6 LAND EVALUATION

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6.1 INTRODUCTION

The term land has been used in a comprehensive integrating sense to refer to a wide variety of natural resource attributes in a profile from the atmosphere above a surface area down to some metres below the surface (Stewart, 1968). The characteristics embrace all reasonably stable, or predictably cyclic, attributes of the biosphere above and below this area, including those of the atmosphere, the soil and underlying geology, the hydrology, flaural and faunal populations, and the result of previous human activity in which the effects significantly influence present or future land uses by man, (Brinkman and Smyth, 1973).

These natural resource attributes are fixed in their location and extent and in general have to be exploited at their location except for water which is naturally mobile and may be transported long distances to meet the needs of people. As well as spatial distributions, some natural resource attributes have temporal distributions including climate, water and some aspects of vegetation (Christian and Stewart, 1968). Land therefore is not the same as soil, with many phsical properties influencing the nature and usefulness of land. As such the suitability of any tract of land involves an area of various sizes and shapes, in which maps may be generally required in land evaluation, (McRae amd Burnham, 1981).

Land evaluation is the process of assessing the possible uses of land for agriculture, engineering, forestry and recreation (Stewart, 1968) and more importantly of late to conservation. In the agricultural context, it is the process of assessing the suitability of land for a specified kind of land use, including arable farming, extensive grazing, irrigated agriculture and so on. According to Nix (1968), land evaluation involves the translation of primary land data into a quantitative expression of site quality for the stated purpose, with such an expresssion including a producivty or performance term.

The demand for such land evaluations arose when it was appreciated that mapping individual natural resources alone (e.g soil maps showing the variation in the soil continuum, and so on) did not provide sufficient guidance on how the land could be used and what would be the consequences, (Beek, 1980). To be of value to land planning and management an intergrated stage relating all environmental features is required (Dent and Young, 1981).

6.2 FACTORS AFFECTING LAND SUITABILITY

The extent of the suitability of a particular land use type is due to two major aspects of land. The first involves the physical resources of land including soil, topography, hydrology and climate. The second is the socio-economic resources of capital, size and configuration of land holdings, land ownership, and infrastructure, (Van Lanen, 1991). Human resources such as available labour, technology and finance also strongly influence people's use of land, paramaters which are not fixed in time or space which vary unpredictably and must therefore be reassessed with changes in human resources and attitudes (Stewart, 1968)..

Invariably then, a particular use of land is dependent not only on any single parameter but on the interaction of many parameters of various attributes both physical and socio-economic. Land evaluation, therefore involves the collection and interpretation of very large amounts of data. Further, with predictions continuously changing as technology and economic factors fluctuate data concerned with land evaluation must be stored away and be re-evaluated readily when any or all of those factors change significantly, as techniques improve and more data becomes available (Stewart, 1968).

The physical resources remain relatively stable, unlike the socio-economic resources which are more time-dependeut because they are affected by the social, ecouomic and political settings. As a consequence of the distinctly different nature of these resources, seperate evaluations have resulted to determine the suitability of a particular land utilisation type physically or economically. The seperate land evaluations may also be processed in an intergrated land evaluation approach, (FAO, 1976; Dent and Young, 1981).

Physical land evaluation aims at assessing land qualities or at the suitability for a specific land use type, as conditioned by biophysical parameters (Beek, 1978; Smit *et al.*, 1984). The following land evaluation is restricted to the physical aspects, in particular the suitability of the soil and the landsape.

6.2 PHYSICAL LAND EVALUATION METHODS

Several land evaluation concepts and analytical procedures exist, which have been broadly grouped into three main approaches by van Lanen (1991), which were as follows:

- qualitative evaluation mainly based on expert judgement;
- qualitative evaluation based on parametric methods, and
- quantitative evaluation based on process-orientated simulation models.

6.2.1 Qualitative evaluation mainly based on expert judgement

Physical suitability is obtained by qualitative procedures presented categorically into a number of dicretely ranked classes, (e.g. highly suitable, marginally suitable, currently and permanantly not suitable). These qualitative physical land evaluation methods are derived and based on previous studies, information from experts and information from actual production in the state, country and so on. This relatively simple method provides useful results generalising the constraints and potentials of a defined land use of an area. Examples of such evaluations include those by Van Lanen and Wopereis (1991) and Van Lanen *et al.,* (1991).

Two types of physical evaluation methods which belong to this group include the land capability classification and the land suitability evaluation. The former is based on predefined major land uses and provides an assessment for specific crop or farm management practise, with a priority system built into the system that assumes a descending desirability sequence. The latter is mainly based on expert knowledge and aims at assessing the suitability for a specified kind of land use, a land utilisation type (LUT). An individual LUT has to be selected and is not specified by the evaluation itself, with the suitability repeated for each LUT in the given area, (Van Lanen, 1991).

6.2.2 Quantitative evaluation mainly based on parametric methods

Parametric approaches generally allocate ratings to seperate land characteristics or qualities. The next step involves the combination of the result into a mathematical equation. Parametric methods assess the suitability of land on a continuous scale, in lue of the discrete classes of the land capability classification and suitability evaluations. The essence of such methods are expressed in mathematical models as follows:

Multiplicative, e.g.	$P = A * B * C$
Additive, e.g.	$P = A + B + C$

where P is the parametric score or index, and A, B and C are the ratings of the land qualities or characteristics. The ideal combination of qualities and characteristics, which best represent the best land would receive the maximum score, with the lower scores representing the less suitable land, (Van Lanen, 1991). The best known parametric method is the Storie Index Rating (SIR), which is a multiplicative procedure of evaluating land.

6.2.3 Quantitative physical land evaluation based on process orientated simulation models

In process modelling, land performance is related to individual land characteristics and land qualities with their net effect assessed using a model of land function. The model is capable of portraying many specific processes including erosion or water movement, or may be more comprehensive and provide predictions of crop yields or financial profit, McKenzie, 1991). Mechanistic models account for the most fundamental mechanisms of the processes as they are currently understood, while deterministic models utilise systems which are assumed to behave in ways that an occurence of events leads to a uniquelly definable outcome, (Van Lanen, 1991). Process modelling recognises the complex interelationships beteween a number of land characteristics and attempts to to represent these explicitly, (McKenzie, 1991).

6.4 A LAND SUITABILITY EVALUATION SYSTEM FOR NEW SOUTH WALES

The parametric approach concentrates on the quantification of land attributes that are considered significant to the particular land use (Stewart, 1968). Zhang (1989) established such an interpretive quantitative parametric system of rural land suitability evaluation within New South Wales. In the following sections the land evaluation system is discussed and used to evaluate the land suitability of a number of crop species in the Edgeroi area.

A membership term is also intoduced which better represents the continuum of suitable land. The suitability evaluiation follows that proposed by the FAO (1976), with seventeen land utilization types considered, eight of which have been evaluated here including, barley, dryland cotton, oats, pasture, soyabean, sorghum, sunflower, and wheat where suitability is determined by matching specific crop requirements with climate and soil land characteristics.

The evaluation criteria established is based on information gathered from the literature, opinion of local experts and by the comparison of measured values of characteristics with experts judgement of limitations to their use. Limitations from degradation were also considered with criteria established to determine the suitability of land for given uses on a sustained basis. That is to say that land capable of producing cash crops in the short term, will have a low suitability if the risk of degradation is high.

The land suitability evaluation attempts to recognize the potential of a given area of land for a specific type of land use within New South Wales by interpreting soil survey data. To assess the suitability of a particular tract of land a limitation scoring system was introduced as suggested by Nix (1968), to quantitatively estimate the overall limitation effect of all relevant land characteristics for a specified crop.

6.4.1 Land characteristics and land use suitability

A land characteristic is an attribute of land which can be measured or estimated (Dent and Young, 1981), for example slope angle, soil drainage, topsoil cation exchange capacity, subsoil pH, etc.. Other useful terms and definitions used in land suitability evaluations by the FAO (1976) can be found in Table FAO. The non-climatic land characteristics which are considered to have a determinative influence at the semi-detailed level in New South Wales, were as follows, (Zhang, 1989):

(1) slope length
(2) landform and slope length
(3) drainage
(4) flooding
(5) texture and structure of the subsoil
(6) texture and structure of the topsoil
(7) surface stoniness
(8) subsurface stoniness
(9) depth which water can penetrate (above the impermeable layer such as a heavy textured soil)
(10) depth to root impenetrable layer
(11) topsoil CEC
(12) base saturation
(13) organic matter
(14) topsoil salinity
(15) subsoil salinity
(16) topsoil ESP
(17) subsoil ESP
(18) topsoil pH
(19) subsoil pH

Table 41. (near here)

6.4.2 Climate and land use suitability

Climate is one of the aspects of land suitability which must be included in land evaluation (Brinkman and Smyth, 1973; FAO, 1983). If the land is suited to a specific type of utilization, the climatic condition should also be satisfactory. For agricultural land evaluation, climate is the dominant factor in determining the suitability of a given crop for a given area, since it is difficult to conceive of any component of a farming system that is not influenced by climate and weather, (Zange, 1989), particulasrly when considering that large areas of Australia fall within arid and semi-arid climatic regimes.

There are many climatic characters which influence land use suitability, these factors can be considered as the land qualities of:

(1) temperature regime;
(2) radiation regime; and
(3) moisture regime (FAO, 1983).

Meeting the climatic requirements of a crop is considered to be the first hurdle in land evaluation. If the crop is suited climatically to a given area, the land can then be assessed for suitability to the crop. For each of the selected land utilization types, climatic suitability zones within New South Wales, were recognized and treated as broad mapping units by Zhang (1990).

The climatic suitability of a specific crop was considered by calculating indices from a generalized plant growth model, GROWEST (FitzPatrick and Nix, 1970) with special requirements of crops used as criteria to evaluate the suitability of an area from the data obtained from 99 meteorological stations within N.S.W.. Further, some crops require more specific temperature and moisture conditions at particular growth stages, thus the climatic parameters of seasonal temperature and rainfall were also used as criteria to evaluate the climatic suitability. These criteria were based on previous studies, information from experts and information from actual production in the state, Zhang (1989).

The land utilisation types considered for further investigation were selected based on their climatic suitability on the state wide scale by Zhang (1989), including barley, dryland cotton, oat, pasture, sorghum, soybean, sunflower and wheat. The scale of the maps presented by Zhang (1989) however are small and hence may not account for local microclimate variations. Nevertheless, they do indicate whether or not to proceed with the land evaluation. Of the land utilisation types selected the climatic suitability of dryland cotton, may be limited, particularly in the western third of the area due to the poor moisture regime which may exist here. The other crops evaluated for their land characteristic suitability should be well suited climatically throughout the area. The lack of sufficient data to determine the mean extractable water storage capacity prevented examination of the water balance within the area.

6.4.3 Limitation degrees

Once a land characteristic is recognised to influence the land use, the degree of this influence has to be determined in order to evaluate the land. According to the degree of influence on the land use, five degrees of limitation which have been defined (FAO, 1976), where for each limitation degree, Zhang (1989) introduced a limitation score:

Limitation degree 0 (no limitation); the characteristic is optimal for plant growth, **(limitation score = 0).**

Limitation degree 1 (slight limitation): the characteristic is nearly optimal for the land utilization type and affects productivity for not more than 20 percent with regard to optimal yield, or the characteristic has a slight influence on the land degradation on sustained use, **(limitation score = 1).**

Limitation degree 2 (moderate limitation): the characteristic has moderate influence on yield decrease or degradation for sustained use; however, benefit can still be made and use of the land remains profitable, **(limitation score = 3).**

Limitation degree 3 (severe limitation): the characteristic has such an influence on yield decrease or degradation of the land that the use of the land becomes marginal for the considered land utilization type, **(limitation score = 9).**

Limitation degree 4 (very severe limitation): such a limitation will not only decrease the yields below the profitable level or promote a high degradation risk but may even totally prohibit the use of the soil for the considered land utilization type, **(limitation score = 27).**

These definitions provide criteria which rate the severeness of the limitation for all land characteristics, whereby two land characteristics with the same degree of limitation indicates that both characteristics have the same effect on the land use. These definitions can be extended to other land use types since the scales are the same. .The limitation score is the quantitative expression of the limitation effect of a land characteristic. The accumulation of all the land characteristic limitation scores is used to express the overall limitation from all the land characteristics and is termed the 'Accumulated Limitation Score', (Zhang, 1989).

The suitability class can then be determined by the following relationship between the accumulated limitation scoring system and the land suitability classes, (Table 42):

Table 42. (near here)

Some of these non climatic land characteristics can be altered in some way that will enable the land to become more suited to a particular land use type. For example the slope length has been altered in some areas in the eastern third of the study area by the use of contour banks which reduces the risk of erosive runoff events. The effects of flooding can also be negated by the use of levee banks and via the construction of floodways, reducing the risk to cropping and pasture. The area cultivated and prepared for cotton production in the south west corner is protected by extensive levee bank networks. These ensure that water anticipated for a twenty year flood are channeled between fields negating the effects of flooding.

6.4.4 Continuous evaluation of land suitability

The above expression of land suitability via the use of the accumulated limitation scoring system can be made in a more continuous way, which is particularly useful for mapping. Rather than determine a particular site's suitability by a series of subjective cut off classes, (i.e. S1, S2), etc., a more continuous representation can be obtained by the use of a simple membership function. There are several membership functions which are well suited for defining membership grades, one such function is:

$$\mu = e^{(-0.1s)}$$

where μ is the suitability membership and s is the accumulated limitation score. The result is transformed into a membership score with values ranging between 0, membership to the non-suitable land utilisation class, and 1, membership to the suitable land utilisation class. The range of values in between express the gradation of membership between these two classes of not suited and suited for a particular type of land utilization. Figure 36, expresses the relationship between the accumualted limitation scoring system and the land suitability membership function introduced by Zhang (1989). This is similar to the approach suggested by Burrough (1989).

Figure 36.

6.4.5 The purpose of land evaluation

Dent and Young (1990) suggest that the fundamental purpose of land evaluation is to predict the consequences of change, so that no wheat evaluation is required if a tract of land is currently cropped with wheat. However, land evaluation will be required where change is contemplated and where land-use potentials are required. In these cases, prediction of the suitability of the land for various types of land utilization is necessary.

The land evaluation of the lower Namoi Valley was carried out to test the land evaluation scheme introduced by Zhang (1989) on a wide variety of land utilisation types, and to demonstrate the modification of this scheme to fuzzy or continuous suitability classes in a local area. Although wheat and pasture, both native and improved, as well as irrigated cotton are currently the most popular land uses the potential for other crops has not been quantified. Further, the potential for rotations of a number of utilisation types is unknown. The versatility of a particular tract of land is also unknown. With this in mind the following land utilisation types deemed to be suited on the state wide scale climatically to the area, (Zhang, 1989), were evaluated, including barley, dryland cotton, oats, sorghum, soybean, sunflower, pasture and wheat.

The continuous (fuzzy) scoring system introduced above for each individual land utilisation type can be used to express the potential of a particular soil profile or tract of land to a wide variety of land utilizations, that is its versatility. So that according to the above definition, the sum of the individual land evaluation memberships divided by the number of evaluations considered is termed the land versatility:

$$\mu_v = \text{mean}(\mu_a, \mu_b, \mu_c, \mu_d, \mu_e)$$

where μ_v is the membership in the versatility class and μa, μb, μc, μd and μe are the suitability memberships to the land utilisations of a, b, c, d and e.

Similarly, the cycling of a number of land utilisations, that is its rotation could be assessed with respect to the potential for rotation, defined as the minimum suitability membership for any land utilisation in the rotation:

$$\mu_r = \text{minimum}(\mu_a, \mu_b, \mu_c)$$

where μ_r is the membership in the rotation class, and μa, μb and μc are the suitability memberships to the land utilisations of a, b, and c. So that by choosing a small number of suitable crop species, the most suited areas for particular rotations could be assessed. Any number of permutations could be considered for rotation, for example successive dryland cotton crops followed by a wheat crop cycle, as well as a wheat, dryland cotton and sorghum cycle, so that by varying the land utilisations in any given sequence any number of rotations could be examined before implementation.

6.5 EDGEROI LAND SUITABILITY EVALUATION

A number of the land characteristics defined by Zhang (1989) and the land characteristics collected by McGarry *et al.* (1990) based on the conventions of McDonald et al. (1984) were dissimilar. In the following section these differences are highlighted and the method of land characteristic assessment used is illustrated. In some cases an estimate was made to assess a particular land characteristic where land characteristics were not collected or were slightly modified due to ambiguous or ill-defined land characteristics.

