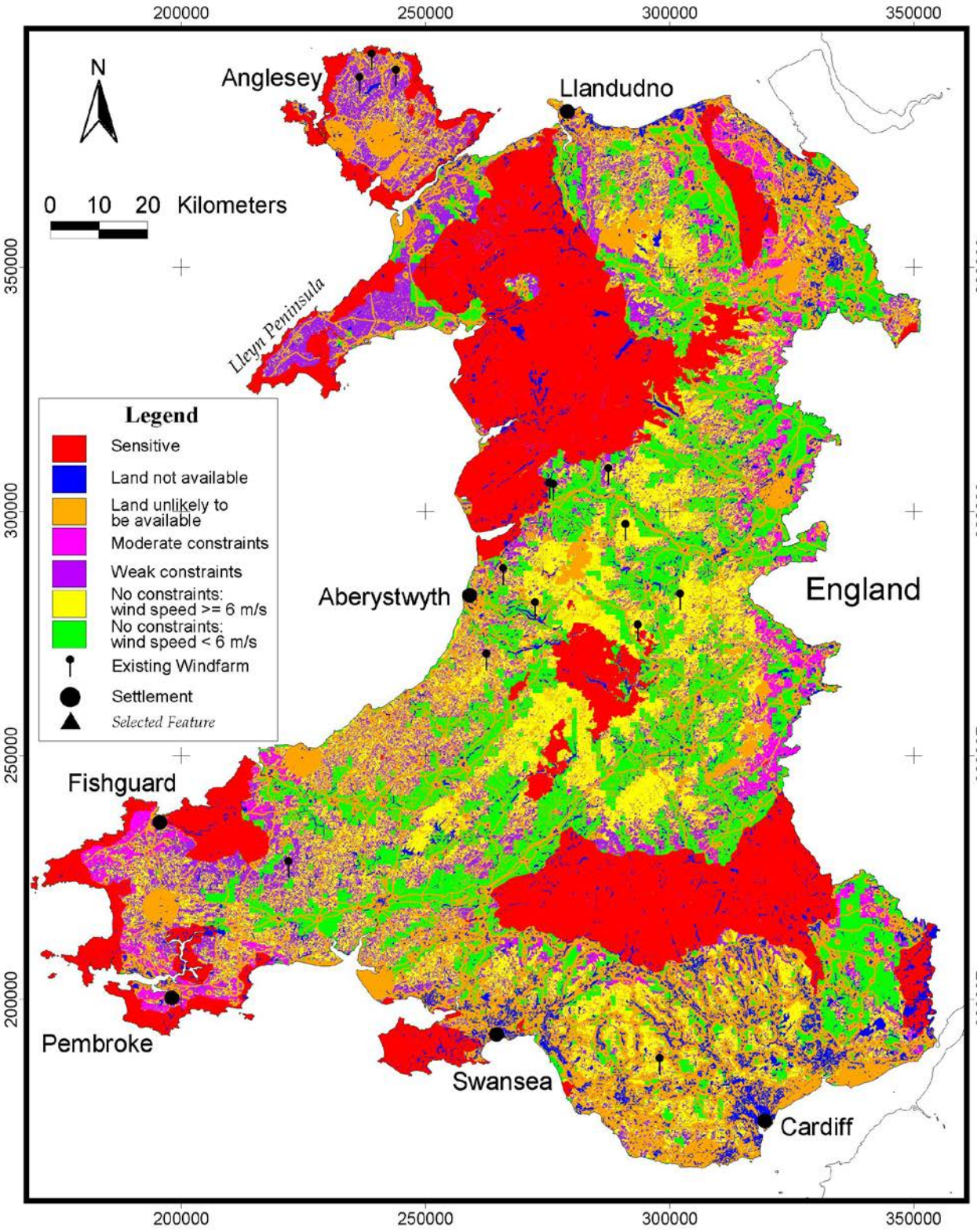

Figure 22. Output of scenario 4: wind speed threshold = 6 ms^{-1}. (Coniferous woodland excluded).

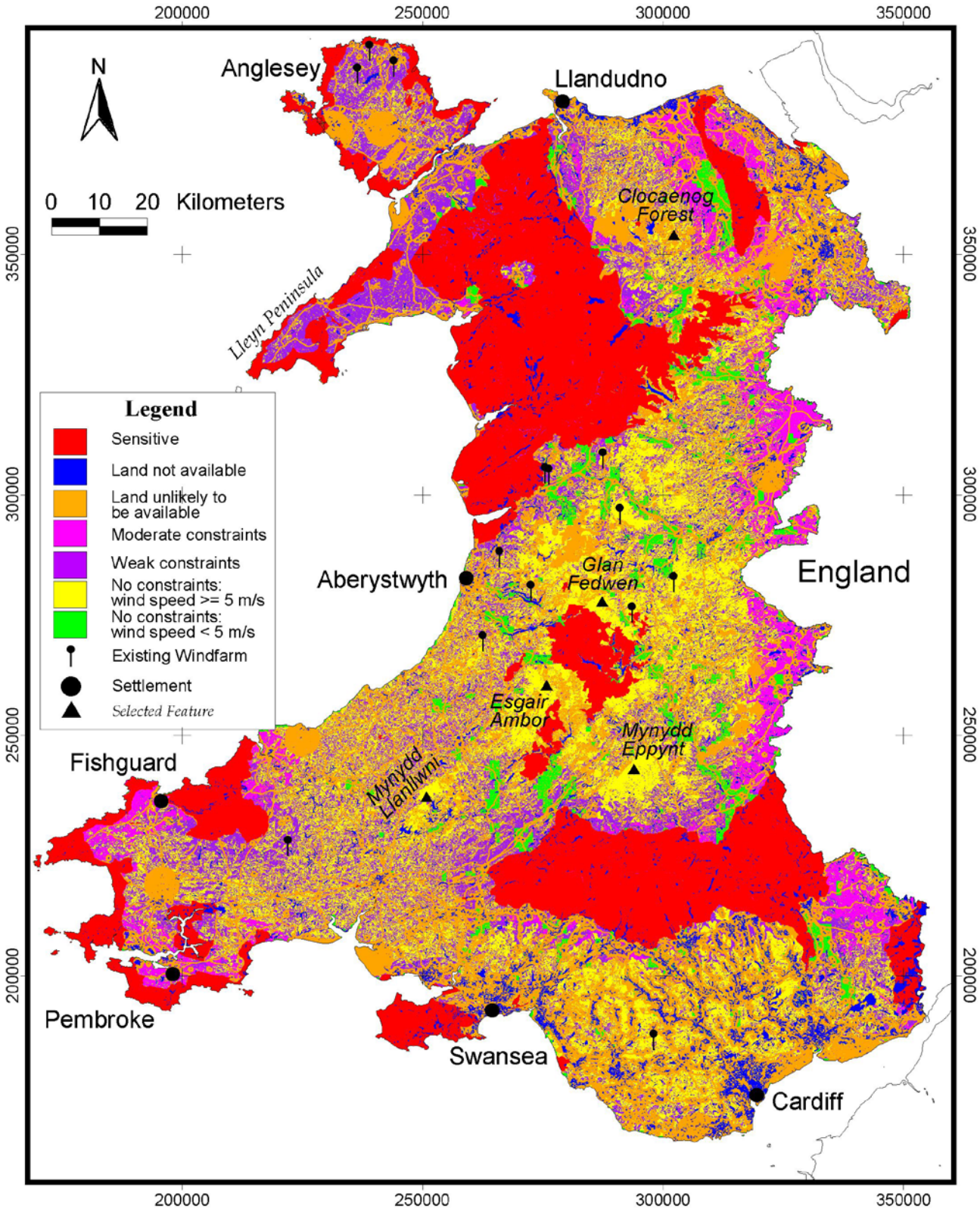

Figure 23. Output of scenario 5: wind speed threshold = 5 ms^{-1}.

