# On-Farm Economics of Laser Landforming for Rice Farmers

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The whole farm financial effects of laser landforming were analysed using a two stage modelling procedure. In the first stage, linear programming models of representative Murrumbidgee Irrigation Area (MIA) rice farms were used to predict the profit-maximising activity mixes with and without successive increments of landforming. In the second stage, the profit-maximising activity mixes with and without an increment became inputs into a spreadsheet model designed to undertake discounted cash flow analysis of investment in the increment. The transition over time of yields to the achievable levels for landformed layouts was accounted for in the spreadsheet model, as were the effects of taxation (including taxation concessions for landforming) and access to concessional credit from the Special Conservation Scheme of the New South Wales Rural Assistance Authority. The analysis suggests that landforming the full area of a typical MIA rice farm is warranted, but that priority in allocating a limited capital budget should be given to areas requiring relatively low volumes of earth to be moved. A financial analysis of 'topsoiling' (replacing topsoil on areas from which it has been 'heavy cut' during landforming) showed it to generate considerably lower rates of return than landforming. Thus it appears landforming should be given priority over topsoiling in allocating a limited capital budget.

## 1. Introduction

Landforming is a process of carefully controlled earthmoving. It aims to modify a farm landscape in order to improve productivity of resource use. The first use in Australia of laser technology to enhance the accuracy of landforming was in 1977 (Hall *et al* 1983). Considerable proportions of irrigated areas in New South Wales (NSW) and Victoria have been laser landformed since that time. The proportions of the aggregate areas of rice farms landformed in the Murrumbidgee and Murray Valley zones of NSW in 1986/87 have been estimated at 29 per cent and 12 per cent respectively (Young 1989). By 1988 a total of 37 per cent of the average area irrigated in the Goulburn Murray Irrigation District of Victoria is estimated to have been landformed (Patto 1989).[1]

The Irrigation Farm Working Group (1986, p. 83) found there was a lack of technical information regarding the effects of landforming and concluded that "any investment in landforming would need the closest assessment to determine if it was justified on the basis of increased returns". Patto (1989) suggested research and extension has lagged in assisting farmers to assess the claims and counter-claims made for the value of the technique.

In this paper, a study of the on-farm economics of landforming on rice farms in the Murrumbidgee Irrigation Area (MIA) in southern NSW is reported. Rice farming (which generally includes pasture and other crops grown in rotation with rice) represents the dominant land-use within the irrigation areas and districts of southern NSW. The on-farm economics of topsoiling (ie. the process of replacing topsoil on areas from which a substantial depth of topsoil is removed during landforming) was also examined. The hypotheses tested in this study were:

(i) farmer wealth is maximised by landforming the full farm area;

(ii) there are constant returns from landforming successive increments of the farm area;

(iii) given a capital constraint, farmer wealth is maximised by positively relating priority of a landforming job to the volume of earthmoving required to attain plane of best fit[2]; and

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[1] Since it is unlikely that any landforming in Australia is now undertaken without laser guidance, landforming will be taken to mean laser landforming for the remainder of the paper. Thus 'not landformed' or 'non-landformed' as applied to a particular area does not rule out the area having been previously landformed without laser guidance.

[2] For a particular area under consideration for landforming, the plane of best fit is the plane (ie. two-dimensional surface) requiring for its attainment the least volume of earth to be moved.

(iv) given a capital constraint, farmer wealth is maximised by giving priority in capital allocation to landforming over topsoiling (ie. topsoiling should be undertaken only where there would be capital remaining after landforming the full farm area).

The purpose of hypothesis (ii) was to examine the impact of the opportunity cost of irrigation water, the availability of which was assumed fixed by a farmer's irrigation entitlement, upon returns from landforming. Irrigation intensities of crops and pastures often increase following landforming as farmers attempt to realise the higher yields achievable from landformed layouts. Irrigation water may then become a more limiting resource with a higher marginal value product. Thus as the total area of landforming increases, there is a possibility of marginal landforming returns declining due to increasing marginal opportunity cost of reallocating water to landformed areas. Hypothesis (iii) was suggested from comments of advisers that they were often asked by farmers whether they should give priority to landforming the 'best' (relatively little earthmoving required to attain a given layout standard) or 'worst' (relatively extensive earthmoving required to attain a similar standard) areas of their farms. Hypothesis (iv) stems from access to capital being limited for most farmers and the choice consequently arising regarding how to allocate available capital between landforming and topsoiling.

## 2. Modelling Approach

A two stage modelling procedure was developed. In the first stage, a single period linear programming (LP) model was used to determine the profit-maximising farm plans of a representative farm with and without a particular landforming investment. This was achieved by parametrically changing the land area constraints associated with landformed and non-landformed layouts. The labour and water use and yield coefficients used were those applicable once soil conditions have attained their steady-state level and management is familiar with the intricacies of landformed layouts.

In the second stage, the profit-maximising 'steady-state' farm plans with and without a landforming investment became inputs into a spreadsheet model designed to undertake discounted cash flow analysis of the investment. This model calculated the present values of post-tax benefits and costs from the increment, allowing the net present value (NPV) and benefit-cost ratio (BCR) for the investment to be derived. The NPV and BCR of topsoiling during an increment were also calculated. The spreadsheet model also took into account changes in yield coefficient values during the transition to steady-state levels (see Section 3.1.1 for details).

In fact, three representative farms were modelled, differentiated by a number of characteristics influencing the cost and physical effects of landforming. These were adapted from Jones (1991)[3]. The size of each representative farm was 200 hectares. It was assumed each farm could be landformed in up to five 40 hectare increments. The question being addressed was that of how much of each farm should be ultimately landformed, rather than that of the optimal scheduling of increments through time. Hence farmers were modelled as deciding in year 0 the number of increments to be undertaken and also as completing all those increments in that year.

