

A GIS BASED GROUNDWATER MANAGEMENT TOOL FOR LONG TERM MINERAL PLANNING

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ABSTRACT

The East Mendip Hills in Somerset, England have historically been an important source of aggregate materials, particularly limestone, for the construction industry. The local limestone formations are however also recognized major aquifers, and exploited in the region for both private and public water supply. Given the current demand for aggregates and considering the increased pressure on groundwater resources posed by a growing population, the planning authorities are faced with the challenge of providing the public with an adequate balance on the exploitation of both resources.

This paper describes a local planning tool, based on a framework for the collection and collation of available data and its conversion into an accessible information system. The selected platform for the framework development was MapInfo, a geographical information system (GIS) interface. The system contains over 40 layers of information, distributed and combined within five main topics: local information, mineral resources, water environment, monitoring networks and conservation areas. In addition, a Target Plan was generated by combining layers representing the main factors that affect groundwater management and mineral planning in the region. A ranking system was developed to identify areas of high and low sensitivity with regard to groundwater resources and therefore allow better decisions for future planning. The final system is to be published onto a website, which will eventually be available to all interested parties, including the general public. Although this study was focused on a specific area in southern England, the adopted methodology will be of value to quarry operators and planners elsewhere.

1. INTRODUCTION

The Mendip Hills are situated in Somerset, Southern England (Figure 1) and have historically been an important area of hard rock quarrying, with some of the older quarries operating since the 19th century. Considering the present demand and reserves, it will remain so for the foreseeable future. There are many technical, commercial, socio economic and planning aspects that go into decision making with regard to quarrying. One of the key concerns to all interested parties in the region is the impact on groundwater and the management of this resource by the quarry operators, as the same limestone formations that constitute the main mineral source for the aggregate industry are also recognized major aquifers. Groundwater is abstracted from these aquifers and used regionally for both private and public water supply.

This paper concentrates on a Geographical Information System (GIS) that was developed to assist the local planning authority in their decision making process regarding future mineral development and water management in the East Mendip area. The main object of this work was to collect and collate available data on groundwater, mineral resources and environmental aspects of the study area, integrating this information into a useable, easily accessible system.

The project required the involvement of a range of stakeholders to ensure that the approach and the results

would be as meaningful as possible. The project team therefore had representation from the Somerset County Council Mineral Planning, the Environment Agency (EA), the Mendips Quarry Producers Association, and SRK Consulting as specialist consultants in mine and quarry water management.