6.5.1 Definition of topsoil and subsoil

The topsoil as defined by Zhang (1989), is considered to be the top 0.20m of the profile. The Edgeroi data set contains two values within the first 0.20m of the profile, for example within profile ed101 layers ed10101 and ed10102 were sampled at 0.00-0.10 and 0.10-0.20m respectively. To obtain a value for comparison with the land characteristics of topsoil texture, surface stones, cation exchange capacity, base saturation, organic matter, salinity, exchangable sodium percentage and pH these two layers were averaged before evaluation.

Similarly, the subsoil land characteristics were assessed for each profile by averaging the values of each character, including subsoil texture, stoniness, base saturation, salinity, exchangable sodium percentage and pH at the following depths 0.30-0.40m, 0.70-0.80m, 1.20-1.30m and 2.40-2.50m. Although, the rooting depth is considered to extend practically no further than 1.30m the values for 2.40-2.50m were included to assess the potential of salinization. Many of the other characteristics throughout most of the profiles varied little in value from 0.30-0.40m to 2.40-2.50m and were also included due to the lack of continuous data throughout the profiles.

6.5.2 Slope angle, land form and slope length

According to Zhang (1989) slope angle is non-limiting when slopes are less than 5% and are considered to be flat with respect to landform and slope length. Much of the area then is essentially flat with only subtle gradients recognisable on the footslopes of the Nandewar Ranges. Profiles sites with gradients greater than 5% were then assessed, with respect to slope length by estimating the length of the slope from the 1:50000 topographic Edgeroi map sheet.

6.5.3 Drainage

The definitions of drainage were incorporated into the land evaluation introduced by Zhang (1989) from McDonald *et al.* (1984), which appears to be one of the major limitations of this scheme. The definitions were considered to be to ambiguous and ill defined. Drainage was evaluated according to the field perceptions of Ward (in prep) and his interpretation of the drainage of each soil profile.

In general grey clay profiles were located in slower draining areas than brown clay and black earth profiles. The grey clay soil profile classes of **BELAR**, **WAUGAN**, **KEERA** and **ROMA BORE** were considered to be of 'moderate' drainage, whilst the brown clay and black earth soil profile dominated classes of **CURRAMANGA**,

GREEN TIMBERS and **COWIMANGHIAH** were assessed as 'well' drained. 'Imperfectly' drained profiles, including many **YERI** profiles exhibited signs of mottling and evidence of prolonged wet periods, whilst the **DOYLE** soil profiles which are generally of a solodic nature and are associated with the impermeable Pilliga Sandstone within the State Forests were considered to be 'poorly' drained. In these areas mottling was severe and a perched water table was suspected. Drainage in the majority of profiles assessed in this way were not excessively limiting to many of the utilisation types, except within the State Forest areas.

6.5.4 Flooding

Flooding, of any significance to land evaluation is relatively limited to the floodplains associated with the Namoi River, and many of the well defined local drainageways, with **MANAMOI** profiles most at risk. Due to the large cash crop value and infrastructure expenditure required for cotton production much of the area utilized for irrigated cotton is protected by a network of levee banks which channels floodwaters of the Namoi River between the fields during peak flood periods. Hence, in these areas the risk of flooding has been reduced, however, in a number of unprotected areas the risk has increased and limits the potential for agriculture accordingly.

On the local scale, many areas receive much water in inundative events, however these are channeled through well defined ephemeral creeks in the upper coarses which dispense the water onto the alluvial plains with minimal flooding or water ponding. Only in a relatively few areas does the water sit on the surface for any great period of time. Floodways and contour banks have also been constructed to channel and contain water within the drainageways of Bobbiwaa and Spring Creeks.

6.5.5 Texture and structure

Texture was assessed by averaging the topsoil and subsoil layer textures. If the texture difference was to large to make a reasonable average prediction, the particle size analysis data was used to predict an average. Structural differences were resolved by considering the most limiting structure. For example if an 0.00-0.10m layer of a particular profile was a structured medium clay and the underlying 0.10-

0.20 layer was a massive medium clay, the structure of the topsoil was assessed as a massive medium clay.

The areas with limiting structure and texture tended to be the lightly textured poorly structured **DOYLE** soil profiles and to a lesser extent the weakly to massive structured heavy and medium clay layers of the **WAUGAN** and **BELAR** profiles located on the alluvial terraces.

6.5.6 Stoniness

Stoniness was assessed using the morphological descriptions of each profile with an average estimated for the topsoil and subsoil. Most sites were not limiting with regard to this land characteristic at the surface, ed208 the exception, where as much as 50% is covered with 20-60mm angular basalt fragments at the 0.00-0.10m depth while 50-90% of the underlying 0.10-0.20m sample is interspersed with subrounded basalt fragments greater than 0.60m diameter.

Subsoil stoniness was generally associated with **GREEN TIMBERS** profiles which are derived from *in situ* weathering of basaltic parent material. Profiles of the **COWIMANGHIAH** and **WOODLANDS** classes situated on the footslopes of the Nandewar Range which are shallow and often lie in contact with underlying basalt are also slightly limited by the sometimes excessively stony subsoil.

6.5.7 Depth to water penetration and root impenetrable layer

Generally, most profiles within the area facilitated the passage of roots to at least 1.20m with the criteria used to delineate depth of water penetrability and root impenetrability the presence of a rocky layer or subsurface parent material. The areas which were stony were also generally shallow, with the areas on the footslopes of the Nandewar Range limiting to croppping due to the shallowness of the soil. Otherwise in general root and water impedence was not limiting except within many of the **DOYLE** profiles.

6.5.8 Topsoil C.E.C., base saturation, & topsoil organic matter

Ttopsoil C.E.C. and topsoil and subsoil base saturation were generally non limiting land characteristics in most profile classes, except **DOYLE.** Organic carbon content on the other hand was a non-limiting character of the above mentioned profiless, however this is due to their native state. The remaining profile classes contain sufficient levels for cropping, with some limitation within many **BELAR** profiles, due to the highly cropped nature of these areas.

6.5.9 Topsoil and subsoil salinity

Topsoil salinity was not evident within any profile examined by the land evaluation. However, in the north within many **WAUGAN** and some **BELAR** profiles large levels of subsoil salt may limit a number of crop species. Although dryland cotton, pasture and wheat are slightly more tolerant to the presence of salt, irrigation which is now carried out extensively within the area has the potential for causing widespread salinization. Although not currently evident, it is difficult to control and ameliorate once the problem has arisen and hence should be monitored.

6.5.10 Topsoil and subsoil E.S.P.

Of all the land characteristics, the most limiting within the area to a wide variety of the land utilisations is the excessively high subsoil E.S.P. values. Very sodic layers such as the ***Boolcarrol, Nundi*** and many ***Couradda*** layers, generally tend to reduce aeration and may limit drainage within the profile. Wheat, and to a lesser extent the land utilisations of barley and oats are not as limited by large E.S.P. values as the utilisations of sunflower and soyabean. **BELAR, WAUGAN** and **WOOLANGABBA** profiles characterised by many of the above layer classes are unsuited to either of the latter land evaluations with many other more tolerant utilisations including wheat poorly suited to these areas.

Topsoil E.S.P. was not as limiting a land characteristic as subsoil E.S.P. with a small number of profiles with moderate levels of E.S.P. at the surface, located in the northern areas again mostly associated with **BELAR** profiles..

6.5.11 Topsoil and subsoil pH

Nundi, ***Moplain***, ***Bald Knob***, ***Togo*** and ***Noelurma*** soil layers are all strongly alkaline with the many profile classes characterised by these layers high in pH, particularly **WOOLANGABBA** profiles. Topsoil pH in some areas was high but in a couple of profiles the limit to suitability was minimal to most land utilisation types. Subsoil pH, however, in a number of profiles particularly those within the **WOOLANGABBA** profile class which have inherently strongly alkaline subsoil layers as a consequence of large ESP values, suggest severe limitations with the potential suitability to any type of land utilisation restricted. Many areas have been left uncleared.

6.6 AN EXAMPLE: WHEAT LAND EVALUATION OF ed101

The criteria to evaluate the non-climatic characteristics for barley, dryland cotton, oats, sorghum, soyabean and sunflower in New South Wales, (Zhange, 1989) are presented in Appendix 1. An introduction to the land evaluation proposed by Zhang (1989) is presented by Kopppi, (1991) with the criteria for the non climatic characteristics of wheat and pasture also presented.

In the following example, profile ed101 from the Edgeroi data set (McGarry et al., 1990), is used to illustrate the method of land suitability evaluation of the non-climatic data for wheat utilisation, (Table 43). The final evaluation result or Accumualted Limitation Score of 2. In terms of the membership function, μ_W = 0.819, where μ_W is the membership to the suitable land utilisation of wheat, and indicates that this site is very well suited to wheat utilisation. Slope length and subsoil structure were assessed to limit this land utilisation type only marginally.

Table 43. (near here)

6.7 LAND EVALUATION RESULTS

The land evaluation results obtained for the different land utilisation types including wheat, oat, barley, dryland cotton, pasture, sorghum, soyabean and sunflower were used to produce continuous (fuzzy) land suitability evaluation maps. To produce a curvelinear representation, a smooth contour interpolation algorithm which specifies that a bivariate quintic interpolation was used, (ARC/INFO, 1989). The rotation and versatility evaluations were also contoured in this way. The following maps indicate the areas of poorly or non-suited areas, (0.00-0.20) to suitable areas (0.80-1.00) for each land utilisation evaluation. The 0.50 membership contour has also been included.

The evaluation based on the 210 sampling sites located on the systematic equilateral grid with approximately 2.8km spacing reflects the general trends of suitability within the Edgeroi area, however, a more detailed study would be required to verify these results and ensure the continuum is better represented. In many instances insufficient data meant estimates were used to substitute missing values.

Nevertheless the land evaluation indicated patterns which reflect the general continuum of the Edgeroi map sheet. It was evident that a number of sites were clearly not suited to any of the conventional agricultural utilisations considered. The land evaluation also reiterated the importance of the current major land uses of wheat and pasture and the importance of irrigated agriculture in the lower lying areas, due to the tolerance of these utilisations to very sodic conditions and also to the neagating effect of irrigation to other more serious limitations.

The areas associated with the State Forests and dominated by **DOYLE** soil profiles were unsuited to all of the conventional land utilisations considered. Characterised by ***Couradda*** soil layers which are lightly textured, generally poorly structured, often strongly sodic and have generally low base saturations are also infertile incapable of sustaining any long term agricultural utilisation. The profiles themselves have impermeable subsurface layers which impede drainage and cause mottling at depth. Previous clearing of such areas has caused rilling and other forms of degradation, with these areas best left uncleared and preserved for their native value.

Other areas which consistantly appeared to have serious limitations included many of the **WOOLANGABBA** soil profiles which were dominated by ***Nundi*** soil layers at all depths. These excessively sodic and hence quite alkaline soil layers, often had large amounts of salts and chlorides also present. However, the large values recorded with respect to ESP appears to severly affect the potential of these sites for many of the land utilisations considered. Many of these are however cultivated with wheat, which of all the utilisations is most tolerant to large amounts of E.S.P. Similarly, the

In general, the areas associated with the alluvial plains of the Namoi River, were also not well suited due to the large ESP values inherent wiyhin many of these profiles, including the more tolerant utilisations of wheat, barley and oats. These three utilisations generally tended to be the most suited land use types along with pasture. The areas which proved to be the most versatile were the areas associated with the basaltic outcrops at Bald Hill, 'Green Timbers' and at 'Oakvale'. Many of the areas associated with the local drainageways of Bobbiwaa and Spring Creeks as well as the floodplain of the Namoi River were also consistantly suited to a wide variety of land utilisations. Areas to the east of Terry Hie Hie Road were also found to be quite versatile, due to the rich basaltic nature of the soil here, and the small amounts of s.

6.7.1 Wheat, Barley and Oats

The excessively large levels of ESP often associated with ***Nundi*** and ***Boolcarrol*** soil layers located in many **WOOLANGABBA, WAUGAN** and **BELAR** soil profiles restricts the suitability of these areas to a wide variety of agricultural land utilisations according to Zhang (1989). However, the land utilisations of wheat, barley and oat are tolerant to large levels of E.S.P.. While many other utilisation types are totally unsuited when E.S.P. is greater than 15%, wheat and to a lesser extent the utilisations of barley and oat, as illustrated by the criteria in Appendix 2, have only slight limitations at these levels.

Figure 37. (near here)
Figure 38. (near here)

Barley and oats which have identical land characteristic requirements for suitable growth in New South Wales, according to Zhang (1990) differ only in the land characteristics of subsoil salinity and subsoil E.S.P.. The land evaluation results were accordingly similar with the potential for barley and oat utilisation recognised in those areas presently cropped for wheat. However, economic considerations may limit the introduction of these land utilisations, which are not as consistantly profitable as wheat.

6.7.2 Dryland Cotton

The irrigation potential of cracking grey clay soil identified throughout many areas of NSW and particularly with respect to irrigated cotton production, has until the last twenty years been unrealised. With the successful introduction of irrigation to many trial sites, including the original experiments conducted within the Myall Vale Research Station, irrigated cotton production is now extensively practised in the Edgeroi area to the west of Bald Hill Road and on the larger scale throughout northern New South Wales and south-western Queensland.

Dryland cotton although not extensively practised has previously been grown in a number of areas including 'Oakvale', 'Murrumbilla' and at 'Lyndon'. The land evaluation of the non climatic factors of this crop highlighted these areas as suitable for dryland cotton utilisation particularly at 'Oakvale', with the potential of other areas also recognised. However, climatically the area may not be suitable enough on a long term basis with further study required on the consistancy of rainfall and the water storage capacity of the soil on which they are to be grown. At present the data is not sufficient to estimate the potential available water storage of these areas.

Figure 39. (near here)

Further, the areas in which irrigated cotton is presently grown appears to be unsuited to dryland production, due essentially to large E.S.P. values, heavy textures and often weak to massive structures. The limitations which affect the dryland cotton production appear to be negated by the extensive scheduled irrigation which produces consistanly large amounts of cotton.

6.7.3 Pasture

The other major enterprise, of importance to the area is pastoral agriculture, both improved and native. The improved areas tend to be those associated with the lower lying areas of the landscape generally, the alluvial plians of the Namoi River and also the local alluvial fans. The native pasture areas are more commonly located on the footslopes of the Nandewar Range east of the Newell Highway, interspersed with sparingly cleared areas, (Figure 40).

Figure 40. (near here)

Tolerant to moderate levels of salinity and E.S.P., pasture species can tolerate wide pH ranges. Overall, this land utilisation had the greatest potential as all but a few land characteristics were only slightly limiting. In those areas which may limit cropping due to long or steep slopes, shallow subsoil and light textures do not limit this utilisation type. Only in the areas within the State Forest and in those profiles with excessively large E.S.P. values, where this utilisation was unsuited.

6.7.4 Sorghum

Although not extensively cultivated sorghum is presently cropped in a number of areas with the potential for sorghum utilisation illustrated. Similar, to the land utilisation of cotton in a number of land characteristics the potential for this crop is not as great as that for dryland cotton utilisation. Again as with so many of the land utilisations considered the excessively large E.S.P. values affect the implementation of such a crop. The moderate levels of salt as well as the heavy clay nature and the weak to massive structures, plus the strongly alkaline nature of many of the profiles associated with the lower lying areas also limits the cropping of sorghum, (Figure 41).

Figure 41. (near here)

6.7.5 Soyabean

Not extensively cropped within the area the potential for cropping is limited to a few areas, mainly in the eastern half of the Edgeroi sheet associated with the outcropping basalts and the areas close to the local drainage ways and the Namoi River floodplain. Along with sunflower which is poorly suited to a large number of areas and as with many of the other utilisations the small number of areas which are suited are due to the minmal traces of salt, sodium and the generally, better structured, medium textured fertile soil profiles of the area.

