COLOUR AERIAL PHOTOGRAPHY IN THE REAPPRAISAL OF ALPINE SOIL EROSION

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DISTRICT SOIL CONSERVATIONIST

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Previous widespread summer grazing and burning practices in the alpine tract of what is now the Kosciusko National Park have left a legacy of soil and vegetation deterioration which still poses problems for the conservationist. One of these problems is the monitoring of the status of soil erosion in an area where relatively fast natural changes are taking place. Difficult terrain and inaccessibility during much of the year are further deterrents to the rapid accumulation of information for management. The need for reassessment since a ground-based survey in 1964 has prompted the use of aerial colour photography as a basis for survey. A test transect was flown in a Cessna 177 light aircraft and photography in colour and colour infrared at large and medium scales, and in black-and-white panchromatic at medium scale, was obtained using 70 mm aerial reconnaissance cameras.

A range of interrelated soil and vegetation criteria for soil erosion assessment has been compiled following interpretation of the photography. Classification and measurement of these criteria are also possible from photo-interpretation.

The use of matching colour and colour infrared photography improved the identification and selection of criteria. It was found that colour photography revealed differences in soil and rock colour more clearly than colour infrared, but the latter was preferable for detecting small vegetation occurrences, situated predominantly on areas of non-continuous plant cover, including recently eroded areas and naturally occurring snow patches and feldmarks. Although most plant communities were readily recognizable on both film types, differences within communities and contrasts between vegetated and non-vegetated areas were usually more distinct on colour infrared.

Descriptions of photographic techniques and materials used, and of photo-interpretation facilities, are included.

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† Formerly Resident Soil Conservationist, Cooma.
INTRODUCTION

Following a century of exploitative and, in places, destructive land use, the catchment of the Snowy River in the Snowy Mountains of southeastern Australia was declared an Area of Erosion Hazard in 1938. Since then, the N.S.W. Soil Conservation Service has carried out erosion survey and control programmes and in 1957 a permanent field station was set up near Carruthers Peak, on the Kosciusko Main Range, to deal with serious erosion problems peculiar to the alpine tract.

The earlier use of this valuable catchment area for the summer grazing of sheep, and to a lesser degree, of cattle, and the deliberate routine burning of plant communities such as alpine herbfields and heath, resulted in widespread destruction of vegetation ground cover and the subsequent removal of soil. Once initiated, deterioration of these resources was aggravated further by the extreme climatic conditions, including frequent frosts, strong winds, heavy storms, and occasional drought.

Ground-based surveys were made by Taylor (1957–8) and Morland (1958–9) and by Greenup (1964) who produced a map showing the areas affected by soil erosion in the alpine and sub-alpine tracts to be approximately 30,000 acres (12,000 ha) with about 3,000 acres (1,200 ha) classed as “moderate” to “severe” erosion. The disproportion between these figures and the number of acres reclaimed up to that time, about 75 acres (30 ha), indicates the size of the task which was ahead of the Soil Conservation Service working in this very difficult environment.

With protection of the alpine areas from grazing and fires since 1944, however, there has been a natural regeneration of plant communities in many areas (figures 1 and 2) and there is a need for continual reassessment of the situation. Such revaluation is needed quickly so that realistic management, including soil conservation works, where still needed, can be planned and executed.

The first requirement for such planning is a rapid and accurate survey of the present erosion situation, taking account of changes in soil and vegetation conditions which have taken place since earlier surveys. These changes include the gradual stabilization of areas of eroding and eroded terrain by the development of stony pavements (Costin, 1958; Clothier and Condon, 1968) and a gradually increasing regeneration by native species colonizing them (Costin, 1958; Keane, 1972 pers. comm.).

In order to assess the types, sites and distribution of these newer features it was decided to use colour aerial photography at large and medium scales to provide a synchronous and comprehensive bank of detailed information on the soils and vegetation, the conditions of which may be altering with time. Accurate photo-interpretation could provide a basis for the inventory and classification, of both plant communities and erosion types for the compilation of maps and measurements, and could clarify priorities for soil conservation works including the sort of remedial action or modifications to present soil conservation techniques that may be required.

In Australia, until recently, there has been little use of large or medium scale photography specially flown for detailed ecological analysis. Although much valuable photo-interpretation from small scale aerial survey photography has been done in various disciplines in Australia, the main deterrent to detailed ecological mapping and monitoring has been the lack of specialized equipment and materials, and of personnel able to provide experimental photography in a range of photo-scales and on a variety of photographic emulsions. In the United States, however, the use of specialized aerial photography for resource planning has been recognized for many years. For example, the Soil Conservation Service (U.S. Department of Agriculture), from as early as the mid-1930's, has included planned aerial photography as an integral part of its management programmes (Kuhl, 1970; Poulton, 1970). More recently, Anson (1970) has reported on colour aerial photography in the reconnaissance of soils and rocks, and Kuhl (1970) has indicated the superiority of colour stereo-photography over both panchromatic black-and-white and infrared for
Two views indicating the general present status of vegetation in the alpine tract of the Kosciusko National Park

*Figure 1*—Lake Cootapatamba below the southeastern slopes of Mt Kosciusko. Slopes of tall alpine herbfield in the foreground and middle distance with *Celmisia* and *Euphrasia* spp. flowering vigorously

*Figure 2*—General view of Main Range looking north from Rawson's Pass. Note the continuous herbfield cover. The lighter patches on the slopes are the *Celmisia longifolia* component of tall alpine herbfield
interpreting drainage classes and for classifying slopes. Lauer (1969) has suggested that colour infrared (false colour) photography is superior to panchromatic photography for vegetation mapping, and Carnegie and Reppert (1969) and Driscoll (1970) have reported on the use of comparative colour and false colour in the study of plant/soil relationships, plant phenology, the activities of earth-burrowing (and hence, erosion-causing) animals, and other range criteria.

