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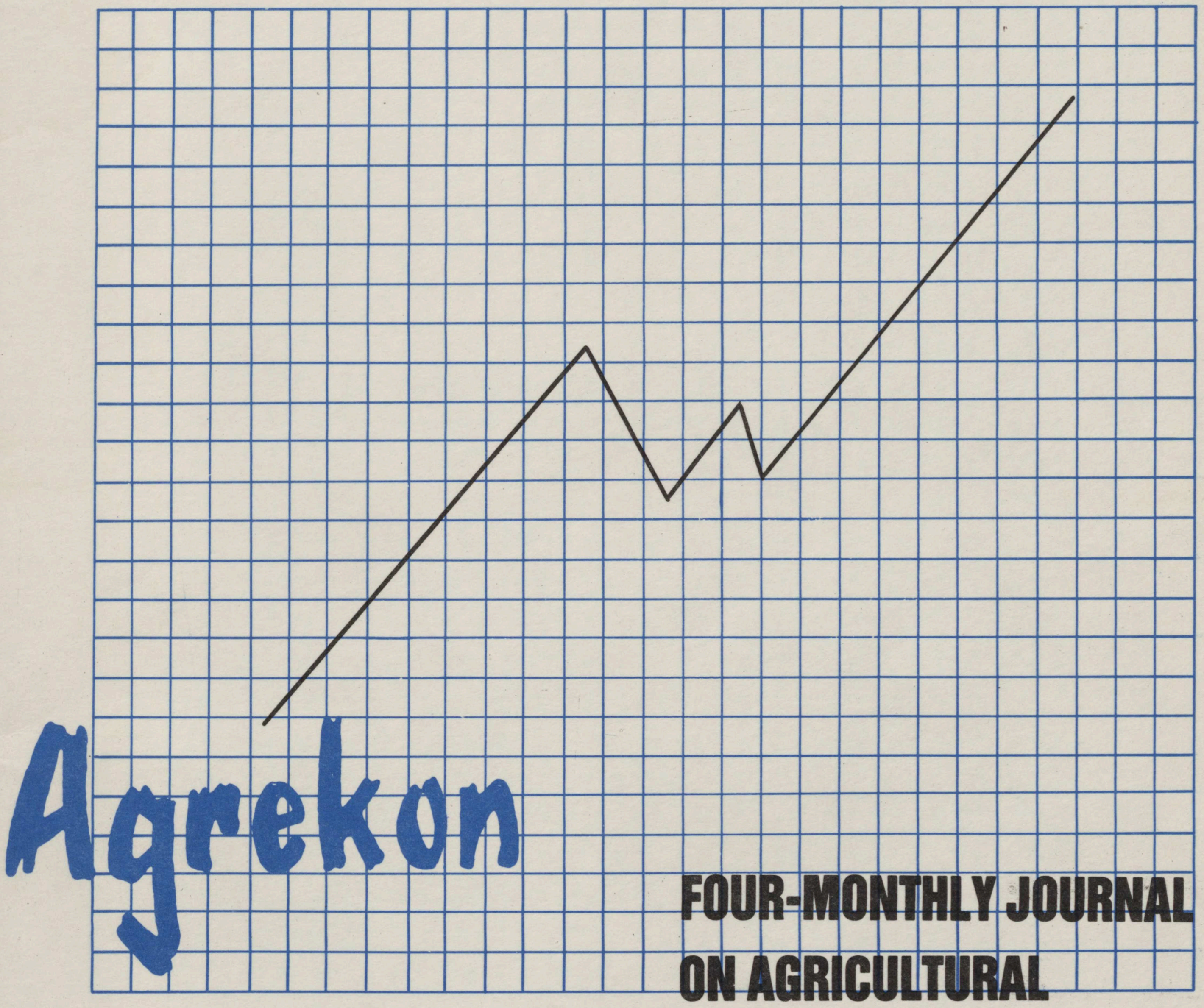

