LAND EVALUATION AND SITE ASSESSMENT

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Summary

Land evaluation is undertaken in order to determine its most suitable use, while site assessment is necessary for development. In both instances, the impact on the environment should also be assessed. The extent to which any survey should be undertaken depends on the type of survey; for example, a feasibility study does not need to be as detailed as an investigation for a large construction project. Various methodologies can be employed in land evaluation and site assessment. Remote sensing imagery and aerial photographs may be used in the initial stages of an investigation, and provide useful data for planning the more detailed investigation. Various types of maps are of value in land evaluation and site assessment, including topographic maps, geological maps and soil maps. Geographical information systems make use of data derived from remote imagery and aerial photographs, as well as from maps and aero-magnetic surveys. After computers have acquired the data, it is analyzed, processed, and presented in map form. Terrain evaluation is a system of landscape analysis that classifies a landscape into units of various sizes based on geomorphological features. Land capability studies attempt to match land with the appropriate land use.

Before any construction project goes ahead it must be preceded by a site investigation to determine the suitability of the site for the proposed development and to provide data for design purposes. A site investigation normally begins with a desk study that makes an assessment of the site from existing data such as maps, aerial photographs, and

available literature. The desk study, together with the preliminary survey—primarily a site walkover—provides data that helps to plan the site exploration. Site exploration involves investigation of both the surface and the subsurface of the area in question, and is usually not restricted to within the boundaries of the site. Surface investigation involves mapping the ground-surface conditions. The subsurface is explored by digging trenches and pits in soils or weak rocks, and/or by sinking boreholes in soils or drillholes in rocks. Soil and/or rock samples are taken for laboratory investigation during these operations. *In situ* tests may be carried out at the surface, down boreholes or drillholes, or in adits to obtain data on ground failure or likely settlement when loaded. Frequently, the hydrogeological conditions such as pore-water pressures, permeability, and perhaps water quality, need investigating. Indirect exploration of the subsurface is carried out by using geophysical testing; the most commonly used tests being seismic refraction and resistivity. The results of the investigation form the basis of a report, which includes maps and plans, which makes an assessment of the site in relation to the project and provides data for project design.

1. Introduction

Land evaluation and site assessment are undertaken to help to determine the most suitable use of land in terms of planning and development, or for construction purposes. In the process the impact on the environment of a particular project may have to be determined,; this is especially the case as far as large projects are concerned. Obviously, there has to be a geological input into these processes. The impact of land development is usually most notable in urban areas where the human pressures on land are greatest. Urban development, together with the growth of industry and mining, in particular, have led to spoilation and dereliction of land in the past, and no doubt will do so in the future, but hopefully to a much lesser extent. This is where planning has a vital role to play and where the geologist must be involved.

Investigations in relation to land-use planning and development can obviously take place at various scales, from regional, to local, to site investigations. Regional investigations are generally undertaken on behalf of government authorities at, for example, state or county level, and may be involved with the location and use of mineral resources, with the identification of hazards, with problems caused by past types of land use, or with land-capability studies and zoning for future land use. In this context, it is necessary to recognize those geological factors that represent a resource or constitute a constraint. A constraint imposes a limitation on the use to which land can be put, so that a particular locality that is so affected is less suited to a specific activity than another. Local site investigations tend to be undertaken for specific reasons, for instance, the location of a suitable site for a landfill, of a site for the construction of a reservoir and dam, or the development of a gravel pit. In such cases investigations will be necessary to obtain the relevant information, including geological, for the planning processes, which in many countries will include a public enquiry. Regional investigations frequently entail the production of engineering geomorphological and environmental geological maps, including hazard maps, with associated reports. Site investigations tend to involve the production of engineering geological—or geotechnical—maps and reports.

