Terrain Evaluation for Highway Planning and Design

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Studies of the terrain to select route locations and sites for detailed geotechnical investigations are essential preliminaries to highway survey and design. The process of using all sources of information, including remote sensing, to derive an understanding of the engineering characteristics of an area is known as terrain evaluation. The basis of terrain evaluation is a terrain classification, whose purpose is to act as a geographical indexing system into which all terrain-related data, collected throughout the duration of a project, may be fitted. A terrain classification can be based on land form patterns, which are related to the underlying geology, soils, and water conditions. A land form classification has the advantage of being readily mapped from aerial photographs or remote-sensing images. It can be used to predict changes in soil conditions and to relate data from individual sampling sites to areas of terrain. The two most useful forms of remote-sensing imagery are aerial photographs for detailed work and Landsat imagery for regional studies. Panchromatic photography is available in many parts of the world, and there is increasing experience of its use in the tropics. If more detailed photography using special films is required, the use of a light aircraft that carries small-format cameras can provide high-quality photography at low cost. Landsat imagery has proved useful for preliminary surveys. Photographic prints of imagery are inexpensive and easy to produce. Detailed analysis by using digital images can be carried out with a computer, normally in conjunction with an interactive processor, and the use made of these systems will probably increase as their cost decreases. The principal aspects of terrain evaluation for highway surveys are illustrated by examples of work carried out in Africa and Asia.

The objective of highway planning and design is to construct a road at the appropriate standard to satisfy an expressed need for transportation. Consideration of the terrain is an integral part of the planning process and contributes much to the success of the design. The design stage itself is controlled by codes of practice and manuals that set out specifications and procedures to be followed. In contrast with this, the early stages of a project, notably the location of initial tentative alignments and the choice of sites for investigation in the field, are poorly supported by guides to practice. The reason is that the appraisal of terrain requires an assessment of many related natural factors, sometimes over very large areas, for which the writing of a simple manual is impracticable.

It is important that decisions taken during the early stages of a project be based on some reasonably accurate and comprehensive assessment of terrain conditions. The object of this paper is to show how aerial photographs and remote-sensing techniques can be used to gain an appreciation of the important engineering characteristics of the terrain and to devise a representative sampling and site-investigation procedure along routes that are considered to be feasible. The process of using all sources of information, integrated within a single scheme that can be applied throughout the duration of the project, is known as terrain evaluation. Terrain evaluation techniques are of most immediate value in areas where information is limited or not available, although they can equally well be applied in parts of the world where terrain information is available but not coordinated.

The examples given of work carried out in Africa and Asia each illustrate a particular stage or aspect of the projects they describe, rather than the project as a whole. At the end of the paper, the various techniques are brought together in a table that shows which technique is considered to be most relevant to each individual stage of the survey.

PRINCIPLES AND TECHNIQUES OF TERRAIN EVALUATION

Terrain evaluation is the appraisal of the capabilities and limitations of an area of ground in relation to a particular kind of land use. The word "terrain" refers not merely to the shape of the land surface but to all the factors that act in combination to mold the land itself, namely the relief, geology, soils, and water conditions. The advantages of using a terrain evaluation approach to engineering surveys are as follows:

1. By studying a problem within its region, it is possible to see all available options for routes.
2. A terrain evaluation will indicate points where the terrain changes from one type to another. It is possible to devise a sampling program to cover sites that are typical of large areas and thus to extrapolate information from known to unknown ground with some degree of confidence. A regional approach to mapping also helps to draw attention to particularly important individual sites that may influence the design.
3. The study of sites in relation to the terrain emphasizes the fact that data should not be treated as a series of isolated points but as being representative of a continuous medium that varies in ways that can be defined.
4. By relating information to a classification of terrain units, it is possible to use the same units from the early phases of planning through to the final stage, so that data can be carried forward and amplified as necessary in each succeeding stage.

For the highway engineer, the terrain evaluation process should aid such diverse activities as determining the alignment of a highway, identifying deposits of gravel or rock for use in construction, or arranging a soil sampling program. A terrain evaluation is able to do this effectively when based on a terrain classification, or map of terrain types, where each type has its own engineering characteristics to which survey work can be related. The process of terrain evaluation takes place in two stages, of which the production of a terrain classification map represents the first stage. The evaluation stage is completed when engineering characteristics are related to each of the terrain units in the classification, which are gathered from information collected during the field survey stages.

Certain techniques have proved themselves to be particularly suitable for terrain evaluation, especially those that provide information to establish an appropriate form of terrain classification. These mainly involve the use of imaging remote-sensing systems, which convey a large amount of information about the terrain, especially when supported by basic thematic mapping such as geology or soils maps.

Aerial photographs are the oldest form of remote-sensing imagery, and they are still the most important form for highway engineers. New forms of imagery have appeared in the past two decades, which create images that yield new types of information, but which can still be interpreted in the traditional way provided due allowance is made for their individual characteristics. One of the first systems to be available was infrared line scan, and this has had some limited application. Airborne multispectral scanners have also been used, but by far the greatest use is that made of small-scale multispectral data from the Landsat satellites.

A potential source of imagery is radar, which is

currently available as an airborne system, although in the future satellites will carry versions capable of a 20-m ground resolution. The great advantage of radar is its independence of weather and time of day, which indicates that it will become of increasing importance in areas where persistent cloud cover prevails. Airborne radar surveys have been carried out in parts of Central and South America, West Africa, and Southeast Asia, but for commercial or strategic reasons the imagery is often difficult to obtain.

Aerial photography and Landsat imagery have found the widest acceptance of all remote-sensing systems by virtue of their versatility, wide coverage, and relatively low cost. It is the interpretation of the imagery from these systems that has provided the basis of most terrain evaluation studies that have been made.

TERRAIN CLASSIFICATION

The basis of a formal terrain evaluation is the recognition of land surface patterns that can be grouped together into a terrain classification. Most engineers recognize the repetitive nature of terrain in areas that they know well, and they can see the association between landforms, with their typical soils, drainage conditions, and vegetation, and the underlying rocks on which they occur. Terrain classification sets out to define these relations in a systematic way. There are many different systems of terrain classification in existence, as illustrated by the range of published thematic maps such as geology, geomorphology, or soils maps. These classifications may be used as the basis of a terrain evaluation for highway engineering where they exist. For an engineer, it would be advantageous to combine several types of mapping (e.g., geology, topography, and soils mapping) to produce a classification that consists of composite units that reflect the engineer's interest in a variety of aspects of the terrain.

In developing countries, detailed thematic mapping is often not available, but a form of mapping that offers a convenient compromise is landform mapping. Preliminary resource surveys often contain maps of this type, and many parts of the world have been mapped in this way (1,2). Landform mapping has the advantage in that it consists of units that represent a combination of geological, soils, and hydrological factors, and that they are relatively easy to map. Landform classification can be used where no other form of survey exists, although such a classification is considerably improved if it is augmented by information from existing thematic maps. A landform classification can be extracted from topographical maps, but it is much more effectively compiled from remote-sensing images.