An optimising routine such as LP was used because it was expected that changes in a range of input-output coefficients resulting from landforming (mainly associated with activity labour and water use and with yields) would lead farmers to significantly alter their farm plans so as to realise the profit gains afforded by investment in landforming. Ignoring these changes in a farm plan would therefore result in the profit gain from landforming being significantly under-estimated. Tainsh (1985) accounted for change to a farm plan following landforming by exogenously predicting what the new feasible farm plan would be. Application of LP to this problem in this study had the advantage of endogenously identifying the farm plan which maximises whole farm gross margin at the same time as ensuring compliance with a wide range of

[3] The adaptation involved revision of yield coefficients for non-landformed layouts to take into account losses from ponding and sub-optimal timing of field operations, revision of variable costs of activities to take into account effect of layout on field efficiency and revision of water application coefficients according to the irrigation efficiency of a layout.

technical constraints. This is an outcome which an iterative exogenous procedure would have achieved much less efficiently.

The fundamental distinguishing characteristic of a representative farm, influencing a number of other characteristics, was the volume of earth required to be shifted during landforming to attain the plane of best fit. The volumes 200 $m^3$, 350 $m^3$ and 500 $m^3$ per hectare were chosen to cover the range of MIA rice farming layouts on which landforming would realistically be undertaken (Darnley-Naylor, pers. comm. August 1990). Greater requirements for earthmoving are generally associated with greater undulation of the current land surface within paddocks. In turn, greater undulation is often associated with paddocks with 'steeper' slopes (where 'steep' MIA rice farming country would have a slope of 1:1000 compared with 1:3000 for 'flat' country).

### 2.1 Further details regarding the linear programming models

The objective function of the LP models was assumed to be that of a risk-neutral farmer aiming to annually maximise expected whole farm gross margin.

The full 200 hectares of each representative farm was assumed to be laid out for irrigation. The irrigation water entitlement corresponding with a MIA farm this size is 1,360 megalitres. However, MIA rice farmers receive at least their entitlement in 96 years in every 100 and on average receive up to 120 per cent of annual entitlement (Jones *et al* 1992).[4] The allocation specified in the models was 1,496 megalitres (110 per cent of entitlement). Following Ryan (1969), each representative farm's permanent labour supply consists of the owner-operator and one permanent employee.[5] The model also provides for employment of casual labour.

Crops and pasture were included as components of rotation activities. The basic rotation structure was rice followed by wheat followed by annual pasture. Rotations were distinguished according to the number of seasons in which each component is consecutively grown. (Some rotations did not include wheat at all, although all included some rice and annual pasture). The areas of representative farms landformed and not landformed were specified separately as constraints. Yield and other technical coefficients differed according to whether the land on which a rotation activity occurs had been landformed or not. The area planted to rice was restricted to a maximum of 71 hectares per farm in accordance with the policy implemented by the NSW Department of Water Resources in conjunction with the Rice Industry Co-ordination Committee. Land not irrigated could be used for dryland (unirrigated) pasture.

The model provides for a choice from a number of sheep activities, including a merino self-replacing enterprise, prime lamb production (both first and second cross) and wethers, which withdraw from seasonal feed pools. Unused spring feed can be transferred to summer with 30 per cent efficiency. Hay can be made from irrigated annual pasture in spring to supplement the summer or autumn feed pools. Wheat stubble contributes to the summer feed pool.

### 2.2 Simplifying assumptions regarding the landforming situation

Simplifying assumptions used to focus the study are discussed below.

2.2.1 Farm activities following landforming

The representative farmers are assumed to consider landforming as a means of improving the profitability of conventional rice rotations rather than as an opportunity to diversify into other activities such as perennial pasture, alternative summer crops or vegetables. Lack of alternative summer activities offering comparable gross margins to rice, together with unfamiliarity with management of

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[4] This ratio applies to entitlements classified as having 'normal' supply security. Entitlements held by rice farmers fall into this class.

[5] Recent support for the representativeness of this level of permanent labour supply comes from a survey of the NSW rice industry relating to 1986-87 (Australian Bureau of Agricultural and Resource Economics 1988). For the Murrumbidgee Valley, family rice farms are seen to have utilised on average two work-years of family labour. For all rice farms in the Murrumbidgee Valley, 1.6 work-years of labour were utilised on average.

these alternatives, has meant that after landforming many farmers do retain the contour bay layout necessary for rice culture[6].

2.2.2 Slope modification by landforming

With rice growing retained after landforming, the relatively flat gradients within the contour bays prior to landforming are unlikely to require significant modification. The rice plant, which thrives under waterlogged conditions and which usually provides a high proportion of the total gross margin for rotations in which it is included, does not gain from any improvement in surface drainage associated with increasing bay slope. Hence rice farmers were assumed to aim for plane of best fit in their landforming operations.[7]

2.2.3 Soil type

Rice farms in the MIA generally encompass a variety of soil types. Soil type affects the impact of landforming on soil structure and fertility and consequently on plant growth. To simplify the decision problem being modelled, the full area of each representative farm was assumed to be underlain by a duplex soil (having a sharp differentiation in the soil profile between topsoil and subsoil) with shallow topsoil (less than 10 centimetres) and a heavy clay subsoil.

2.2.4 Adequacy of off-farm surface drainage system

The potential benefit of improved surface drainage from landforming will be fully realised only if the increased volume of drainage water (due to lower losses from evaporation and deep percolation[8]) can be drained from the farm rather than be allowed to pond in low-lying sections of the farm. Representative farms were assumed to have access to an off-farm drainage network (as is the case in the MIA) and to have adequate on-farm drainage systems. Hence the full surface drainage benefits of landforming should be realised.

2.2.5 Watertable depth

It was assumed that, during the time horizon of the analysis, the depth of the watertable underlying each representative farm remains below the level at which soil salinisation occurs and waterlogging is exacerbated. This removed the need to model the differential effects of shallow watertables on yields according to whether a layout is landformed or not. While incorporation of watertable effects would be desirable, there is a lack of documented research evidence regarding these effects.

## 3. Accounting for the Benefits and Costs of Landforming

Landforming affects whole farm financial performance in a variety of ways. In this section these effects are discussed and the manner in which they were accounted for in the financial analysis is indicated.