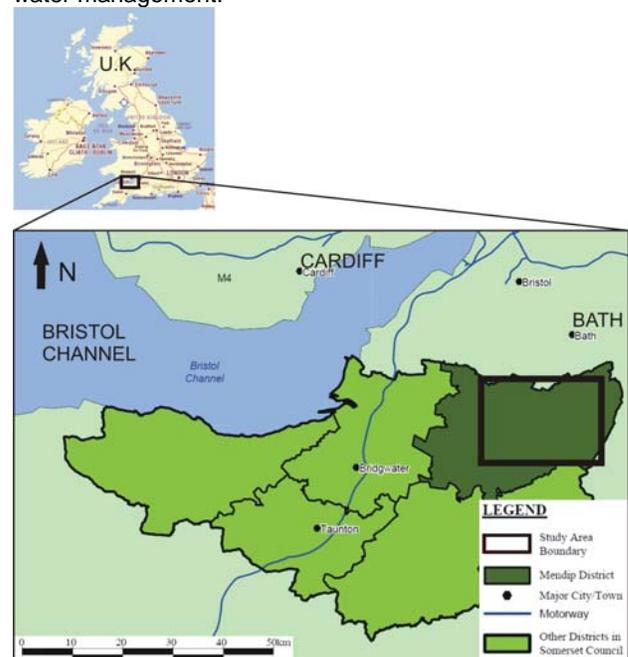


Figure 1: Study area location map

2. LIMESTONE HYDROGEOLOGY AND QUARRYING IN THE EAST MENDIPS

The East Mendips correspond to the eastern portion of the Mendip Hills in Somerset and was selected for this study as it represents an area of very active quarrying, and one that is likely to be so for the foreseeable future. The majority of the groundwater resources available for exploitation in the East Mendips are associated with the Palaeozoic and Mesozoic limestone formations. These are part of a sedimentary sequence that was deposited over volcanic rocks of Silurian age and later compressed and folded, generating a major geological structure within the study area, oriented along an east-west direction, known as the Beacon Hill Pericline. This structure divides the limestone rocks in two domains, a northern one, where Carboniferous limestone predominates, and a southern one, dominated by the Jurassic formations. The Carboniferous Limestone is recognized as the main regional aquifer and is characterized by a low porosity matrix, with poor connection between the pores, resulting generally in a low permeability medium. The fractured rock mass provides however a moderate permeability which is considerably enhanced by solution widening and karst development. Numerous caves and other karstic features have been mapped in the East Mendips, which bear significant implications on the groundwater flow regime. Overall the limestone aquifer is heterogeneous and anisotropic, with flow taking place preferentially through fractures and other secondary structures. Transmissivity values have been reported to vary in more than three orders of magnitude (Harrison et al. 1992), and the regional groundwater flow within these domains occurs from west to the east, following approximately the surface water flow direction. Springs outlets connected to karstic features and other structures in the limestone are common in the area.

In the context of quarries operating below the water table in such a formation, a number of potential impacts to the operations and to other groundwater users in the area must be considered.

The main mineral commodities produced in the East Mendips are hard-rock aggregates for the construction industry. These are mostly sourced from the Carboniferous limestone formations, which have a surface cover of approximately 11% of the study area. Other exploited minerals include Silurian andesites and other limestone varieties from Triassic and Jurassic formations.

Five of the six main quarrying operations in the East Mendips extract limestone, and all of them operate to variable extents below the natural groundwater table, and have dewatering schemes in place. In order to monitor and mitigate, in some instances, the effects of their operations, these quarries have been responsible for the installation of a comprehensive surface and groundwater monitoring network, which constitute significant part of the database gathered for the GIS.

In addition to these main operations, there are smaller-scale quarries, some of which are dedicated to the production of building stone. Inactive quarrying sites also exist in the area, some of which have developed lakes as a result of groundwater recovery after the interruption of their dewatering operations.

Figure 2 shows the distribution of quarries and the surface expression of the various limestone formations within the study area.

3. GIS DEVELOPMENT

3.1 Concept

A GIS can be described as:

A computer system for capturing, storing, checking, integrating, manipulating, analysing and displaying data related to positions on the Earth's surface. Typically, GIS is used for handling maps of one kind or another. These might be represented as several different layers where each layer holds data about a particular kind of feature. Each feature is linked to a position on the graphical image of a map. UEIG (2003)

The application of this concept to the present study meant that all of the data gathered as part of the project was geo-referenced and collated in a format that made it readily available for use and management within the system. As recognized by Fischer and Nijkamp (1993), the great strength of a GIS is the ability to handle large, multilayered, heterogeneous databases and to query about the location and properties of a wide range of spatial objects in an interactive way.

The GIS enables users to visualize data presented as a number of layers. A layer typically portrays information about one specific class of real world elements, such as rivers or towns, which can also be referred to as themes or overlays. Different layers can be superimposed and an active planning tool can be very rapidly developed to link several issues that potentially may be very diverse, but which are spatially related.

3.2 Methodology

The GIS was developed in four main steps:

- Identification of themes of interest and potential data sources
- Data collection
- Data collation and entry into the GIS
- Development of workspaces grouping datasets by category

The themes of interest were numerous, ranging from geology and topography to the spatial distribution of

environmental conservation areas. The data was obtained from a variety of sources, including the Somerset County Council, Environment Agency, British Geological Survey, Mendip District Council and individual quarry operators in the East Mendips.

The collected data was received in various formats, including hard copies and digital plans and reports, as well as electronic databases. A significant part of the work involved screening the data received and adjusting it to a format suitable for entry into the GIS database. As the incoming information was processed, individual plans and datasets were prepared, and these were later imported into the selected GIS interface (MapInfo), to generate the individual information layers. Each layer included in the GIS was registered by the creation of a metadata file, which gives a description of the data contained within the layer.

With the collected data organized into different layers, the next step was to combine these layers into workspaces, or interactive maps, which a user would eventually be able to access and combine the different types of information for a specific purpose.

A final stage of the system development involved consideration of the methods for accessing the information, which resulted on the development of a trial website for data publication and access.