Landform Mapping: Land Systems and Land Facets

There are strong links between patterns of landform, drainage, and vegetation with the underlying geological formations and hydrological regime. Therefore, a landform map to some extent reflects the properties of the terrain beneath and, in addition, takes account of aspects of the terrain that relate directly to the engineer's sphere of interest, namely relief and slope, bedrock, materials of the subgrade for use in construction, and surface and subsurface water flow. The mapping units are relatively easy to map from the air and space, and large areas can be covered in a short time.

A version of landform mapping, which incorporates aspects of geology, geomorphology, and soil distribution, has been formalized in England after a period of research and comparison with similar work carried out in South Africa and Australia (3). This is similar to the use of physiographic units in the United States (4) but extends the classification to include smaller areas of ground. It was recognized that landscapes fall naturally into hierarchical associations, in which groups of small terrain units combine to form larger ones. The two most important units are the land system and its constituent land facets (see Figure 1). A land system is a large area of characteristic landform, drainage pattern, and associations of materials developed on a single geological unit or sequence. It is typified by a distinctive scenery and is generally mappable at about a 1:250 000 to 1:1 000 000 scale. The component parts of a land system, called land facets, are defined in a similar way, but they are smaller and less variable, such that an engineer would normally expect a single design to be appropriate for sections of road built on each facet. The number of land facets in a land system is generally few, and they always occur in the same relation; the land system is made up of land facet associations repeated over a wide area. Figure 1 also shows how land facets may be subdivided into land elements--the smallest features of the terrain. These would only be mapped where they are of particular importance (e.g., an outcrop of gravel), but their presence would be included in the description of the land facet.

At the other end of the scale, land systems may be grouped into larger units called land regions, comprising land systems that have similar geology and topography. At this level of detail, a land region inevitably contains a considerable variety of landforms and a lower degree of homogeneity than would be expected of smaller units. Nevertheless, general engineering characteristics, such as the range of soil types, depth to bedrock, subgrade moisture conditions, and recurrent problems, often remain consistent over these large areas. Land region classification is useful during the earliest reconnaissance stages of an investigation to identify the principal characteristics of an area. It is equivalent to the "section" in the American classification (4).

Examples of Terrain Classification in Highway Engineering

Reconnaissance Survey: Trans-African Highway

The Trans-African Highway project is part of the African international network of roads, the first stage of which is to provide an all-weather road between Lagos and Mombasa. To identify the agreed route, a prefeasibility study of the whole area was commissioned to inventory existing roads and identify sections that needed improving. To assist in this work, the Transport and Road Research Laboratory (TRRL) prepared a land region map of the area (Figure 2), which covers all of the routes that were likely to be considered. Where possible, this map was prepared from existing land system mapping but, where this was not available, the best topographic and geological maps were used, assisted by air photograph mosaics in a few places.

The map defines regions with distinct topographic and foundation conditions, within which it can be assumed that the costs of road building are reasonably consistent. A map prepared in this way, without the assistance of field work to check it, is likely to require some revision before a final land region map can be published. However, the proposed boundaries provided workable survey units for collecting and classifying engineering and other land

Figure 1. Relation among land system, land facet, and land element.

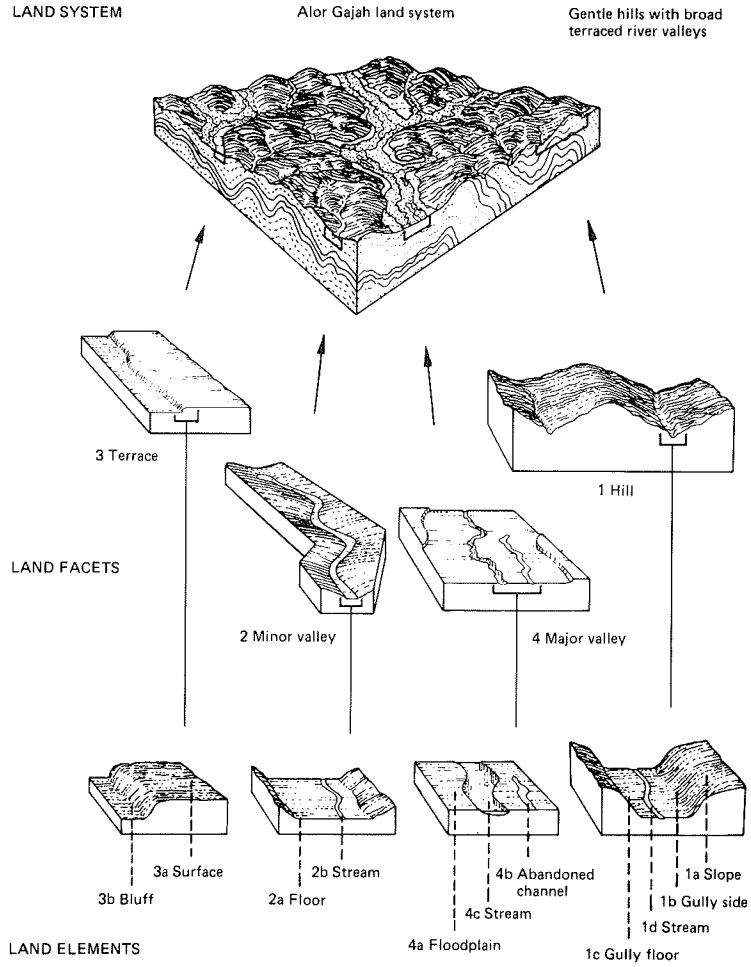
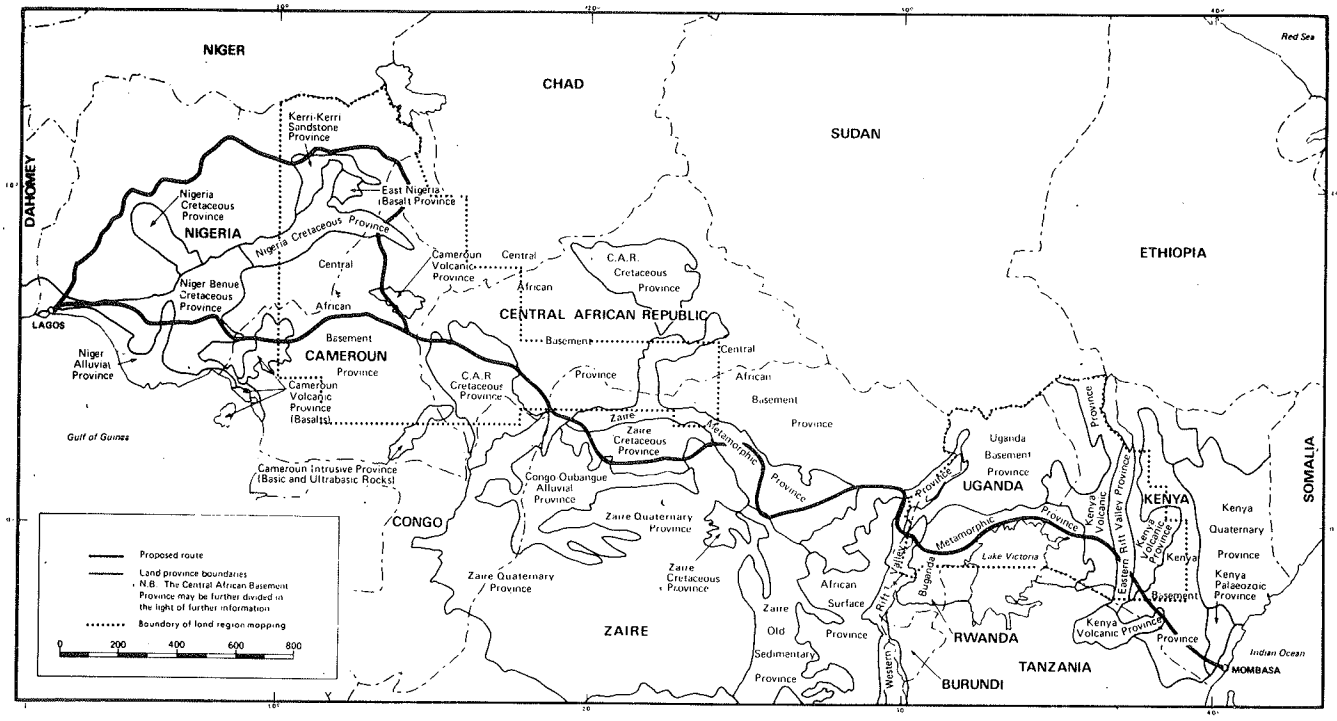