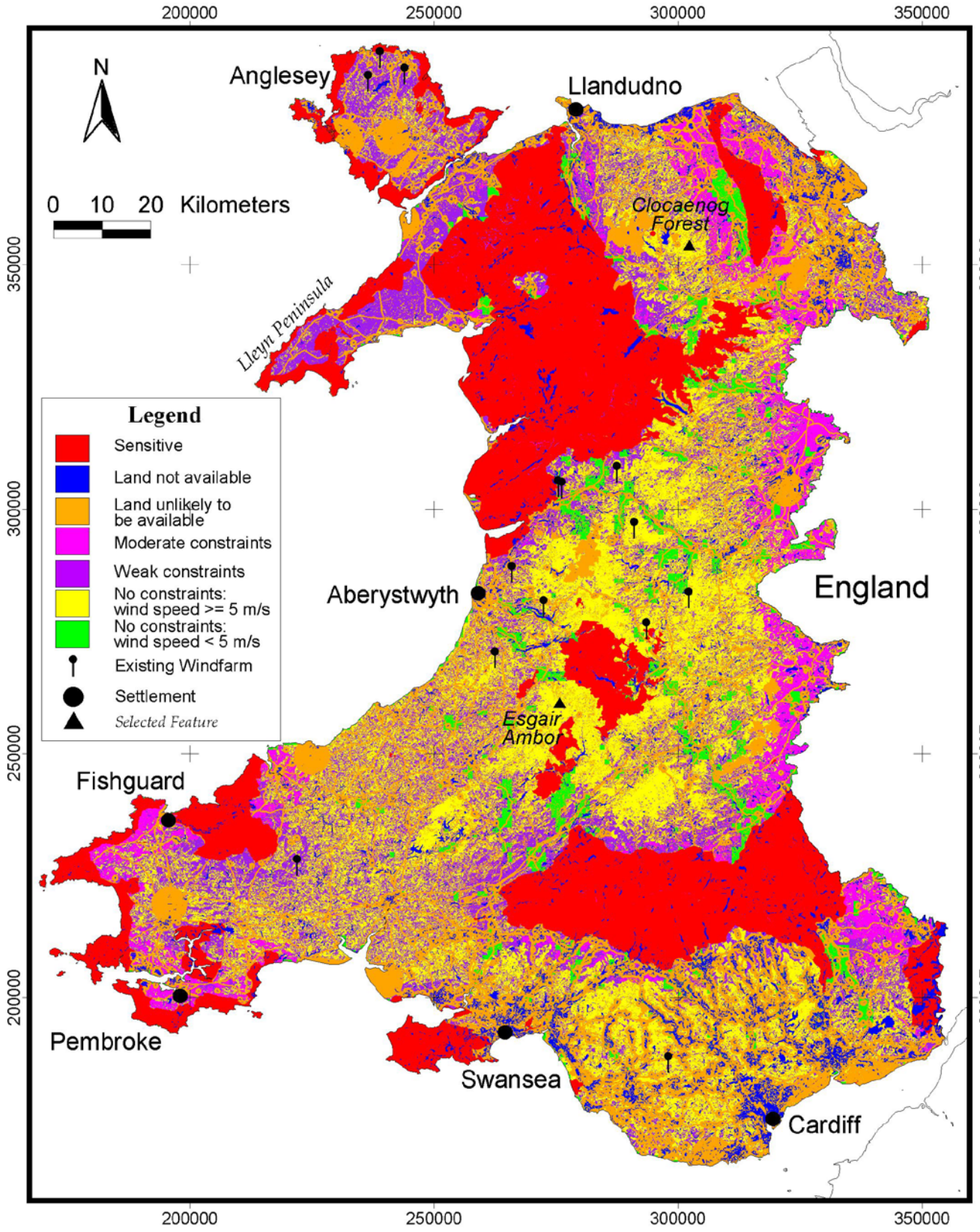

Figure 24. Output of scenario 6: wind speed threshold = 5 ms^{-1}. (Coniferous woodland excluded).

A significant difference between the outputs of scenarios 1 (Figures 19) and 5 (Figure 23) is the presence of large areas that were below the threshold wind speed of 7 ms^{-1} and are within one either of the Moderate or Weak constraint classes. The effect of the rule including high visibility from Offa's Dyke has been to allocate much of the central border of Wales to the Moderate class. A similar effect has been caused by visibility from the Pembrokeshire Coastal Path in the south-west, and around the Brecon Beacons National Park and Clwydian Range AONB. A lower level of visibility has allocated much of the Lleyn Peninsula and Anglesey into the Weak constraint class.

Scenarios 2, 4 and 6 exclude coniferous woodland from consideration, thus do not allocate areas of this land use into the Unlikely class. Therefore, these three scenarios provide an indication of the potential land that could be released for turbine development under certain circumstances. A comparison of Scenarios 5 (Figure 23) and 6 (Figure 24) in particular illustrates the extent to which woodland occupies land (such as Esgair Ambor east of Aberystwyth, and Clocaenog Forest south-east of Llandudno) that could be considered to be suitable for turbine developments, if a wind speed of 5 ms^{-1} were considered to be a credible proposition from an economic perspective.

In general, the outputs suggest that certain areas in south and central Wales may provide opportunities for further development onshore at the 7 ms^{-1} threshold, although in relatively small geographical units. However, if it were economic to produce wind power at lower wind speeds, the areas of the locations where opportunities appear to arise are more extensive. If the 'weak' constraint is relaxed, the scope for those opportunities increases further, particularly in the areas of eastern Wales, in the vicinity of the Brecon Beacons, and the Lleyn Peninsula, although other environmental impacts not included within the rule-base may be a basis for objection to developments in such locations. For example, no assessment of the potential visual impacts of developments from housing, or key locations of visitor interest have been included.

3.5 Forestry Commission wind speed data

To illustrate the potential of the higher resolution data offered by use of a derivation Forestry Commission DAMS data, two variations on Scenario 1 have been recalculated using data for wind speeds at 10 m above ground level rather than the 45 m above ground level used previously. This is because the data shown in Figure 3 was only available for a height value of 10 m and the extent of the land above a specified wind speed threshold is less than for the equivalent speed calculated for 45 m above ground level (Figure 2). Neither dataset has been

processed with the current height of wind turbines in mind, *i.e.* approximately 65 m above ground level to nacelle.

The results of the application of the rule-base on these two datasets are shown in Figures 25 and 26, and enable some comparison to be made of the consequences of using an alternative source approach to modelling, and resolution of data. The results in each figure appear to show locations of the land without constraints, but above the 7 ms^{-1} wind speed threshold, in each figure to be similar (*e.g.* Mynydd Llanllwni), but at Cilfaesty Hill, on the border with England, the 1 km x 1 km data show an area above 7 ms^{-1} whereas the higher resolution data do not.

For the purposes of increasing the area within which the differences between the two datasets may be explored further, the rule-base for scenario 5 (a wind speed of 5 ms^{-1} and forestry land included) has been run, using the two wind speed datasets calculated for 10 m above ground level (Figures 27 and 28). The results show similarity in the broad distribution of the split in land allocated above and below the threshold wind speed, with the areas such as those around Mynydd Llanllwni, Mynydd Eppynt, Glan Fedwen and Esgair Ambor all being classified as having the relevant wind speed threshold and clear of rule-base constraints.

Areas of disagreement are evident, such as the Lleyn Peninsula in north-west Wales, where the high resolution data suggests a higher wind speed, and the land has been classified as having a Weak constraint, whereas more of the 1 km x 1 km dataset for this area has been classified as being below the 5 ms^{-1} wind speed threshold.

The valley south of Mynydd Llanllwni, running between Haverfordwest and Llandovery, has predominantly been classified as having wind speeds below the 5 ms^{-1} threshold, and the rectilinear pattern of the 1 km resolution of the dataset is also identifiable. This compares with a more diverse range of classes when the higher resolution data was used, suggesting that the modelled wind speed is more heterogeneous, and slightly higher values when using the high resolution dataset.