Any investigation begins with the formulation of aims: what does it wish to achieve, and which type of information is of relevance to the particular project in question? Once the pertinent questions have been posed, the nature of the investigation can be defined and the process of data collection can begin. The amount of detail required depends largely on the purpose of the investigation. For instance, less detail is required for a feasibility study for a project than is required by engineers for the design and construction of that project. Various methodologies are employed in data collection. These may include the use of remote sensing imagery, aerial photography, existing literature and maps, fieldwork and mapping, subsurface exploration by boring and drilling, sample collection, geophysical surveying, and *in situ* testing. In some instances geochemical data may need to be gathered, notably when water or ground is polluted or contaminated, or monitoring programs carried out. Once the relevant data has been obtained it must be interpreted and evaluated, then embodied along with the conclusions in a report, which will contain maps and/or plans. Geographical information systems (GIS) may be used to help process the data.

2. Remote Sensing

Remote sensing imagery and aerial photographs have proved valuable aids in land evaluation, particularly in those underdeveloped regions of the world where good topographic maps do not exist. They commonly represent one of the first stages in the process of land assessment. However, the amount of useful information obtainable from imagery and aerial photographs depends on their characteristics, as well as the nature of the terrain they portray. Remote imagery and aerial photographs prove of most value during the planning and reconnaissance stages of a project. The information they provide can be transposed to a base map, and this is checked during fieldwork. This information not only allows the fieldwork program to be planned much more readily, it also should help to shorten the period spent in the field. The data can also be used in GIS.

Remote sensing involves the identification and analysis of phenomena on the earth's surface, using devices borne by aircraft or spacecraft. Most techniques used in remote sensing depend on recording energy from part of the electromagnetic spectrum, ranging from gamma rays through the visible spectrum to radar. The scanning equipment used measures both emitted and reflected radiation, the employment of suitable detectors and filters permitting the measurement of certain spectral bands. Signals from several bands of the spectrum can be recorded simultaneously by multi-spectral scanners.

Infrared line scanning is dependent on the fact that all objects emit electromagnetic radiation generated by the thermal activity of their component atoms. Emission is greatest in the infrared region of the electromagnetic spectrum for most materials at ambient temperature. It involves scanning a succession of parallel lines across the track of an aircraft with a scanning spot. Since only an average radiation is recorded, the limits of resolution depend on the size of the spot. The diameter of the spot is usually around 2–3 milliradians, which means that if the aircraft is flying at a height of 1000 m, the spot measures 2–3 m across. The radiation is picked up by a detector that converts it to electrical signals, which in turn are transformed into visible light via a cathode ray tube, thereby enabling a record to be made on film or magnetic tape. The data can be processed in color, as well as black and white. Unfortunately, prints are increasingly distorted with increasing distance from the line of flight, which limits the total useful angle of scan to about 60° on either side. In order to reduce the distortion along the edges of the imagery, flight lines have a 50–60% overlap. A temperature difference of 0.15 °C between objects of 500 mm diameter can be detected by an aircraft at an altitude of 300 m. The spatial resolution is, however, much lower than that of aerial photographs, in which the resolution at this height would be 80 mm. At higher altitudes the difference becomes more marked. Although temperature differences of 0.1 °C can be recorded by infrared linescan, these represent differences not in the absolute temperature of the ground but in emission of radiation. Careful calibration is therefore needed in order to obtain absolute values. Emitted radiation is determined by the temperature of the object and its emissivity, which can vary with surface roughness, soil type, moisture content, and vegetative cover.

The use of infrared linescan depends on clear, calm weather. The time of the flight is also important, as thermal emissions vary significantly throughout the day. From the geological point of view, pre-dawn flying proves most suitable for thermal infrared linescan. This is because radiant temperatures are fairly constant and reflected energy is not important, whereas during a sunny day radiant and reflected energy are roughly equal, so the latter may obscure the former. Also, because sun-facing slopes are warm and shade slopes cool, rough topography tends to obliterate geology in post-dawn imagery.

A gray scale can be used to interpret the imagery, it being produced by computer methods from linescan data that have been digitized. This enables maps of isoradiation contours to be produced. Color enhancement has also been used to produce isotherm contour maps, with colors depicting each contour interval. Identification of gray tones is the most important aspect as far as the interpretation of thermal imagery is concerned, since these provide an indication of the radiant temperatures of a surface. Warm areas give rise to light tones and cool areas to dark tones. Relatively cold areas are depicted as purple, and relatively hot areas as red, on a color print. Thermal inertia is important in this respect since rocks with high thermal inertia, such as dolostone or quartzite, are relatively cool during the day and warm at night. Rocks and soils with low thermal inertia, for example, shale, gravel, and sand, are warm during the day and cool at night. In other words, the variation in temperature of materials with high thermal inertia during the daily cycle is much less than in those with low thermal inertia. Because clay soils possess relatively high thermal inertia they appear warm in pre-dawn imagery whereas sandy soils, because of their relatively low thermal inertia, appear cool.