4. RESULTS

4.1 Geographical Information System

The GIS contains a total of 42 layers of information, combining the data collected from the various sources and collated into the system. To facilitate access to specific categories of information, the layers included in the GIS were distributed and combined within five main topics:

- Local Area Information
- Mineral Resources
- Water Environment
- Monitoring Networks
- Conservation Areas

Each topic represents a workspace in the GIS. A workspace can be understood as a virtual working area (interactive map) containing a pre-defined set of information layers (map elements), where the user is able to access and visualise simultaneously any combination of the selected layers. The various workspaces are briefly described below. Each workspace is presented with a base plan, over which the other pre-defined layers can be superimposed.

Local Area Information: this workspace includes layers containing information categories that cover the entire

extension of the study area, such as geology and topography.

Mineral Resources: presents information associated with mineral resources and the local quarrying activity. The full surface expression of the main geological bodies is available (for example, the Carboniferous Limestone), in conjunction with mineral planning information, such as the present Mineral Consultation Areas.

Water Environment: includes information related to natural features associated with water resources, such as springs and sinkholes, as well as to surface water and groundwater users in the study area.

Monitoring Networks: this workspace allows the user to visualize individual monitoring points and to access the monitoring record available for groundwater, surface water and climate monitoring points throughout the study area.

Conservation Areas: this workspace allows the user to visualise the spatial coverage and location of conservation areas, and their relative positions with relation to Mineral Consultation Areas and quarrying areas.

In addition to the above, a User Workspace was created, to allow the user to perform layer combinations that have not been pre-defined in the five main topics. Table 1 provides a summary of the layers contained within the five main workspaces.

WORKSPACE	GIS LAYERS
Local Area Information	Study area, Rivers, Lakes. Mendip District Council area, Parishes in study area, Mineral consultation areas (MCA), Quarries planning permission extents. Geological faults, Bedrock geology, Superficial (drift) deposits, Karstic features, Karst incidence Topography (10 and 50m contour plans). Landuse and Soil type.
Mineral Resources	Study area, Rivers, Lakes. Carboniferous limestone, Triassic limestone, Jurassic limestone. Mineral consultation areas (MCA), Quarries planning permission extents, Quarries permitted extents. Quarries recent survey.
Water Environment	Study area, Rivers, Lakes, Springs, Sinks. Surface water catchment. Carboniferous limestone, Potentiometric surface. EA Groundwater vulnerability map. Active and inactive public groundwater abstraction points, Licensed abstractions, Private supplies. Quarries planning permission extents.
Monitoring Network	Study area, Rivers, Lakes, River quality monitoring (GQA). River quality monitoring sampling sites. Borehole unlicensed abstractions. Borehole licensed abstractions. River flow gauging points, River discharge points. Borehole monitoring points. Bedrock geology. Quarries planning permission extents.
Conservation Areas	Study area, Rivers, Lakes. Areas of Outstanding Natural Beauty (AONB). Sites of Special Scientific Interest (SSSI). Special Areas of Conservation (SAC). Source Protection Zones (SPZ). Natural areas, Character areas. Quarries planning permission extents.

Table 1: Individual layers within the main GIS workspaces

4.2 Local Planning Tool

One of the main challenges facing the Mineral Planning Authority in the East Mendips is to find a balance between the future development of the local mineral extractive industry and the sustainable exploitation of groundwater resources. Dealing with such planning issues will often

involve an assessment of many different factors, such as the geographic distribution of mineral resources and location of protection areas.

In this context, a GIS can be a powerful tool, by allowing the superposition of plans showing the spatial distribution of the various factors involved, so that their cumulative effect can be assessed for a given section of the area under consideration. This cumulative information is critical in the planning process, and constitutes the basis of a preliminary planning tool that was developed as part of this project, herein referred to as a Target Plan.

The preparation and use of target plans involves a significant amount of professional judgment. The purpose of the Target Plan will determine the weight that is given to each factor involved in the analysis. In this study the main goal was to identify zones of relatively high and low sensitivity with regard to potential impact on groundwater resources. In addition, areas that present major planning constraints for mineral extraction independent of sensitivity to groundwater were identified, such as urban areas and certain conservation areas.

The plan that was prepared for the study area did not involve a complete survey of major planning constraints, but rather aimed at demonstrating the technique and providing an initial indication of which areas in the East Mendips may be considered for future mineral development.