Figure 42. (near here)

6.7.6 Sunflower

Presently, sunflowers are grown in only a limited number of areas including the rich basaltic soil located at 'Oakvale', and the versatile areas generally associated with the floodplains of the area. The land evaluation indicated the limited potential of this crop, which is extremely sensitive to large levels of E.S.P. which would be considered moderate levels or evewn non limiting levels for a number of other utilisations including wheat. The generally, excessively large E.S.P. levels present restricts this particular land utilisations to the non-sodic areas

Figure 43. (near here)

6.7.7 Versatility

The most versatile areas were those associated with the Namoi River floodplain as well as many areas in which the soil was derived from basalt particularly at 'Oakvale'. In general the soil found to the east of the Newell Highway associated with the footslopes of the Nandewar Range were the most versatile areas exhibiting the greatest potential for a number of currently underutilised land utilisations. Many of the local flooplains particularly Bobbiwaa and Sprig Creeks as well as the floodplain of Bourne Creek were also consistantly well suited to a wide variety of land uses even the generally poorly suited utilisations of soyabean and sunflower. The soil profiles associated with Namoi River were also quite versatile, however, some areas prone to regular flooding were limited in their agricultural use, unless extensive levee banks are constructed.

Figure 44. (near here)

The areas which were least versatile were those which were excessively sodic and alkaline at depth particularly those on the alluvial terraces and fans, in particular the many profiles of the **WOOLANGABBA** profile class. Many of the soil profiles within the State Forest areas identified as **DOYLE** profiles showed little agricultural potential generally attributable to the sandy, weakly structured nature of the soil.

6.7.8 Rotation: Wheat, cotton, sorghum

Much of the area at present is utlised extensively for wheat. The potential in many areas of dry land cotton and the cultivation of sorghum within the area indicated that a possible rotation could involve these three land utilisations. In our example the rotation is a simple one involving a rotation in succession of the three utilisation types, although this could be altered to facilitate three continuous crops of cotton which is perhaps followed by a single rotation of wheat or sorghum etc. The rotation crops could also be altered when one or all of these utilisations is not well suited and substituted with other utilisations considered.

Figure 45. (near here)

The potential for such a rotation is as mentioned previously limited by the least suited utilisation which in our example is that of sorghum. Thus many areas previously shown to be well suited to the utilasations of wheat and cotton have been reduced with respect to the suitability of such a rotation due to the less suitable land characters which prevail at the sites for the sorghum utilisation.

7 DISCUSSION

The data reported by McGarry *et al.* (1989) were analysed using a relatively novel approach of continuous classification using fuzzy k-means with extragrades to produce a soil layer classification defined largely in terms of quantitative chemical and textural attributes. These layer classes showed reasonable contiguity and could be identified and interpreted with pedological, geological and geomorphological entities.

The layer classes thus identified and defined were then assembled into soil profile classes by recognition of common sequences of layer profiles. These 14 profile classes provided a more conventional soil profile class map of the area, which can provide a basis for soil management. These classes also closely reflected the pedological, geological and geomorphological understanding of the area, with many profile classes correlating quite strongly with the field perceptions of conventional classification procedures and soil profile class boundaries. Ward (in prep.) identified three broad types of country, identifying 23 soil units. In Table 43, these field defined units are compared to the profile class map of the Edgeroi area obtained by the current methods.

Table 43. (near here)

The soil profile classes identified also reflected the different stratigraphic processes which have occured in different areas but have resulted in similar profile sequences, with the continuum represented more clearly. During the initial field work soil profiles were classified with respect to great soil groups (Stace et al., 1968) and the Factual Key, (Northcote, 1971). In many instances these classification schemes were unable to sufficiently distinguish the different soil profile classes defined within this report, many classes included a wide variety of great soil groups not usually grouped together.

Finally, an alternative analysis of the data, was the soil suitability classification for various agricultural crops. This analysis did not use the layer or profile classes but rather used point information from the profile and layer descriptions. The twice modified FAO (1976) approach, once by Zhang (1989) to limitation scores, and once by the authors to suitability membership provides a continuous map of suitability across the region. The use of fuzzy set operators provided definitives and quantification of the concepts of versatility (akin to, but not the same as capability) and rotation suitability, with the continuous result proving quite useful in mapping.

The results provide a basis for further research on the sustainable management of soil in the lower Namoi Valley, which is currently a highly productive area and is subjected to many stresses thereby imposed. The work presented here points quite directly to further research. Firstly, the soil maps produced here need to be tested, (e.g. de Gruijter and Marsmann, 1989) with data on the physical properties of the soil generated. Physical soil properties for example which appear to be important for management including plastic limit for scheduling field operations and profile available water capacity required for simulation coton growth could be collected to compliment the existing soil chemical and morphological descriptions. This will allow the layer classes to be better utilised in soil suitability and more importantly soil management strategies.

Further, one of the layer classes, ***Boolcarrol***, reflects an excessively saline layer, which needs to be further investigated due to the extensive irrigation now practised throughout the lower Namoi Valley. The value of such a crop economically and the viability of the industries associated with irrigation depends on the assurance that the natural soil and water resources are not under any threat of any type of degradation.

With new technologies improving rapidly particularly in the fields of Ground Positioning Systems and Geographic Information Systems a number of attributes can be continually assessed, updated and mapped to provide baseline data on which models can be bassed to assess the potential for widespread salinisation. Salinity, could in this way be monitored once techniques are established which are capble of measuring and hence monitoring the movement of such saline soil layers presently leaching deeper into the soil. The potential for grounwater to rise toward the surface as a direct consequence of irrigation is a possibility and should not be underestimated when on the global scale such events have occured throughout history.

Secondly, McKenzie (1991) recently reviewed several Australian approaches to soil survey and land evaluation. Some of the methods presented here were not discussed in that report. It appears to the authors that the concept of the layer class is a powerful one, potentially more powerful than that of the soil profile class, and requires further investigation, with a view to providing a new soil layer classification scheme capable of representing soil stratigraphic units which by their nature are capable of better representing the anisotropy inherent within the soil continuum.

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APPENDIX

A ATTRIBUTE DEFINITIONS (after Zhange, 1990).

A.1 Slope length

Flat: slope angle <5%;
Short slope: less than 500m from the top;
Moderately long slope: 500m - 2500m from top;
Long slope: >2500m from the top.

A.2 Topsoil and subsoil

Topsoil: 0.20cm from the surface.
Subsoil: below A2 horizon or below 20cm from the surface.

A.3 Flooding

No: once in more than 20 years, for less than 2 days;
Slight: once in 20 years, for 3-7 days;
Moderate: once in 10 years for 3-7 days, or once in 10-20 years for one week to a month;
Severe: once in 5 years for 3-7 days, or once in 5-10 years for one week to a month, or once in 10-20 years for more than a month.
Very severe: yearly for 3-7 days, or once in 5 years for one week to a month, or once in 5-10 years for more than a month.

A.4 Drainage

Well: Water is removed from the soil readily but not rapidly. Excess water flows downward readily into underlying moderately permeable material or laterally as subsurface flow. The soil is often medium in texture. Significant additions of water by subsurface flow are neccessary in coare textured soil. Some horizons may remain wet for as long as one week after water addition.

Moderate: Water is removed from the soil somewhat slowly in relation to supply, due to low permeability, shallow water table, lack of gradient, or some combination of these. Soils are usually medium to fine in texture. Significant additions of water by subsurface flow are neccessary in coarse textured soil. Some horizons may remain wet for as long as one week after water addition.

Imperfect: Water is removed only slowly in relation to supply. Precipitation is the main source if available water storage capacity is high. but subsurface flow and/or groundwater contribute as available water storage capacity decreases. Soil has a wide range in texture and depth. Some horizons may be mottled and/or have orange or rusty linings of root channels, and are wet for periods of several weeks.

Poor: Water is removed very slowly in relation to supply. Subsurface or groundwater flow, as well as precipitation, may be significant water source. Seasonal ponding resulting from run-on and insufficient outfall also occurs. A perched water table may be present. Soil may have a wide range in texture and depth; many have horizons that are gleyed mottled or possess orange or rusty linings of root channels. All horizons remain wet for periods of several months.

Very poor: Water is removed from the soil so slowly that the water table remains at or near the surface for most of the year. Surface flow, groundwater and subsurface flow are major sources of water, although precipitation may be important where there is a perched water table and precipitation exceeds evapotranspiration. There are usually a wide range in texture and depth, and often occur in depressed sites. Strong gleying and accumulation of surface organic matter are usually common features.

A.5 Definitions for stoniness

Gravels: 2-60mm
Cobbles: 60-200mm
Stones: 200-600mm
Boulders: >600mm

A.6 Symbol for texture and structure

HCm: Heavy clay, massive or dense weakly structured
HCs: Heavy clay, structured
Cs: Light or medium clay, structured
Cm: Light or medium clay, massive or weaky structured
ZCm: Silty clay, massive
ZCs: Silty clay, structured
CLs: Clay loam, structured
CLm: Clay loam, masive
ZCL: Silty clay loam
SCs: Sany clay, structured
SCm: Sany clay, massive
Ls: Loam, structured
Lm: Loam, massive
SL: Sandy loam
LS: Loamy sand
SCL: Sandy clay loam
ZL: Silty loam
Z: Silt
S: Sand

Appendix 2: Criteria to evaluate the non-climatic characteristics for cotton land evaluation, (after Zhange, 1990).

Limitation degree	0	1	2	3	4
Limitation score	0	1	3	9	27
Slope angle	0-2	3-5	6-10	11-25	>25
Landform and slope length	flat	short slope	moderately long slope	long slope	edge of gully
Drainage	good	moderte	imperfect	poor	very poor
Flooding	no	slight	moderate	severe	very severe
Teture and structure of topsoil	Z, ZL, ZCs, Cs, CLs, Ls, SCL	ZCL, SCs, SCm, SiCm, Cm, HCs, CLm, Lm, SL	HCm, LS, S		
Teture/structure of subsoil	ZL, ZCL, SCL, SiCs, SCs, Cs, CLs, Ls	CLm, SCm, Z, Cm, Lm, HCs	SL, LS, HCm	S	
Surface stoniness (%)	<5% gravel <3% C, S, B	6-10% gravel 3-10% C,S,B	11-25% gravel 11-20% C,S,B	26-35% gravel 21-30% C,S,B	>35% gravel >30% C,S,B
Subsoil stoniness (%)	<10%	11-20	21-35	>35	
Depth with which water can penetrate (m)	>1.50	0.80-1.50	0.30-0.79	0.15-0.29	<0.15
Depth to root impenetrable layer (or rocky layer for annual crop)	>1.50	0.80-1.50	0.30-0.79	0.15-0.29	<0.15
Topsoil CEC (meq/100g)	>10	5-10	<5		
Base saturtion (A and B horizon)	B >50% A >80%	B any A >50%	B any A 35-50%	B <50 A <35%	
Topsoil Organic Matter	>3.2	2.1-3.2	1-2	<1	
Topsoil Salinity (ECe S/m)	<0.4	0.4-0.8	0.9-1.5	1.6-2.5	>2.5
Subsoil Salinity (ECe S/m)	<0.4	0.4-1.0	1.1-2.0	2.1-3.0	>3.0
Topsoil ESP	<4%	4-6%	7-9%	10-18%	>18%
Subsoil ESP	<5%	5-15%	16-25%	26-35%	>35%
Topsoil pH	5.5-8.0	5.0-5.4 8.1-8.5	4.5-4.9 8.6-9.0	<4.5 9.1-9.5	>9.5
Subsoil pH	5.6-8.5	5.1-5.5 8.6-9.0	4.5-5.0 9.1-9.5	<4.5 >9.5	

Appendix 3: Criteria to evaluate the non-climatic characteristics for oat and barley land evaluation, (after Zhange, 1990).

Limitation degree	0	1	2	3	4
Limitation score	0	1	3	9	27
Slope angle	<2	2-8	9-16	17-25	>25
Landform and slope length	flat	short slope	moderately long slope	long slope	edge of gully
Drainage	moderte-good	imperfect	poor	very poor	
Flooding	no	slight	moderate	severe	very severe
Teture and structure of topsoil	Z, SiL, ZCL, ZCs, SCLs, Cs, CLs, Ls	SCL, SCm, ZCm, Cm, HCs, CLm, Lm	HCm, SL, LS, S		
Teture/structure of subsoil	ZL,Z CL, ZCs, SCs, Cs, CLs, LS, CLm	SCL, SCm, Z, ZCm, Cm,HCs, CLm, Lm	HCm, SL, LS	S	
Surface stoniness (%)	<10% gravel <3% C, S, B	10-15% gravel 3-10% C,S,B	16-30% gravel 11-20% C,S,B	31-45% gravel 21-30% C,S,B	>45% gravel >30% C,S,B
Subsoil stoniness (%)	<15%	15-40	41-75	>75	
Depth with which water can penetrate (m)	>1.50	0.81-1.50	0.21-0.80	0.10-0.20	<0.15
Depth to root impenetrable layer (or rocky layer for annual crop)	>1.50	0.80-1.50	0.30-0.79	0.15-0.29	<0.15
Topsoil CEC (meq/100g)	>10	5-10	<5		
Base saturtion (A and B horizon)	B >50% A >80%	B any A >50%	B any A 35-50%	B <50 A <35%	
Topsoil Organic Matter	>3.2	2.1-3.2	1.0-2.0	<1.0	
Topsoil Salinity (ECe S/m)	<0.4	0.4-0.6	0.61-0.8	0.81-1.0	>1.0
Subsoil Salinity (ECe S/m)	<0.5	0.5-0.7	0.71-1.0	1.01-1.4	>1.4
Topsoil ESP	<8%	8-16%	17-25%	26-35%	>35%
Subsoil ESP	<10%	10-20%	21-30%	31-40%	>40%
Topsoil pH	5.6-8.0	5.1-5.5 8.1-8.5	4.5-5.0 8.6-9.0	<4.5 9.1-9.5	>9.5
Subsoil pH	5.6-8.2	5.1-5.5 8.3-8.7	4.5-5.0 8.8-9.2	<4.5 >9.2	

Appendix 4: Criteria to evaluate the non-climatic characteristics for pasture land evaluation, (after Zhange, 1990).

Limitation degree	0	1	2	3	4
Limitation score	0	1	3	9	27
Slope angle	0-7	8-15	16-25	26-30	>30
Landform and slope length	flat	short slope and moderately long slope	long slope	edge of gully	
Drainage	moderte-good	imperfect	poor	very poor	
Flooding	no-slight	moderate	severe	very severe	
Teture and structure of topsoil	Z, ZL, ZCL, ZCs, SCs, Cs, CLs, Ls	SCL, SCm, ZCm, Cm, HCs, SL, CLm, Lm	HCm, LS, S		
Teture/structure of subsoil	ZL, ZCL, ZCs, SCs, Cs, CLs, CLm, Ls	SCL, SCm, Z, ZCm, Cm, HCs, Lm	HCm, SL, LS, S		
Surface stoniness (%)	<15% gravel <3% C, S, B	16-30% gravel 3-15% C,S,B	31-45% gravel 16-40% C,S,B	46-60% gravel 40-75% C,S,B	>60% gravel >75% C,S,B
Subsoil stoniness (%)	<20%	21-40	41-60	61-75	>75
Depth with which water can penetrate (m)	>1.50	0.80-1.50	0.20-0.79	<0.20	
Depth to root impenetrable layer	>1.50	0.80-1.50	0.30-0.79	0.15-0.29	<0.15
Topsoil CEC (meq/100g)	>10	5-10	<5		
Base saturtion (A and B horizon)	B >50% A >80%	B any A >50%	B any A <50%		
Topsoil Organic Matter	>3.2	2.1-3.2	1-2	<1	
Topsoil Salinity (ECe S/m)	<0.4	0.5-0.8	0.9-1.3	1.4-1.8	>1.8
Subsoil Salinity (ECe S/m)	<0.5	0.6-0.9	1.0-1.4	1.5-2.0	>2.0
Topsoil ESP	<8%	8-15%	16-20%	21-25%	>25%
Subsoil ESP	<8%	8-15%	16-25%	26-40%	>40%
Topsoil pH	5.5-8.0	4.5-5.4 8.1-8.5	<4.5 8.6-9.0	9.1-9.5	>9.5
Subsoil pH	5.0-8.5	4.5-4.9 8.6-9.0	<4.5 9.1-9.5	>9.5	

Appendix 5: Criteria to evaluate the non-climatic characteristics for sorghum land evaluation, (after Zhange, 1990).