Figure 2. Land provinces of Trans-African Highway.



use data for a prefeasibilty survey. Soil changes noted during the ground reconnaissance were related to boundaries drawn on the map, and from this background it was possible to forecast conditions on routes that were put forward as alternatives after the completion of field work.

Feasibility Survey: Rumpi-Chiweta Road, Malawi

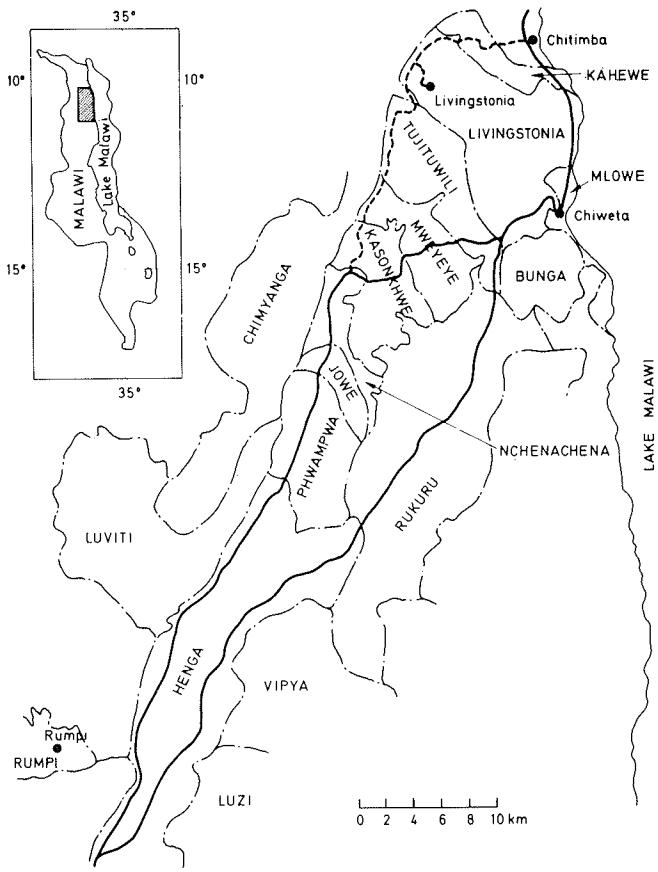
For the next stage of work--a feasibility study of a selected section--more detailed mapping would be needed over a narrower corridor. Land systems mapping is suitable for this, provided air photograph cover can be obtained, although in some areas Landsat cover might provide an alternative source of imagery for this purpose, so long as changes in topography are sufficiently pronounced.

An example of terrain evaluation used in more detailed surveys is a materials survey undertaken for a road project in Malawi. The consulting engineers responsible for the design of this project wished to use the information collected during field work carried out for the feasibility study to prepare tender documents without further field investigations. The project involved two alternative alignments that totaled 130 km (Figure 3). Although the two routes run quite near to each other, the topographic and geological conditions are quite distinct on each. The materials survey commenced before the final choice of alignment; therefore, it was necessary to devise a sampling and testing program of the soils in such a way that a pavement design could be prepared for a road located in any part of the whole area.

Two possible routes were identified. Before field work commenced, the area that contained the two routes was studied to establish the pattern of land systems, facets, and elements. Having identified all the terrain units, the field survey was arranged to collect at least one major soil sample from all units that would be crossed by either of the alternative routes. Where the soil or moisture conditions of any land facet appeared to be variable, extra samples were collected for testing in the laboratory.

The laboratory testing program was arranged to determine the strength of the soils for all likely conditions of subgrade density and moisture content. From the test data, together with measurements of actual moisture content, a pavement design was prepared for every land facet traversed by the road, including a provisional estimate of the quantities of materials needed for construction.

Figure 3. Rumpi-Chiweta transportation corridor land systems.



AIR PHOTOGRAPH INTERPRETATION

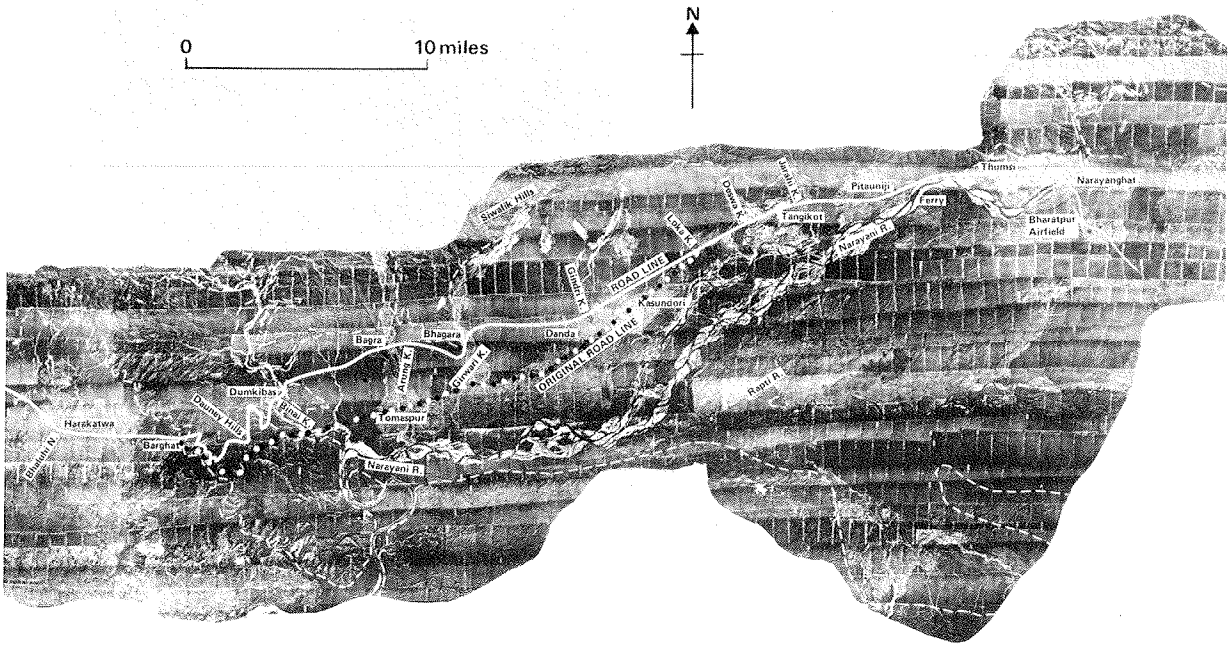
Aerial photographs contain a complete record of the land surface and can be interpreted to predict subsurface conditions and provide information on many features important in engineering design. Although some knowledge of the natural sciences is helpful in interpreting aerial photographs, an engineer need not be deterred from attempting to use them due to lack of experience or knowledge of geology. It is possible to carry out useful work with air photographs after only a basic tuition, and expertise in interpretation rapidly comes with practice. Air photographs should always be viewed under a stereoscope to achieve the significant benefits offered by the three-dimensional linage.