In general, the high resolution dataset of the Forestry Commission appears to be broadly comparable with the 1 km resolution data of the DTI. If the tests of the approach to modelling the higher resolution dataset were to prove that it was a satisfactory alternative to the 1 km x 1 km data, there would be greater opportunity for local application of the rule-based approach, and one less uncertainty associated with estimating the ‘carrying capacity’ of turbine numbers within Wales.

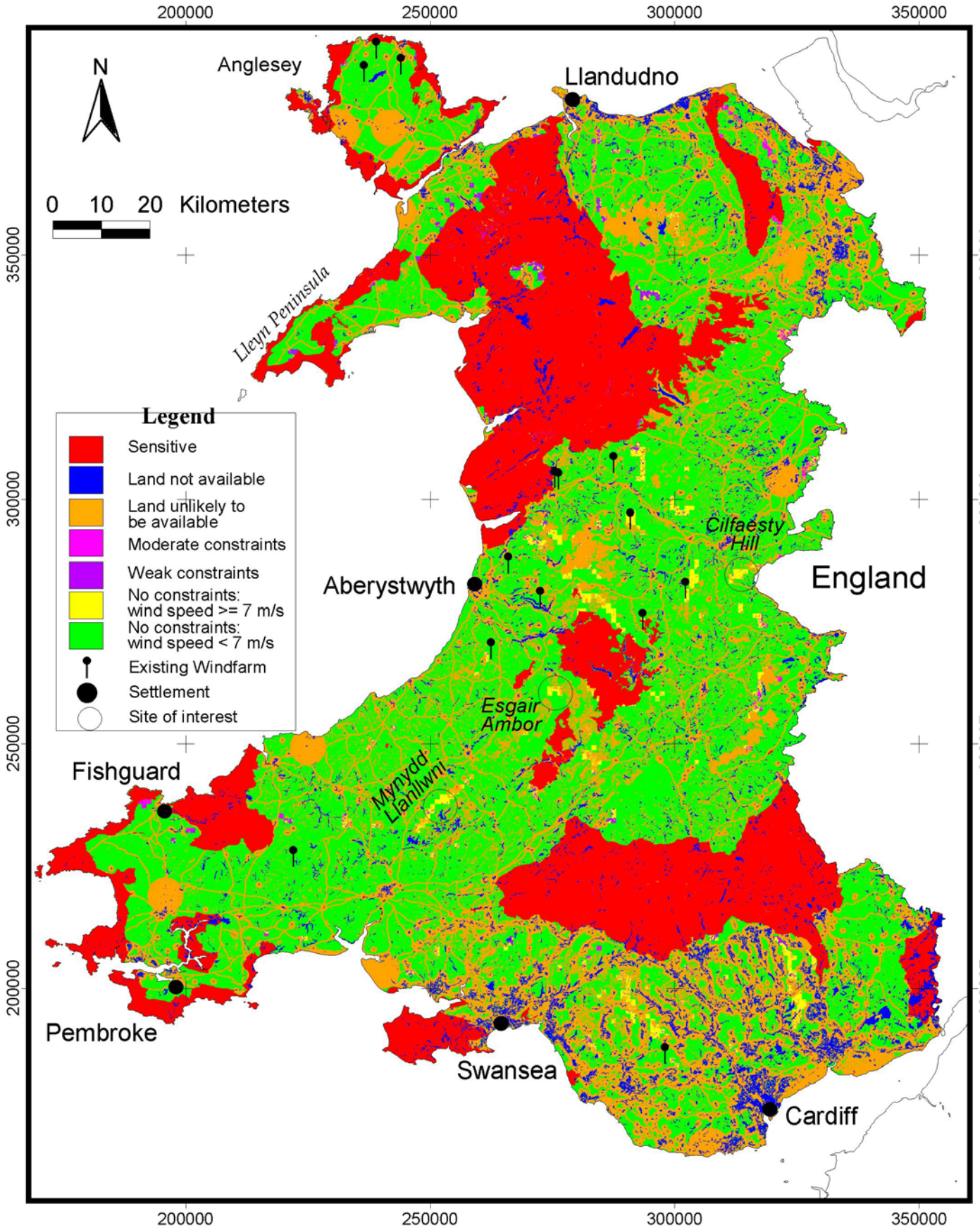

Figure 25. Map of output from scenario 1 using wind speed modelled at 10 m above ground level: wind speed threshold = 7 ms^{-1}.

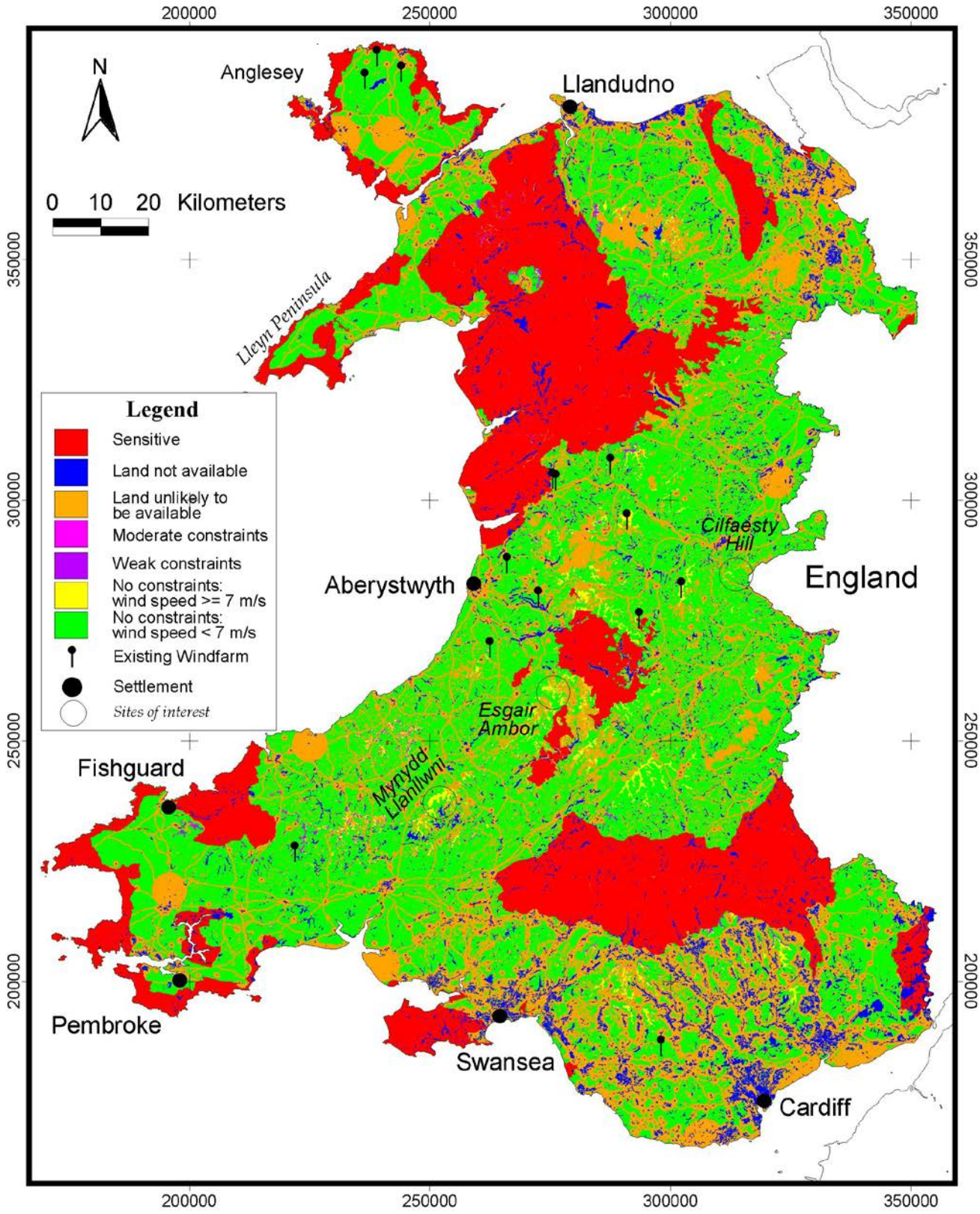

Figure 26. Map of the output of scenario 1, using wind speed data modelled for 10 m above ground level, from the Forestry Commission DAMS dataset, at 50 m resolution: wind speed threshold = 7 ms^{-1}.