The moisture content of soil influences the image produced: that is, soils that possess high moisture content may mask differences in soil types. Fault zones are often picked out because of their higher moisture content. Similarly, the presence of old landslides can frequently be detected because their moisture content differs from that of their surroundings. Free-standing bodies of water are usually readily visible on thermal imagery; however, the high thermal inertia of highly saturated organic deposits may approach that of water masses, and the two may therefore prove difficult to distinguish at times. Texture can also help interpretation. For instance, outcrops of rock may have a rough texture due to the presence of bedding or jointing, whereas soils usually give rise to a relatively smooth texture. However, where soil cover is less than 0.5 m, the rock structure is usually observable on the imagery since deeper, moister soil occupying discontinuities gives a darker signature.

In side-looking airborne radar (SLAR), short pulses of energy in a selected part of the radar waveband are transmitted sideways to the ground from antennae on both sides of an aircraft. The pulses of energy strike the ground along successive range lines and are reflected back at time intervals related to the height of the aircraft above the ground. The reflected pulses are transformed into black and white photographs with the aid of a cathode-ray tube. Returning pulses cannot be accepted from any point within 45° from the vertical, so there is a blank space under the aircraft along its line of flight. Also, the image becomes increasingly distorted towards the track of the aircraft. The belt covered by normal SLAR imagery varies from 2 to 50 km, and although the scanning is oblique, the system converts it to an image that is more or less planimetric.

There are some notable differences between SLAR images and aerial photographs. For instance, although variations in vegetation produce slightly different radar responses, a SLAR image depicts the ground more or less as it would appear on aerial photographs devoid of vegetation. Displacements of relief are to the side towards the imaging aircraft and not radial about the center as in aerial photographs. Furthermore, radar shadows fall away from the flight line and are normal to it. The shadows on SLAR images form black areas that yield no information, whereas most areas of shadow on aerial photographs are partially illuminated by diffused lighting. The subtle changes of tone and texture that occur on aerial photographs are not observable on SLAR images.

Because the wavelengths used in SLAR are not affected by cloud cover, imagery can be obtained at any time. This is particularly important in equatorial regions, which are rarely free of cloud. Consequently, this technique provides an ideal means of reconnaissance survey in such areas.

Typical scales for radar imagery available commercially are 1:100 000–1:250 000, with a resolution of between 10 and 30 m. Smaller objects than this can appear on the image if they are strong reflectors, and the original material can be enlarged. Mosaics are suitable for the identification of regional geological features and for preliminary identification of terrain units. Lateral overlap of radar cover can give a stereoscopic image, which offers a more reliable assessment of the terrain. Furthermore, imagery recorded by radar systems can provide appreciable detail of landforms as they are revealed because of the low angle of incident illumination.

Small-scale space imagery provides a means of initial reconnaissance that allows areas to be selected for further, more detailed investigation, by aerial and/or ground survey methods. Indeed, in many parts of the world a Landsat image may provide the only form of base map available. The large areas of the ground surface that satellite images cover give a regional physiographic setting and permit the distinction of various landforms according to their characteristic photo patterns. Accordingly, such imagery can provide a geomorphological framework from which a study of the component landforms is possible. The character of the landforms may afford some indication of the type of material of which they are composed, and geomorphological data can aid the selection of favorable sites for field investigation on larger-scale aerial surveys. Small-scale imagery may enable regional geological relationships and structures to be identified that are not noticeable on larger-scale imagery or mosaics.