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A COMPARISON OF RESULTS WITH DIFFERENT MODELS USED TO ALLOCATE IRRIGATION WATER*

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ABSTRACT

Models according to which irrigation water can be allocated among areas were compared: The incremental benefit/cost model, based upon a predetermined cropping pattern (as used by the Department of Water Affairs and based upon data of the Department of Agriculture and Water Supply), a linear programming model taking the same cropping pattern as given, and linear programming models in which crop selection and water allocation are optimized simultaneously. Results indicate that models aimed at simultaneous optimization yield results that are economically superior to models based on fixed cropping patterns.

INTRODUCTION

Water and capital are scarce in South Africa. Water works such as dams and reticulation systems require large capital investments. In planning irrigation works, it should therefore be endeavoured to pursue the largest possible economic benefit from water allocation. Therefore, one should also employ those models which exhibit the largest potential for realising this ideal. Models yielding better benefit/cost ratios should therefore be developed.

It has been shown that irrigation water availability plays a determining role on optimal cropping patterns (Groenewald and Van Zyl, 1986; Van Rooyen, 1973; Van Rooyen, 1983; Hancke and Groenewald, 1972). This implies (*inter alia*) that cropping patterns and water allocation at irrigation schemes should be optimized simultaneously. If only the allocated quantity of water should be optimized and a fixed cropping pattern be accepted (or *vice versa*), one cannot expect the economically optimum position to be achieved. In this context, Backeberg (1984) criticizes static models based upon fixed cropping patterns as foreseen by the former Department of Agricultural Technical Services (ATS) and recommends that determination of the optimal cropping pattern by optimization should already be done during financial planning.

In this article, four different models for allocating irrigation water are compared with each other, namely the incremental benefit/cost method as thus far applied by the Department of Water Affairs, and three linear programming models which will conveniently be classified as a conditional, a short-term and a long-term model.

AREA OF INVESTIGATION

The Theewaterskloof Scheme was selected as area of investigation. The scheme was started in the 1970 s and is a part of the more comprehensive Western Cape Water Development plan. The Theewaterskloof Dam was built in order to accumulate a portion of the superfluous flow of the Riviersonderend River and to make it available for urban, industrial and irrigation purposes in the Eerste and Berg River valleys.

Since the timeous supplementation of the ensured water supply for Cape Town and surroundings was regarded as top priority, the project was deliberately divided into phases. The first phase of the scheme was completed in 1980 and since November 1980 water supply has occurred at the Franschhoek Mountain Tunnel outlet and the Theewaterskloof Dam outlet.

A second phase comprises the erection of tunnels, balancing dams and diversion structures. The main purpose is to make surplus water of the Berg, Dwars, Wolwekloof, Banghoek and Eerste Rivers available for urban, industrial and irrigation purposes. This phase is presently (1987) approaching completion.

A third phase consists of the construction of water reticulation works in the Berg and Eerste River Valleys in order to make water from the Theewaterskloof Scheme available for irrigation in these two valleys. The State will construct and control the main reticulation systems. Irrigation water will be delivered in bulk to irrigation boards at the various points of delivery. This allocation comprises 153 million m^3 of water per annum. Of this, a fixed allocation of 110,9 million m^3 was made by the authorities to certain areas. The main considerations with this allocation were threefold. Firstly, fertile areas in close proximity to tunnel outlets were regarded as logical allocation areas because of the relatively low costs. In the second instance, two schemes had previously been approved

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by Parliament and there were, thirdly, riverine soils which had already been irrigated for a considerable time, and where riparians already had water rights.

The water allocations dealt with in this article comprise a total volume of 42,1 million m^3 per annum.