### 3.1 Landforming Benefits

3.1.1 Increased crop and pasture yields

Landforming contributes to improved crop and pasture yields as follows:

(a) evenness of water application across an irrigation bay is increased, thereby improving seedling establishment and uniformity of plant growth and maturity;

(b) uniformity of ponding depth for rice is increased, thereby improving weed control and providing better protection against cold stress at the time of pollen microspore (an early stage of pollen development);

(c) time needed to irrigate and drain an irrigation

[6] This is essentially a system of terraced irrigation bays within a paddock, the banks of the bays following the prevailing contours. The area within a bay slopes only slightly toward the bank, enabling relatively even depth of ponding across the bay.

[7] In some instances the plane of best fit may create a near level slope on which the rate of surface drainage is undesirably slow, particularly where inaccuracies in lanforming have left some areas sloping in the wrong direction. In these cases a minimum slope should be adopted.

[8] Deep percolation represents infiltration of water through a soil profile to below the crop or pasture rootzone.

bay is lessened, thereby reducing problems of transient waterlogging and scalding and enabling scheduling of irrigations more closely to plant needs;

(d) the productive area of a paddock is expanded by reducing area lost to banks and water supply channels;

(e) the productive area of a paddock can be expanded by lowering any areas previously too elevated to be irrigated given the existing water supply network; and

(f) chronic waterlogging in low-lying areas of irrigation bays is overcome.

The yield and pasture production estimates shown in Table 1 for layouts landformed and not landformed incorporate effects (a), (b), (c) and (d). These yield estimates were provided by advisory agronomists and presume average seasonal conditions. They can be considered achievable yield levels for a reasonable manager, and do not account for problems such as chronic waterlogging or deterioration of soil structure and fertility following landforming. The estimation of post-landforming yields presumed that management is adapted following landforming to capitalise on the benefits of the new layout.

Consideration (e) was incorporated by assuming the full areas of representative farms prior to landforming were low enough relative to the existing water supply network that they could be irrigated by unassisted water flows (i.e. without pumping). Regarding consideration (f), the proportion of a non-landformed area prone to chronic waterlogging, in years experiencing high rainfall, was assumed to be five per cent. The expected frequency of a high rainfall winter was assumed to be one season in three. For wheat, and annual pasture in winter, yield levels in areas prone to chronic waterlogging in high rainfall winters were assumed to be 50 per cent of the respective achievable levels for non-landformed areas shown in Table 1. For annual pasture in spring and autumn the corresponding proportion was assumed to be 80 per cent. These assumptions were accounted for in the calculation of average annual yields across the full non-landformed area.

Realisation of potential yield increases following landforming is likely to require increased application of certain inputs. Changes in input levels after landforming, particularly of fertilisers and irrigation water, were accounted for in calculations of variable costs of crop and pasture activities undertaken on landformed layouts. The increased frequency of irrigation indicated in (c) above was reflected in the LP labour input coefficients.

**Table 1: Achievable Crop Yield and Pasture Production Levels for Landformed and Non-Landformed Layouts**

| Crop or Pasture | Yield Unit | Achievable yield | |
|---|---|---|---|
| | | Non Landformed Layout | Landformed Layout |
| Rice sod sown | t/ha | 8.00 | 9.00 |
| Rice aerial sown | t/ha | 8.50 | 9.00 |
| Wheat sod sown | t/ha | 1.75 | 2.50 |
| Wheat combine sown | t/ha | 3.25 | 4.00 |
| Annual pasture - autumn | (LSM[a]/ha) | 15.00 | 35.90 |
| - winter | (LSM[a]/ha) | 78.00 | 85.00 |
| - spring | (LSM[a]/ha) | 90.40 | 122.40 |

[a] Livestock months

Furthermore, agronomic problems and management inexperience are likely to delay full realisation of potential yield increases. Crop and pasture yields can be considerably reduced in areas from which topsoil has been substantially removed ('heavy cut') during landforming. This is because much of the soil fertility is concentrated in the topsoil and because poor subsoil structure impedes plant growth and seedling establishment.

Particularly vulnerable to these problems are duplex soils with shallow topsoil (Pritchard *et al* 1988). It is this soil type which was assumed to underlie the three representative farms. Yields of crops grown on exposed subsoil of this soil type in south-eastern Australia have been shown to be 50 per cent or less than those from undisturbed soil (Pritchard and Mason 1982). Soil nutrition deficiencies in exposed subsoil areas have been found to cause substantially lower rice yields (Heenan 1982). Replacement of 75 millimetres of topsoil on exposed subsoil areas, however, has been shown to restore dry matter production of irrigated maize to the level of an undisturbed soil (Pritchard *et al* 1988). The same authors found that amelioration of exposed subsoil with ploughing, and application of gypsum and fertilisers restored production to only 71 per cent of that of an undisturbed soil. Similar responses were found for irrigated perennial pasture (Kelly *et al* 1989).

In this study, the proportion of landformed areas that are heavy cut was assumed to be positively related to the volume of earth required to be moved during landforming. Heavy cut areas were defined as those from which greater than 80 millimetres depth of topsoil is removed during landforming. Thus for the representative farm in which 200 $m^3$ per hectare is moved, the proportion of the landformed area that is heavy cut was assumed to be five per cent. For the representative farms in which 350 $m^3$ and 500 $m^3$ per hectare are required to be moved, the respective heavy cut proportions were assumed to be 15 and 30 per cent.

Yields within heavy cut areas were modelled as follows. It was assumed that either topsoiling or the alternative procedure of applying single superphosphate (at 200 kg/ha) and urea (at 326 kg/ha) to heavy cut areas would be performed in order to reduce problems of soil fertility and structure in these areas. If the latter option were to be pursued, it was assumed that yields within heavy cut areas in the first year following landforming would be 40 per cent of achievable post-landforming levels (i.e. the levels shown for landformed layouts in Table 1). Thereafter yields were assumed to increase linearly until achievable levels were attained in the seventh year following landforming. If instead topsoiling were performed, so that 80 millimetres depth of topsoil were replaced on heavy cut areas, crop yields and pasture production in these areas were assumed to follow the same pattern as described below for areas that were not heavy cut[9].