Limitation degree	0	1	2	3	4
Limitation score	0	1	3	9	27
Slope angle	<2	2-8	9-15	16-25	>25
Landform and slope length	flat	short slope	moderately long slope	long slope	edge of gully
Drainage	good	moderte	imperfect	poor	very poor
Flooding	no	slight	moderate	severe	very severe
Teture and structure of topsoil	Z, ZL, ZCL, ZCs, SCs, Cs, CLs, Ls	SCL, SCm, ZCm, Cm, HCs, CLm, Lm, SL	HCm, LS, S		
Teture/structure of subsoil	ZL, ZCL, ZCs, SCs, Cs, CLs, LS, CLm	SCL, SCm, Z, ZCm, Cm, CLm, Lm, HCs,	HCm, SL, LS	S	
Surface stoniness (%)	<10% gravel <3% C, S, B	11-15% gravel 3-10% C,S,B	16-30% gravel 11-20% C,S,B	31-45% gravel 21-30% C,S,B	>45% gravel >30% C,S,B
Subsoil stoniness (%)	<20%	20-40	41-75	>75	
Depth with which water can penetrate (m)	>1.50	0.81-1.50	0.31-0.80	0.15-0.30	<0.15
Depth to root impenetrable layer (or rocky layer for annual crop)	>1.50	0.81-1.50	0.31-0.80	0.15-0.30	<0.15
Topsoil CEC (meq/100g)	>10	5-10	<5		
Base saturtion (A and B horizon)	B >50% A >80%	B any A >50%	B any A 35-50%	B <50 A <35%	
Topsoil Organic Matter	>3.2	2.1-3.2	1.0-2.0	<1.0	
Topsoil Salinity (ECe S/m)	<0.2	0.2-0.4	0.41-0.6	0.61-0.8	>0.8
Subsoil Salinity (ECe S/m)	<0.4	0.4-0.8	0.81-1.20	1.21-1.6	>1.6
Topsoil ESP	<6%	6-10%	11-15%	16-20%	>20%
Subsoil ESP	<8%	8-14%	15-20%	21-25%	>25%
Topsoil pH	5.6-8.0	5.1-5.5 8.1-8.5	4.5-5.0 8.6-9.0	<4.5 9.1-9.5	>9.5
Subsoil pH	5.6-8.5	5.1-5.5 8.6-9.0	4.5-5.0 9.1-9.5	<4.5 >9.5	

Appendix 6: Criteria to evaluate the non-climatic characteristics for soybean land evaluation, (after Zhange, 1990).

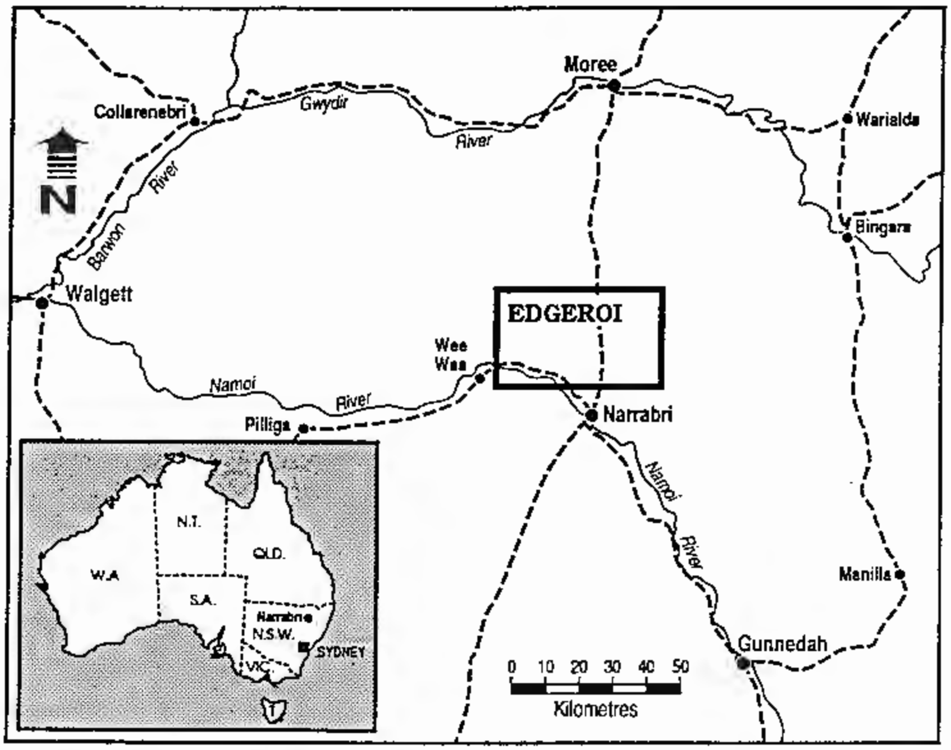
Limitation degree	0	1	2	3	4
Limitation score	0	1	3	9	27
Slope angle	<2	3-5	6-10	11-25	>25
Landform and slope length	flat	short slope	moderately long slope	long slope	edge of gully
Drainage	good	moderate	imperfect	poor	very poor
Flooding	no	slight	moderate	severe	very severe
Teture and structure of topsoil	Z, ZL, ZCL, ZCs, SCs, Cs, CLs, Ls, SCL	SCm, SiCm, Cm, HCs, CLm, Lm, SL	HCm, LS, S		
Teture/structure of subsoil	ZL, ZCL, SCL, ZCs, SCs, Cs, CLs, Ls	CLm, SCm, Z, ZCm, Cm, Lm,	HCs, SL, LS, HCm	S	
Surface stoniness (%)	<10% gravel <3% C, S, B	10-15% gravel 3-10% C,S,B	16-30% gravel 11-25% C,S,B	31-45% gravel 26-35% C,S,B	>45% gravel >35% C,S,B
Subsoil stoniness (%)	<20%	20-40	41-75	>75	
Depth with which water can penetrate (m)	>1.50	0.81-1.50	0.31-0.80	0.15-30	<0.15
Depth to root impenetrable layer (or rocky layer for annual crop)	>1.50	0.81-1.50	0.31-0.80	0.15-30	<0.15
Topsoil CEC (meq/100g)	>10	5-10	<5		
Base saturation (A and B horizon)	B >50% A >80%	B any A >50%	B any A 30-50%	B <50 A <30%	
Topsoil Organic Matter	>3.5	2.1-3.5	1.0-2.0	<1.0	
Topsoil Salinity (ECe S/m)	<0.4	0.4-0.7	0.8-1.5	1.6-2.0	>2.0
Subsoil Salinity (ECe S/m)	<0.4	0.4-1.0	1.0-2.0	2.1-2.5	>2.5
Topsoil ESP	<5%	5-8%	9-10%	11-18%	>18%
Subsoil ESP	<8%	8-10%	11-15%	16-25%	>25%
Topsoil pH	5.6-8.0	5.1-5.5 8.1-8.5	4.5-5.0 8.6-9.0	<4.5 9.1-9.5	>9.5
Subsoil pH	5.6-8.2	5.1-5.5 8.3-8.7	4.5-5.0 8.8-9.5	<4.5 >9.5	

Appendix 7: Criteria to evaluate the non-climatic characteristics for sunflower land evaluation, (after Zhange, 1990).

Limitation degree	0	1	2	3	4
Limitation score	0	1	3	9	27
Slope angle	<2	2-5	6-10	11-25	>25
Landform and slope length	flat	short slope	moderately long slope	long slope	edge of gully
Drainage	moderte-good	imperfect	poor	very poor	
Flooding	no	slight	moderate	severe	very severe
Teture and structure of topsoil	Z, ZL, SiCL, ZCs, SCs, Cs, CLs, Ls, SCL	SCm, ZCm, Cm, HCs, CLm, Lm, SL	HCm, LS, S		
Teture/structure of subsoil	ZL, ZCL, SCL, ZCs, SCs, Cs, CLs, CLm, Ls	SCm, Z, ZCm, Cm, Lm,	HCs, SL, LS	HCm,S	
Surface stoniness (%)	<10% gravel <3% C, S, B	10-15% gravel 3-10% C,S,B	16-30% gravel 11-20% C,S,B	31-45% gravel 21-30% C,S,B	>45% gravel >30% C,S,B
Subsoil stoniness (%)	<25%	20-40	41-75	>75	
Depth with which water can penetrate (m)	>1.50	0.81-1.50	0.31-0.80	0.15-30	<0.15
Depth to root impenetrable layer (or rocky layer for annual crop)	>1.50	0.81-1.50	0.31-0.80	0.15-30	<0.15
Topsoil CEC (meq/100g)	>10	5-10	<5		
Base saturtion (A and B horizon)	B >50% A >80%	B any A >50%	B any A 30-50%	B <50 A <30%	
Topsoil Organic Matter	>3.5	2.1-3.5	1.0-2.0	<1.0	
Topsoil Salinity (ECe S/m)	<0.4	0.4-0.6	0.61-1.00	1.01-1.50	>1.50
Subsoil Salinity (ECe S/m)	<0.4	0.4-0.6	0.61-1.00	1.01-1.50	>1.50
Topsoil ESP	<5%	5-8%	9-10%	11-12%	>12%
Subsoil ESP	<6%	6-9%	10-13%	14-16%	>16%
Topsoil pH	5.6-8.0	5.1-5.5 8.1-8.5	4.5-5.0 8.6-9.0	<4.5 9.1-9.5	>9.5
Subsoil pH	5.6-8.2	5.1-5.5 8.3-8.7	4.5-5.0 8.8-9.2	<4.5 >9.2	

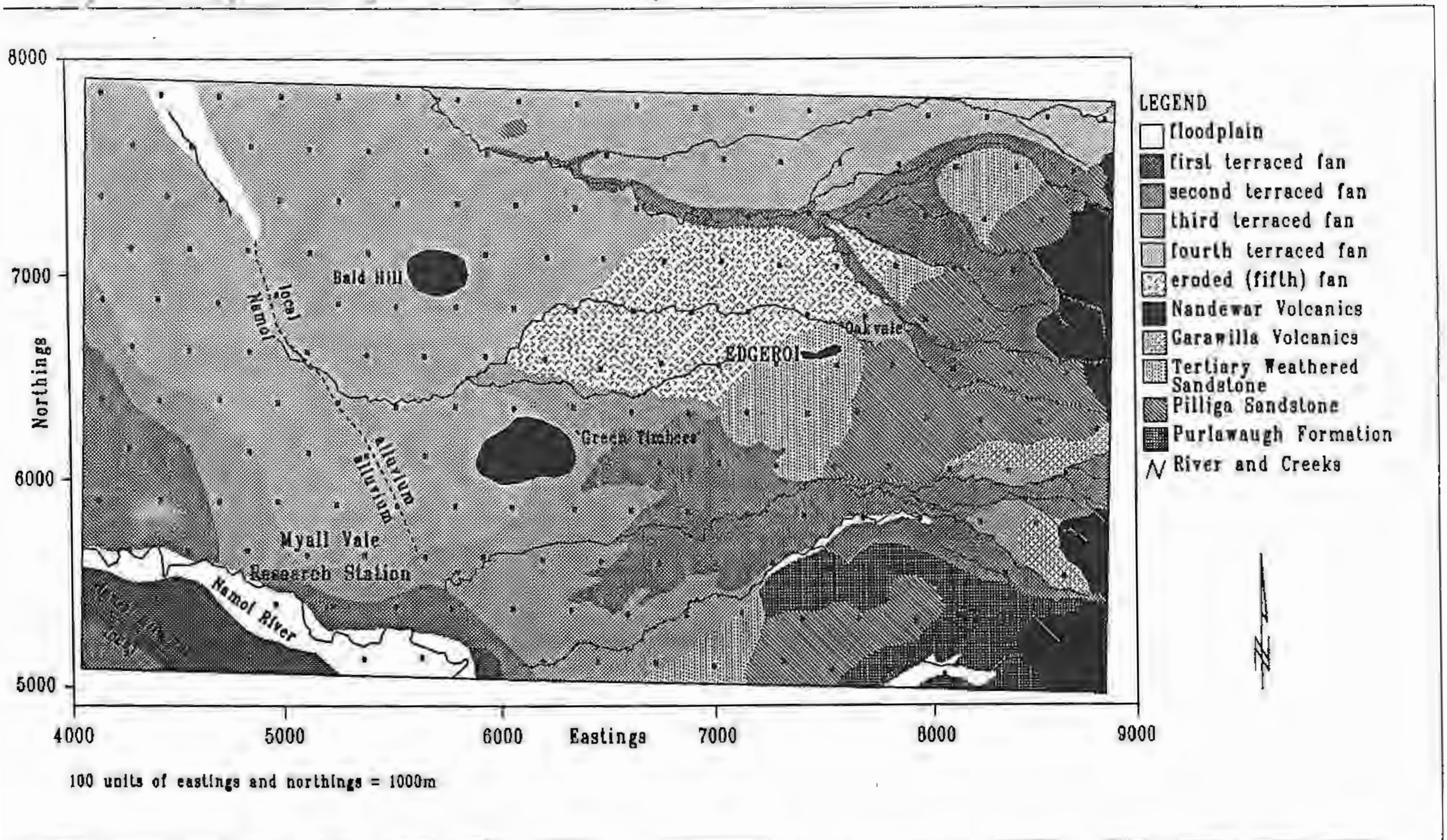
Appendix 8: Criteria to evaluate the non-climatic characteristics for wheat land evaluation, (after Zhange, 1990).

Limitation degree	0	1	2	3	4
Limitation score	0	1	3	9	27
Slope angle %	<2	2-8	9-16	17-25	>25
Landform and slope length	flat	short slope	moderately long slope	long slope	edge of gully
Drainage	moderte-good	imperfect	poor	very poor	
Flooding	no	slight	moderate	severe	very severe
Teture and structure of topsoil	Z, ZL, ZCL, ZCs, SCLs, Cs, CLs, Ls	SCL, SCm, ZCm, Cm, HCs, CLm, Lm	HCm, SL, LS, S		
Teture/structure of subsoil	ZL, ZCL, ZCs, SCs, Cs, CLs, LS, CLm	SCL, SCm, Z, SiCm, Cm,HCs, CLm, Lm	HCm, SL, LS	S	
Surface stoniness (%)	<10% gravel <3% C, S, B	10-15% gravel 3-10% C,S,B	16-30% gravel 11-20% C,S,B	31-45% gravel 21-30% C,S,B	>45% gravel >30% C,S,B
Subsoil stoniness (%)	<15%	15-40	41-75	>75	
Depth with which water can penetrate (m)	>1.50	0.81-1.50	0.21-0.80	0.10-0.20	<0.15
Depth to root impenetrable layer (or rocky layer for annual crop)	>1.50	0.80-1.50	0.30-0.79	0.15-0.29	<0.15
Topsoil CEC (meq/100g)	>10	5-10	<5		
Base saturtion (A and B horizon)	B >50% A >80%	B any A >50%	B any A 35-50%	B <50 A <35%	
Topsoil Organic Matter	>3.2	2.1-3.2	1.0-2.0	<1.0	
Topsoil Salinity (ECe S/m)	<0.4	0.4-0.6	0.61-0.8	0.81-1.0	>1.0
Subsoil Salinity (ECe S/m)	<0.5	0.5-0.7	0.71-1.0	1.0-1.5	>1.5
Topsoil ESP	<8%	8-16%	17-25%	26-35%	>35%
Subsoil ESP	<15%	15-25%	26-34%	35-45%	>45%
Topsoil pH	5.6-8.0	5.1-5.5 8.1-8.5	4.5-5.0 8.6-9.0	<4.5 9.1-9.5	>9.5
Subsoil pH	5.6-8.2	5.1-5.5 8.3-8.7	4.5-5.0 8.8-9.2	<4.5 >9.2	



Moree
Collarenebri
Gwydir
River
Warialda
Barwon
River
N
Bingara
Walgett
EDGEROI
Wee
Waa
Namoi
River
Narrabri
Pilliga
N.T.
QLD.
W.A.
S.A.
Narrabri
N.S.W.
SYDNEY
VIC.
T
Namoi
River
Manilla
Gunnedah
0 10 20 30 40 50
Kilometres

Figure 1



8000
7000
6000
5000
Northings
4000
5000
6000
Eastings
7000
8000
9000
Bald Hill
local
Namoi
alluvium
alluvium
Myall Vale
Research Station
Namoi River
'Green Timbers'
EDGEROI
Oakvale
LEGEND
floodplain
first terraced fan
second terraced fan
third terraced fan
fourth terraced fan
eroded (fifth) fan
Nandewar Volcanics
Garawilla Volcanics
Tertiary Weathered Sandstone
Pilliga Sandstone
Purlawaugh Formation
River and Creeks
N
100 units of eastings and northings = 1000m

Figure 2

Figure 4.