Among the information available, the key factors to determine the sensitivity level of a given portion of the study area were identified. Subsequently, ranges representing the sensitivity variations within each factor were created and, finally, a numerical weighting was applied to each sensitivity level, for each factor. The weighting applied to individual categories in this part of the study is subjective, and was based on an initial interpretation of the relative relevance of the selected factors.

Table 2 illustrates the ranking system for some of the factors considered in the Target Plan, with the relative weight that was applied to the sub-categories within each factor, based on numerical range between 0 (low sensitivity) and 10 (high sensitivity).

Aquifer classification						
Classification	Major aquifers	Minor aquifers	Non aquifers			
Weight	8	2	0			
Thickness of unsaturated zone						
Thickness Intervals (m)	0-10	10-20	20-30	30-40	40-50	>50
Weight	10	8	6	4	2	0
Incidence of karstic features						
Incidence level	High	Medium	Low			
Weight	6	4	2			

Table 2: Example of ranking system used for the various factors considered in the Target Plan

In order to create the Target Plan, the study area was divided in a regular grid of 100 m by 100 m cells.

Individual maps were then created for each factor considered in the Target Plan, with each cell in each of the maps being assigned a numerical weight (or sensitivity level), according to the previously defined ranking system.

Twelve key factors were selected for the development of the Target Plan, and distributed within two general categories: factors that have a direct influence on the groundwater resource sensitivity; and factors that represent major planning constraints (Table 3). Twelve individual maps were then created, and overlapped to generate the Target Plan. In the Target Plan, a total score was obtained for each cell, by adding up the weights applied to each factor superimposed on that cell. For example, considering only the three parameters indicated in Table 2: a cell located over a major aquifer, with an unsaturated zone thickness of 25m and in an area of high karst incidence would result in an overall score of 20. This score indicates an area with a higher sensitivity level in terms of the criteria applied than for example a cell with a total score of 12.

Category	Factor	Primary nature of concern
Groundwater Resource	Aquifer classification	Protection of groundwater resources
	Depth to groundwater (thickness of the unsaturated zone)	
Geological Structure	Proximity to faults	
	Karst occurrence density	
Water Abstraction	Proximity to public supplies (groundwater)	
	Proximity to licensed abstractions (surface and groundwater)	
	Source Protection Zones	
Surface Water Bodies	Proximity to rivers and streams	Planning constraints
Conservation	Proximity to Special Areas of Conservation	
	Proximity to Areas of Outstanding Natural Beauty	
	Proximity to Sites of Special Scientific Interest	
Land use	Land use type	

Table 3: Target Plan key factors

The different scores obtained for the individual cells are represented on the plan by a color code, as shown in Figure 3. In this case higher scores (or more sensitive areas) are indicated by dark gray colors and lower scores (or less sensitive areas) are indicated by light gray colors.

Although this plan does not incorporate all factors involved in the planning process, it does provide an initial indication of areas that may be considered for future mineral development with least impact on groundwater resources. Some preliminary considerations can be drawn from the Target Plan, as discussed below.

High sensitivity areas appear to be generally aligned along a central belt extending from west to east. These areas coincide broadly with the surface expression of the Carboniferous Limestone formations, and are in part due to their classification by the EA as major aquifers. The comparatively high sensitivity levels are also related to the present distribution of groundwater Source Protection Zones, as well as, on the west portion of the study area, with the relatively higher density of karstic features.

From this perspective, the northern and southern portions of the study area would be more indicated for mineral

development, from a groundwater sensitivity point of view. This is, however, limited due to the extensive sedimentary cover in these areas, represented by rocks such as sandstones and mudstones. Dip angles as steep as 80° in the Carboniferous Limestone mean that the thickness of the sedimentary cover increases rapidly with distance from the surface contact between the two rock types, making most of these areas unsuitable for limestone exploitation.

Considering the surface distribution of the Carboniferous Limestone formations and of the sensitivity zones within the study area, three main areas were identified where mineral extraction could have least impact on the environment. These areas are indicated in Figure 3 by the numbers I, II and III. They have the advantage of not coinciding with any of the considered conservation areas, although blocks II and III do fall within groundwater Source Protection Zones as defined by the EA.