Realisation of the achievable yield increases from landforming, in areas that are not heavy cut, is also likely to be delayed. However, this will not be to the same degree as in areas that are heavy cut. Redistribution of topsoil and subsoil within paddocks can result in unevenness of soil fertility and moisture availability. Consequently for some years crop maturity is likely to be uneven across the area landformed, thereby limiting realisation of yield increases. Management inexperience, particularly with irrigating a landformed layout, can also delay realisation of achievable yield increases. Finally, numerous passes of heavy machinery over a paddock during landforming causes damage to soil structure (Mount 1985). The extent of damage to soil structure from this cause will be related to frequency of heavy machinery traffic across the area being landformed which will be largely dependent upon the volume of earth to be moved.

The effects of these factors in areas that were not heavy cut (and in topsoiled heavy cut areas) were modelled as follows. The proportion of the achievable yield realised in the first year after landforming was assumed to be negatively related to the volume of earth moved during landforming. For the representative farm requiring earthmoving of 200 $m^3$ per hectare during landforming, 95 per cent of achievable yield was assumed to be realised in the first

[9] Inexperience in managing landformed areas can in fact be expected to be most significant in relation to the first field landformed. Thus the assumption of the same level of inexperience for subsequent increments will tend to overstate the yield penalties in the early years following landforming and therefore to underestimate the NPV of subsequent increments.

year following landforming. For the representative farms requiring earthmoving of 350 $m^3$ and 500 $m^3$ per hectare, first year yields were assumed to be 85 and 70 per cent of achievable levels respectively. Yields were assumed to increase linearly from these bases to achievable levels in the third year following landforming.

3.1.2 Benefits from reconfiguring irrigation bays

Efficiency of field machinery operations (hereafter referred to as field efficiency[10]) is reduced where the shape or size of a layout requires overlapping passes of machinery and frequent sharp cornering. Contour bays are bounded by banks following the contours of a paddock. Prior to a paddock being landformed, it is unlikely that banks of contour bays will follow smooth curves and run roughly parallel to each other and thereby facilitate field efficiency. Irregularity in the rate of altitude fall across a paddock causes contour banks to be irregularly spaced. This causes considerable variation in areas of irrigation bays which, particularly in the case of small bays, reduces field efficiency. By enabling reconfiguration of contour bay shapes and sizes, landforming can appreciably increase field efficiency and thereby lower variable costs (including machinery maintenance, fuel, seed and fertiliser), free labour for other tasks and increase the disposal value of field machinery.

It was assumed that the three representative farms originally differ in terms of field efficiency but that landforming raises the field efficiency of each to a uniform 'good' level. The increase in field efficiency was assumed to be positively correlated with the volume of earth required to be shifted to attain plane of best fit. This is because greater volumes generally indicate greater undulation within a paddock and therefore greater irregularity of irrigation bay size and shape (Darnley-Naylor, pers. comm. August 1990). For the representative farm requiring 200 $m^3$ of earth to be shifted per hectare, an increase in field efficiency of 18 per cent following landforming was assumed. For the representative farms requiring 350 $m^3$ and 500 $m^3$ of earth to be shifted per hectare, respective rates of field efficiency increase following landforming of 25 per cent and 67 per cent were assumed. A description of how original field efficiency differences between the representative farms were reflected in their variable costs, labour use and machinery disposal values can be found in Marshall and Jones (1993).

3.1.3 Greater efficiency in monitoring individual irrigations

The time taken in monitoring individual irrigations is likely to be reduced after landforming for reasons including the following:

(a) greater regularity of irrigation bay shape is likely to increase ease of inspecting the full area of each irrigation bay;

(b) the time necessary to irrigate a paddock is reduced due to faster surface drainage from each bay; and

(c) the removal of high spots within bays means that lower volumes of water need to be run into bays to achieve a depth that covers them, thereby reducing the need for monitoring.

These labour savings were reflected in the LP model coefficients for labour inputs per hectare of rotation activities on landformed layouts.

3.1.4 Increased efficiency of irrigation water use

Irrigation water is used more efficiently after landforming as a result of its faster application to and drainage from irrigation bays, and due to elimination of areas prone to chronic waterlogging. Each of these effects reduces losses of irrigation water in the forms of evaporation and deep percolation. In addition, levelling of high spots reduces the volume of water needed to cover an entire irrigation bay and thereby reduces the likelihood of excess water leaving the farm as drainage. LP model coefficients relating to per hectare water use by rotation activities reflected the assumption that irrigation effi-

[10] In this study field efficiency is measured by an index indicating generally the productivity of mechanised field operation. It relates to hectares treated per hour of machinery use or per kilogram of input. Although work rates (hectares per hour for tillage, harvesting etc.) and application rates (hectares per kilogram for seed and fertiliser) are situation-specific, increases in field efficiency were assumed to result in equi-proportionate increases in each work and application rate.

ciency (expressed in terms of the proportion of applied water utilised by plants) would increase by 25 per cent after landforming (Darnley-Naylor, pers. comm. August 1990).

3.1.5 Less disruption of field operations by rain

Rainfall shortly before field operations often causes problems for farmers. For rice farmers, the main problems in this context are associated with harvesting of rice and sowing of wheat. Rice harvests were assumed on average to be significantly disrupted by rain in one of every five harvests. Prior to landforming it was assumed that it would take twice as long as normal to harvest in these rain-disrupted years and that preparation for the following crop would require the equivalent of an additional two passes of a disc plough and one pass of a landplane over the entire paddock. A landformed layout was assumed to take 1.25 times as long as normal to harvest in rain-disrupted years, and preparation for the following crop to require the equivalent of an additional pass of a disc plough over the entire paddock and one pass of a landplane over half the paddock. All these costs were attributed to the harvest. The weighted average annual harvest costs for rice on landformed and non-landformed layouts were calculated and incorporated in the variable costs of rotation activities.

Prior to landforming wheat sowing was assumed on average to be affected by rain one year in every five. Prior to landforming it was assumed that 20 per cent of a paddock is not sown in rain-disrupted years and that the remaining area would yield at the normal rate. Averaging the whole paddock yield for a rain-disrupted year with the normal yields of four other years provided an average annual yield for wheat prior to landforming. Improved surface drainage following landforming was assumed to preclude problems with sowing of wheat after rain.