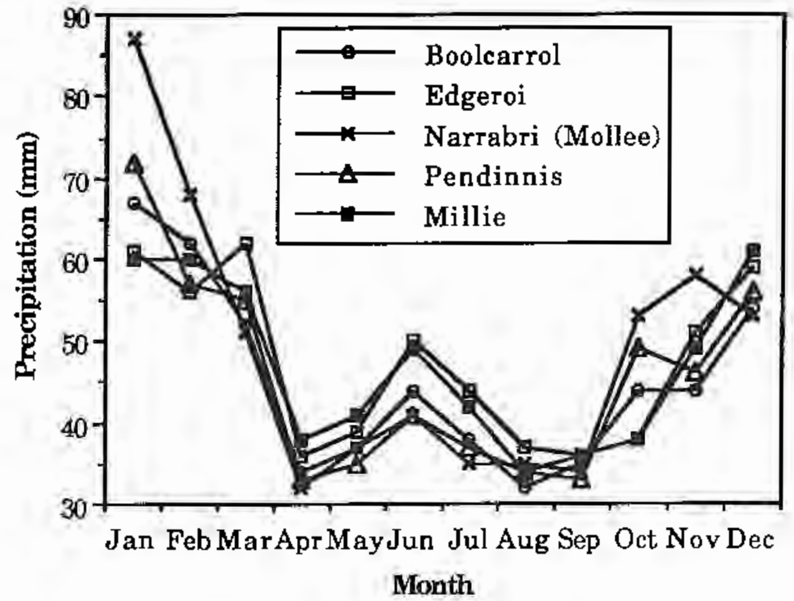
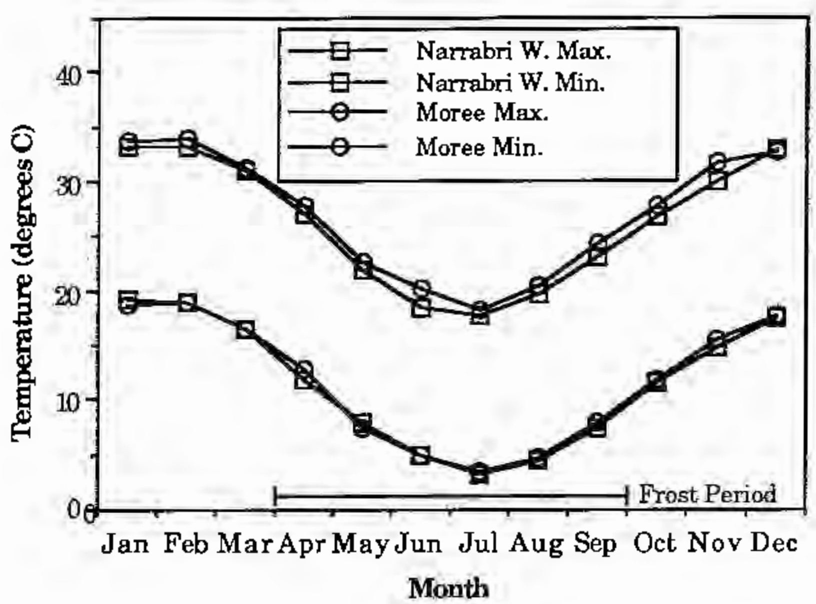
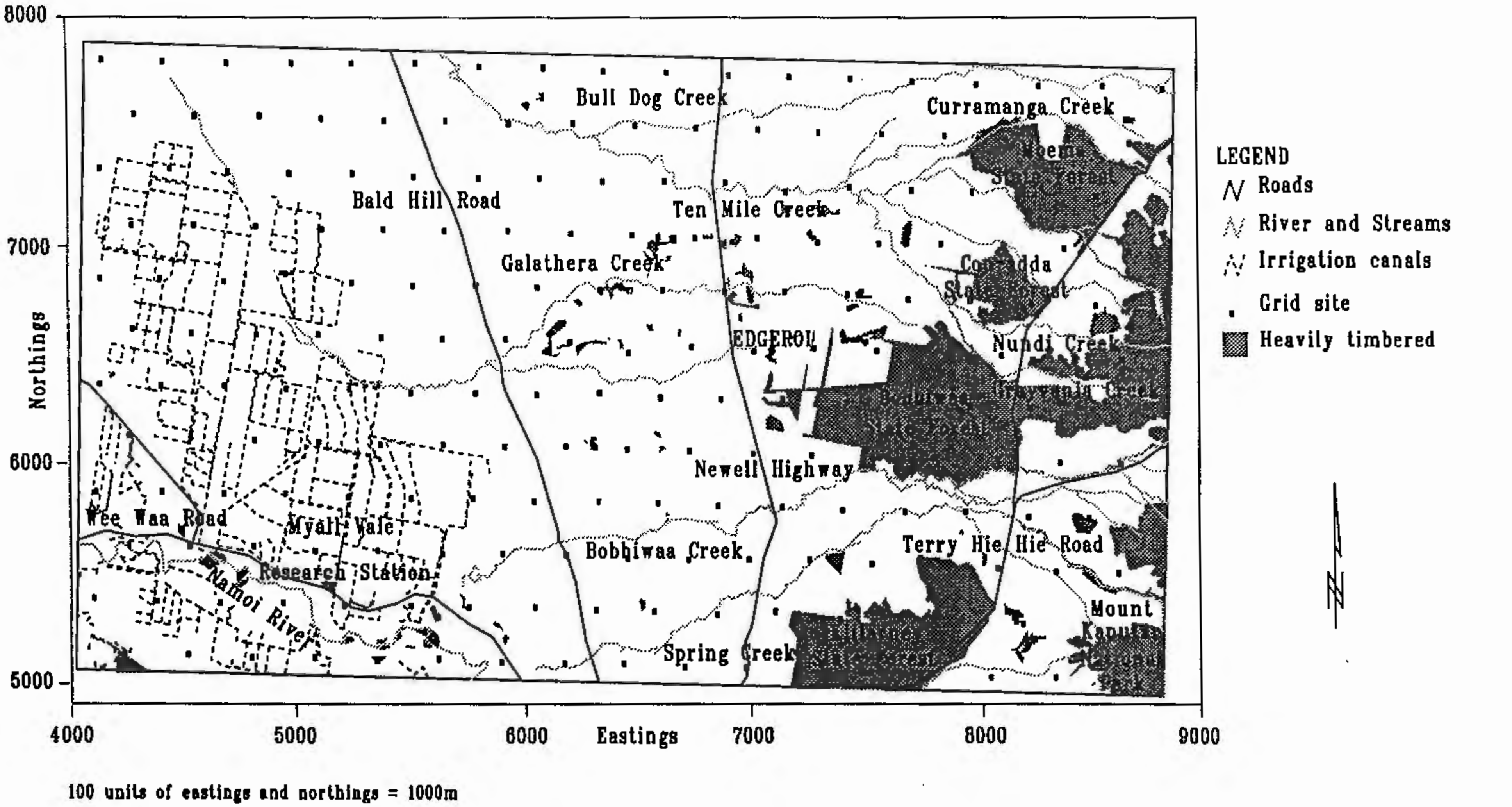


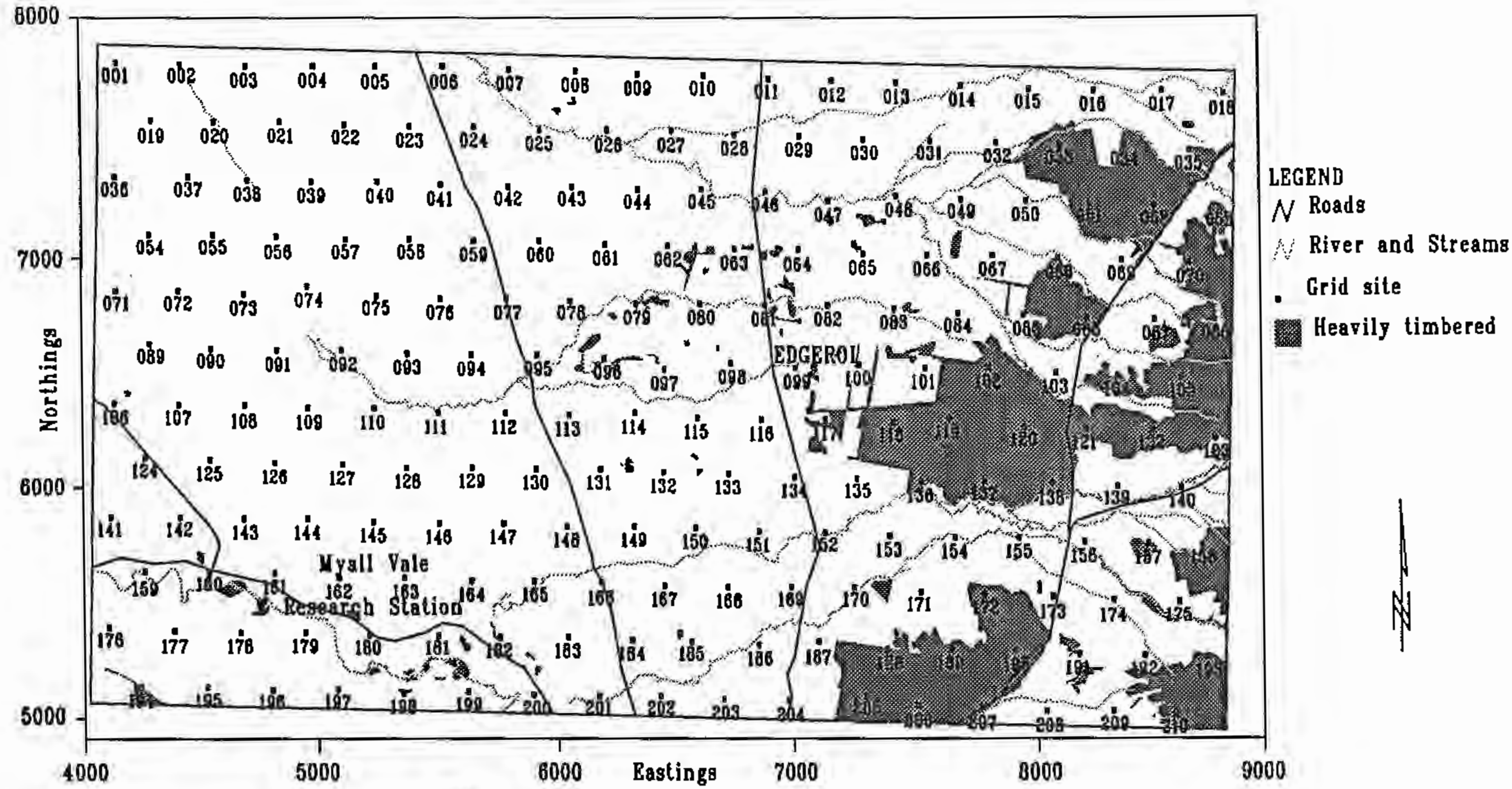
Figure 5.





8000
7000
6000
5000
Northings
4000
5000
6000
Eastings
7000
8000
9000
100 units of eastings and northings = 1000m
Bull Dog Creek
Curramanga Creek
Bald Hill Road
Ten Mile Creek
Galathera Creek
EDGEROI
Nundi Creek
Newell Highway
Wee Waa Road
Myall Vale
Research Station
Namoi River
Bobbiwaa Creek
Terry Hie Hie Road
Spring Creek
Mount
LEGEND
Roads
River and Streams
Irrigation canals
Grid site
Heavily timbered

Figure 6

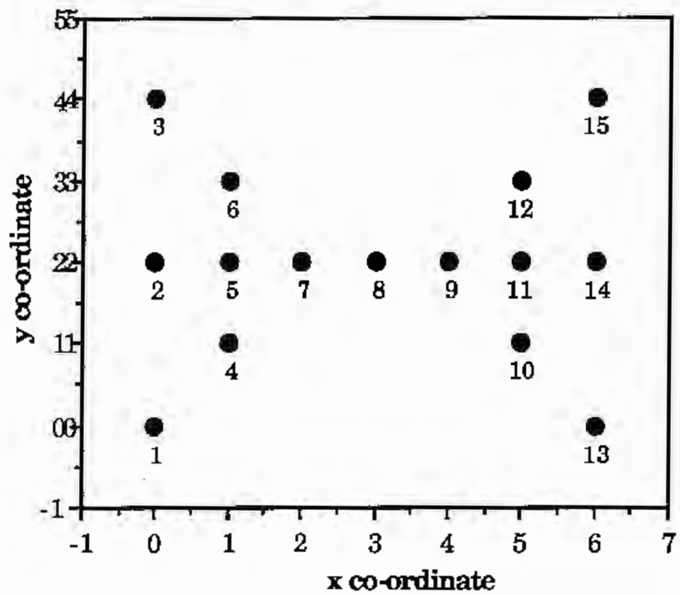


100 units of eastings and northings = 1000m

Internal boundary indicates the Edgeroi 1:50000 topographic map sheet boundary

Figure 7

Figure 8.



y co-ordinate
x co-ordinate
55
44
33
22
11
00
-1
-1
0
1
2
3
4
5
6
7
1
2
3
4
5
6
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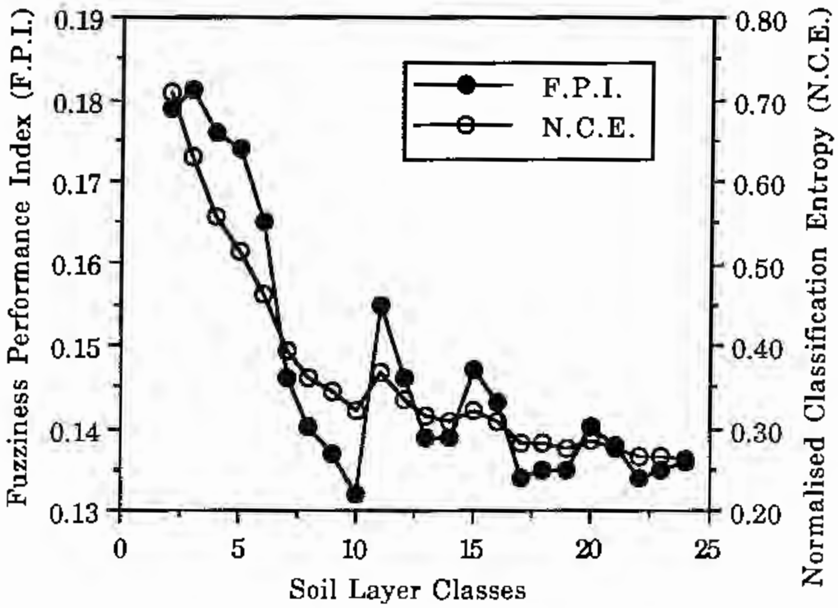
9
10
11
12
13
14
15

Figure 9.