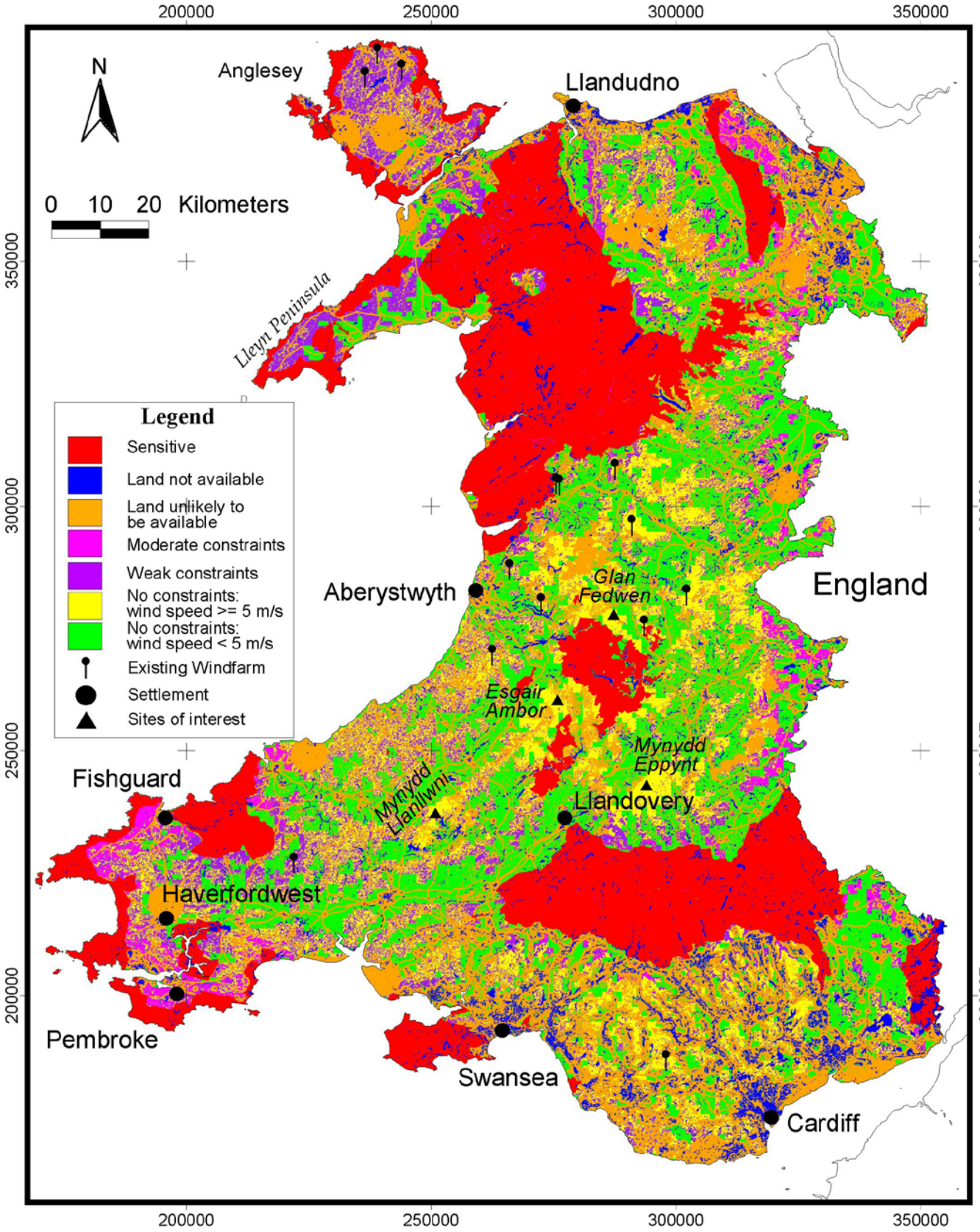

Figure 27. Map of output from scenario 1 using wind speed modelled at 10 m above ground level: wind speed threshold = 5 ms^{-1}.

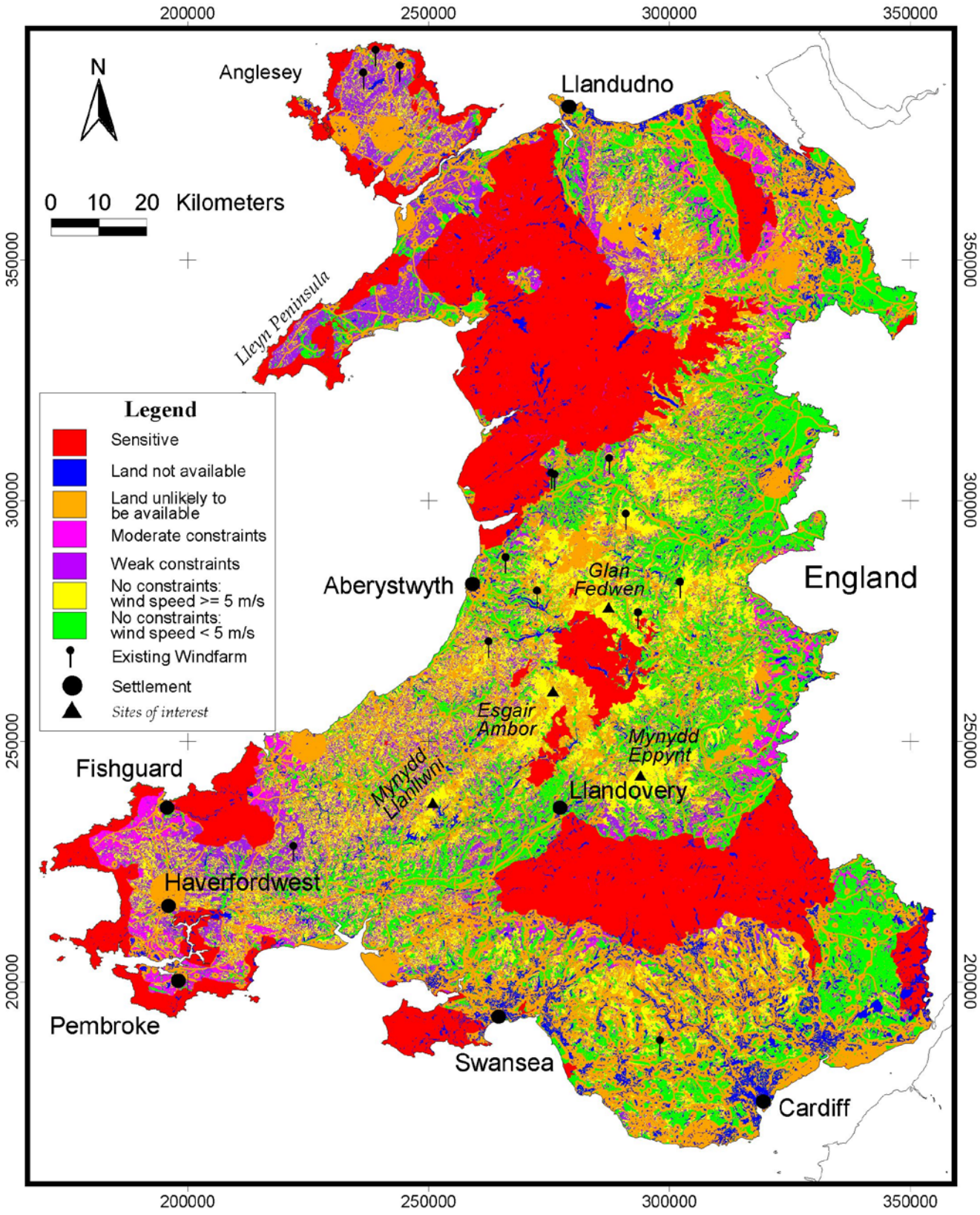

Figure 28. Map of the output of scenario 1, using wind speed data modelled for 10 m above ground level, from the Forestry Commission DAMS dataset, at 50 m resolution: wind speed threshold = 5 ms^{-1}.