**3.2 Costs of Landforming**

3.2.1 The costs of landforming development

Earthmoving costs of landforming differed between the three representative farms according to the volumes of earth required to be moved to attain plane of best fit. For a job requiring 200 $m^3$ per hectare of earth to be moved, the assumed contract rate was $260 per hectare. For jobs requiring 350 $m^3$ and 500 $m^3$ of earth to be moved per hectare, the assumed rates were $420 and $600 per hectare respectively (Darnley-Naylor, pers. comm. August 1990). The costs of the landforming also include those preparatory to the main earthmoving operation. These costs, including those of surveying the paddock, levelling banks, cultivation and laying out grids, were estimated to sum to $65 per hectare (Darnley-Naylor, pers. comm. August 1990).

As indicated in Section 3.1.1, expenditure on soil amelioration is also likely to be required following landforming. Soil amelioration was assumed to be either by application of additional fertiliser on heavy cut areas or by topsoiling. The cost of topsoiling was assumed to be $1,000 per hectare of heavy cut area (Darnley-Naylor, pers. comm. August 1990). This includes the cost of removing an extra 80 millimetres of soil depth from heavy cut areas to provide room for the topsoil.

3.2.2 Foregone income due to disruption of farm program

The time necessary to complete a landforming job can mean that crops or pasture that would otherwise generate income from that land cannot be grown. Normally, however, a farmer would be expected to schedule landforming to minimise the extent of foregone income. Representative farmers are assumed to schedule landforming developments to avoid significantly foregoing income.

3.2.3 Increased investment in livestock

The pasture productivity-increasing effect of an increment of landforming may, depending on the increment's impact on a farm's activity mix, increase the livestock carrying capacity of the farm. To take advantage of this involves further investment in livestock. Livestock numbers were assumed to change to levels indicated in LP solutions in the first year following landforming. However, it follows from Section 3.1.1 that the achievable post-landforming pasture yields specified in the LP models are not realised until the seventh year following landforming. This discrepancy was accounted for by incorporating a sub-routine in the spreadsheet model to calculate seasonal feed shortfalls resulting from the lag in pasture production increase. Where seasonal feed shortfalls were shown to occur in any year, the outlay on purchasing additional hay was included as a cost of landforming.

3.2.4 Repolishing of landformed areas

Maintenance ('repolishing') of a landformed area is required periodically to retain the standard of the original job. If repolishing is undertaken frequently enough the benefits of the landformed layout should continue indefinitely. The assumed cost of repolishing was $60 per hectare landformed. The cost was assumed to be first incurred in the third year following landforming and thereafter in every fifth year. The need for a shorter initial interval is due to settling of the soil profile in the early years after landforming (particularly in 'fill' areas) as well as to the effects on land surface evenness of field machinery operations. The longer subsequent intervals are possible since the settling of the soil profile has already occurred and compensation for only the effects of field machinery operations is required.

### 3.3 Summary of Features of the Representative Farms

The assumed relationships between the volumes of earth required to be shifted during landforming of the three representative farms and their respective earthmoving costs, areas heavy cut and field efficiency increases following landforming have been specified above. To simplify discussion, the three representative farms are referred to as 'low cost' (of earthmoving and of field operations), 'medium cost' and 'high cost'. The distinguishing features of the representative farms are summarised in Table 2.

## 4. Features of the Discounted Cash Flow Model

Full detail regarding the discounted cash flow model is provided in Marshall and Jones (1993). This section focuses on a number of important features of the model.

### 4.1 Marginal income tax rate

The majority of farmers pay income tax under the income averaging provisions of the Income Tax Assessment Act (Douglas *et al* 1990). Representative farmers were assumed to utilise these provisions. Approximately 75 per cent of farmers using these provisions in 1989-90 had a marginal tax rate of below 25 per cent (Davenport *et al* 1992). A marginal income tax rate of 15 per cent, approximately the modal rate for primary producers using income averaging in 1989-90, was assumed to apply to the representative farmers. However, the effects of other rates were also examined during sensitivity analysis.

### 4.2 Other income tax considerations

Under Section 75D of the Income Tax Assessment Act, outright deduction of landforming expenditure from taxable income in the year of expenditure is usually allowed (Commissioner of Taxation

**Table 2: Distinguishing Features of the Representative Farms**

| Representative Farm (cost of earthmoving) | Earthmoving Cost ($/ha) | Increase in Field Efficiency Following Landforming (%) | Proportion of Landformed Area Heavy Cut (%) |
|---|---|---|---|
| Low Cost | 260 | 18 | 5 |
| Medium Cost | 420 | 25 | 15 |
| High Cost | 600 | 67 | 30 |

1987). Increased income resulting from increases in trade-in values of field machinery are not taxable if a farmer makes an appropriate election under Section 59 (2A) of the Income Tax Assessment Act. It was assumed that both these concessions apply to representative farms. It was also assumed that field machinery is not sold at a price higher than the original cost adjusted for inflation. Otherwise there would be capital gains tax liability. Purchases of livestock to increase flock size do not affect income tax liability of representative farmers since it was assumed that the trading profit/loss from the transactions is zero (ie. the disposal value of livestock is equal to the acquisition cost).

The income tax effect (ie. payment of tax liabilities or receipt of tax refunds) of a transaction was assumed to occur in the year following the transaction.

### 4.3 Discount rate

Discount rates were used to reflect the opportunity cost to a farmer of the capital invested in landforming. The opportunity cost to farmers of capital was derived from the nominal rate of return on fixed bank deposits. The rate used was the average of rates offered for fixed bank deposits each month over the period 1980-81 to 1989-90, for sums less than $50,000 and for terms of less than 12 months (Reserve Bank of Australia 1990). This average rate was calculated to be 12.4 per cent per annum.

The opportunity cost, however, is the rate of return on the alternative investment net of the tax paid on it. By deducting the present value of the income tax liability (assumed to arise in the year after receipt of interest) on a one dollar investment from the current return on that investment, the nominal opportunity cost of capital net of income tax (ie. nominal discount rate) was calculated.