0.19
0.18
0.17
0.16
0.15
0.14
0.13
Fuzziness Performance Index (F.P.I.)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
Normalised Classification Entropy (N.C.E.)
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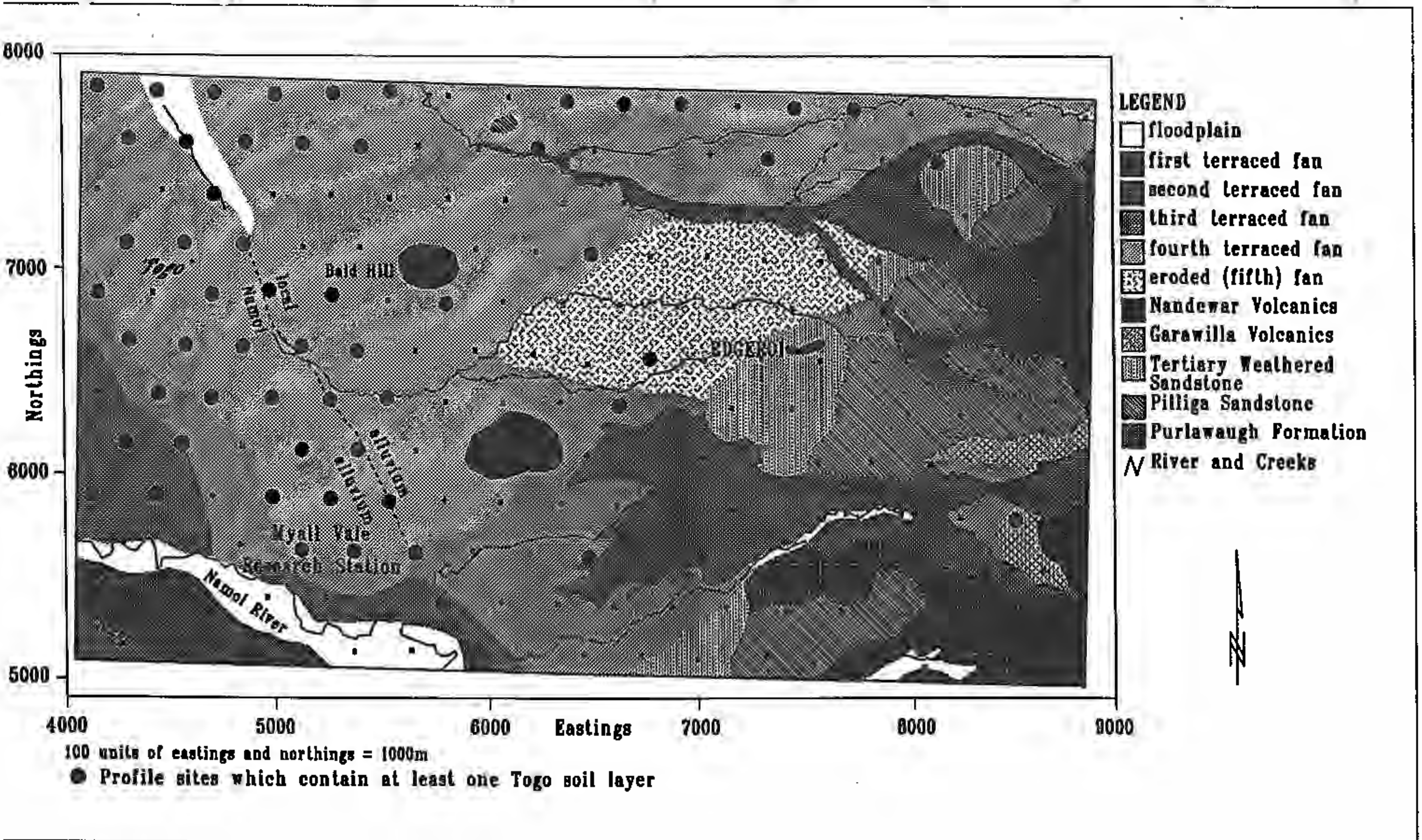
5
10
15
20
25
Soil Layer Classes
F.P.I.
N.C.E.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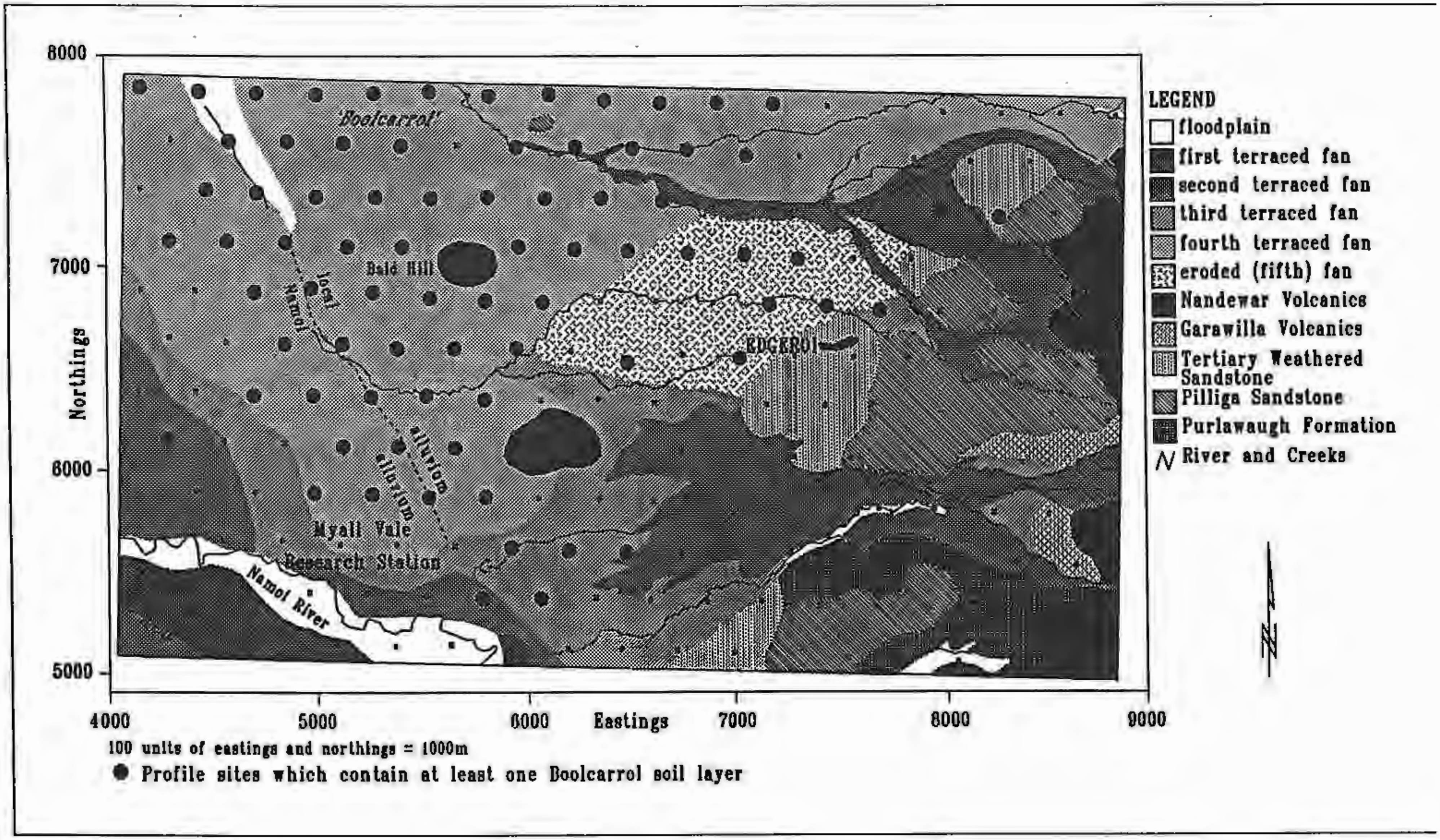
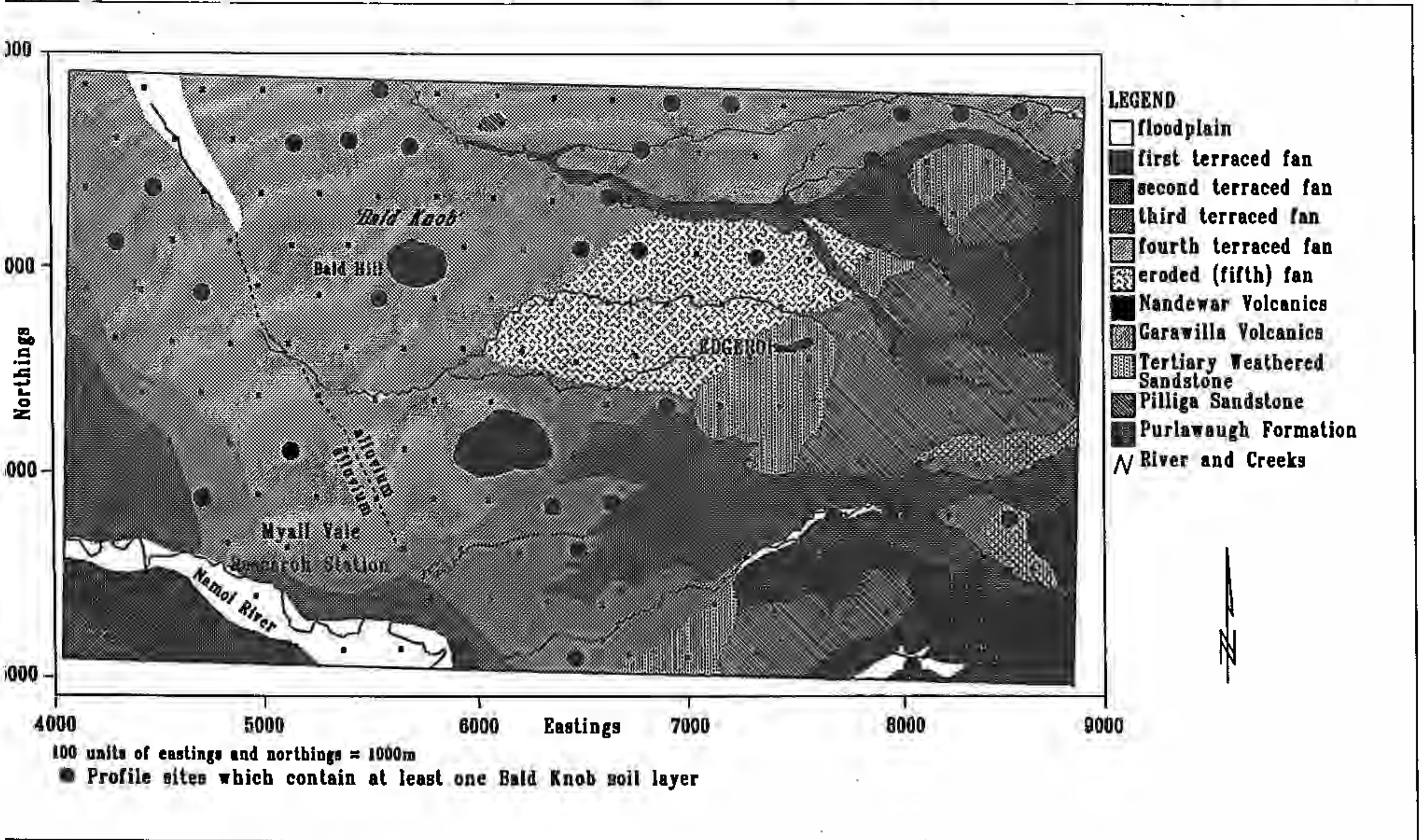
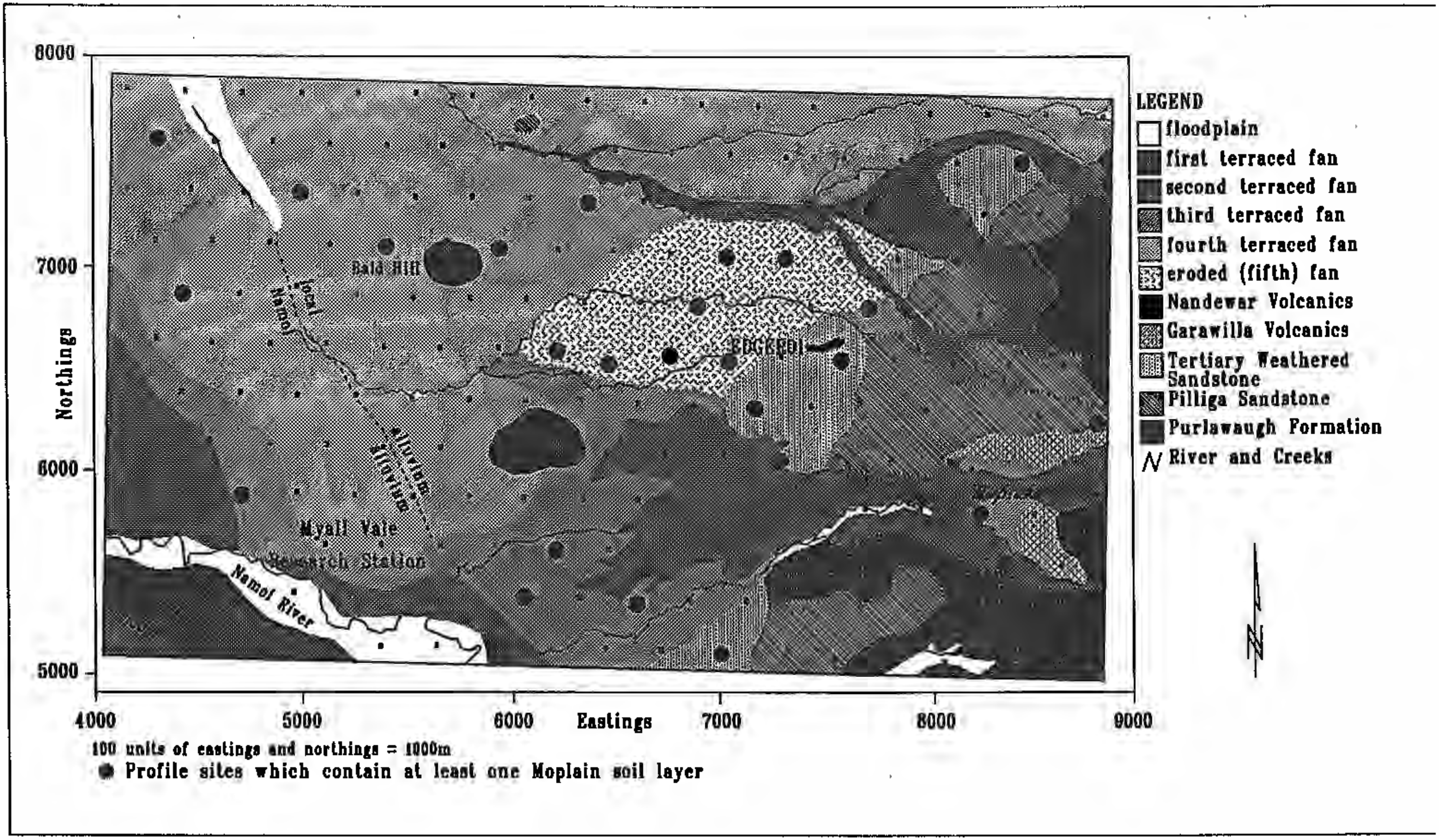
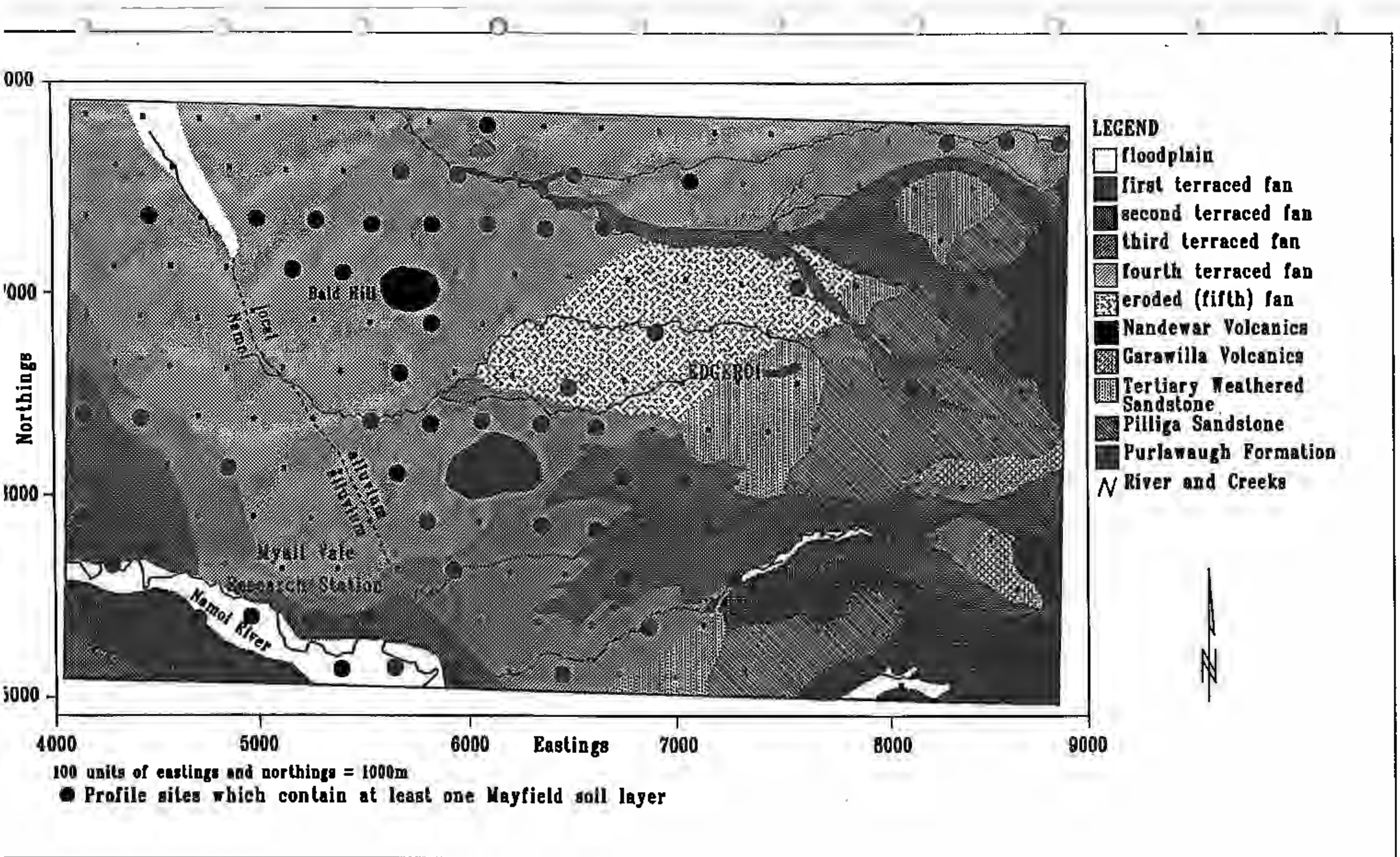
7000
6000
5000
Northings
4000
5000
6000
Eastings
7000
8000
9000
Togo
local
Namoi
Bald Hill
alluvium
alluvium
Myall Vale
Research Station
Namoi River
EDGEROI
LEGEND
floodplain
first terraced fan
second terraced fan
third terraced fan
fourth terraced fan
eroded (fifth) fan
Nandewar Volcanics
Garawilla Volcanics
Tertiary Weathered Sandstone
Pilliga Sandstone
Purlawaugh Formation
River and Creeks
100 units of eastings and northings = 1000m
Profile sites which contain at least one Togo soil layer