4. Discussion and Future Developments

4.1 Method

The methods used in the development of options for future wind turbine developments in Wales enable some flexibility in the type of scenarios that may be considered. Specifically, testing can be undertaken of the consequences of alternative combinations of constraints and the range of wind speeds that may be relevant, now or in the future. The approach, although developed within ERDAS IMAGINE, can be implemented in most GIS packages, only with variations in the nature of the implementation and testing. The principal limitations of the method relate to the availability, quality and suitability of the input data.

4.2 Data

For use at a local level, a spatial resolution of 50 m x 50 m resolution data would be more appropriate than the 1 km x 1 km dataset. The use of windiness data at the lower resolution also suffers from the effects of averaging of the elevation for calculating the wind speed for each 1 km square. When combining the data with other sources at a higher resolution there is a risk of misrepresenting the available resource. For example, if part of a 1 km x 1 km square that has a suitable wind speed is excluded from consideration for development by the superimposition of data representing a designation constraint, the area left (within the same square) may not include the land that was above the wind speed threshold. Therefore, the outputs from the analyses should be considered to be indicative of where further investigation would be merited.

Taking advantage of improvements in computing resources, the effect of land cover on the calculation of windiness could also be incorporated, such as the shelter and turbulence provided by forestry. This is a topic in which further development could be undertaken in collaboration with groups that possess the relevant models and data such as ETSU Ltd. and the Forestry Commission. However, further checks would also be required on the availability and applicability of meteorological data.

In general, there is a need for a wind resource dataset for the United Kingdom, derived at higher resolution than 1 km x 1 km, and calculated for a nacelle height of approximately 65 m, to reflect the size of wind turbines currently being planned or installed.

At national or regional levels, the quality of the data on the urban and built environment is limited by the quality of the classification of land cover in the outputs from the LCGB dataset

used. The date of the classification used is approximately 1990, but a more recent classification now exists, dated 2000, which will take into account some changes in land use over the preceding decade.

The same satellite classification has been used for the woodland classes, but there is potential for misclassification between woodland and other classes, *i.e.* the classification of a non-woodland class as woodland, or the classification of woodland as non-woodland, and between the woodland classes used. Therefore, using the woodland data as an input to the buffering process could result in an overestimate of the influence of woodland in some areas, and an underestimate in others.

A more accurate dataset of woodland would be that of the woodland inventory of the Forestry Commission. This dataset is compiled from aerial photographic interpretation and extensive field data, and is being continually revised and updated as relevant information becomes available. However, the data is not generally available external to the Forestry Commission and thus access may be a future option that could be considered and negotiated. The use of the OS Master Map dataset (Ordnance Survey, 2001b) would provide a source of the most widely available data on woodland and urban areas. The maintenance of data currency for features such as woodland is the subject of on-going discussion between OS and the user community.

The scale of data used for the road and railway networks requires to be improved from the small scale 1:250 000 that was available. Although this has been edited with respect to larger scale 1:50 000 raster maps for parts of the area of Wales, it was not possible to undertake this task for the entire country. Therefore, the locational inaccuracy of the transport routes limits its use in large scale, site specific applications. The principal issues that relate to alternatives are data availability and cost.

Unlike the provision of data on urban areas and built land, the solution offered by the OS Master Map, with a topologically coherent dataset, will only partially address the issues of a topologically coherent road and rail network. This is because, currently, Landline data contains a centreline entity and code for all metalled roads. However, the first release of the new OS data does not contain centreline data. Therefore, the current centreline information would require to be used, together with Landline data for unmetalled roads.

The limitation of the availability of accurate transport datasets will be greatest to a national agency such as CCW due to the cost of coverage for all of Wales. This issue is less significant when implementing GIS based solutions to planning at a local level, where

complete coverage is available for the area. Under the current Local Authority Service Level Agreement with Ordnance Survey, all local authorities have full access to all of the Landline data (and therefore also the Master Map data) for the area of their authority, plus coverage for areas for which they have additional responsibilities (*e.g.* common land spanning the Powys County Council border is the responsibility of that local authority, and so they have access to the data for those areas) Therefore, under current agreements, the options open to the local authorities will be different to those for CCW.

Some other datasets used were not complete, most significantly that of the National Trails. The inclusion of the complete versions of such datasets would be a priority in the early implementation of the method described.

4.3 Processing

The majority of the data used was for Wales, but data on roads and railways in England have also been included within the derivation of Figure 8 (buffered transport and airfield sites) and 10 (buffered urban areas). However, certain rules would require further consideration of relevant sites or designations on the English side of the border. For example, calculations of visibility from the Offa's Dyke path include elevation data for land in England, but no check has been carried out on equivalent trails or designations in England that would come within the 10 km distance threshold used in the derivation of the results shown in Figure 12.

The inclusion of land cover or land use data in the provision of a strategic assessment, particularly at local level, should consider testing the sensitivity of the output to the use of the alternative sources of relevant data. It is possible that with greater importance placed on the potential of brownfield sites in the future, the level of detail in the land use categories used may require substantial improvement.

The analyses of visibility of land from either areas designated as having landscape significance, or from national trails do not enable a differentiation between land of high or low visual quality. Therefore, visibility data such as that presented in Figures 13 and 14 could be calculated to indicate, the proportion of the view which is made up of the National Park or AONB; the proportion of its visibility that is only from the National Park, AONB or National Trail.

Further, the analysis of only the overall visibility of the land takes no account of the character of the landscape, its structure, the content of the views, nor the potential contributions made

by cultural features that may influence people's responses to changes in the landscape, such as the introduction of wind turbines. However, the analysis used does provide an indication of where changes in land use may be most visible. Improvements in the model content would increase the relevance of the measure to inferences that may be drawn about the potential visual impact of turbine developments.

The requirements of the Ministry of Defence and the Civil Aviation Authority may not be fully satisfied by the airfield sites selected or the distances from those sites that have been used. No account was taken of the location of aircraft navigation beacons or radar, and the likely restrictions imposed to minimize the risk of interference in the radar signal. Such radars are located at each RAF major civilian airfield. Therefore their presence is implicit in the constraint applied around the airfields. However, the distances used may be too short and additional locations would probably require to be added to address all of the limitations related to defence and aeronautical safety.

4.4 Scenarios

Changes in the rules and processing of individual datasets could reallocate land between classes. Specific changes could have particular influence in certain geographical areas of the country, and exploring where those changes would occur, would probably require to be done at a national level, although their acceptability may be judged at a local level.

The outputs from the strategic modelling have not dealt with the topics of reporting or presentation of the results, both of which are important elements in the process of supporting decision making. Outputs may be restructured around any specified spatial unit to provide an input to further analysis. Examples include restructuring according to local authority boundaries, sub-catchments of major rivers, access to appropriate electricity infrastructure, and population census units. All of these options have some associated methodological issues but do offer options for communicating the results in ways that are of most relevance to users and decision makers.

The evaluation of alternative strategies has not been directly addressed within the development of the rule-based approach described. This may utilize the means of reporting strategy options as identified in point 17 above, and use these as inputs to the modelling of potential impacts and the benefit/cost of each strategy. In addition, no account has been taken of the accessibility of sites for vehicles during the construction, or a future re-turbining phase of the development.

A comprehensive evaluation of the scenario being tested would incorporate a summary of the areas of land in the categories of the strategy which have been triggered by each rule as a proportion of that resource. For example, the area of cultivated agricultural land that may be included within the 'weak constraint' class expressed as a proportion of the total area of cultivated land. This would enable the classification results to be interpreted with respect to the portfolio of the land resources of Wales. No such evaluation has been undertaken for the scenarios presented.