There are many standard textbooks (5) and reports (6) that describe the practice of air photograph interpretation, which draw on North American and European examples. The technique for organizing an air photograph study does not differ significantly when applied in the tropics, although tropical terrains themselves are generally very different from those in temperate zones. Interpretation is often based on photography taken for photogrammetric purposes, typically 9-in panchromatic film in large cameras at a scale of between 1:20 000 and 1:50 000. Where more specialized photographs are needed, a simpler camera system can be used in a light aircraft to obtain high-quality nonmetric photographs at the required scale, using color film if necessary (7). The use of conventional and specialist photography is illustrated by two separate road schemes in Nepal.

The Butwal-Narayanghat section of the East-West Highway in Nepal, which was funded by the British government, provides an example of the use of air photograph interpretation to align a road and organize the search for materials on a rational basis based on a terrain evaluation. The eastern section of the road (Figure 4) runs roughly east-west for 56 km; it is constrained on the north by the foothills of the Himalayas and on the south by the Narayani River. Between the lower slopes of the mountains and the floodplain of the river lies a complex arrangement of terraces with a well-defined piedmont-fan system that extends southward from the foot of the mountains.

An original alignment, lying to the south near the Narayani River, traversed low-lying terraces and floodplains of fine-grained plastic soils used for wet paddy cultivation, and it involved the crossing of wide ill-defined watercourses. It became clear that a relocation of the road 1-3 km to the north of the original route would place the road within the zone of gravel terraces, where materials are plentiful and the river courses are better defined. Existing black-and-white air photographs of the area at a scale of 1:12 000 were examined to identify the main

Figure 4. Part of Butwal to Narayanghat Road, Nepal.



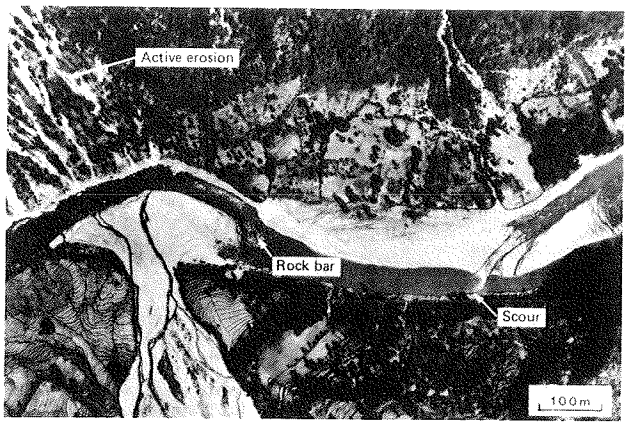
terrain types, potential sources of gravel, old stream channels, and areas liable to inundation. Particular attention was paid to identifying the best crossing points of three large and several smaller rivers in this section of the route at points where the floodplains are narrowest and most stable. In order to compare the relative merits of the two routes in this section, rough quantities were taken off by scaling from the photographs. Arbitrary unit rates were applied to these quantities, which showed a gross cost reduction of the order of 30 percent in favor of the northerly route. Although this figure was only a crude estimate of the potential cost difference between the two routes, it was felt that there was ample justification from the purely engineering point of view to direct subsequent survey and design effort on the northerly alignment. The road was opened to traffic on this line in 1975.

A second road project in Nepal, for which specialized aerial photography was flown, lies in the east of the country. The road runs from Dharan, on the plains, to Dhankuta, situated in the foothills of the Himalayas. The road is 51 km long and involves a cumulative ascent and descent of some 3000 m.

The geotechnical problems encountered in this area are severe; they involved widespread instability and the location of a large bridge site across a major river that is known to scour its banks and bed (Figure 5). There are no roads and few major footpaths in the area; movement across the country is made slow by dense vegetation and intensive terrace cultivation, and the slopes are extremely steep and often dangerous. Under these circumstances, an engineering survey cannot adequately be carried out by field work alone. Air photograph interpretation proved vital in evaluating features (especially unstable ground) that were either inaccessible or too large or too diffuse to be recognized at ground level.

Black-and-white aerial photography at 1:25 000 scale was available, but for some sites, particularly the major bridge site, the scale was too small to

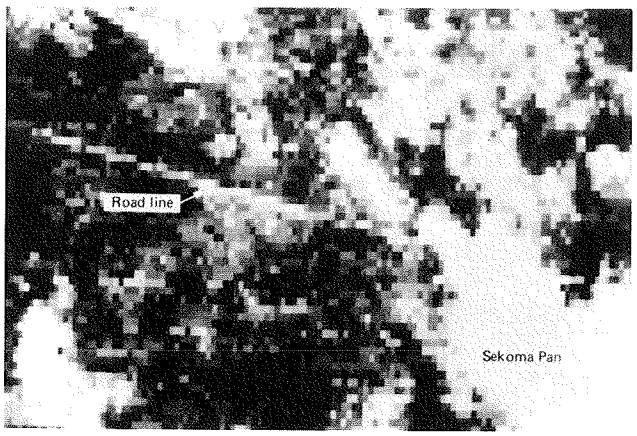
Figure 5. Detail of bridge site to be located on rock bar, Nepal.



identify all the salient features of the locality. To have the area reflown at a larger scale would have been difficult, owing to the isolated nature of the area and the very variable weather conditions that prevail. However, at a time when possible routes were being considered by the consultants responsible for the design of the project, TRRL was developing a range of camera systems to provide a package that can be taken overseas easily and fitted simply to a light aircraft. A lightweight bracket allows the cameras to be mounted in a housing fixed to the side of the aircraft (Figure 6). This camera system was used to acquire large-scale multispectral photographs of the area through which the proposed road would run. In Nepal, a Pilatus Porter aircraft was available that had an internal mount for cameras, thus simplifying the mounting and operation of the cameras. It was possible to use two camera sets at one time, so a comparison was made of photographs taken with an intermediate format camera that used 125-mm film and a cluster of four 70-mm format Hasselblad cameras. The larger size of camera covered a

Figure 6. Pod to carry up to four 70-mm cameras fitted to Cessna 172 aircraft.