This 42,1 million m^3 of water can be distributed over an area which is heterogeneous with respect to climate, soil type, soil depth and topography. The area was consequently subdivided into 17 fairly homogeneous distribution areas (for more detail, see Pansegrouw (1986)). The distribution areas were, in their turn, further subdivided into smaller sub-areas which, for the first two water allocation models, were analysed in incremental fashion along the main reticulation routes. The irrigation water can in most sub-areas be utilised for vineyards, deciduous fruit, pastures and/or vegetables.

ANALYTICAL METHOD

Incremental benefit/ cost analysis

The incremental benefit/cost method has often been used by the Department of Water Affairs, and was also used in this project (Republic of South Africa, 1982a and b.) The point of departure in this technique is the formulation of expectations by agriculturalists, based *inter alia* on soil surveys and also with consideration of market factors, on which cropping patterns would be followed in a sub-area had irrigation water been available. Expected water deficiencies are subsequently estimated, or otherwise stated, the amount of water which would be required for this expected or proposed cropping pattern. These water deficiencies are used to calculate a gross irrigation requirement. The calculations are based upon a formula (Republic of South Africa, 1984) which includes factors such as evapotranspiration, evaporation pans, effective rainfall, crop water requirements, existing water supplies and irrigation transmission losses.

The next step is the determination of annual irrigation benefits. This figure consists of the difference between the net farm income (NFI) which is expected to materialise from the formulated expected cropping pattern and the existing net income. Thus:

Irrigation benefit
= NFI with additional irrigation water
- NFI without irrigation water.

A unit benefit is calculated next by dividing the irrigation benefit by the additional quantity of water needed. The unit benefit is thus expressed per m^3 of water.

This step is followed by the calculation of unit costs, which are defined as the equivalent uniform annual costs to transport a unit volume of water up to the farm boundary. It consists of three basic components:

- Primary unit costs are the costs involved in transporting water from the tunnel outlets through the main aquaducts to the servicing area concerned.
- Secondary unit costs consist of costs that will have to be incurred by local irrigation boards to deliver water from a central point within a concerned servicing area to the farm boundary.
- Tertiary unit costs comprise distribution costs on the farm itself. In the present exercise, this was included in the calculation of respective gross margins.

At this stage certain potential servicing areas, *viz.* those with unit benefits which are smaller than secondary unit costs, can already be eliminated. It appears from various reports that secondary unit costs normally differ little between servicing areas (Republic of South Africa, 1979, 1980, 1981a and b, 1982c). In the calculation of primary unit costs a model for optimizing design and choice of water transport (Pansegrouw, 1978) is used.

A net unit benefit is obtained by subtracting the sum of primary and secondary unit costs for each incremental sub-area from its unit benefit. The net unit benefit data reflect the relative advantages of delivering water to the different sub-areas. The net unit benefit of each sub-area can thus be defined as the relative benefit, in cents per cubic metre of water, which may be derived from delivering water there.

The remainder of the process involves that the full calculated water deficit will be allocated to the area with the highest net unit benefit, followed by the area with the second highest net benefit, etc.

In this way an attempt is made to maximize net benefit per m^3 of water.

"Conditional" linear programming

In the "conditional" linear programming model the condition under which the incremental cost/benefit study was executed, was scrupulously imitated in all respects. It could thus be determined whether linear programming would under identical conditions yield the same or approximately the same results as the incremental benefit/cost method. It had been argued that the simplex algorithm of linear programming also utilizes an incremental procedure and that consequently, under identical conditions, the two methods should yield identical results.

Two common conditions applied in the execution of incremental benefit/cost analysis and "conditional" linear programming:

- The predetermined cropping pattern as previously described was adhered to in both models.
- Upstream water requirements were satisfied before allocating water to downstream areas.

This procedure, without always realising or considering the financial and economic implications thereof, has been applied fairly regularly by the Department of Water Affairs, because from a socio-political point of view it is apparently difficult for the State to refuse irrigation water to upstream owners and to allocate it to downstream owners with higher potential irrigation land.