Existing aerial survey photography was not suitable for the present survey because more detailed information than is obtainable

Figure 3—Oblique aerial photograph of the Kosciusko Main Range. Extensive sheet erosion on the western slopes of Mt Twynam is visible in the foreground. This is one of the worst areas of active erosion yet to be treated. In many areas, bare soil still remains; this must be stabilized using revegetation techniques. Aerial colour photography can help establish the areas involved and the proportion of the disturbed area that is already erosion pavement. Note the generally continuous nature of the vegetation elsewhere

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Figure 4—Snow patch and herbfield slopes in the Upper Blue Lake cirque area 1968, following severe drought period. See dotted square in Fig. 15 depicting the same area 4 years later, after good rain seasons. This comparison demonstrates the regenerative power of the communities protected from grazing, burning and accelerated erosion.

Figure 5—Lower snow patch slope showing Plantago-Neopaxia short alpine herbfield
from such photography was required. The
time factor as well as the physical difficulties
difficulties of terrain and climate ruled out rapid land-
based survey. Furthermore, it is doubtful
whether such techniques could ever provide
the same body of information as is obtain-
able from large to medium scale photo-
graphy with selected ground control.

Overseas experience and recent reports in
Australia on the use of specialized aerial
colour photography in rangeland evaluation
in Western Australia by Carnegie, Wilcox
and Hacker (1971), and for large scale
mapping of coastal heath vegetation in
southeastern Australia by Groves and Tot-
derell (1971) prompted the use of 70 mm
colour aerial photography in the present
study.

SOIL EROSION AND VEGETATION
TRENDS

Description of the region

The alpine tract of the Snowy Moun-
tains varies in elevation from the treeline, at between 6,000 ft (1,829 m) and 6,500
ft (1,981 m), to the summit of Mt Kos-
ciusko at 7,318 ft (2,230 m). The area is
small, less than 100 square miles (25,900
ha), and is predominantly covered with tall
alpine herbfields, grassland and heaths, with
smaller areas of fen, bog, snow patch (short
alpine) herbfield and feldmarks (which,
on the Australian mainland, are unique to
this area) (figures 1 and 2). The main soil
type is the friable, coarse-textured alpine
humus soil with occurrences of peats and
lithosols. The alpine region receives pre-
cipitations ranging from 70 to 120 inches
(1,778 – 3,048 mm) per annum, including
heavy snow which covers the area for the
winter and most of the spring, and persists
on the semi-permanent snow patch slopes
well into summer (figures 3, 4 and 5). Even
in summer the alpine tract is subject to
occasional snowfalls, frequent freeze-thaw
activity, strong winds and heavy thunder-
storms. Comprehensive descriptions of the
ecological relationships of the alpine soils
and vegetation are to be found in the work of Costin (1954).

TABLE 1

<table>
<thead>
<tr>
<th>Major Plant Alliances of the Kosciusko Alpine Region Occurring Along Transect</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Modified from Costin (1957))</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alliance</th>
<th>Form</th>
<th>Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celmisia-Poa</td>
<td>Tall alpine herbfield</td>
<td>Alpine climatic climax on alpine humus soil and humified peats. Predominant alliance.</td>
</tr>
<tr>
<td>Brachycome-Danthonia</td>
<td>Tall alpine herbfield</td>
<td>Rock ledges and precipitous slopes associated with above.</td>
</tr>
<tr>
<td>Plantago-Montia*</td>
<td>Short alpine herbfield</td>
<td>Lower snow patch situations. Recolonising in old bog and fen sites and on flood deposits.</td>
</tr>
<tr>
<td>Epacris-Veronica</td>
<td>Feldmark</td>
<td>Exposed alpine peaks, ridges and plateau with very strong winds. Lithosols and alpine humus soil.</td>
</tr>
<tr>
<td>Coprosma-Colobanthus</td>
<td>Feldmark</td>
<td>Upper snow patch situations; lithosols.</td>
</tr>
<tr>
<td>Carex</td>
<td>Fen</td>
<td>Level and gently undulating situations; permanently wet. Often found partly covered with silt deposits below eroding snow patch—erosion pavement and other flood source areas.</td>
</tr>
<tr>
<td>Carex-Sphagnum</td>
<td>Valley bog</td>
<td>Moderate slopes, permanently wet.</td>
</tr>
<tr>
<td>Epacris-Sphagnum</td>
<td>Raised bog</td>
<td>As above.</td>
</tr>
<tr>
<td>Oxylobium-Podocarpus</td>
<td>Heath</td>
<td>Relatively rocky and sloping situations.</td>
</tr>
<tr>
<td>Epacris-Kunzea</td>
<td>Heath</td>
<td>Level and gently sloping situations.</td>
</tr>
</tbody>
</table>

* (syn. Neopaxia).

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Soil erosion and vegetation

Estimates of the amount of topsoil removed by accelerated erosion from the vulnerable herbfield slopes are in the order of one million tons (Costin 1959). At the time such estimates were made, soil erosion was very active in the alpine area, particularly between Carruther's Peak (2 149 m) and Mt Anderson (2 003 m) including Mt Twynam (2 198 m). Representatives of all the alpine plant communities described by Costin (1954, 1957), with the exception of sod-tussock grassland, occur in this region, the predominant one being tall alpine herbfield dominated by species of *Poa* grasses and other associated herbs (*Celmisia-Poa* alliance (Costin, 1954)].

In their undisturbed state, the tall and short alpine herbfields, bogs, fens and heaths provide a continuous ground cover. On the other hand, both feldmark communities are made up of discrete plants or small groups of plants separated by bare stony patches which form the lithosol surface. In extreme situations both these communities can appear to be almost devoid of plants (figure 6). These criteria are important for aerial photo-interpretation of natural and relatively stable as distinct from unstable and eroding situations.