Figure 7. Digital Landsat image of Sekoma Pan area, Botswana, which shows part of pan and trace of road.



greater area of ground for a given scale, but only negative film was available for this camera size. It was thus very suitable for producing large prints. The range of film types for 70-mm cameras is very extensive, and processing is more widely available. A range of 70-mm films was tested, including high-resolution films suitable for small-scale photography, natural and false color films, and panchromatic films with filters. Three of the panchromatic images can be combined by using a color additive viewer to recreate a normal or false color image. For general-purpose investigations, the natural color films proved most useful. False color films do show up minor variations in vegetation that are very hard to see in natural color, but in Nepal the hills cast strong shadows that are accentuated by the high contrast of infrared film. The added complexity of manipulating the multiband panchromatic photography has not been justified by the extra information obtained from the interpretation.

Small-format aerial photography offers advantages beyond the low cost of the survey. A light aircraft can usually be hired locally and should therefore be relatively easy to obtain. Many light planes, which operate from unsurfaced airstrips, can fly in areas that would be too dangerous for larger aircraft. Moreover, they can be more easily held on standby, ready to operate at short notice between spells of bad weather or on occasions when it is necessary to photograph the terrain at specific times.

LANDSAT SATELLITE IMAGERY

Since the launch of the Landsat program in 1972, three successive satellites have returned more than 1 million images of the earth's surface to receiving stations in the United States, Argentina, Australia, Brazil, Canada, India, Italy, Japan, South Africa, and Sweden. The orbit of the satellites is so arranged that they pass in a north-south direction over the same piece of ground every 18 days, and on command they can transmit an image to one of these receiving stations. Most of the information has been collected by the multispectral scanner (MSS), which builds up an 185x178-km image of the ground by recording successive west-east scan lines as the satellite moves south. The images are issued to customers either as a computer-compatible tape (CCT) or as photographs at a scale of 1:1 million.

Within each scan line, reflectance is measured at four separate wavelengths equivalent to green and red light and two bands of infrared. The scan line is sampled at a frequency that is equivalent to a movement of 57 m along the ground, and the data are reproduced conventionally as picture elements (pixels) 79x57 m in size. Within a pixel, small features such as buildings or roads cannot be resolved individually, but they contribute to the total reflectance of that pixel and may bias it. Thus, the road in Figure 7, although less than 10 m wide, alters the reflectance of the pixels that cover it so that they stand out from the background. The line of the road can be seen, but there is no way of determining its width from Landsat data alone. (Note in Figure 7 that the individual elements are visible. The original scale on a television screen was 1:22 000.)

A higher resolution is achieved with the return-beam vidicon (RBV) camera on Landsat 3. This system uses two cameras, each covering one-quarter of the area of the MSS scene, and has a resolution of 30-40 m. Currently, the data are usually made available in photographic form at a scale of 1:250 000, but CCTs are now being produced. The high resolution of this system generates such a large amount of data that it has been necessary to restrict it to one channel; thus, it is not possible to produce an RBV color image. However, experiments have been made to add the MSS data to the higher-resolution RBV data in order to obtain the benefits of both systems. The thematic mapper (TM) on Landsat D, due for launch in 1982, will combine the advantages of false color representation and 40-m resolution.

INTERPRETATION OF LANDSAT IMAGES

The interpretation of Landsat data consists of two phases: data preparation and extraction of information. The preparation of an image in a form suitable for interpretation (as a false color composite, for example) is a necessary first step to facilitate the interpretation process. An interpretation, carried out at its simplest level, can be made in a similar way to the interpretation of small-scale air photograph mosaics.

Landsat Photographic Techniques

The basic Landsat data are held on four photographic negatives that can be usefully enlarged to a scale of about 1:250 000. Larger prints may be useful to correlate with maps but give no extra information. These images may be interpreted individually but, to take full advantage of the system, it is necessary

to combine data from more than one band. The normal way to study three different images is to use a color composite, and the simplest method is to purchase a standard product, either a transparency at 1:1 000 000 scale or an enlarged print. The process of making a master color negative is relatively simple but requires experience to obtain good color balance. An alternative method of producing a color composite is to use a color additive viewer, where the three images are projected through color filters and accurately superimposed on the screen. The effect of changes in color filters is seen immediately and the image can be interpreted as projected, but it is usual to make a color photograph that can be studied more conveniently.

Images may also be combined in pairs, if desired. A simple technique is to view two different spectral bands, or images taken at different dates, under a stereoscope. No stereoscopic view is obtained, but the effect is to reduce disturbances caused by scan lines and image "grain", thereby leaving unchanging terrain features to stand out more clearly. Pairs of images may be combined photographically as ratio images, in which a positive transparency of one spectral band is superimposed on a negative transparency of another. If the two images are identical, they cancel each other and leave a neutral tone. Any differences between the bands will show as either darker or lighter areas to give a simple form of ratio image. More complex ratios are produced by digital processing in a computer.

Use of Landsat for Materials Investigations in Sudan

Individual Landsat scenes at scales between 1:500 000 and 1:1 000 000 were used in a study of the terrain of the Wad Medani-Kosti area of Sudan to locate materials for road construction in two projects in the area (see Figure 8; scale is 1:1 300 000). The projects involved the construction of the Wad Medani-Sennar-Kosti road and the extension of the road network east of Sennar in connection with new irrigation works. In both areas there was difficulty in locating sufficient quantities of gravel for road construction. Some field work had been carried out, but the known deposits were inadequate for the needs of the project. Topographic mapping was old and of poor quality, and air photograph cover was limited to very small areas. Under these circumstances, satellite imagery afforded the only comprehensive view of the land surface that was available. Basic topographic details such as towns, major roads, and river systems were readily identified on the imagery, which incidentally also provided an up-to-date picture of the extent of irrigation development.

The area consists of two contrasting terrain types: the predominant and very extensive black clay plains through which protrude occasional outcrops of granitic rock, and the valleys of the White and Blue Nile, which cut across the plains in a wide tract of alluvium. Several types of natural gravel occur in the area, indications of some of which can be discerned in the images, for which confirmation in the field was obtained. One of the most positive indicators of natural gravel is the aureole of light-toned (sandy) soils that surround even very low outcrops of rock in the plains. These materials contain pockets of weathered rock that can provide a usable gravel. The outcrops themselves consist of hard rock that can be used for quarrying. The black clay plains contain a variety of coarser soils that form contrasting tones in the images. At the western end of the road, sandy ridges associated with the White Nile provide firmer foundations but yield no gravels. Lateritic gravels are present in

Figure 8. Landsat satellite image of Wad Medani area, Sudan, which shows (A) valley of Blue Nile, (B) black clay plains, (C) areas of red quartzitic clayey gravel, and (D) rock outcrop.