All further input data such as irrigation benefit data, water requirements, etc. used in the incremental benefit/cost study were accepted in identical form in this linear programming model in order to facilitate objective comparison between this model and the incremental benefit/cost method.

The constraint matrix consists of 12 rows and 17 columns. The columns identify the areas among which the available irrigation water has to be divided.

The constraint rows state the preferential upstream water satisfaction conditions, the land area constraint and water requirement data for the respective sub-areas. For the first n sub-areas ($n > 1$), the upstream water requirement conditions are based on the following principle:

$$[({}^{W}\text{tot})\,n-1 - ({}^{W}\text{allocated})n] \geqslant [({}^{W}\text{tot})n-1 - ({}^{W}\text{tot})n]$$

where:

${}^{W}\text{allocated}$ = the quantity of water allocated to the respective sub-area and

${}^{W}\text{tot}$ = the total water requirement of the sub-area according to ATS's fixed future cropping pattern for the sub-area.

Total water requirements are introduced into the constraint matrix in the form of total irrigable areas with the cropping pattern and its water requirement as upper limit.

In the economic analysis of projects it is usually desirable to use more than one economic choice criterion. In linear programming models these criteria are optimized as objective functions. In this study, four choice criteria were used:

(i) (Benefit-cost) objective

The (benefit-cost) objective maximizes the net present value of irrigation development. According to Kuiper (1971), the (benefit-cost) criterion can be recommended if capital is limited and the alternative choices are mutually exclusive. It can be accepted that State funds for irrigation development will in future be rather limited and that the extension schemes in the Upper Berg and Eerste River valleys can be instituted separately. This choice criterion should therefore yield good results.

The (benefit-cost) objective function was formulated as follows:

$$(B\text{-}C) = \sum_{s=o}^{n} (DF.B_s - DF.C_s).A_s$$

where:

B_s = annual irrigation benefit per unit (hectare) of irrigated area in sub-area s with the future cropping pattern

C_s = annual cost (capital cost + running cost + overheads), per unit of irrigated area to transport the needed irrigation water to sub-region s

A_s = the irrigated area (in hectares) in sub-area s

n = number of sub-areas (17 in total)

DF = discounting factor used to discount, at 6% per annum, a series of amounts over the scheme's productive life of 45 years to the present value (Grant and Ireson, 1970; Republic of South Africa, 1982a).

(ii) (Benefit/cost) objective

This criterion is appropriate if capital is limited and if there are a considerable number of alternative project choices (Kuiper, 1971). It can also be recommended when schemes differing in size have to be weighed up against each other (Van Rooyen, 1983).

The (benefit/cost) objective was formulated as follows:

$$(B/C) = \sum_{s=o}^{n} \left(\frac{DF.\ B_s}{DF.\ C_s}\right).A_s$$

with the symbols having the same meaning as those already mentioned under (i)

(iii) ($\frac{\text{Benefit-cost}}{\text{Cost}}$) objective

This criterion is closely related to the (benefit/cost) criterion and is recommended if capital is limited and the alternative project choices relatively unlimited. This objective was formulated as:

$$\left(\frac{B - C}{C}\right) = \sum_{s=o}^{n} \left(\frac{DF.\ B_s - DF.\ C_s}{DF.\ C_s}\right).A_s$$

with the symbols having the same meaning as in (i)

(iv) ($\frac{\text{Benefit-cost}}{m^3}$) objective

This objective is not a generally used economic criterion. The results thus obtained should therefore be viewed with circumspection, particularly if this objective yields results radically different from those of the previous three objectives. This objective is appropriate only if water is a more limiting source than capital - a situation that seems to be improbable for the foreseeable future. This objective was used because it was implicitly used in the incremental benefit/cost method and as it was decided to use the conditional linear programming model as test for the incremental benefit/cost study.