The stability of most of the communities is important in the efficient infiltration, detention and release of the large quantities of silt-free water from snow-melt and rain. Where the herbfield cover has been seriously damaged, erosion of the soils has followed, and the resulting accelerated runoff has caused gullying and entrenchment of peats and other drainage areas downslope. The soil conservation activities described by Clothier and Condon (1968) were designed to arrest this trend, initially in the Carruther's Peak area. Meanwhile, erosion continued to a more advanced level on other parts of the Main Range, in many places resulting in the more or less complete removal of topsoil with the concentration of stones as a lag deposit on the surface. Although such areas of stony erosion pavement contribute to surface runoff which damages areas downslope, they are relatively stable themselves, and in many areas are revegetating naturally (figures 8 and 9).

The recolonizing communities contain several feldmark species (which are adaptable to other habitats) as well as the naturalized "sorrel" (*Rumex acetosella*). Where the topsoil is still eroding and the erosion pavement has not yet formed, re-establishment of continuous herbfield cover should be attempted, using the methods developed on Carruther's Peak. Where the erosion pavement has developed and secondary succession is taking place there is no need for extensive revegetation works on the pavement areas themselves, although downslope areas receiving accelerated runoff should still be protected, as well as the abrupt edges of erosion pavements where soil is still exposed to water, wind and frost.

The differentiation of stony erosion pavement areas which are stabilizing, from areas of active erosion, is important in planning the most efficient soil conservation programme for the rest of the Main Range. It is also important to be able to recognize erosion pavements which, because of their extent and situation, constitute flood-source areas of hazard to areas downslope. The photographic methods and criteria described here achieve these distinctions.

PHOTOGRAPHY OF MAIN RANGE

A transect, 7 miles (11.3 km) long, including almost the entire ridge area of the Main Range was selected for photography, ensuring that all types of erosion disturbance as well as representative plant communities would be photographed (figure 10). Yellow P.V.C. markers were placed on the summits of Mt Kosciusko (2 230 m), Carruther's Peak (2 149 m), Mt Twynam (2 198 m) and Mt Anderson (2 003 m). It was planned to expose colour and colour infra-red films at scales of 1:3,000, 1:6,000 and 1:12,000. A scale check consisting of two marker sheets 70 m apart was placed on Carruther's Peak. Because of the steeply undulating terrain it was not feasible to place scale checks elsewhere; scale calculations for all the photography have been made in reference to the Snowy Mountains Hydro-Electric Authority's 4 inch series...
Coprosma-Colobanthus feldmark on semi-permanent snow patches. These areas are stable, but are subject to gullying where flood-source areas exist above them. In their undisturbed condition they require no soil conservation treatment.

*Figure 6*—Feldmark community in an area of persistent snow cover. Small *Colobanthus* cushions can be seen amongst the rocks.

*Figure 7*—Extensive mats of *Coprosma pumila* and *Colobanthus* sp. where snow has melted early.

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Figure 8—Adjacent erosion pavements in tall alpine herbfield showing extensive natural regeneration. These areas were once part of the continuous herbaceous cover. The pavements are stable in themselves and do not need treatment, but in some cases, action to prevent accelerated water runoff may be needed. Vulnerable edges with exposed soil must also be protected from further erosion.

Figure 9—Close-up of colonizing plants on a small erosion pavement. Classification of erosion pavements, according to the degree of regeneration on them and their appearance on large scale colour infrared photography, is possible.

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Figure 10—Small scale aerial photograph showing part of the Kosciusko Main Range most seriously affected by accelerated soil erosion. The dotted line represents the transect selected for large and medium scale colour photography. It also denotes the highest points on this part of the range roughly separating the catchments of the Snowy and Geehi Rivers.

Photo: Snowy Mountains Hydro-Electric Authority.

(1:15,840) maps and the Carruther’s Peak scale check. Due to flying conditions the proposed scales were not realized and slightly smaller scales resulted: 1:3,550, 1:8,161 and 1:12,000 at Carruther’s Peak. The various scales were obtained in order to assess which would be most suitable for recognition of criteria for the treatment of soil erosion, ranging considerably in size from large areas of vegetation or erosion...
pavement, down to individual plants, or small plant groups.*

Although it was hoped to photograph early in December, 1971, unsuitable weather conditions and the persistence of snow on the Range delayed the flight until February, 1972. Even then, some misty cloud was encountered, despite a clear weather report, and some of the photography, particularly between Mt Twynam and Mt Anderson, was impaired.

Dual-mounted Vinten 70-mm reconnaissance cameras, installed in a Cessna 177 aircraft and operated through a variable intervalometer (Totterdell, Condon and Rath, 1971), were used to obtain matching colour and colour infrared imagery with a minimum overlap of 60 per cent for stereoscopic viewing; minus-blue panchromatic photography was obtained separately. The advantages of using 70-mm equipment and materials in experimental photography such as this are compactness and flexibility in changing film magazines and lenses (3-in and 6-in focal length lenses were used), the ability to mount two aerial cameras for simultaneous operation in a light aircraft, and significantly lower survey costs.

The three film types used were:
- Kodak Ektachrome MS Aerographic Type 2448 (colour).
- Kodak Aerochrome Infrared Type 2443 (colour infrared).
- Ilford FP3 Aerial (panchromatic).

A Wratten 12 (yellow) filter was used with both colour infrared and panchromatic films and an ultraviolet absorbing filter, Wratten HF3, was used with the colour film.

The basic principles of aerial colour photography and its interpretation cannot be discussed in this paper, but are treated clearly by Tarkington and Sorem (1963) and Sorem (1967). However, brief descriptions and comparison of the colour films can be made.

Colour photography

Both Ektachrome MS and Aerochrome infrared are colour reversal films producing positive transparency images.† Both films contain three emulsion layers which have been sensitized to different regions of the electromagnetic spectrum. In each case, after exposure and processing, the resulting images are formed by the subtractive colour effects of white light passing through the yellow, magenta and cyan dyes which are coupled with the three emulsion layers.