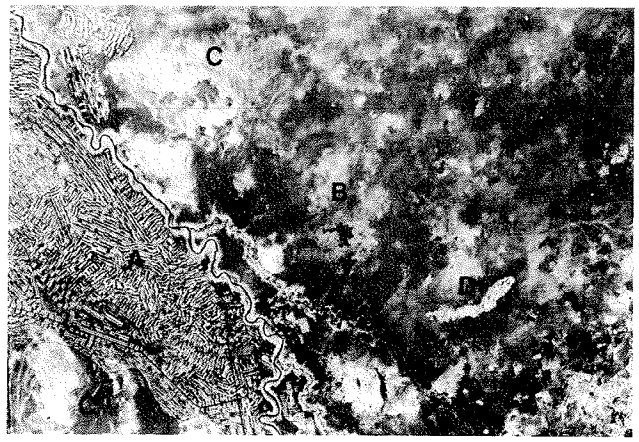
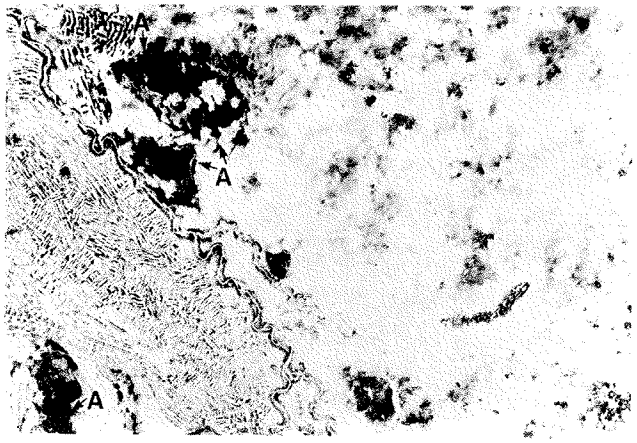


Figure 9. Photographic density slice of part of same area as in Figure 8, which enhances contrast of red quartzitic clayey gravels (A).



this area, which have a high and distinctive reflectance in the red and infrared bands. But their outcrop of up to 300 m² is generally too small to allow a positive identification to be made from Landsat. To the east, on each side of the Blue Nile valley, extensive areas of red quartzitic clayey sand occur within the clay plains. The sands contain deposits of gravel, but it is not possible to separate the sands from the gravels in the images. Sands and gravels also occur along the banks of the river itself, and they are easily identifiable by their distinctive shape and position and high contrast with their surroundings. But, as before, it is not possible to separate the sands from the gravels by interpretation alone.

The interpretation of the satellite images was assisted by the use of color composites as well as black-and-white pictures and by a density-slicing technique that was used to enhance the appearance of the red quartzitic gravels and make them stand out more clearly. The color composites were made in an additive viewer. The density-slicing technique was carried out photographically. The scene was photographed onto high-contrast film to bring out all areas of a specified grey tone at the expense of contrast in the remainder (see Figure 9). Three spectral bands of the scene were treated in this way and combined into a color composite. This technique

can be very effective for areas of uniform tone that contrast well with their surroundings, as in this case. However, in complex images it is difficult to avoid including areas in the density slice that have a similar brightness value (color) on the ground but that are not, in fact, related. Methodical field work is required at the right time of year to check that surface characteristics of the terrain (soil, color, vegetation, etc.) are both diagnostic of the features of interest and consistent over a wide area before attempting to use density slicing to identify features in the terrain.

Processing of Landsat Data: Digital Methods

The original Landsat data are recorded on a tape that contains four bands of reflectance data for the 8 million pixels that make up a scene, which total more than 30 million reflectance values in all. These data may be mathematically analyzed in a computer, for example, to count the percentage of pixels of a certain value for correlation with some known ground feature. Alternatively, the pixels from three bands can be displayed on a color television screen to generate a full-color image that may be interpreted in the normal way. However, the data can also be manipulated mathematically before output to the screen, thereby enhancing the picture for interpretation and analysis. Television viewing systems, when connected to a computer to enable the effect of data transformations to be seen immediately, are known as interactive processors.

The use of an interactive processor for the study of Landsat data offers two major advantages over photographic techniques. First, the range of data transformations available in the processor is much greater than those achievable by photographic processing, and the results are available almost instantaneously. There is thus a greater opportunity to find an enhancement best suited to the user's needs. Second, the intensity range of the data can be stretched over the full range of the display system, which allows very subtle color variations to be observed. A computer-generated image, therefore, is a very high-quality product that makes the most appropriate display of the data in terms of the user's requirements.

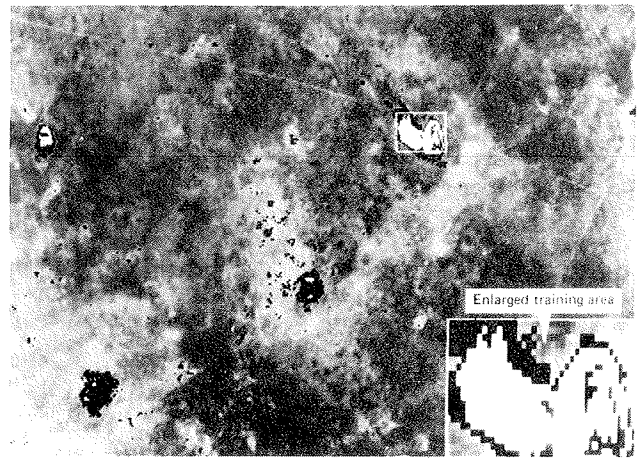
There are, however, certain aspects of digital-image processing that have discouraged its use in the past in favor of simpler photographic techniques. These are

1. Higher costs in terms of both original data on tape and either the capital costs of a processor or hire of a computer (the cost of computer time may be considerable if many options are explored before arriving at a suitable image), and
2. The need to produce a hard-copy picture, either by an expensive color writing process or by photographing the television screen directly, with consequent loss of image quality.

Despite these disadvantages, the use of interactive viewers is becoming more common, and this trend will undoubtedly increase as they become adapted to minicomputers and microcomputers at correspondingly lower cost.

The U.K. Remote Sensing Centre at the U.K. Royal Aircraft Establishment operates a typical large interactive processor, which is linked to a mainframe computer for bulk processing of data. The processing facilities are of two types: geometric, in which the size or shape of the whole image is modified, and spectral processing, in which the reflectance values of the pixels are enhanced.

Figure 10. Classification of calcrete areas in vicinity of Sekoma Pan, Botswana.



1. Geometric transformation of data: Simple processing can skew the original rectangular array of pixels into an image that takes account of earth rotation and that is geometrically fairly accurate, even at a scale of 1:250 000. More elaborate processing, in conjunction with control points, can be used to resample the pixel array so that it conforms with a map projection. Experiments have been made to combine topographic maps and Landsat data to produce an image that has height information superimposed onto a detailed topographic base.
2. Spectral processing of data: Spectral processing involves changing the original pixel intensity values to a new set by mathematical transformation. The range of processes available is therefore very wide to serve a number of purposes. Often some form of preprocessing is applied to correct atmospheric and radiometric distortions in the data in preparation for interpretation. At the interpretation stage, most images require some color enhancement or "stretching", in which the original pixel values, crowded into a narrow part of the brightness range as they normally are, are redistributed over the whole range to improve the brillance and separation of the colors.

In the process known as density slicing, data between certain levels of a single band are displayed to the exclusion of the remainder. The automatic classifier uses a form of density slicing to select pixels that have a range of intensity defined for all bands and hence have similar reflectance characteristics on the ground (Figure 10). Ratio images, generated by dividing the pixel values of one spectral band with those of another, emphasize the differences between bands. Ratio images may be combined with normal bands to produce new images or used in classifications to refine groups of pixels into tightly defined color populations. More elaborate processing can be used to enhance the edges of features where strong tonal contrasts are present and thereby to heighten the edge of sharp features (e.g., fault scarps) that have a linear trend on the ground.