The real discount rate (R) was then calculated using equation (1) (adapted from Donnet 1982):

$$R = ((1 - T)\, i - I)/(1 + I) \qquad (1)$$

where i is the nominal opportunity cost of capital gross of income tax, T is the marginal income tax rate and I is the annual inflation rate. The annual inflation rate used was 8.7 per cent which is the average of annual percentage increases in the Australian Consumer Price Index over the period 1980 to 1989 inclusive (ABARE 1990). The real discount rate for a marginal income tax rate of 15 per cent was thus calculated as 2.0 per cent.

### 4.4 Eligibility for concessional credit

Under its Special Conservation Scheme (SCS), the NSW Rural Assistance Authority provides concessional credit to farmers undertaking landforming. Loans under this scheme are available at an interest rate of 8 per cent per annum[11]. The size of loan is limited to 90 per cent of the reasonable cost of the works. The maximum term of a loan is 15 years. To be eligible for a loan, criteria including the following must be met:

(i) the proposed works must have a beneficial impact on the land, the community and the environment at large;

(ii) the farming enterprise must provide the majority of total income of the applicants; and

(iii) the applicant must be in working occupation of the farm and have net assets not exceeding $800,000 in value (NSW Rural Assistance Authority 1990).

In the context of discounted cash flow analysis, the benefit of being provided credit at a concessional rate of interest arises from incurring a lower cost for use of capital than the opportunity cost of capital reflected in the discount rate. The margin by which the opportunity cost of capital for a farmer exceeds the cost actually incurred for the use of that capital can be considered the equivalent of a cash subsidy paid during the term of the SCS loan.

Farmers were assumed to be provided the maximum amount of SCS credit possible for the maximum possible term. The loan was assumed to be repaid in amortised annual instalments, at the end

[11] This rate may change from time to time as determined by the Government.

of each year. The outstanding principal during each year was calculated accordingly. Hence, the subsidy equivalent of SCS credit in year t was calculated using equation (2):

$$S_t=P_t(i-u) \qquad (2)$$

where S is the subsidy equivalent of the SCS loan, P is the outstanding principal on a SCS loan, u is the interest rate charged for SCS credit and i is as defined above.

### 4.5 Length of planning horizon

The benefits of landforming can continue indefinitely as periodic repolishing usually prevents deterioration of a landformed layout. A relatively long planning horizon for analysis, during which time the stream of benefits and costs from landforming continues being considered, is therefore appropriate in most situations. Shorter planning horizons may be appropriate if there is a risk that the benefits of landforming may become obsolete in the future (Daubert and Ayer 1982). This could be due to the land going out of agricultural production (for example due to land being rezoned for residential use) or the value of landformed layouts declining in future due to alternative irrigation methods becoming available. The planning horizon was assumed to be 30 years, but sensitivity of results to a planning horizon of 15 years was also examined.

### 4.6 Data sources for activity returns and input costs

The values of farm-gate crop returns and livestock gross margins used in the analysis are the average levels for the six year period 1985-90 (NSW Agriculture & Fisheries 1990). Values for variable costs of crops and annual pasture were derived from McKenzie (1989, 1990a and 1990b). Values for casual labour wage rates, contract cost of haymaking and cost of purchasing hay were obtained from McKenzie (1990a). These values were assumed to remain constant in real terms.

## 5. Results

In this section the results of the discounted cash flow analysis of landforming and topsoiling on the three representative farms are presented and discussed in relation to the study hypotheses framed in Section 1. Where required to explain these results, the outcomes of the preceding LP stage are also discussed. Results calculated using the baseline assumptions specified in previous sections are discussed first. An assessment of the implications of uncertainty regarding key coefficient values then follows.

### 5.1 Baseline Assumptions

Under the NPV criterion, an investment should be undertaken if its NPV exceeds zero (Barnard and Nix 1981). It is seen from Table 3 that the NPV of landforming is positive for all increments for all three representative farms. Hence farmer wealth is maximised by landforming the full area of each of the farms. Hypothesis (i) is therefore accepted.

For the low and medium cost representative farms, the NPV of landforming continues to decline marginally over the first four landforming increments.

**Table 3: Net Present Value of Landforming**

| Representative Farm Type (cost of earthmoving) | NPV or Landforming Increment ($/Farm) | | | | |
|---|---|---|---|---|---|
| | Landforming Increment | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| Low cost | 74,291 | 71,282 | 68,097 | 66,333 | 27,843 |
| Medium cost | 71,217 | 68,752 | 66,565 | 64,028 | 24,730 |
| High cost | 89,620 | 89,620 | 85,533 | 81,494 | 28,431 |

For the high cost representative farm, the NPV of landforming is constant for the first two increments and declines slightly over the third and fourth increments. Except in the case of the third increment on the high cost farm, these marginal declines are explained by farm water allocation having become limiting, and by it becoming increasingly limiting with successive increments undertaken. This is evidenced by positive, and increasing, dual prices for water allocation in the LP solutions as these increments are included. However, the decline for the third increment on the high cost farm is not due to water allocation having become limiting, but to permanent labour having become limiting in March and April, rather than only in April as was the case for the first two increments.

Farm water allocation is sufficient to irrigate only 25 hectares of the final increment landformed. To irrigate the final increment landformed, water must be reallocated from other landformed areas rather than from lower productivity non-landformed areas as had been possible for previous increments. Hence the dual price of water increases considerably during the fifth increment, resulting in the considerably lower NPV of the fifth (and final) increment for each of the representative farms. It is apparent from this and the preceding paragraph that hypothesis (ii) should therefore be rejected.

The increase in the extent to which water allocation becomes limiting as additional landforming is undertaken is explained by the assumptions made regarding changes in irrigation water use by crops and pasture following landforming. For pasture and crops other than rice, irrigation applications across a season were in total assumed to be higher after landforming despite an increase in irrigation efficiency following landforming (see Section 3.1.4). This is because landforming reduces the duration of transient waterlogging following each irrigation and thereby allows yields to be increased by reducing irrigation intervals. For these activities the increased number of irrigation applications outweighs water savings from increased irrigation efficiency such that total water applied in a season is greater than prior to landforming.