Whereas properly exposed and processed colour photography will appear fairly representative of the original scene, colour infrared photography will appear dramatically dissimilar to it (hence the expression “false colour”). This difference is mainly due to the variations in the basic spectral sensitivities of the two films. In colour film, the emulsion sensitivities are to blue, green and red, the range of the “visible” part of the spectrum from about 400 to 700 nanometers. In colour infrared films the sensitivities are to green, red and infrared, from about 500 to 900 nanometers (table 2). It can be seen that the same dyes produce the same colour range, but are activated by different energy (colour) bands. The combined use of these two films offers potentially much more information than either one used alone (figure 11).

Value of colour infrared

The main advantage of using colour infrared for vegetation studies is the recording of near-infrared wavelengths, usually re-

* Johnson has compared aerial photography at the ecosystem level with the role of the electron microscope in molecular biology and emphasizes that "the solution of many resource problems depends on adequate assessment of physical and biological characteristics integrated over areas of a few feet to thousands of square miles" (1970).

† Ektachrome MS is also processed to colour negative and, as such, forms the basis of the Kodak “Aero-Neg” system. Kodak colour infrared films are designed for reversal processing. Although a measure of success was enjoyed by some workers in processing Ektachrome infrared (type 8443) to negative (Pense, 1970), the currently available emulsion (type 2443) has not responded so successfully to this technique (Bowden, personal communication).
TABLE 2
COMPARISON OF NORMAL AND FALSE COLOUR FILMS

The same dyes produce the same colour resultants but are activated by different bands of spectrum energy.

<table>
<thead>
<tr>
<th>Normal Colour Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral region</td>
</tr>
<tr>
<td>Emulsion sensitivity</td>
</tr>
<tr>
<td>Coupled dye layer</td>
</tr>
<tr>
<td>Resultant colour on film</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Colour Infrared Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral region</td>
</tr>
<tr>
<td>Emulsion sensitivity</td>
</tr>
<tr>
<td>Coupled dye layer</td>
</tr>
<tr>
<td>Resultant colour on film</td>
</tr>
</tbody>
</table>

* A yellow filter is used to eliminate wavelengths shorter than 500 nm.

Relected very strongly from most types of vegetation, in terms of a visible colour. The enhanced colour contrast between vegetation and non-vegetation achieved with colour infrared is particularly useful for soil erosion studies. Furthermore, the increased near-infrared reflectance over visible light reflectance from vegetation (Fritz, 1967) indicated a potential value in detecting minute vegetation occurrences (as, for example, in secondary succession on erosion pavements), which in practice has proved correct. Many workers have reported the capability of colour infrared photography to provide clear vegetation community differentiation (Anson, 1968; Driscoll, 1971; Grimes and Hubbard, 1971). In comparison with normal blue-sensitive colour films such as Ektachrome MS, the image degrading effects of atmospheric (Rayleigh) scattering using colour infrared are minimized, at least at lower altitudes (Pease and Bowden, 1969). A Wratten 12 or 15 (yellow) filter is usually used with colour infrared to screen all the emulsions from wavelengths shorter than about 500 nm.

Confusion between colour infrared photography and thermal infrared sensing has appeared from time to time. Whereas thermal line-scanning techniques record passive heat emissions in infrared wavelength "windows" (e.g., between 8 and 14 microns), infrared photography records reflected infra-
red wavelengths rarely exceeding 0.9 to 1.0 micron. Near-infrared photography records just beyond the range of human vision.

The coincidence of this capability with the high near-infrared reflectance from vegetation has been a fortunate one for users of photography in plant/soil studies. Figure 11 compares the spectral range of the two colour films in relation to a classical vegetation reflectance spectrum.

Minus-blue panchromatic photography of the Main Range was obtained mainly for mosaic and base map compilation.

Photo-Interpretation

Rolls of 70-mm transparency film can be viewed on light boxes equipped with adequate illumination both in the laboratory and in the field. Although processing cost was one of the factors influencing the use of transparencies rather than prints, the superiority of transparency imagery in brightness range and resolution is generally acknowledged. The disadvantages of using original transparency film include the risk of damage to valuable record photography and the need for specialized viewing equipment. A small portable light box, on which two rolls of film could be viewed together, was used in the field (figure 12). A 2x-4x magnification Abrams stereoscope was used for close examination of the films. A larger light box with four sets of independently operated rollers is being used for more intensive interpretation in the laboratory (Totterdell and Parkes, 1972). A Leitz Focomat...
11c enlarger has been used to transfer erosion and vegetation features on to maps, and a Bausch and Lomb zoom stereoscope has a potential value in enabling the recognition and counting of vegetation (often on an individual plant basis), particularly on colour infrared film. Finely-ruled grids (1-mm spacing) and graticules (0.1-mm spacing) are used for measurements.

Field Observation

The area between Carruthers Peak and Mt Twynam was visited the day following the photography and again two weeks later when the film had been processed. Black-and-white (9 × 9 inch) prints were annotated and as many correlations as possible between ground situations and the photo-
images were made. Photographs of special features were taken (e.g. erosion pavements and stages in secondary succession). Most of the interpretations were made in the laboratory, after the ground was covered with snow.

Although further visits would have been desirable, the interpreters were able to use past knowledge of the mountain environment and the comprehensive body of ecological information available in the literature in the analysis of the photography. Personal knowledge of an area and familiarity with the apparent soil and vegetation trends are major advantages in establishing ground truth.

RESULTS OF PHOTO-INTERPRETATION

The formidable body of information provided by two colour film types taken at three scales over the transect poses some problems of selection and classification. The approach to significant interpretation should be based on the primary consideration behind the work, and attempts to extract too much information, at least in the initial stages of the analysis, should be avoided.