A more general transformation is to calculate the principal components of the data; this is a mathematical technique that takes any number of data sets and calculates an equivalent number of components with the more significant information contained in the first few sets. Thus, the four bands of Landsat data yield four principal components, of which most of the relevant information is contained in the

first three. The fourth component almost completely consists of noise. The three components can be displayed on the monitor as a color image and interpreted in the normal way. For images in which the reflectance data are highly correlated between the four bands, principal component displays present the interpreter with well-defined color groupings that are easy to discriminate.

Digital Processing in Search for Construction Materials in Botswana

TRRL has used the image processor in a study to assist the Ministry of Works and Communications, Botswana, to assess reserves of calcrete for road construction within a route corridor between Jwaneng and Takatswaane in central Botswana. The corridor is about 400 km long and 40 km wide, and it provides access to a large part of western Botswana with possible extensions into Namibia. Calcrete is a calcareous material that forms within the Kalahari sands. It accumulates abundantly in large bare depressions (pans) but also in smaller quantities beneath the sand itself in areas where no pans occur. Calcrete is the only form of natural gravel in the area, and this study to determine the distribution of deposits has been undertaken to decide whether relocation of the existing sand track through areas that contain more calcrete would be justified.

Over most of the corridor, the Kalahari sands, which cover central Botswana to a considerable depth, form an almost imperceptibly undulating plain with scattered pans. Some of these pans are very large (up to 5 km across) and are abundant sources of calcrete. The smallest are less than 50 m across and are much less reliable sources of the material. Large parts of the corridor contain no pans at all, but calcretes can still be found beneath the Kalahari sand, where the only clue to the existence of the material is a change in the color of the sand from its normal reddish or brownish hue to a neutral grey.

The pan features are visible in Landsat digital imagery down to about 100 m in diameter, provided good contrast exists between the pan surface and the surrounding sand plain. Black-and-white aerial photographs were used successfully to map even the smallest calcrete-bearing features, but they were quite unable to map the grey sands because the change in sand color from red to grey is not depicted. In contrast, it was found that the Landsat scanner is extremely sensitive to this color change, the principal component display being particularly effective in the discrimination of this subtle feature. Owing to the small size of many of the grey sand areas, they are poorly visible and barely mappable in photographic Landsat products. But the increased resolution of the computer-generated image, enhanced by the principal component transform and contrast stretching, enables the interpreter to map grey sand areas as small as 100-300 m across (Figure 11). (Note: For Figure 11, the aerial photograph, although able to resolve tiny details on the land surface, does not distinguish areas of grey sand where calcrete occurs from the surrounding reddish-brown sands. The computer image has been enhanced to maximize the difference between sand colors and shows them clearly in dark tones. Numbers 1-6 indicate corresponding features in each image.) An image was produced that depicts the grey sand areas to the exclusion of all other features from which a photographic negative was made by an optical film writer. This image has formed the basis of a map of the grey sand areas between Jwaneng and Takatswaane. The computer images have shown that the existing route passes few deposits of calcrete, but that it could be relocated through areas where many potential sources of the material exist.

CONCLUSIONS

The application of geotechnical survey techniques to highway engineering covers a great diversity of operations and involves many environments, but the development of sophisticated remote-sensing systems has improved our ability to evaluate ground conditions in all types of terrain. The foregoing examples illustrate some of the ways in which remote-sensing and terrain classification methods can be incorporated into engineering surveys, although the precise ways in which they are employed depend on the circumstances of the survey and the types of imagery available. It is important to use a scale of imagery appropriate to the level of detail of a

Figure 11. Comparison between black-and-white aerial photograph (left) and computer-generated Landsat image at some scale of area near Sekoma, Botswana.

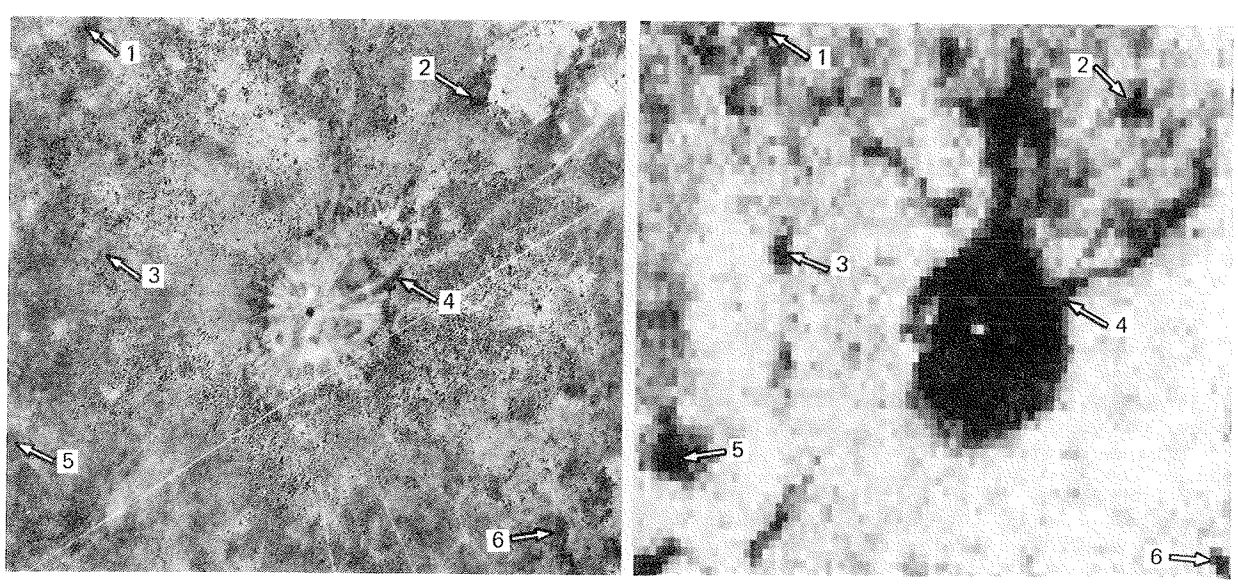


Table 1. Summary of road alignment survey activities typically augmented by widely available remote-sensing techniques.