It is clear from these preliminary observations that there is a limited potential for expansion of the quarrying of Carboniferous Limestone in the East Mendips. However, significant areas covered by other limestone formations of Jurassic age remain in relatively low-sensitivity areas, in the northern and southern parts of the study area (areas IV and V, Figure 3).

The Target Plan as exemplified above can be understood as a screening tool, and once initial target areas are identified, then additional, more detailed assessments can be conducted to verify the suitability of the areas for mineral development. It provides therefore initial guidance to assist in the planning process and constitute also a valuable tool for stakeholder communication.

4.3 System Publication

One of the main objectives of the present work was to disseminate the information collated during this study and make the project results available to all interested parties, including the wider public. To achieve this, a website was created and made available initially to the members of the project steering committee for a trial period.

The website presents a basic design, and constitutes an interface that allows users to access the GIS, and it is also a platform for the publication of other materials, such as reports. In addition, it hosts a library searching facility, which was generated to facilitate the access to the list of technical references that was compiled as part of the study. The website is to be eventually published in the internet.

5. CONCLUSIONS

A Geographic Information System (GIS) was developed based on a framework for the collection and archiving of available data in the East Mendips. The local database

was integrated into the GIS, which presently comprises over 40 layers of information. MapInfo Professional was the adopted GIS interface for the project.

Using information included in the GIS, an initial tool for long term mineral planning was developed. The main purpose of this tool, denominated Target Plan, was to identify zones of high and low sensitivity with regard to potential impact of mineral extraction on groundwater resources. The Target Plan indicated a concentration of relatively high-sensitivity areas along a central belt extending in an east-west direction, corresponding broadly to the surface expression of the Carboniferous limestone, a recognized major aquifer. Five zones within the study area were identified where mineral extraction could have least impact on the environment.

This assessment was, however, based on a limited amount of parameters, and relevant information, such as depth to the groundwater table, is not available for all sections of the study area. Nevertheless, the Target Plan demonstrates a principle that can be used to assist planning authorities in making improved decisions in terms of locating future quarrying operations with minimum impacts to the environment, and in preventing potential sterilization of suitable mineral reserves. Although this study was conducted on a specific area in southern England, the adopted methodology will be of value to quarry operators and planners elsewhere.

6. ACKNOWLEDGEMENTS

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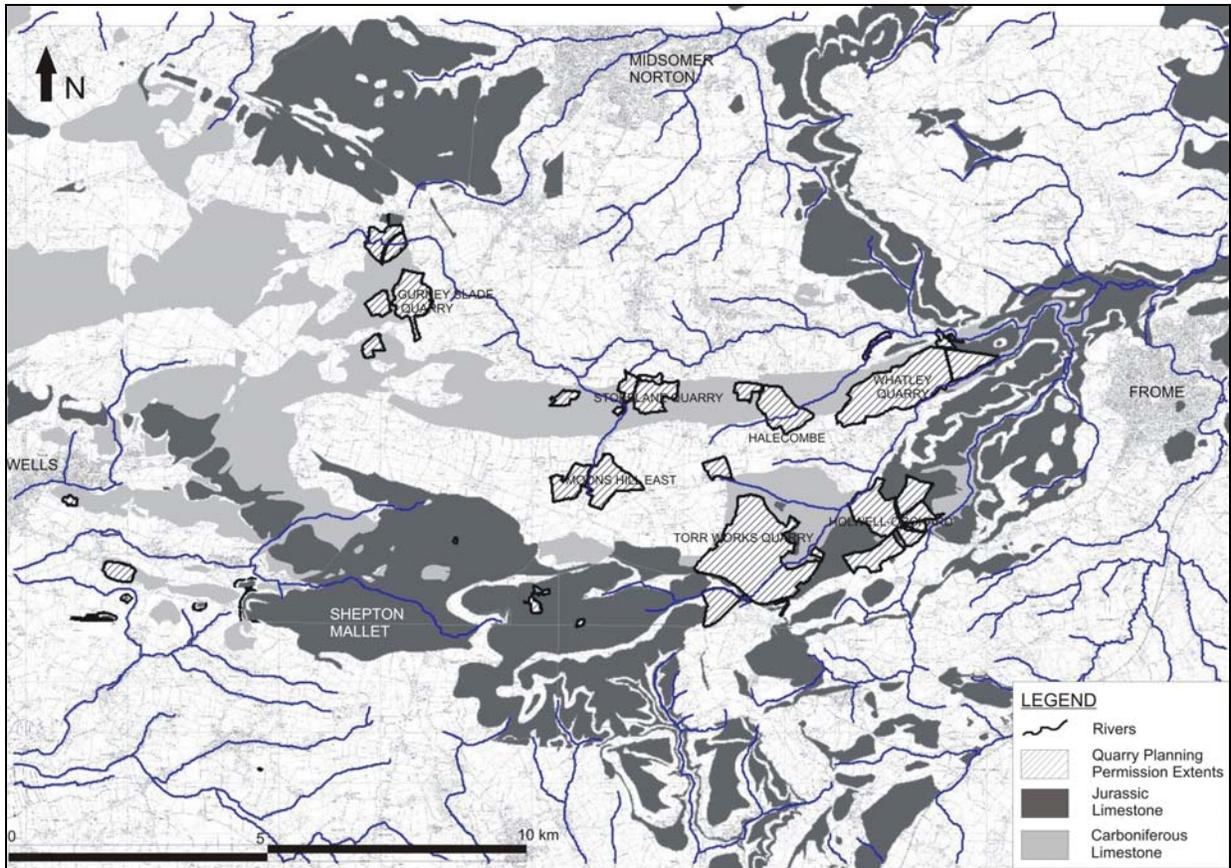