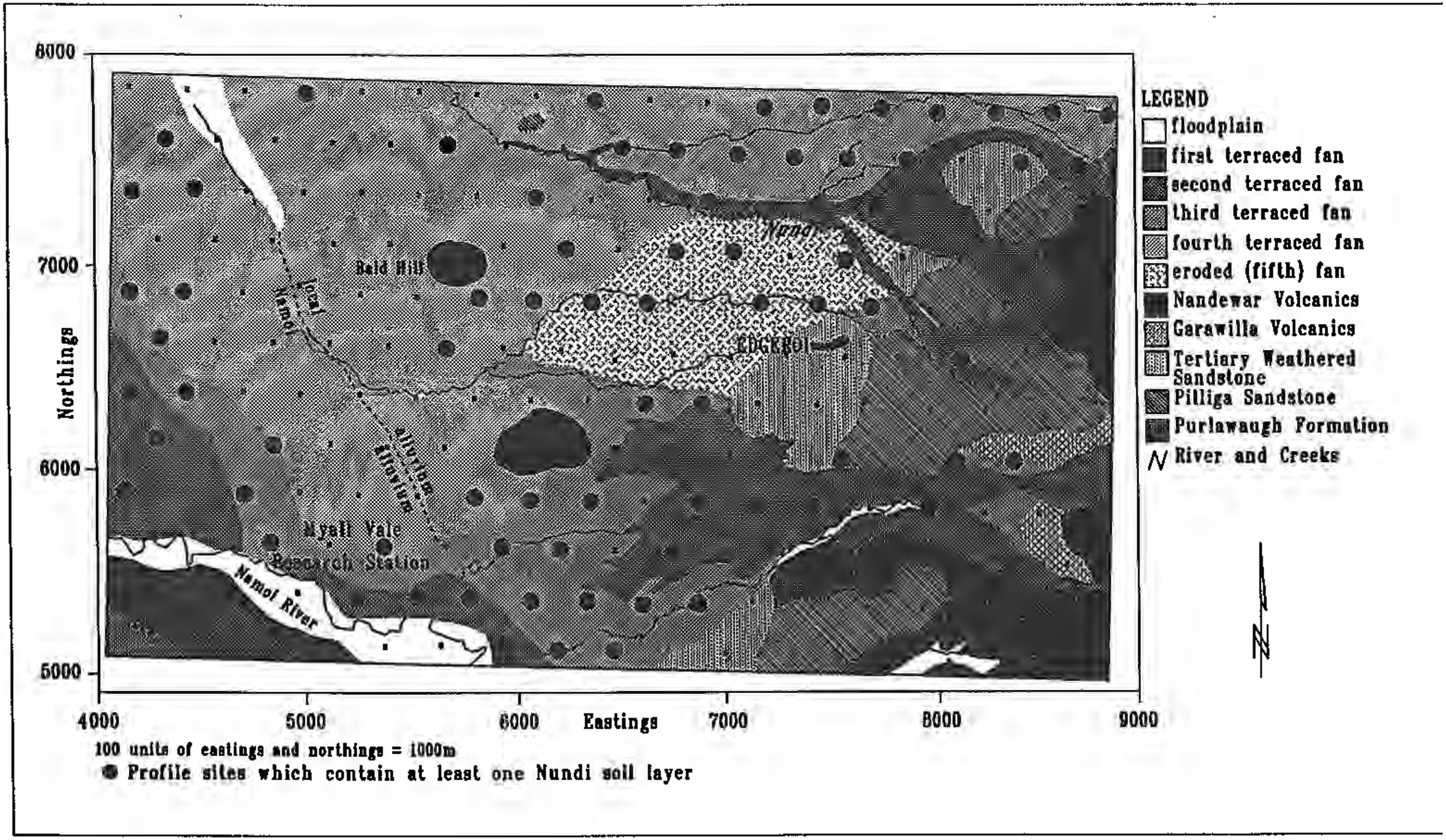

8000
7000
6000
5000
Northings
4000
5000
6000
Eastings
7000
8000
9000
'Boolcarrol'
Bald Hill
local
Namoi
alluvium
alluvium
EDGEROI
Myall Vale
Research Station
Namoi River
LEGEND
floodplain
first terraced fan
second terraced fan
third terraced fan
fourth terraced fan
eroded (fifth) fan
Nandewar Volcanics
Garawilla Volcanics
Tertiary Weathered Sandstone
Pilliga Sandstone
Purlawaugh Formation
River and Creeks
100 units of eastings and northings = 1000m
Profile sites which contain at least one Boolcarrol soil layer


LEGEND
floodplain
first terraced fan
second terraced fan
third terraced fan
fourth terraced fan
eroded (fifth) fan
Nandewar Volcanics
Garawilla Volcanics
Tertiary Weathered Sandstone
Pilliga Sandstone
Purlawaugh Formation
River and Creeks
'Bald Knob'
Bald Hill
EDGEROI
alluvium
eluvium
Myall Vale
Research Station
Namoi River
Northings
Eastings
4000
5000
6000
7000
8000
9000
100 units of eastings and northings = 1000m
Profile sites which contain at least one Bald Knob soil layer

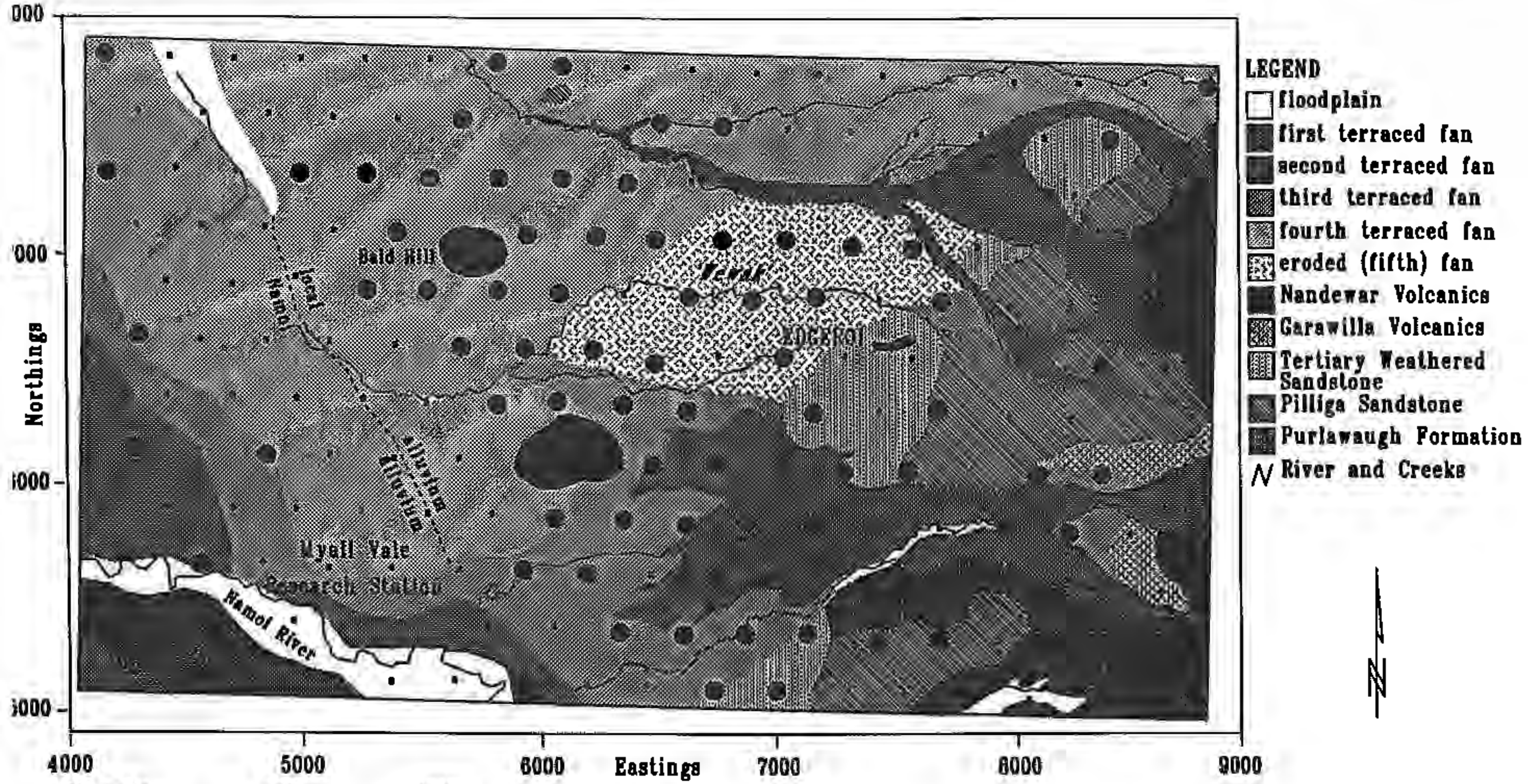


8000
7000
6000
5000
Northings
4000
5000
6000
Eastings
7000
8000
9000
Bald Hill
local Namoi alluvium
Myall Vale
Research Station
Namoi River
EDGEROI
LEGEND
floodplain
first terraced fan
second terraced fan
third terraced fan
fourth terraced fan
eroded (fifth) fan
Nandewar Volcanics
Garawilla Volcanics
Tertiary Weathered Sandstone
Pilliga Sandstone
Purlawaugh Formation
River and Creeks
N
100 units of eastings and northings = 1000m
Profile sites which contain at least one Moplain soil layer


LEGEND
floodplain
first terraced fan
second terraced fan
third terraced fan
fourth terraced fan
eroded (fifth) fan
Nandewar Volcanics
Garawilla Volcanics
Tertiary Weathered Sandstone
Pilliga Sandstone
Purlawaugh Formation
River and Creeks
Bald Hill
local Namoi alluvium
Myall Vale Research Station
Namoi River
Northings
Eastings
4000
5000
6000
7000
8000
9000
100 units of eastings and northings = 1000m
Profile sites which contain at least one Mayfield soil layer

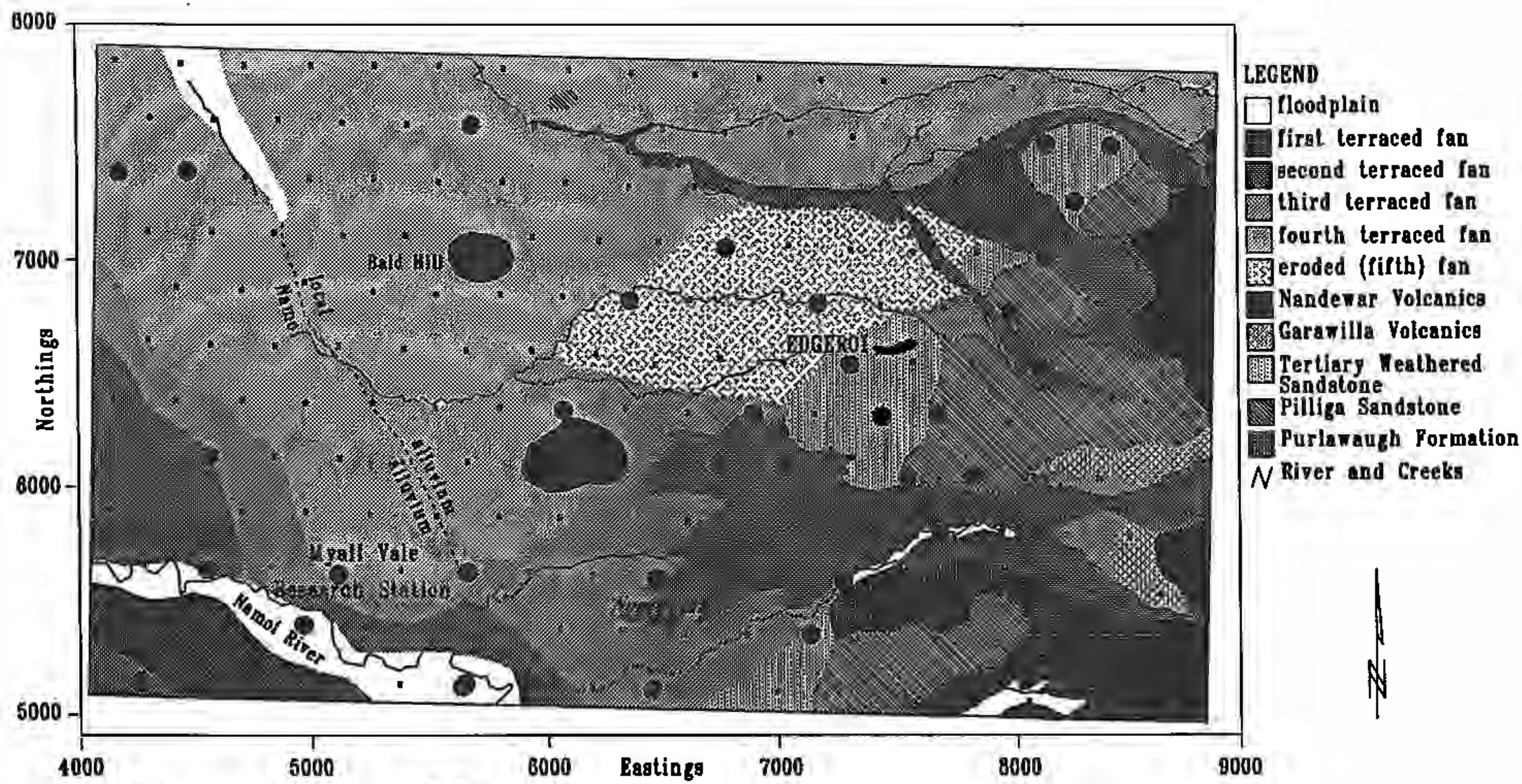


8000
7000
6000
5000
Northings
4000
5000
6000
Eastings
7000
8000
9000
Bald Hill
local
Namoi
alluvium
alluvium
Myall Vale
Research Station
Namoi River
Namoi
EDGEROI
LEGEND
floodplain
first terraced fan
second terraced fan
third terraced fan
fourth terraced fan
eroded (fifth) fan
Nandewar Volcanics
Garawilla Volcanics
Tertiary Weathered Sandstone
Pilliga Sandstone
Purlawaugh Formation
River and Creeks
100 units of eastings and northings = 1000m
Profile sites which contain at least one Nundi soil layer