The ($\frac{\text{benefit-cost}}{m^3}$) objective was formulated as follows:

$$\frac{(B - C)}{m^3} = \sum_{s=o}^{n} \left(\frac{DF.\ B_s}{m^3} - \frac{DF.\ C_s}{m^3}\right).A_s$$

where: m^3 = the total quantity of irrigation water (in cubic metres) annually delivered per unit area of irrigated land to sub-area s, and where all other symbols have the same meaning as in (i)

The short-term linear programming model

In the Great Fish River Valley, Backeberg (1984) found that proposed cropping patterns, as foreseen for that area by the then Department of Agricultural Technical Services and used in official irrigation planning, deviated substantially from the optimum combination and did also not realise it in practice. It was therefore decided to handle cropping pattern as well as water allocation by linear programming and to optimize these two simultaneously. Two models were used - a short and a long-term model.

The point of departure for the short-term model was that in the sub-areas that may receive water allocations, existing crop selections and combinations will remain relatively unchanged in the short term. Farmers will, for example, not remove vineyards and immediately replace them with deciduous fruit orchards or vegetables merely because they have more water at their disposal. Such changes will rather occur in the long term.

The following assumptions apply to the short-term model:

- Present irrigated areas under perennial crops form the lower bound with respect to these crops.
- Upper bounds are placed where irrigated areas cannot be extended because of physical limitations.
- No conditions that upstream water requirements must be satisfied before downstream areas may be allocated water have been incorporated in this model.
- Input data such as irrigation benefit data, water requirements, etc. are identical to the input data used in the incremental benefit/cost study and the other linear programming models.

The constraint matrix consists of 12 rows and 38 columns. The columns represent alternative crops among which irrigation water can be allocated in the distribution sub-areas concerned.

The constraint matrix includes conditions that the combined areas under different crops in any sub-area are bounded by the total available irrigable area in that sub-area. There are also upper bounds for those cases where further irrigation expansion cannot occur.

The short-term linear programming model was subjected to the same economic choice criteria as the conditional linear programming model. The objective functions in this model are as follows:

$$(\text{Benefit-cost}) = \sum_{g=o}^{z} (DF.\,B_{s_g} - DF.\,C_{s_g}).A_{s_g}$$

$$(\text{Benefit/cost}) = \sum_{g=o}^{z} \left(\frac{DF.B_{s_g}}{DF.\,C_{s_g}}\right).A_{s_g}$$

$$\left(\frac{\text{Benefit-cost}}{\text{Cost}}\right) = \sum_{g=o}^{z} \left(\frac{DF.B_{s_g} - DF.C_{s_g}}{DF.C_{s_g}}\right).A_{s_g}$$

$$\left(\frac{\text{Benefit-cost}}{m^3}\right) = \sum_{g=o}^{z} \left(\frac{DF.B_{s_g}}{m^3_{s_g}} - \frac{DF.C_{s_g}}{m^3_{s_g}}\right).A_{s_g}$$

where:

B_{s_g} = the annual irrigation benefit yielded by crop g per unit area (hectares) in sub-area s.

C_{s_g} = the annual cost (capital cost + running costs + overheads) to supply irrigation water per unit area to crop g in sub-area s and to facilitate irrigation development of crop g (per unit area) in the sub-area.

$m^3_{s_g}$ = the total quantity of irrigation water (in cubic metres) annually supplied per unit area of crop g in sub-area s.

A_{s_g} = the irrigated area (in hectares) utilized by crop g in sub-area s.

z = the number of independent crops in the sub-area.

DF = discount factor that discounts a series of annual amounts at 6% per annum over the scheme's productive life of 45 years to present value (Grant and Ireson, 1970; Republic of South Africa, 1982a).

The long-term linear programming model

The difference between this model and the short-term model lies therein that in this model the currently irrigated areas under perennial crops are not used as lower bounds. With this exception, the constraints and objective functions are identical to those of the short-term model.