The images are reproduced on photographic paper and are available for four spectral bands plus two false-color composites. The infrared band is probably the best for geological purposes. Because separate images within different wavelengths are recorded at the same time, the likelihood of recognizing different phenomena is enhanced significantly. Since the energy emitted and reflected from objects commonly varies according to wavelength, its characteristic spectral pattern or signature in an image is determined by the amount of energy transmitted to the sensor within the wavelength range in which that sensor operates. As a consequence, a unique tonal signature may frequently be identified for a feature if the energy that is being emitted and/or reflected from it is broken into specially selected wavelength bands. If reflected energy from the shorter and longer ends of the visible spectrum is recorded separately, differentiation can be made between rock types. The ability to distinguish between different materials increases when imagery is recorded by different sensors outside the visible spectrum: the spectral characteristics are then influenced by the atomic composition and molecular structure of the materials concerned.

In addition to the standard photographs at a scale of 1:1 000 000, transparencies—positive and negative—and enlargements, at scales of 1:250 000 and 1:500 000, are available, as are false-color composites. The latter often show up features not easily observable on black and white images.

Satellite images may be interpreted in a similar manner to aerial photographs, although the images do not come in stereopairs. Nevertheless, a pseudostereoscopic effect may be obtained by viewing two different spectral bands (band-lap stereo) of the same image or by examining images of the same view taken at different times (time-lap stereo). There is also a certain amount of side lap, which improves with latitude. This provides a true stereographic image across a restricted strip of a print; however, significant effects are only produced by large relief features. Interpretation of satellite data also may be accomplished by automated methods using digital data directly, or by using interactive computer facilities with visual display devices.

The value of space imagery is particularly important where existing map coverage is inadequate. For example, it can be of use for the preparation of maps of terrain classification, for regional engineering soil maps, for maps used for route selection, for regional inventories of construction materials, and for inventories of drainage networks and catchment areas. A major construction project is governed by the terrain, optimum location requiring minimum disturbance of the environment. In order to assess the ground conditions it is necessary to make a detailed study of all the photo-pattern elements that comprise the landforms on the satellite imagery. Important evidence relating to soil types or surface or subsurface conditions may be provided by erosion patterns, drainage characteristics, or vegetative cover. Engineering soil maps are frequently prepared on a regional basis for both planning and location purposes in order to minimize construction costs, the soils being delineated for the landforms within the regional physiographic setting.

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* More advanced text.

Biographical Sketch

Fred Bell graduated with a B.Sc. and M.Sc. from the University of Durham, UK, and received his Ph.D. from the University of Sheffield, UK, in 1974. More recently, he received a D.Sc. from the University of Natal, Durban, South Africa. He is a fellow of the Royal Society of South Africa, a fellow of the Institution of Civil Engineers and the Institution of Mining and Metallurgy, and a fellow of the Geological Society, being both a chartered engineer and a chartered geologist. He is the recipient of several awards.

Professor Bell is currently a Visiting Research Associate at the British Geological Survey. Previously, he was Professor and Head of the Department of Geology and Applied Geology at the University of Natal, during which time he was also a Distinguished Visiting Professor, Department of Geological Engineering, University of Missouri-Rolla, USA.

Professor Bell's research subjects have included ground stability; subsidence; ground treatment; engineering behavior of soils (clays, expansive clays, saprolites, tills, laminated clays, dispersive and collapsible soils, sands); engineering behavior of rocks (sandstones, carbonates, evaporites, shales, basalts, dolerites, granites); cement, lime, and PFA stabilization of clay soils; acid mine drainage; mining impacts; landfills; derelict and contaminated ground; rock durability in relation to tunneling; slope stability; aggregates; building stone; and geohazards.

In his professional activity Professor Bell has been involved in a variety of work in the UK, southern Africa, and Malaysia concerning site investigations; foundations; settlement problems on clays, fills, and sands; old mine workings and subsidence; longwall mining and subsidence; ground treatment; groundwater resource assessment; slope stability; use of mudrocks for brickmaking; assessment of various rock types for aggregates; contaminated ground; acid mine drainage; landfills; and dam sites.

Professor Bell is the author/editor of 17 books, several reprinted, one in its fourth edition, one translated into French, two into Italian, and yet another into Malay, as well as an Indian edition (in English). He is also the author of over 200 papers on geotechnical subjects. He has served on the editorial boards of five international journals and has been a series editor for three publishers.