In the present study, the primary consideration is catchment stability in an area consisting of specialized plant communities, soils and topography. Therefore, the choice of interpretation criteria can be made on the basis of the stability of these communities, which implies the necessity to be able to recognize them. Costin's vegetation classification for the alpine area (1954) provides the basis for this.

Four main interpretation categories in the assessment of the criteria are as follows:

- Establishment
- Recognition
- Classification
- Measurement

ESTABLISHMENT AND RECOGNITION OF CRITERIA

While many erosion interpretation criteria can be established before photography, examination of the photography itself often suggests further clues. As discussed above, the main consideration in using large scale (1:3,000–1:4,000) colour infrared photography was the possibility of recording better vegetation/non-vegetation boundaries with the extreme red/blue contrasts characteristic of this film. This has been achieved, and since examining the photography it is considered possible also to classify the erosion pavements according to the degree of secondary succession by feldmark species. Other criteria, at first only vaguely realized, have become clearer since interpretation began.

The basic distinction for the initial evaluation of erosion hazard is between areas of continuous vegetation and areas of non-continuous vegetation.

<table>
<thead>
<tr>
<th>TABLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TERRAIN ACCORDING TO VEGETATION COVER</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(1) Vegetation continuous (or nearly so)</th>
<th>(2) Vegetation non-continuous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tall alpine herbfield</td>
<td>Feldmark (Epacris-Veronica).</td>
</tr>
<tr>
<td>Short alpine herbfield</td>
<td>Feldmark (Coprosma-Colobanthus).</td>
</tr>
<tr>
<td>Fen and bog</td>
<td>Semi-permanent snow patch.</td>
</tr>
<tr>
<td>*Heath (closed)</td>
<td>Flood-source areas.</td>
</tr>
<tr>
<td>Dead Poa spp.</td>
<td>Erosion pavement (sheet erosion).</td>
</tr>
<tr>
<td>*As distinct from open feldmark heath</td>
<td>Cliffs.</td>
</tr>
<tr>
<td></td>
<td>Rock outcrops.</td>
</tr>
<tr>
<td></td>
<td>Rock screes.</td>
</tr>
<tr>
<td></td>
<td>Block streams</td>
</tr>
<tr>
<td></td>
<td>Gullies.</td>
</tr>
<tr>
<td></td>
<td>Blowouts.</td>
</tr>
</tbody>
</table>

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All these criteria can be recognized on both colour and colour infrared film. Recognition on black-and-white medium scale (1:12,000) photography is limited and wrong identifications are more likely (e.g., of rock outcrop v. erosion pavement), without reference to colour. This deficiency in using panchromatic photography has been noted also by Wimbush and Costin in vegetation mapping at Kosciusko (1973).

These major criteria can be subdivided further from the colour photography analysis.

1. VEGETATION CONTINUOUS (OR NEARLY SO)

Tall alpine herbfield: *Celmisia-Poa* alliance (Costin, 1954).

This is the most widespread of all the features appearing on the photography. The *Celmisia longifolia* component is easily recognized on both film types. The possible role of this strongly rhizomatous plant in the stabilization of pavement edges has been noted by Keane (1972 pers. comm.) (figure 13).


This community can be recognized by its distinctive colour and situation. *Neopaxia australasica* (syn. *Montia australasica*) is very distinct. Its intense white appearance, particularly on colour infrared taken when flowering in February, underlines the importance of exploiting plant phenology in the photo-interpretation of vegetation. Time of photography should be selected, whenever possible, to coincide with the occurrence of maximum contrasts between vegetation types (figure 5).

Fen: *Carex gaudichaudiana* alliance (Costin, 1954).

Dissection of these low-lying, moist communities (very distinct on colour infrared) by meandering streams caused by accelerated runoff from flood-source areas and the resulting deposition of silt is recognizable on both film types. These features impair the water holding efficiency of the fens (Costin, 1954, 1959) (figures 15, 16).

Dead *Poa* spp.

This component within tall alpine herbfield is more easily identified on colour infrared film. Dead areas can be caused by late-lying snow, drought or insect damage, but could also indicate flood-source areas above them (Costin, Wimbush, Kerr and Gay, 1959) (figures 18, 19).

2. VEGETATION NON-CONTINUOUS

This broad category is more directly related to the detection of active soil erosion. Distinction must be made between non-continuity of cover due to accelerated erosion and that which is naturally occurring.

### TABLE 4

**VEGETATION NON-CONTINUOUS**

<table>
<thead>
<tr>
<th>(a) Naturally</th>
<th>(b) Due to accelerated erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feldmark:</strong></td>
<td></td>
</tr>
<tr>
<td>(a) <em>Epacris-Veronica.</em></td>
<td>(a) Recolonizing strongly.</td>
</tr>
<tr>
<td>(b) <em>Coprosma-Colobanthus.</em></td>
<td>(b) Recolonizing weakly.</td>
</tr>
<tr>
<td>Semi-permanent snow patches.</td>
<td>(c) Bare.</td>
</tr>
<tr>
<td>Rocky outcrops.</td>
<td>Blowouts.</td>
</tr>
<tr>
<td>Block streams.</td>
<td>Flood-source areas.</td>
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<tr>
<td>Cliffs.</td>
<td>Gullies.</td>
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<tr>
<td>Screes and Moraines.</td>
<td>Bare soil.</td>
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<td></td>
<td>Areas treated by soil conservation works.</td>
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<td>Silt deposits.</td>
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<td>Tracks.</td>
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*July, 1973*
(a) Vegetation naturally non-continuous

Feldmark

The two feldmark communities are extremely variable in the degree of plant cover from site to site. However, in their natural state, both communities are stable despite the paucity of plant cover. It is important to be aware of the patterns and possible locations of these communities, as confusion can arise in interpreting areas shown on the photography which are similar in colour and often in pattern. Familiarity with feldmark vegetation is necessary for understanding the type of recolonization occurring on eroded areas and for distinguishing semi-bare areas not needing soil conservation treatment from areas of active erosion which do need treatment.