The analysis of the potential of areas for supporting wind power production has excluded conditions offshore. There is scope for development in the area offshore of the Welsh coastline, but insufficient data was available on the modelling of wind speed. This is a subject which may attract greater attention in the near future and for which a similar approach to the analyses of potential and suitability may be conducted. Issues relating to offshore safety, navigation, the visual environment or habitat consideration and designations may be represented within a GIS and used to identify where there may be the greatest potential for development.

A final element of the evaluation of the scenarios of strategic planning is the linkage between the identification of sites offering potential for development with measures of impact assessment. Certain measures are provided for each site directly from analyses of the input data, such as location with respect to selected types of designation. However, additional measures could be considered, such as the intervisibility of identified sites from existing developments or urban areas or locations of particular interest to visitors. Therefore, the output from these scenarios would be a guide to sites and does not incorporate a complete set of analyses as in the environmental assessment that would be required for any proposal.

5. Conclusions and Future Work

The methods used, or developed, within this project have provided a basis for identifying areas where there may be the greatest potential for wind turbine development. The results at a national level should be considered as indicative of where opportunities exist for the generation of wind power as one means of achieving government targets for the production of electricity from renewable sources.

The application of GIS in the provision of information to aid in decision-making can be limited because of the lack of suitable data, either due to inappropriate scales, low reliability or unavailability of data on the topic. Although the system enables weights to be allocated to each dataset, the outputs are credible only if the weights are valid. Therefore the assumptions made should be considered when evaluating the outputs of the indicative appraisal.

Priorities for future work would focus on six topics:

1. Implementation of completed datasets once available.
2. Inclusion of data on the electricity network within the identification of sites offering potential for turbine development.
3. Testing, and inclusion of alternative sources of land cover and transport data.
4. Testing, and inclusion of higher resolution wind speed data.
5. Exploration of alternative rule-bases.
6. Evaluation of outputs from scenarios.

Finally, there has not been a direct comparison with other studies into the potential for identifying, at a national level, where electricity may be produced from renewable sources. A more comprehensive assessment of the potential for electricity production by sources of renewable energy could include consideration of other sources such as short-rotation coppice, wave or tidal sources of power. Combining such information with that on existing production by wind and hydro-power, an overview of the diversity of options available in Wales could be developed, to consider:

1. The overall capacity for the production of electricity from renewable sources.
2. Identification of potential competition for resources in the same geographical area for different means of electricity production.
3. An assessment of the capacity for production versus the potential impacts across different geographical areas, thus enabling one means of prioritising options for development.

The output of such an overview of the options for renewable energy developments could then be a basis for strategic planning and impact assessments.

6. Acknowledgements

The authors wish to acknowledge the Ordnance Survey for the use of the Panorama DTM and Strategi data, the Centre for Ecology and Hydrology for use of the Land Cover of Great Britain (1990) dataset, the Department of Trade and Industry and the Forestry Commission of Great Britain for access to the data on wind speed. Acknowledgement is also due to ERDAS (UK) Ltd. and ESRI (UK) Ltd. for the software used under license.

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Ordnance Survey (2001b) Master Map, http://www.ordnancesurvey.co.uk/osmastermap, Ordnance Survey, Southampton.

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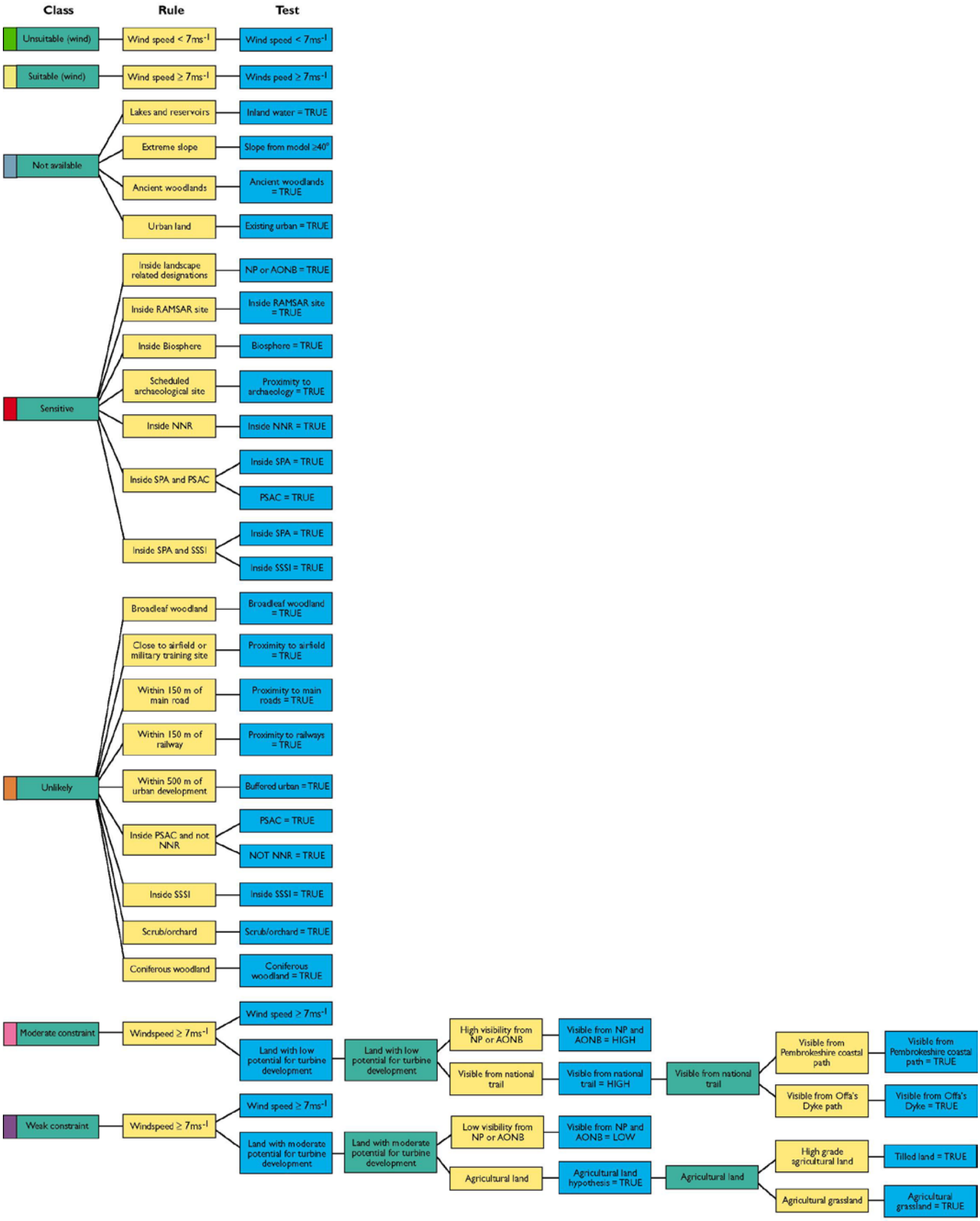
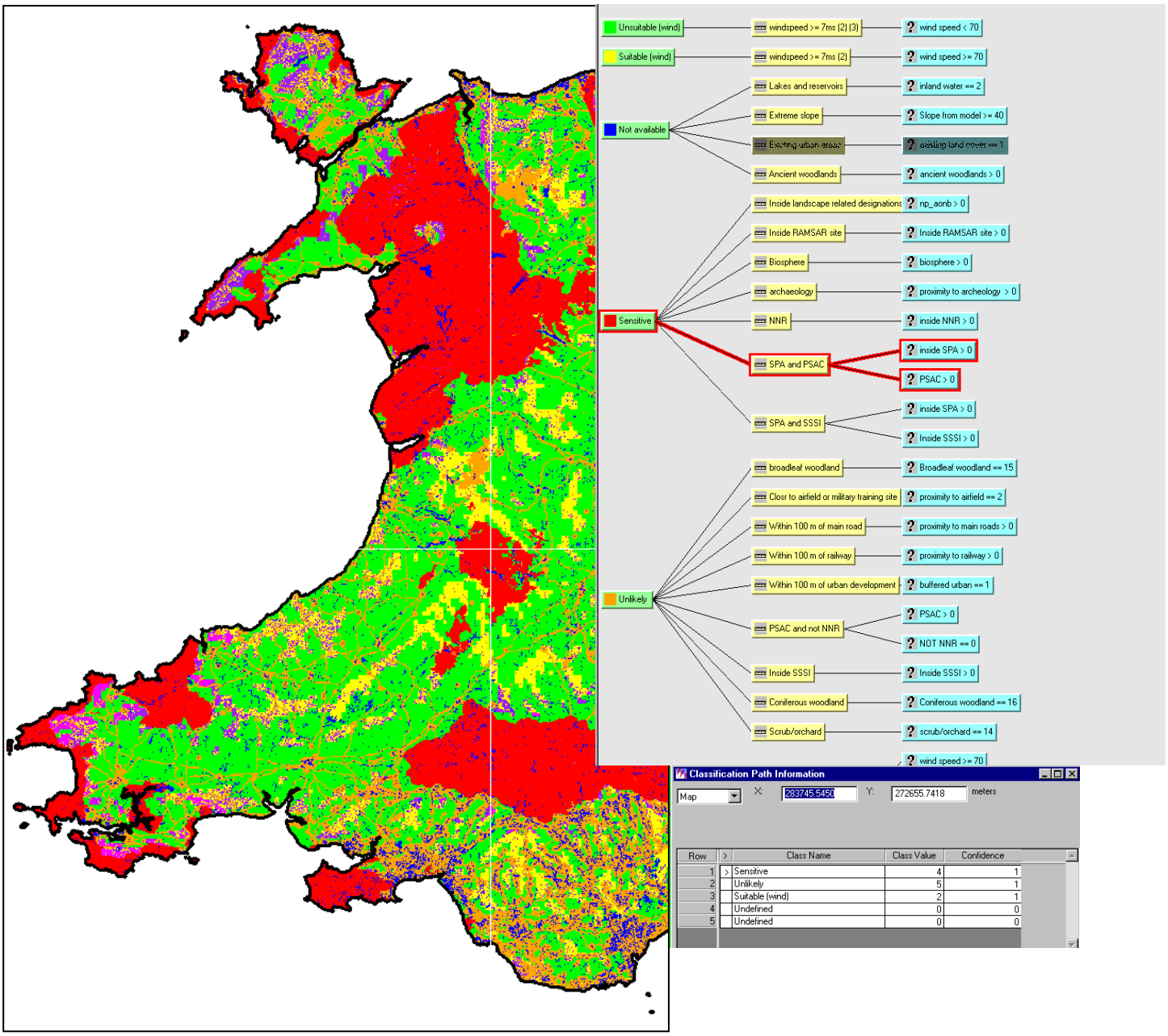
Appendix 1. Acronyms and abbreviations