For rice the number of irrigation applications is unaffected since the crop is ponded for most of its season, so total water applied falls following landforming as a result of improved irrigation efficiency. However, the net effect of these assumptions is that the volume of water applied during a full rotation cycle is increased following landforming. Hence water allocation becomes increasingly limiting as the area landformed is increased.

A system allowing permanent transfers of water entitlements between farmers within the Murrumbidgee Valley was introduced for the 1991/92 irrigation season. It is possible that the opportunity to purchase additional entitlement will lessen the effect of current water allocation on the NPV of the final increment. Whether this is the case or not will depend on the market price established for entitlement transfers. In the 1991/92 season, however, water allocations in the MIA were set at 120 per cent of entitlements, with the result that water was abundant and there were no purchases of entitlement by MIA rice farmers. Hence there is as yet no indication of the price at which megalitres of permanent entitlement will trade.

Examination of dual prices for water allocation, found in the LP solutions, shows that once the representative farms are fully landformed it would be rational for profit-maximising farmers to pay as much as $33 per ML per year to acquire a further 43 ML of entitlement and up to $31 per ML per year for yet a further 49 ML of entitlement[12]. Beyond this accumulated level of entitlement, water availability ceases to be a binding constraint for farm plans. Alternatively, if the market price of a permanent entitlement transfer exceeds the present value of a $33 per ML annuity, a profit-maximising farmer would sell marginal units of entitlement and water availability would become a more limiting

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[12] The maximum price that a profit-maximising farmer would rationally pay for permanent acquisition of additional entitlement can be calculated as the present value of an annuity, where the dual price for water is the value of the annuity. For example, if the real post-tax discount rate is 2 per cent, as derived in Section 4.3, and the dual price for additional water is $33 per ML per year, the maximum price a farmer would pay for permanent entitlement would be $739 per ML if a 30 year planning horizon is used, and $296 per ML if a 10 year planning horizon is used. This presumes that the level of water allocation is expected to remain at 110 per cent of entitlement during the planning horizon.

**Table 4: Benefit-Cost Ratios for Landforming**

| Representative Farm Type (cost of earthmoving) | B/C Ratio for Landforming Increment | | | | |
|---|---|---|---|---|---|
| | Landforming Increment | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| Low cost | 5.66 | 5.63 | 5.61 | 5.49 | 2.69 |
| Medium cost | 4.18 | 4.12 | 4.07 | 3.95 | 2.10 |
| High cost | 3.88 | 3.87 | 3.80 | 3.72 | 1.84 |

constraint on farm plans, thus lowering the NPV of the final increment of landforming.

The BCRs for landforming shown in Table 4 allow a comparison of the relative returns from landforming on the three representative farms. The NPV values of Table 3 cannot be used for this purpose since the magnitude of the landforming investment per increment differs substantially between the farms (Dasgupta and Pearce 1978).

The BCR for corresponding increments is seen to be significantly higher for the low cost farm than for either the medium or high cost farms. Thus hypothesis (iii) is rejected. The BCR for corresponding increments is seen to be marginally higher for the medium cost farm than for the high cost farm. These results demonstrate that the increases in field efficiency gains with higher cost landforming jobs are not sufficient to justify the increase in landforming cost. The rate of return from landforming is thus seen to decline with increasing cost of required earthmoving.

Note that if there were a single owner for the three farms the BCRs could be used to rank the fifteen possible increments so that any choice necessitated by a capital budget constraint would be consistent with maximising NPV from the available capital.

For each of the representative farms, the NPV of topsoiling is positive for the first four landforming increments, but negative for the fifth (Table 5).

This variation is explained by topsoiling having been assumed to improve the yields of alternative crop and annual pasture activities equi-proportionately. The financial benefit from topsoiling depends then on the mix of activities undertaken on a topsoiled area, since the value of a proportionate

**Table 5: Net Present Value of Topsoiling**

| Representative Farm Type (cost of earthmoving) | NPV of Topsoiling During Landforming Increment[a] ($/farm) | | | | |
|---|---|---|---|---|---|
| | Landforming Increment | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| Low cost | 974 | 661 | 748 | 737 | (312) |
| Medium cost | 2,381 | 1,540 | 1,757 | 1,747 | (1,160) |
| High cost | 1,399 | 1,399 | 2,260 | 3,353 | (3,633) |

a brackets denote negative values

**Table 6: Benefit-Cost Ratios for Topsoiling**

| Representative Farm Type (cost of earthmoving) | B/C Ratios for Topsoiling | | | | |
|---|---|---|---|---|---|
| | Landforming Increment | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| Low cost | 1.49 | 1.33 | 1.37 | 1.37 | 0.84 |
| Medium cost | 1.40 | 1.26 | 1.29 | 1.30 | 0.81 |
| High cost | 1.12 | 1.12 | 1.19 | 1.30 | 0.70 |

yield increase depends on the output price for an activity. Given the assumptions made regarding output values, the value of an equi-proportionate yield increase is significantly greater in the case of rice than for wheat or annual pasture. Hence a high NPV of topsoiling reflects a relatively large increase in the area of 'landformed' rice production following the associated increment of landforming, and vice versa.

All of the BCRs for topsoiling (Table 6) are lower than the lowest BCR of landforming among the fifteen possible increments of the three representative farms. Hence landforming should take precedence over topsoiling in allocation of scarce capital. Topsoiling should only be undertaken if the estimated cost of landforming the full area of any of the representative farms falls short of the available amount of capital. Thus hypothesis (iv) is accepted.

### 5.2 Sensitivity Analysis

The two stage modelling procedure was repeated under alternative values of uncertain coefficients which were expected to have a relatively high influence on the results. This was to ascertain the sensitivity of the NPV of landforming to assumptions regarding these values. With landforming found to be quite a high-returning investment subject to the baseline assumptions, alternative values were chosen on the basis that they would test how far NPV for landforming is reduced by specifying pessimistic, yet still credible, values for uncertain coefficients. For the sake of brevity the following discussion, and the associated tables, focuses on the NPV of the first landforming increment for each of the representative farms. In all cases the NPV results for other increments showed similar effects.