In the case of feldmark of the Epacris-Veronica alliance (Costin, 1954), there is a superficial resemblance of the stony surface to erosion-induced pavements in alpine humus soils. This could lead to wrong identifications, both on the ground and on the photography (figures 20, 21). These induced feldmarks, while often displaying a vigorous secondary succession of feldmark species, may often require specialized erosion control treatment. Detailed discussion of the Epacris-Veronica feldmarks is found in the work of Costin (1954), Costin, Thom, Wimbush and Stuiver (1967), and Barrow, Costin and Lake (1968).

The other feldmark type is restricted to the extensive semi-permanent snow patch slopes and comprises the Coprosma-Colobanthus alliance (Costin, 1954) (figures 6, 7). Superficial resemblance of naturally occurring feldmark to erosion pavements on areas bordering the steeply sloping snow patches could again lead to wrong identification (see flood-source areas below and figure 15).

Semi-permanent snow patches

These regions support the Coprosma-Colobanthus feldmark and do not normally support other vegetation types. They are naturally stable, except where denudation of tall alpine herbfield has taken place above them and accelerated runoff has caused gullying on the slopes (figure 15). Where snow has persisted until late summer vegetation is extremely sparse and mainly confined to small cushions of Colobanthus sp. (figure 6).

Other features

The remaining areas where vegetation is naturally non-continuous are the grosser features of rocky outcrops, block streams, cliffs, screes and moraines which occur along the Main Range. These features, which support broken vegetation of heath and short and tall alpine herbfields, are easily recognized on all film types (figures 22, 23) and contain little accelerated erosion. Smaller rocky outcrops, however, can occasionally be confused with erosion pavements but relief, as perceived with stereo-viewing, helps to distinguish raised outcrops from pavements which are usually slightly below the herbfield level (figure 8).

(b) Vegetation non-continuous due to accelerated erosion

In general these are the features which have been brought about following grazing and burning over the last century and include sheet erosion (leading to the formation of erosion pavements), gully erosion and siltation. This category also includes regions where active soil conservation treatments have been used.

Erosion pavements

These can be recognized by their occurrence in otherwise continuous tall alpine herbfield, by the “unnatural” shape of their boundaries, by the presence of topsoil remnants, particularly around their edges where cliffs of bare soil often remain, by “islands” of herbfield, by the lower level of the pavements, and by the presence of small colonizing plants of feldmark species (figures 8, 9). Stabilizing and actively eroding edges can be distinguished stereoscopically. Most of these criteria, especially regeneration, are most readily perceived on colour infrared.
Figure 13—Erosion in tall alpine herbfield showing areas of complete and partial soil removal. Note actively eroding edges. Lighter patches in the herbfield are Celmisia longifolia. Note dead Poa grass in right foreground.

Figure 14—Intensive recolonizing by cushions of Colobanthus sp. and upright tufts of Luzula sp. in a "blowout" within tall alpine herbfield. These species, growing with other fieldmark and herbfield types, are the most common colonizing plants.

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Plates I, Medium scale vertical colour aerial photograph of terrain obtained from synchronised 70 mm film area near Mt Twynam presents a comparison of areas of continuous and areas of non-continuous soil conservation works. Original scale on 70 mm film: 1:8500, Scale as reproduced: 1:8500 (approx.)
and colour infrared photographs of alpine
mm aerial reconnaissance cameras. This
plex pattern of plant communities, erosion
ote the increased colour contrast between
uous vegetation on the colour infrared
(approx.)
Figure 13—Erosion in tall alpine herbfield showing areas of complete and partial soil removal. Note actively eroding edges. Lighter patches in the herbfield are *Celmisia longifolia*. Note dead *Poa* grass in right foreground.

Figure 14—Intensive recolonizing by cushions of *Colobanthus* sp. and upright tufts of *Luzula* sp. in a “blowout” within tall alpine herbfield. These species, growing with other feldmark and herbfield types, are the most common colonizing plants.
Figure 15—Upper Blue Lake cirque. Stereo pair of photos showing flood-source areas (A) between damaged herbfield (B) and steeper semi-permanent snow patches (C). Although the grazing-damaged areas have been treated, the lack of water-absorbing soil and its protective vegetation will constitute a threat to soil stability downslope and a source of accelerated runoff for many years. Note massive gullying on the slopes (D) and eroding stream meanders in low-lying fens (F). Refer dotted square to figure 4.
Figure 16—Carex fen below extensive snow patch slopes and flood-source areas of eroded herbfield. Dissection and entrenchment of peats, and reduction of water carrying capacity is caused by fast streams, and many areas are covered by stones and silt from above. These areas must be protected from flooding from higher ground.

Figure 17—Type of regeneration on some old fen and bog sites. Oreobolus sp., as shown here, and other short alpine herbfield plants colonize these situations. Exposed rocks are often bare of lichen indicating recent exposure by soil removal. Aerial photography often shows this effect.

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Figure 18—Dead Poa grass in tall alpine herbfield. Grass death can be caused by flooding, drought, late-lying snow and insects. The thick cover of dead grass matting acts as a mulch for regenerating species while existing herbs, e.g., Microseris scapigera and Craspedia sp. continue to thrive.

Figure 19—Area of dead Poa showing vigorous growth of Neopaxia australasica, a rhizomatous component of short alpine herbfield which is being used extensively by the Soil Conservation Service for recolonizing damaged areas.
Comparative examination of both film types has revealed an almost total removal of topsoil from the pavement areas along the transect. Exceptions occur near the summit of Mt Twynam where erosion of topsoil is still active (figure 3), and along gully edges. Residual soil “islands” and “streamers” can be perceived and measured. Another recognition criterion is the brightness of the colour of the rocks, which indicates the absence of lichen growth associated with old exposed granites in the alpine tract.