BWEA	British Wind Energy Association
CCW	Countryside Council for Wales
DETR	Department of Transport and the Regions
DTM	Digital Terrain Model
ETSU	Experimental Technology Support Unit
GIS	Geographical Information System
ITE	Institute of Terrestrial Ecology
LCGB	Land Cover of Great Britain
OS	Ordnance Survey

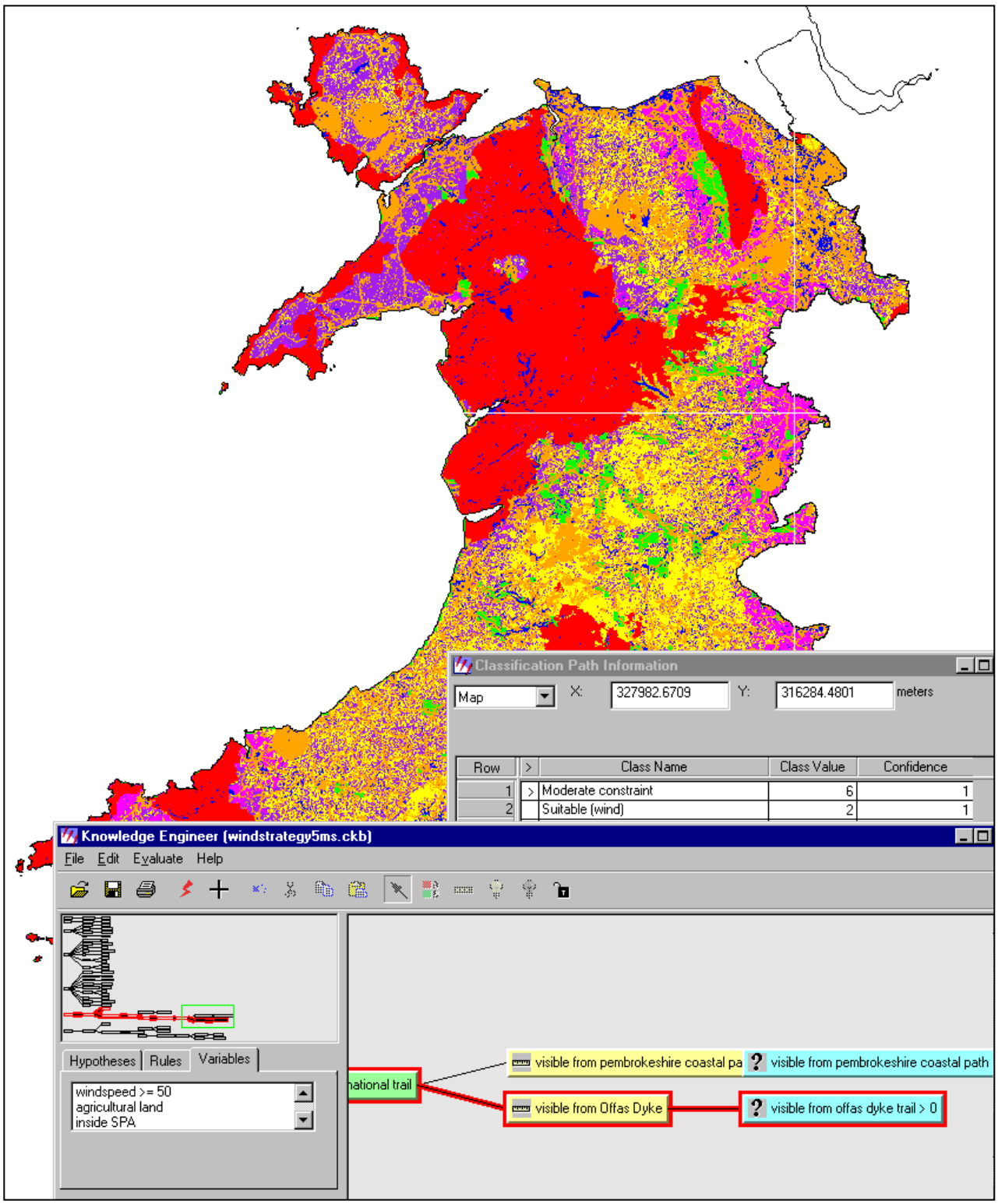
Appendix 2. Illustrations of decision support rule-base, with on-screen query and rule 'track-back'