Figure 2: Location of individual quarries and limestone formations within the study area

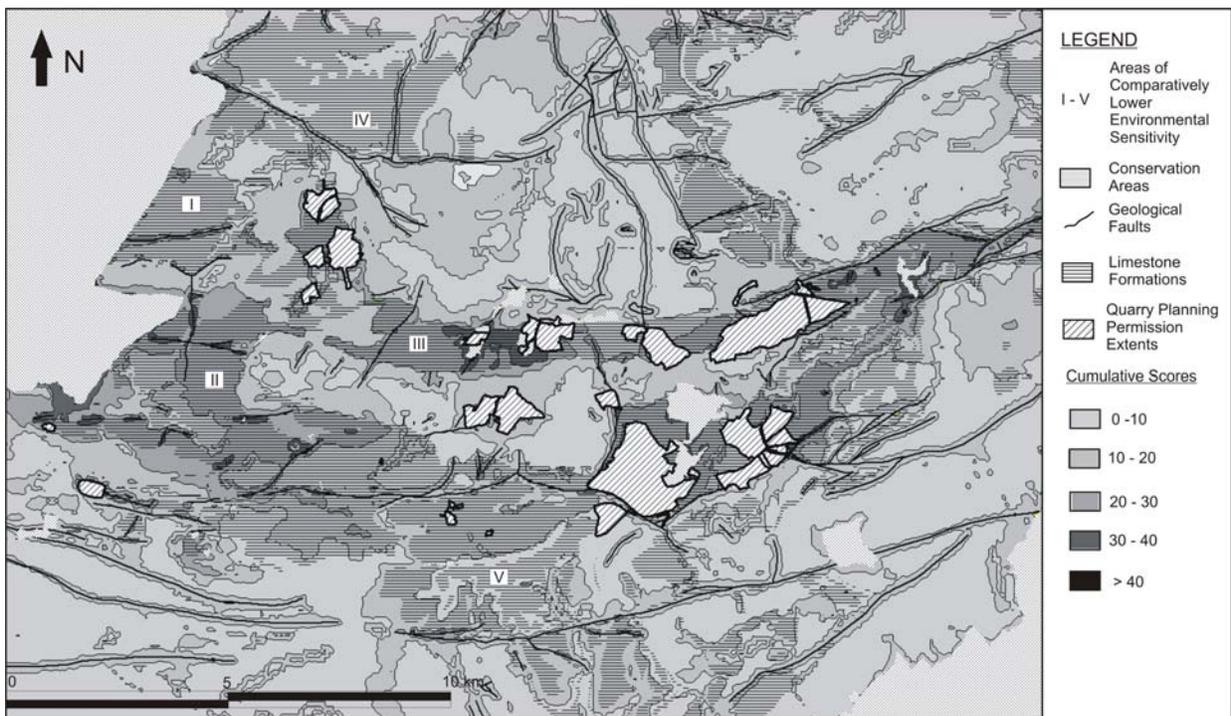


Figure 3: Target Plan derived for the East Mendips