Few erosion pavements studied are completely bare. There is usually some degree of secondary succession. As noted, this is usually feldmark vegetation of the_Epacris-Veronica alliance (typically Luzula and Colobanthus spp.) although some herbfield species (e.g., Pimelea alpina) and the widespread naturalized sorrel (Rumex acetasella) do occur. The dominant feldmark species, Epacris microphylla, only occurs on what appear to be older pavements on the ridges where feldmark communities may have occurred, but the plants appear small and sparse. In some pavement areas Pentachondra pumila, a mat-forming epacrid, seems to be growing vigorously (figure 21). This secondary growth is discernible on both colour films, but can be more certainly perceived and identified on colour infrared. Living plants that do not appear green on normal colour film often can be confused with other features. The characteristic red/magenta of colour infrared or its absence can confirm the presence or absence of vegetation.

Flood-source areas

The most extensive of these are the areas described by Clothier and Condon (1968) which have been extended upslope and outward from the naturally bare or sparsely covered snow patches* (figure 15). Although the boundaries are not now always clear, these areas almost certainly supported a continuous cover of Celmisia-Poa tall alpine herbfield. Both colour and colour infrared photography confirm that most of the topsoil has been removed with the development of an erosion pavement superficially resembling the snow patch lithosol surface. Recognition criteria for these areas are the same as for erosion pavement elsewhere. In addition, these are associated with solifluction terraces and steep gullies through the snow patch areas and herbfields downslope, and often with the entrenchment of streams through fen areas at the base of the slopes. Flood-source areas are significant not only because of the erosion they represent themselves, but also because of the damage they cause downslope (Ellison, 1954; Costin, Wimbush, Kerr and Gay, 1959). Having lost most of their soil, these areas will probably never again support the climax herbfield cover. They have had some erosion control treatment and are also regenerating slowly in places with feldmark species of the Coprosma-Colobanthus alliance. However, because of the loss of soil, they are not able to absorb heavy storm rains. Therefore, these areas will always be a serious erosion hazard to lower sites, unless soil conservation measures are taken downslope to control the runoff water.

Gullies

(a) Small gullies often form in the herbfield from water flooding from erosion pavements and are often associated with dead Poa (figures 13, 14). Stereo-viewing helps in discerning this effect and the associated siltation from unstable, pedestalled herbfield edges.

(b) Another type of gullying is the undercutting and deepening of creeks and drainages due to runoff from higher catchments. These can be discerned easily on the photography and their relation to flood-source areas and fen deterioration is also obvious (figure 15). In most cases they are still actively eroding.

Blowouts

Blowouts are wind-scoured depressions between patches of vegetation. There is usually some topsoil remaining and they have recolonizing vegetation of herbfield and feldmark types. They can be seen on large and medium scale colour photography of both types (figure 14).

* These areas support Coprosma-Colobanthus feldmark (figures 6, 7).
Figure 20—Typical *Epacris-Veronica* feldmark on windswept ridge near Sentinel Peak. The *Epacris microphylla* plants demonstrate highly specialized adaptation to extreme climatic conditions. Such communities are stable, and require no soil conservation treatment.

Figure 21—Erosion pavement area strongly resembling *Epacris-Veronica* feldmark. The mat-forming *Pentachondra pumila* is the main colonizer but usually the pavements have less plant cover than shown here. Note minor gullying and pedestalled herbfield in background. These sites can be distinguished on aerial photography by their patterns and situations. The only treatment needed in such areas is on exposed soil edges, seen in background.
Outcropping rocks, cliffs, screes and moraines are not usually associated with accelerated erosion in the alpine tract and do not require treatment.

*Figure 22*—Etheridge Range with broken vegetation of tall and short alpine herbfields and heaths.

*Figure 23*—Cliffs and crags over Blue Lake.
Treated areas

Evidence of mechanical shaping and terracing associated with soil conservation works is obvious on all the photography. Extensive straw-bitumen mulching can also be readily identified (figure 24). It is possible to perceive the growth of introduced vegetation in these areas (Bryant, 1971), particularly on colour infrared.

CLASSIFICATION AND MEASUREMENT OF CRITERIA

Classifying the erosion criteria is necessary for planning future management, and if the photography is not used comprehensively for this purpose, one of its main advantages, rapidity of survey, would be reduced. The validity of such classification depends on a number of factors, the most important being the ability to accurately and consistently identify recurring criteria over the whole range of the survey.

Good photography, awareness of the films responses (particularly in regard to illumination), accurate scale measurements, familiarity with topography, plant communities, soils and their susceptibility to erosion, as well as with the existing erosion patterns, can ensure confident photo-interpretation. However, adequate correlations between ground features and photo images, followed up by field checking, are essential.

Erosion pavements, for example, can be classified according to their size, the length of unstable edges, the degree of secondary succession, and their threat as flood-sources. Plant communities, such as herbfields and fens, can be classified according to their susceptibility to erosion from accelerated water runoff.

Planning for practical erosion control based on photo-interpretation will depend also on the ability to measure areas (e.g., of erosion pavements) and distances (e.g., lengths of actively eroding edges). This requires accurate scale calculation. Scale on any part of the transect can be determined from the ground measurement of distinct natural control points (e.g., rocks, streams, etc.) and the distances between them.

However, this is time-consuming and for most purposes, reference to the Carruthers Peak scale check and the SMHEA* 4-inch series map is adequate. Photo measurements are made with ruled grids, graticules and magnifiers. Area measurements can be made on enlarged prints with planimeters. A technique of estimating relative plant cover on pavement areas, which can help in classifying these features, can be devised by calibration of the vegetation situation on the pavements according to its appearance on colour infrared film at the largest scale. If this method proves successful, larger scale photography (1:1,000 or more) can be used for recording very small plants. A Bausch and Lomb zoom stereoscope has been used to examine pavement and fieldmark vegetation and its potential for this type of measurement using finely ruled graticules is promising. On the present photography plants or vegetation clumps as small as 6 inches across can be seen.