#### 5.2.1 Marginal income tax rate

For each of the representative farms, NPV of landforming was found to be positively related to the marginal income tax rate (Table 7). This can largely be attributed to higher marginal income tax rates reducing the discount rate. Note, however,

**Table 7: Marginal Income Tax Rate and Net Present Value of Landforming**

| Representative Farm Type (cost of earthmoving) | NPV of First Landforming Increment ($/farm) | | | | |
|---|---|---|---|---|---|
| | Marginal Income Tax Rate (%) | | | | |
| | 0 | 10 | 15 | 20 | 25 |
| Low cost | 68,278 | 72,094 | 74,291 | 76,312 | 78,432 |
| Medium cost | 65,241 | 68,186 | 71,217 | 74,423 | 76,511 |
| High cost | 77,278 | 85,544 | 89,620 | 93,604 | 97,442 |

that the NPV of landforming remained substantial under each of the tax rates tried.

5.2.2 Other experiments

The results of other experimental runs of the two stage modelling procedure are shown in Table 8. The change in assumptions found to have greatest effect on the NPV of landforming were those of increasing the nominal interest rate for savings by 50 per cent (thereby increasing the discount rate) and shortening the planning horizon from 30 to 15 years. Nevertheless, the NPV of landforming the first increments of the three representative farms

**Table 8: Sensitivity Analysis for First Increment of Landforming**

| Experiment | Net Present Value ($/farm) | | |
|---|---|---|---|
| | Low cost farm | Medium cost farm | High cost farm |
| Baseline assumptions | 74,291 | 71,217 | 89,620 |
| Opportunity cost of capital gross of income tax increased by 50 per cent | 30,245 | 21,769 | 29,710 |
| SCS credit not available | 71,453 | 67,562 | 84,919 |
| Ineligibility for full tax deductibility of landforming cost in year of expenditure | 65,662 | 58,196 | 82,575 |
| Planning horizon reduced to 15 years | 32,006 | 22,749 | 31,398 |
| Crop prices and livestock gross margins reduced 20 per cent | 54,504 | 49,473 | 59,621 |
| Earthmoving costs increased 20 per cent | 65,562 | 58,107 | 82,526 |
| Achievable yield increases following landforming reduced 50 per cent | 33,166 | 27,182 | 53,017 |
| Yields in year following landforming reduced 10 percentage points and realisation of achievable yields delayed a further year | 61,879 | 53,431 | 78,042 |
| Heavy cut areas increased by five percentage points | 65,098 | 58,828 | 84,842 |
| Field efficiency increases following landforming reduced by 20 per cent | 65,363 | 56,909 | 74,388 |

remained substantial. However, the NPV of the fifth increment of the high cost representative farm became negative with each of these changes. (These were the only cases in which experiments resulted in negative NPVs for landforming.)

NPV of landforming was reduced to a lesser extent in the two experiments in which crop prices and livestock gross margin were reduced by 20 per cent and achievable yield increases following landforming were reduced by 50 per cent. The remaining experiments were found to have a minor effect on the NPV of landforming. It is of note that neither of the government concessions for landforming (SCS credit and full income tax deductibility of landforming costs in year of expenditure) were found to make a significant difference to the NPV of landforming.

## 6. Conclusions

The discussion above demonstrates that MIA rice farmers can expect a high rate of return from investment in landforming. As expected, water allocation was found to eventually constrain farm plans as the area to be landformed was increased. However, this effect was not sufficiently great that landforming the final increments of farm area was found to be uneconomic for a farmer.

Hence landforming the full area of a MIA rice farm is warranted by the above results. This conclusion may not hold, however, for irrigated farms in other areas with a lower ratio of water allocation to farm size. It is possible that the recent introduction of a system allowing permanent transfers of water entitlement between farmers may reduce the influence of current entitlement levels on the economics of landforming. However, this will depend on the price established for entitlement.

A further factor that may handicap the on-farm economics of landforming in some other areas is lack of access to an off-farm drainage network. Without scope for off-farm drainage, substantial waterlogging losses will still occur on landformed farms due to excess drainage accumulating in low-lying parts of a farm.

Given a choice of layouts differing in the volume of earthmoving required to attain a desired standard of layout, the results suggest that priority in allocating the landforming capital budget should be given to layouts requiring lowest volumes of earth to be moved. Under the assumptions used, the lower field efficiency gains generally found from landforming a less undulating layout are more than compensated by lower earthmoving costs and less damage to soil structure and fertility.

The rate of return from topsoiling (as measured by BCRs) was found to be substantially lower than for landforming. If capital is limiting, this suggests allocation to landforming should be given priority over allocation to topsoiling.

Assumptions regarding the rice farming situation within which landforming has been analysed were discussed in Section 2.2. The applicability of the above results to other situations, particularly perhaps those where shallow watertables have the potential to lower yields, requires further investigation. The study framework could also be relatively easily adapted to explore the on-farm economics of landforming for rice farmers in areas other than the MIA. This would involve respecifying the representative farms, particularly in relation to farm size and farm water allocation.

Finally, this study considered only the private costs and benefits to a farmer from landforming. To determine the economics of landforming from a social perspective, its external costs and benefits also need to be considered. An important external effect of landforming relates to its potential to increase the rate at which rainfall drains from farms, thereby increasing peak drainage volumes in off-farm networks and causing inundation of land elsewhere if drains overflow.

Another external effect arises from the potential of landforming to influence volumes of groundwater accessions from a farm and thereby affect other farmers (either positively or negatively) by influencing watertable levels. Even though taxation concessions for landforming have been justified due to a belief that resulting improvements in irrigation efficiencies would be associated with reduced groundwater accessions, the consensus appears to be that this will not always be the case once increased irrigation frequencies and problems of off-farm disposal of surface drainage are also taken into account.

Formulation of government policy designed to influence rates of adoption of landforming requires valuation of the overall external effects of landforming across the range of situations in which it is applied. Although hard data on these types of landforming externalities are often not available, economic analyses using guesstimates for technical coefficients would still result in a considerable improvement in the information available to policymakers.

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