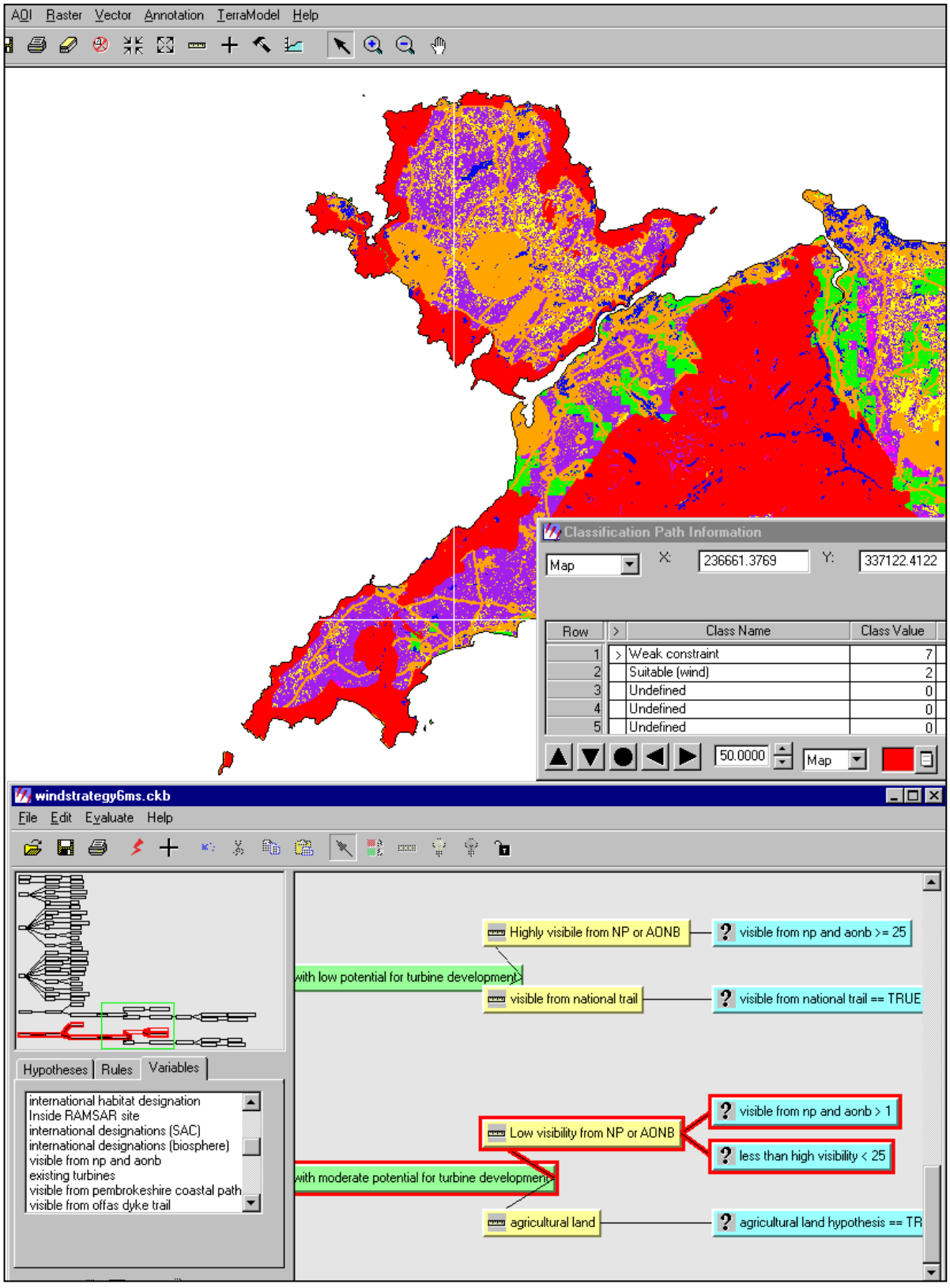
Appendix 2 a. On-screen layout of rule-base for scenario 1 (wind speed >= 7 ms^{-1}, coniferous woodland included).



Appendix 2 b. On-screen querying of 'scenario 2' classification (wind speed 7 ms^{-1}, no coniferous woodland), with three classes that occur at the cursor location, and the rule that determined the highest priority class ('Sensitive: inside a PSAC *and* inside a SPA').



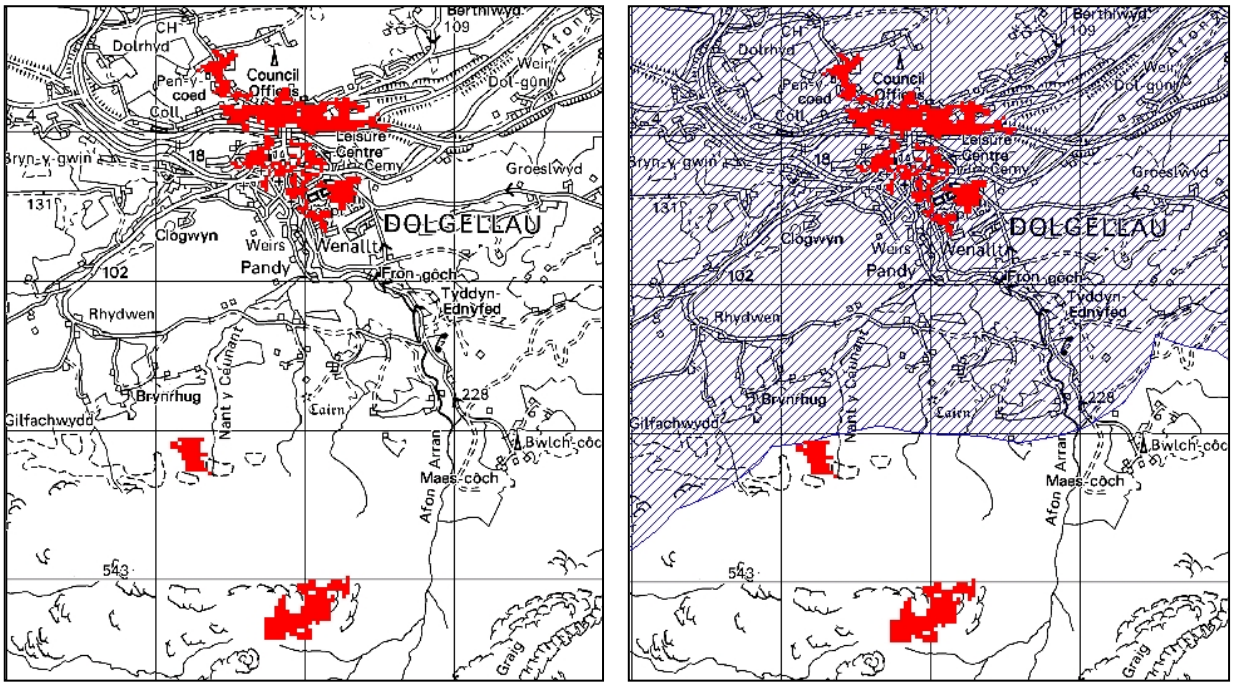
Appendix 2 c. On-screen querying of 'scenario 5' classification (wind speed 5 ms^{-1}), with two classes that occur at the cursor location, and the rule at determined the highest priority class ('Moderate: wind speed greater than 5 ms^{-1} and visible from Offa's Dyke').



Appendix 2 d. On-screen querying of 'scenario 3' classification (wind speed 6 ms^{-1}), with two classes that occur at the cursor location, and the rule at determined the highest priority class ('Weak: wind speed greater than 6 ms^{-1} and low visibility from National Park or AONB').

Appendix 3. Definition of urban areas

(a) (b)



Appendix 3 a Classification of urban land, derived from the Land Cover of Great Britain (Fuller *et al.*, 1994), processed to leave areas greater than 2.5 ha.

Appendix 3 b Selection of urban areas, greater than 2.5 ha within 750 m of a road.

Appendix 4. Sources of additional information

The authors would like to acknowledge the comments of the following people who have contributed information by email or telephone on the topics broadly identified below. However, they are not responsible for the materials that appear in this report, and have no responsibility for any inaccuracies in the text.

Air Safety issues:	Mr David Cutler, Civil Aviation Authority
	Mr Harry Sieppman
Designations and wildlife:	Mr Roger Matthews, Countryside Council for Wales
Environmental issues/water courses:	
	Mr Price, Environment Agency, Welsh Region
Ordnance Survey data:	Mr Peter Roberts, Powys County Council
	Miss Cousins, Landline Product Manager, Ordnance Survey
Ordnance Survey data/Central Government Service Level Agreement:	
	Mr Rod Kedge, Countryside Council for Wales
Planning issues:	Mr Gareth Thomas, Powys County Council
	Mr Dil Sarkar, Department of Environment, Transport and the Regions
Wind speed data:	Dr Fiona Broklehurst, ETSU Ltd.
	Dr Barry Gardner, Forest Research, Roslin.
	Mr Chris Quine, Forest Research, Roslin.