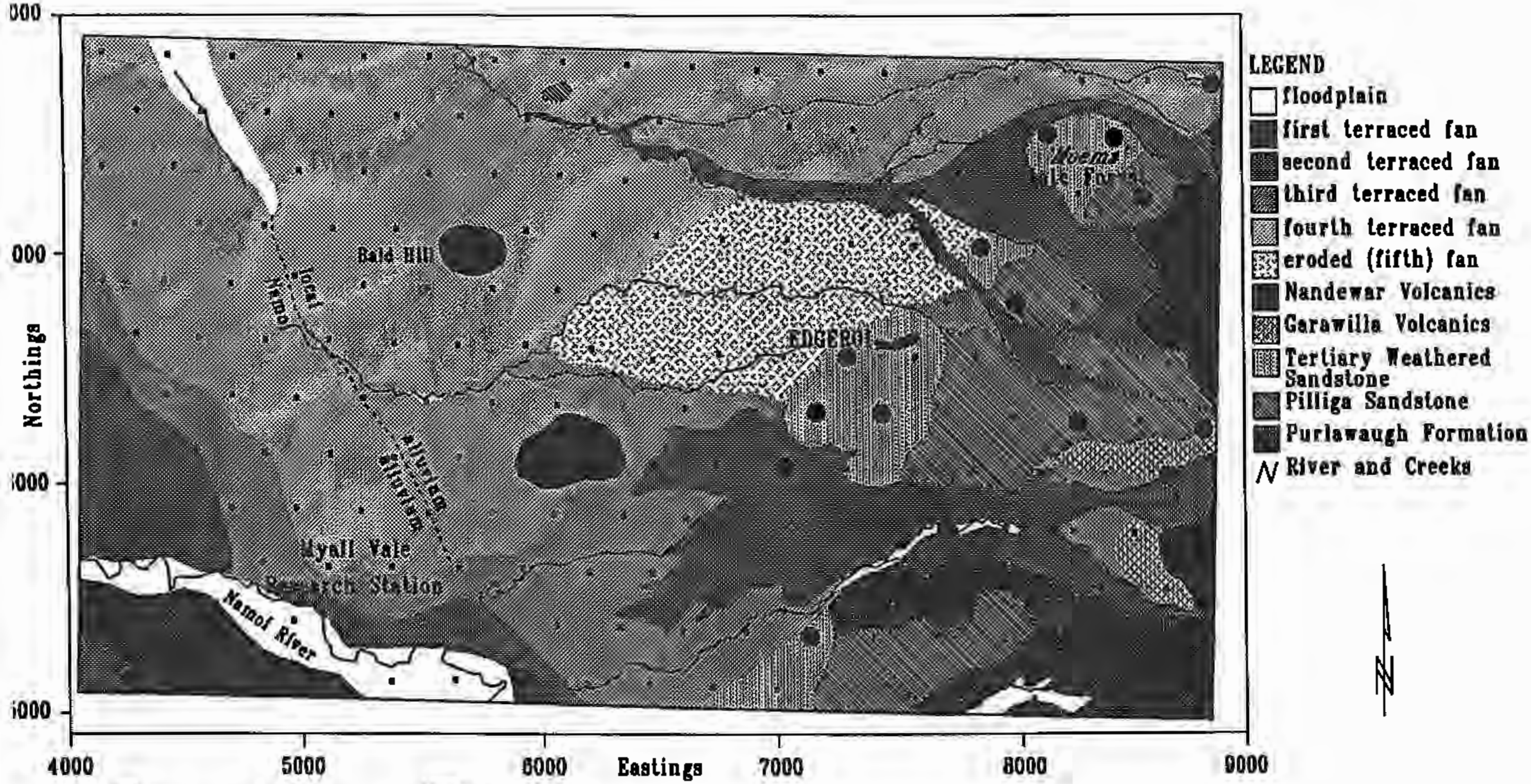
100 units of eastings and northings = 1000m

● Profile sites which contain at least one Wewak soil layer



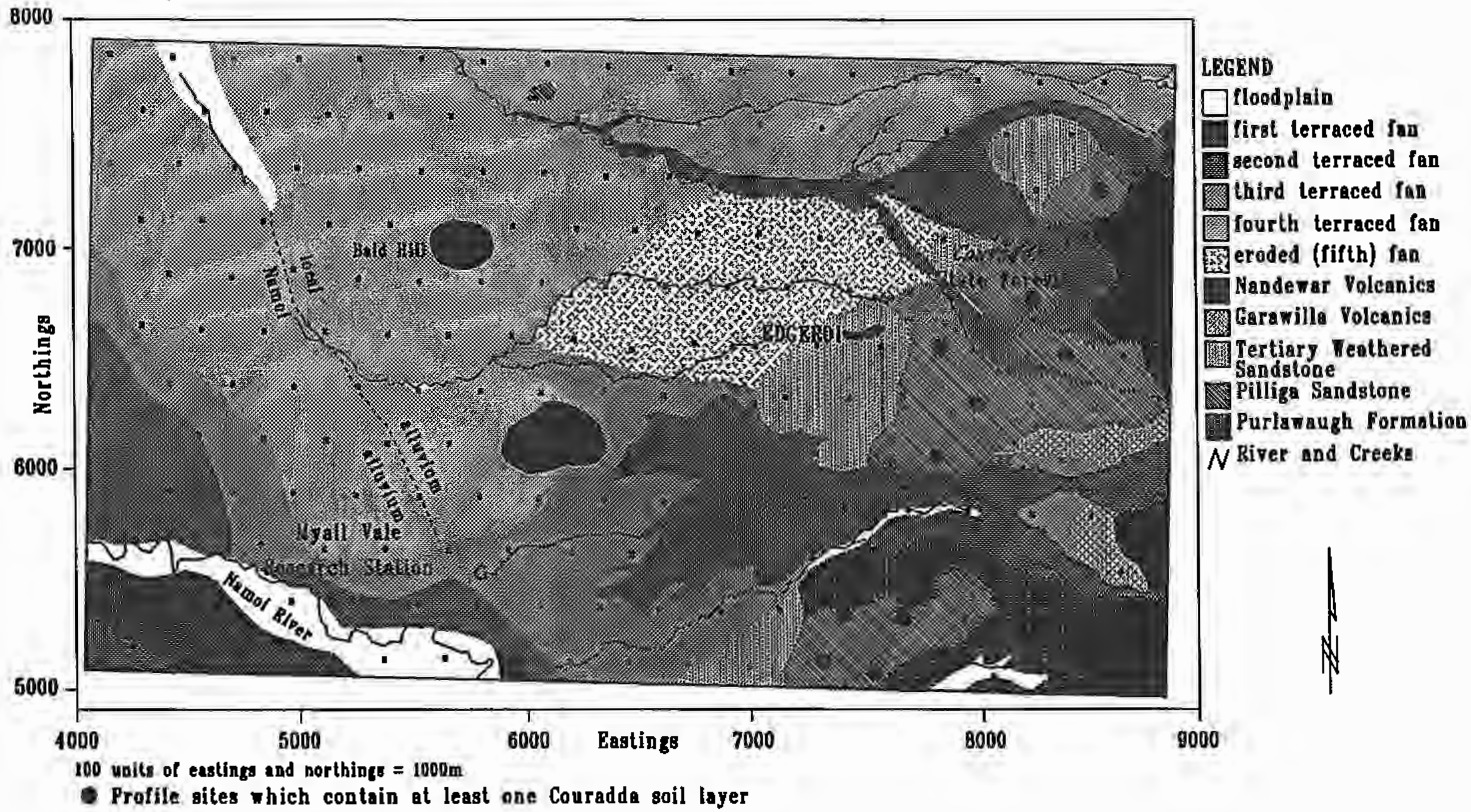
100 units of eastings and northings = 1000m

● Profile sites which contain at least one Noelurma soil layer

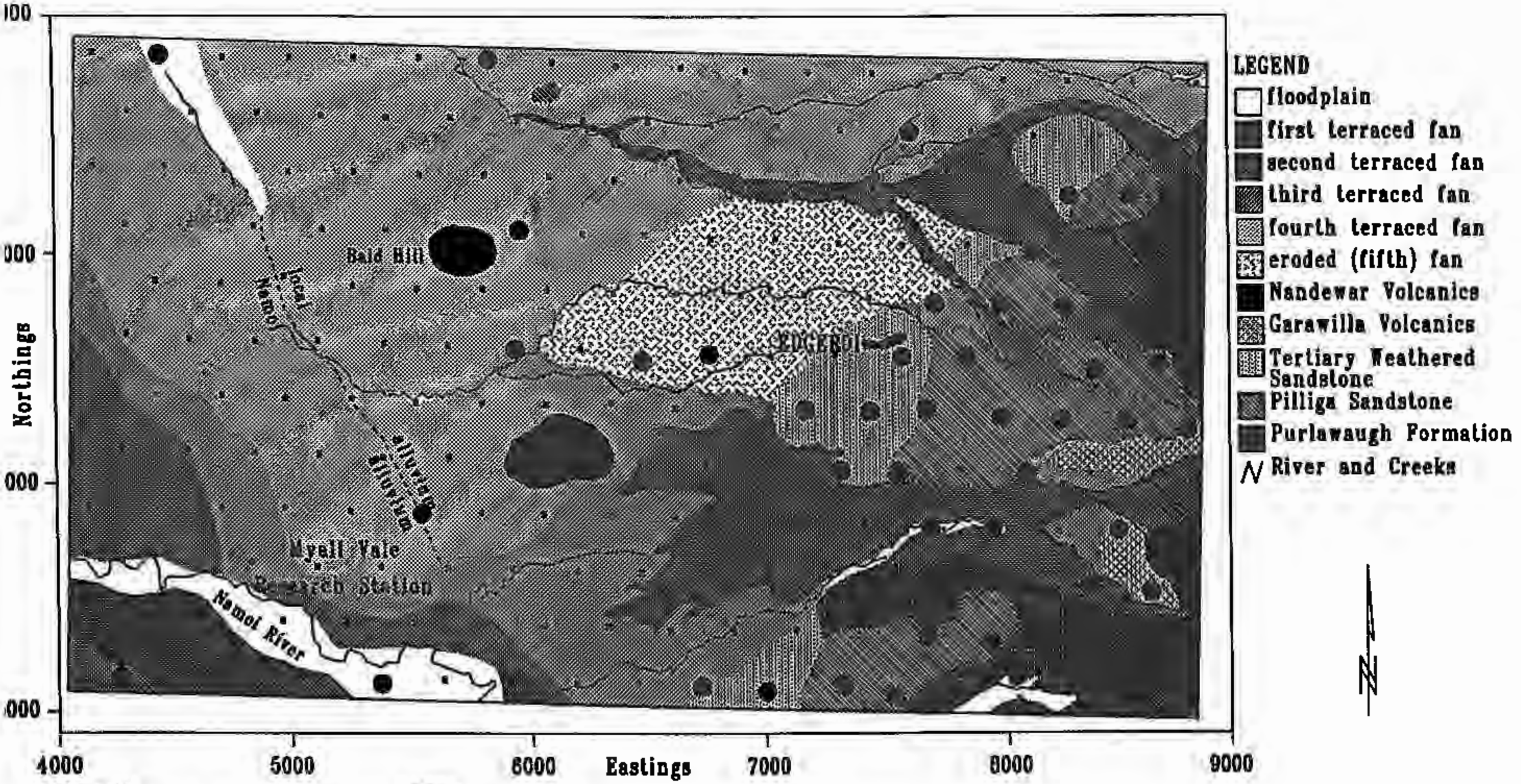


100 units of eastings and northings = 1000m

● Profile sites which contain at least one Moema soil layer



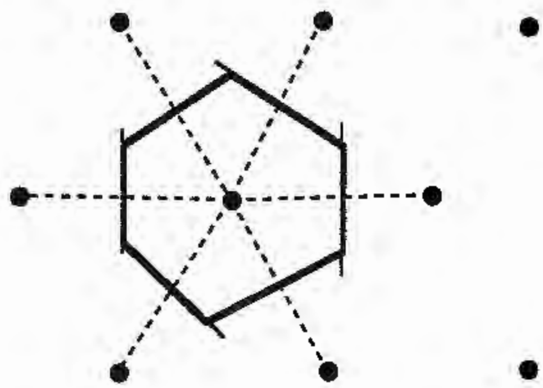
LEGEND
floodplain
first terraced fan
second terraced fan
third terraced fan
fourth terraced fan
eroded (fifth) fan
Nandewar Volcanics
Garawilla Volcanics
Tertiary Weathered Sandstone
Pilliga Sandstone
Purlawaugh Formation
River and Creeks
Northings
Eastings
8000
7000
6000
5000
4000
5000
6000
7000
8000
9000
Bald Hill
local
Namoi
alluvium
alluvium
Nyall Vale
Research Station
Namoi River
EDGEROI
N
100 units of eastings and northings = 1000m
Profile sites which contain at least one Couradda soil layer



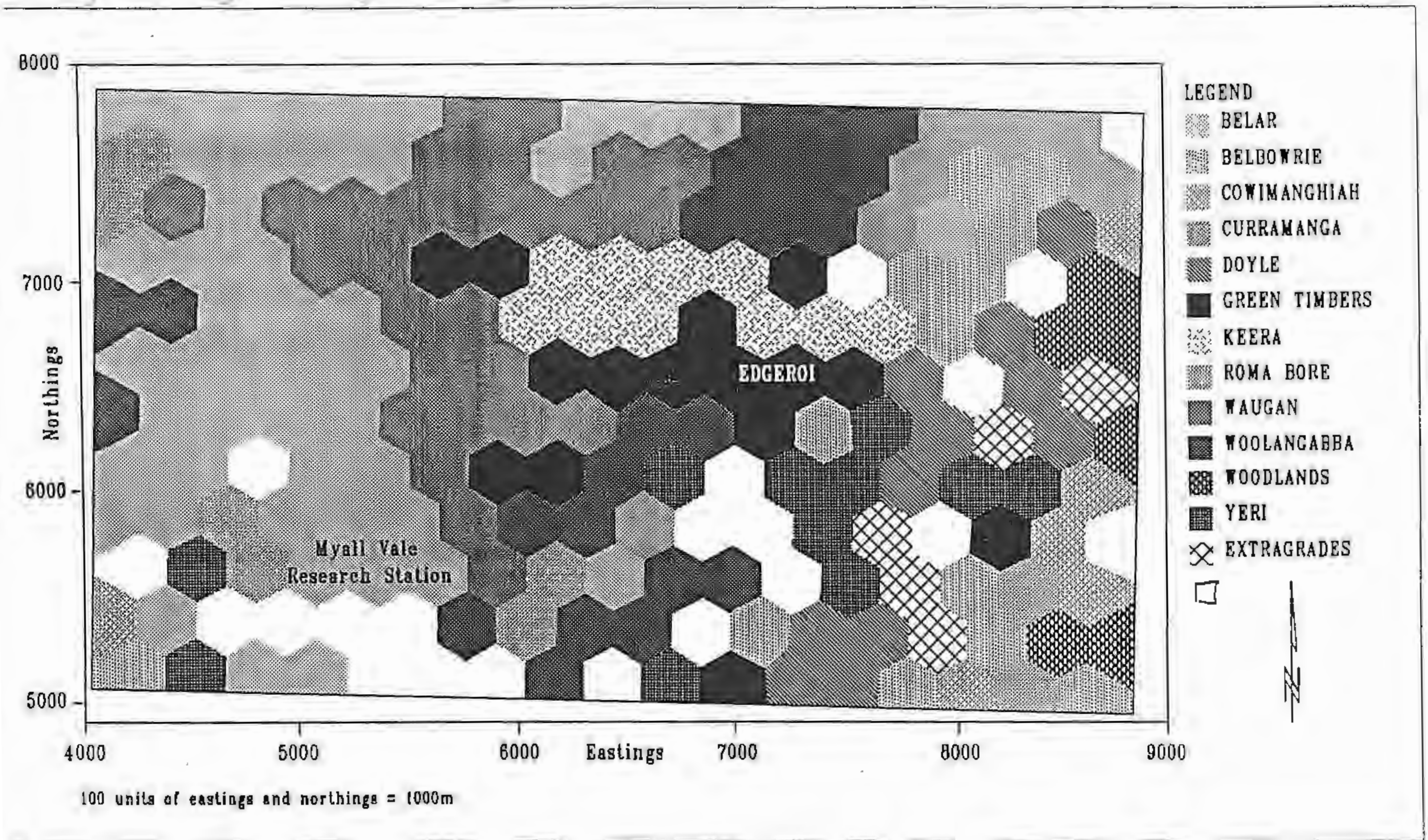
100 units of eastings and northings = 1000m

● Profile sites which contain at least one Extragrade soil layer

Figure 21.



- ● observation point
- - - - - - connecting line between an observation point and neighbouring observation points
- —— mid-normal or connecting line
- ▬▬ boundary of delineated area coincident with mid-normal



8000
7000
6000
5000
Northings
4000
5000
6000
Eastings
7000
8000
9000
EDGEROI
Myall Vale
Research Station
LEGEND
BELAR
BELBOWRIE
COWIMANGHIAH
CURRAMANGA
DOYLE
GREEN TIMBERS
KEERA
ROMA BORE
WAUGAN
WOOLANGABBA
WOODLANDS
YERI
EXTRAGRADES
N
100 units of eastings and northings = 1000m

Figure 22