			Remote-Sensing Techniques		
Project Stage	Aim	Activity	Landsat MSS and RBV	Existing Black-and-White Air Photography	Specialized Remote-Sensing Techniques
Preproject phase	To identify main sources of information and to put project into context with respect to terrain	Collect together all relevant published material relating to project to assess requirements for mapping and interpretation during survey stages	Purchase Landsat MSS imagery in a form suitable for requirements of project; select images from several dates or seasons if necessary; make false color composite images at 1:500 000-1:250 000; purchase Landsat RBV imagery if available, 1:250 000-1:100 000	Make inquiries in Europe or of host government to purchase air photography and air photograph mosaics	Find out if specialized air photography or other form of remote-sensing coverage has been made for some previous project in area
Reconnaissance	To identify possible alternative routes and define strategy for construction program	Define project in terms of size, political and physical constraints, and geotechnical complexity; examine possible routes on maps and satellite images and air photograph mosaics if available; undertake broad terrain classification for collation of regional information; visit site to check interpretations; report on findings and plan next stage	Examine MSS photograph products in conjunction with maps; scale as above; interpret influence of major features on road alignment, e.g., changing course of major rivers; catchment area of major river systems; extent of flooding of low-lying areas; possible sources of water for construction; possible sources of construction materials (e.g., alluvial terraces and fans); pattern of regional instability; extent of erosion; spread of deforestation; assessment of land acquisition or site clearance problems.	Air photograph mosaics at approximately 1:100 000 used in conjunction with Landsat material	
Feasibility	To appraise route corridors and select best route	Make detailed interpretation of conditions on all routes and, if necessary, make a more detailed terrain classification of area; interpret foundation conditions, earthworks (borrow and spoil areas), drainage, materials sources (gravels), major bridge sites, and hazard zones; carry out site investigation of alternative routes, noting key physical and geotechnical features; cost comparisons; selected laboratory and field testing; recommend best route and prepare report	Use MSS and RBV as base map if no more detailed mapping is available; supplement air photograph interpretation with color information from MSS	Use air photographs for all detailed interpretations and terrain-classification study; scale 1:20 000-1:60 000, as available: (a) foundation condition survey; (b) calculate catchment areas and location of culverts; (c) identify spoil areas, also possible borrow areas; minimize erosion risk; (d) identify possible sources of construction material; (e) location of all possible bridge sites, and (f) identify major hazard areas (poorly drained soils, spring lines, unstable areas, erosion in river courses)	Commission specialized air photography (possibly small format) at a scale appropriate to size of task and degree of ground complexity (approximately 1:10 000-1:30 000); examine Landsat computer-compatible tapes in interactive processor (scales 1:20 000-1:100 000)
Design	Detailed study of selected route to engineering design standards	Comprehensive site investigation of selected route with full sampling and testing program; prepare final design documents		Use air photography to support all field survey activities	
Construction and post-construction maintenance period	Build road and carry out repairs prior to handing over	Road construction activities		Use aerial photography to locate access roads for construction traffic in difficult terrain	Large-scale air photography may be used to monitor changes taking place at important sites as construction proceeds; may also be used to record damage done by landsliding, erosion, or flooding in preparation for design of rehabilitation measures

survey, beginning with small scales to cover large areas in a general way and moving to larger scales as the investigation proceeds toward the selection of a final alignment. To emphasize the sequential nature of terrain evaluation procedures and how they are matched to survey requirements, the main engineering activities and appropriate terrain evaluation techniques are summarized in Table 1.

Aerial photographs taken for mapping purposes remain the most important form of remote-sensing imagery for both general terrain studies and investigations of specific sites. The use of aerial photographs to map land systems and land facets--terrain units based primarily on land form--is seen as an effective way of organizing a field survey to sample all relevant parts of a corridor under study. The use of a terrain classification saves time in the field by relating the data collected at individual sites to larger areas. Low-cost nonmetric cameras can provide high-quality photographs for interpretation, and the film type, scale, and timing of the survey can be adapted to the subject under study.

Aerial photography is now supplemented by Landsat satellite imagery as a small-scale mapping tool. The information from Landsat may be presented either in photographic or digital form. Photographic images are inexpensive to produce and require little specialized equipment beyond the facilities of a photographic color laboratory for their reproduction, although an additive viewer extends their scope. The time delay in obtaining original material is usually quite small, and this position is likely to improve with the setting up of regional centers that hold stocks of Landsat negatives. For these reasons,

photographic processing is likely to remain of great importance for surveys in developing countries.

Despite the high quality of Landsat photographic images, Landsat data can only be fully used when images are generated from the digital data held on computer tapes. The resolution of these images is limited to the 80-m pixel size of the scanner, but they convey a large amount of spectral (color) information about the terrain. Developments are taking place in interactive viewing systems away from the concept of large, sophisticated machines toward smaller, simpler systems, which often consist of assemblies of standard components linked to a microcomputer that can perform functions similar to those of a large machine but concede some limitations of speed and flexibility.

With greater international interest being shown in the development of Third World countries, the role of remote sensing to highway engineering, as with all natural resource studies of terrain, will increase in importance. Refinements in sensing systems will enhance our ability to detect subtle changes in terrain conditions, and improvements in data handling will permit more sensitive interpretations to be made.

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REFERENCES

1. I.D. Hill, ed. Land Resources of Central Nigeria. Land Resources Development Centre, Tolworth, Land Resources Study 29, 7 Volumes, 1978-1981.
2. R.G. Robbins, ed. Lands of the Ramu-Madang Area, Papua New Guinea. Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia, Land Res. Series 37, 1976.
3. R. Webster and P.H.T. Beckett. Terrain Classification and Evaluation Using Air Photography: A Review of Recent Work at Oxford. Photogrammetria, Vol. 26, 1970, pp. 51-75.
4. M.W. Witczak. Relationships Between Physiographic Units and Highway Design Factors. NCHRP, Rept. 132, 1972.
5. D.R. Lueder. Aerial Photographic Interpretation. McGraw-Hill, New York, 1959.
6. M.J. Dumbleton and G. West. Air Photography Interpretation for Road Engineers in Britain. Road Research Laboratory, Ministry of Transport, Crowthorne, Berkshire, England, RRL Rept. LR 369, 1970.
7. W. Heath. Inexpensive Aerial Photography for Highway Engineering and Traffic Studies. Transport and Road Research Laboratory, Department of the Environment and Department of Transport, Crowthorne, Berkshire, England, TRRL Rept. SR 632, 1980.

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Terrain Analysis for Transportation Systems in British Columbia

TERJE VOLD

A terrain classification system was developed in British Columbia and accepted nationally in Canada. The mapping system emphasizes features that can be interpreted from aerial photographs and readily verified by field checking. Genetic materials classified according to their mode of deposition form the substance of the terrain map unit. The material's texture, surface expression, and the presence of any geologic processes of modification are additional components of the system. This system also provides the framework for much of the soil mapping in the province, since soils have inherited many properties from these parent materials. A manual on terrain interpretations for roads and linear developments that involve shallow excavations has been prepared. The manual is designed for planners and indicates how terrain information may be used to assess capability for these transportation-related uses. Physical land constraints and natural hazards that affect transportation systems are explained. Interpretive maps that show the distribution of natural hazards and physical land constraints for development can be prepared from base terrain and soil maps. These maps can be of use to planners in assessing alternative transportation corridors and in anticipating potential trouble spots before construction has commenced.

Terrain analysis refers to the inventory and assessment of the physical conditions of land. This is a general term that includes both geological and pedological (soil) evaluations. There are three distinct, although somewhat interrelated, groups of scientists who study the physical nature of land: geologists, soil scientists (pedologists), and soil engineers (geotechnical engineers). Each of these professions focus their work on a slightly different aspect of the earth's surface.

A terrain classification system was developed in British Columbia (1) in 1976 and accepted nationally in Canada in 1978 by soil surveyors (2); it is also widely used by most consultants in British Columbia (3). The system encourages a common approach to terrain inventory and provides standard nomenclature that has improved communications between earth scientists (4). This system also provides the framework for much of the soil mapping in the province and elsewhere in Canada, since soils have inherited many properties from their parent materials.

The terrain classification system was developed for reconnaissance mapping surveys (scales of 1:50 000 to 1:100 000) by government (5,6) but has also been applied for detailed surveys (scales of 1:20 000) by consultants (3). The system emphasizes features that can be interpreted from aerial photographs and readily verified by field checking, thereby enabling coverage of approximately 2590 km^2/mapper/year at a scale of 1:50 000. Genetic materials classified according to their mode of deposition form the basis of the terrain map unit.