Costs

The costs of colour and colour infrared photography are small compared with the value of the information obtainable from them and the planning which can result. There are about 500 exposures in each 100-ft (30.48 m) roll of 70-mm film. Assuming a 60 per cent overlap for adequate stereo-viewsing and line plotting, twenty-four frames will record one mile (1.6 km) of terrain 560 ft (171 m) wide at a scale of 1:3,000. At 1:16,000 five frames will record 1 mile by 3,000 ft (914 m). Each roll of film, including positive transparency processing, costs about $100, making the cost of each frame approximately 20c. Aircraft hire costs vary considerably. The Cessna 177 used was hired for $24 per hour. In the Kosciusko survey, 4 hours flying was involved, over half of this being travelling time to and from the survey site.

*Snowy Mountains Hydro-Electric Authority.

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Figure 24—Vertical panchromatic photograph of region between Carruther's Peak and Mt Twynam. Some of the features recognized from colour photography are indicated. Other criteria for erosion assessment, e.g., stages in secondary succession on erosion pavements, and stable and unstable pavement edges are not discernible on panchromatic photography at this scale. In general, differences, for example between dead Poa spp. and Celmisia longifolia patches, are much clearer on colour photography. Original scale on 70-mm film; approx. 1:13,000.

Key to photograph
1. Tall alpine herbfield (Celmisia-Poa alliance).
2. Celmisia longifolia component of above.
3. Feldmark (Epaasis-Veronica alliance).
4. Feldmark (Coprosma-Colobanthus alliance).
5. Fen (and bog), often with entrenchment.
7. Dead Poa spp. in tall alpine herbfield.
8. Heath (Oxyloum-Podocarpus alliance).
10. Flood-source area.
12. Sheet erosion (usually with residual soil).
13. Erosion pavement (usually with Epaasis microphylla).
17. Tracks.
18. Soil remnants.
20. Snow.

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CONCLUSION

The present study has indicated the capability of large to medium scale colour photography in the selection, classification and measurement of soil erosion criteria, particularly in relation to native plant communities at Kosciusko. The combination of matching colour and colour infrared film is superior to each film used alone (plate 1). While clearer distinctions between communities and more informative analysis of plant regeneration are possible from colour infrared film, the exclusion of normal colour would be a disadvantage; the more familiar aspects of colour photography help in the initial recognition of many plant communities and of some areas of soil deterioration, particularly on sheet eroded plateaux (e.g. on Mt Twynam) where the distinct brown smudges of eroding alpine humus topsoil are visible. (Colour contrasts between bare soil and rock or pavement appear clearer on normal colour film.) Colour infrared, however, is superior in the definition of plant community borders and for the resolution of vegetation on erosion pavements and fieldmarks.

Decisions on the most suitable scale depend upon the ability of emulsions to resolve the detail required for practical interpretation. Although the largest scale used was undoubtedly the best for interpreting most of the criteria, it would not be generally feasible, using narrow angle 70-mm cameras, to survey a large area at a scale of 1:3,000 for example. This would require many parallel flight lines, less than 400 ft (122 m) apart, over difficult and undulating terrain.

Two approaches exist for further surveys with 70-mm cameras:

(a) To photograph the entire region at medium scale, e.g. 1:8,000–1:10,000. With magnifying viewing equipment e.g. zoom stereoscopes, most of the more easily recognized criteria could be assessed, but such scales would not enable finer measuring of secondary vegetation and other small but important features.

(b) To intensively sample selected transects at large scales, e.g. 1:3,000 or larger, incorporating all types of erosion patterns in the transects and at the same time, to block survey the whole area at a much smaller scale, e.g. 1:16,000.

It is intended to use the latter approach for a survey of the Gungartan plateau. It is hoped that extrapolation of data obtained at large scale to the smaller scale imagery will help provide guidelines for planning conservation programmes.

The exercise described here highlights the role of specially-flown colour aerial photography in the improvement of resource management planning in remote and inaccessible areas. Competence and confidence in photo-interpretation based on ground data and familiarity with the photography can result in accurate analysis of widespread and diverse criteria, not only for erosion assessment and control, but also in relation to the other scientific, recreational and aesthetic values associated with the Kosciusko region. The work described here is assisting the more rational and economic planning of soil conservation works at Kosciusko, particularly as regards the distinction between incompletely vegetated surfaces which do, and those which do not, require soil conservation treatment.

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LIST OF PLANTS MENTIONED IN THE TEXT

Brachycome nivalis F. Muell., var nivalis
Carex gaudichaudiana Kunth
Celmisia longifolia Cass.
Colobanthus pulvinatus F. Muell.
Coprosma pumila Hook. f.
Danthonia alpicola J. Vickery
Epacris microphylla R. Br. (Epacris—Veronica fieldmark)
E. paludosa R. Br. (Epacris—Sphagnum bog)
E. sp. aff. E. serpyllifolia R. Br. (Epacris—Kunzea heath)
Euphrasia sp.
Kunzea muelleri Benth.
Luzula oldfieldii Hook. f. var. oldfieldii
Microseris scapigera (Sol. ex A. Cunn.) Shultz-Bip.
Neopaxia australasica (Hook. f.) O. Nilss.
Oreobolus pumilio R. Br.
Oxylabium ellipticum (Labill.) R. Br.
Pentachondra pumila (Forst. et f.) R. Br.
Pimelea alpina F. Muell. ex Meissn.
Plantago sp. nov. aff. P. muelleri
Poa spp.
Podocarpus lawrencei Hook. f.
*Rumex acetosella L.
*Sphagnum cristatum Hampe
Veronica densifolia F. Muell.

* Naturalized.

References


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