WATER ALLOCATION RESULTS

Water allocations as obtained by incremental benefit/cost analysis and the conditional linear programming model appear in Table 1. Tables 2 and 3 contain results obtained with the short-term and long-term linear programming models respectively. Incremental benefit/cost analysis and the conditional linear programming model with the (benefit-cost) and $\left(\frac{\text{benefit-cost}}{m^3}\right)$ objective functions yielded identical results, while the results of the other objective functions also largely correspond to these. Differences occur only in two sub-areas (Perdeberg and Bottelary B_4), and these differences involve in total 0,05 million m^3 per annum. These differences do not have practical significance.

The identical results with incremental benefit/cost analysis and maximization of $\left(\frac{\text{benefit-cost}}{m^3}\right)$ give rise to confidence in the numerical correctness of both methods, without implying that these methods - seen in the context of the rather stringent conditions under which they are

TABLE 1 - Water allocation according to the incremental benefit/cost method and according to the conditional linear programming model with four objective functions

Distribution areas and sub-areas	Method and objective functions			
	Incremental benefit/cost method and conditional linear programming: (i) Benefit-cost (ii) $\frac{\text{Benefit-cost}}{\text{m}^3}$		Conditional linear programming: (i) Benefit/cost (ii) $\frac{\text{Benefit-cost}}{\text{Cost}}$	
	Hectares receiving water	Allocation million m^3/year	Hectares receiving water	Allocation million m^3/year
Idas Valley	798	1,37	798	1,37
Groenberg (Wellington)				
BR 11	849	1,57	849	1,57
Dal Josafat	222	0,24	222	0,24
BR 10	673	2,35	673	2,35
BR 9	1 487	5,39	1 487	5,39
Krom River	1 427	4,18	1 427	4,18
Groenberg	0	0	0	0
Noord-Agter-Paarl	541	2,86	541	2,86
Perdeberg	1 342	6,71	1 332	6,66
Bottelary				
B 1	1 820	9,16	1 820	9,16
B 2	739	3,10	739	3,10
B 3	290	1,64	290	1,64
B 4	628	3,53	637	3,58
B 5	0	0	0	0
Joostenberg Flats				
J 2	0	0	0	0
J 4	0	0	0	0
Riebeek-Kasteel	0	0	0	0
Total	**10 816**	**42,10**	**10 815**	**42,10**

TABLE 2 - Water allocation according to the short-term linear programming model with four objective functions

Distribution areas and sub-areas	Objective functions			
	(i) Benefit-cost (ii) Benefit/cost (iii) $\frac{\text{Benefit-cost}}{\text{Cost}}$		$\frac{\text{Benefit-cost}}{\text{m}^3}$	
	Hectares receiving water	Allocation million m^3/year	Hectares receiving water	Allocation million m^3/year
Idas Valley	1 013	2,43	1 013	2,43
Groenberg (Wellington)				
BR 11	1 060	2,12	1 060	2,12
Dal Josafat	260	0,38	260	0,38
BR 10	208	0,83	315	1,41
BR 9	915	4,09	1 858	6,15
Krom River	1 783	7,44	1 783	4,80
Groenberg	372	1,55	372	1,55
Noord-Agter-Paarl	0	0	0	0
Perdeberg	0	0	0	0
Bottelary				
B 1	2 275	14,46	2 275	14,46
B 2	768	4,06	768	4,06
B 3	18	0,10	18	0,10
B 4	72	0,41	72	0,41
B 5	598	4,23	598	4,23
Joostenberg Flats				
J 2	0	0	0	0
J 4	0	0	0	0
Riebeek-Kasteel	0	0	0	0
Total	**9 342**	**42,10**	**10 392**	**42,10**

used - will necessarily yield a true economically optimal allocation. The strict conditions also lead to almost identical results with different objective functions. Since the conditional linear programming model requires less time inputs than incremental benefit/cost analysis, it is a more efficient technique to use.

In both the short-term and long-term linear programming models identical results were achieved with the (benefit-cost), (benefit/cost) and $(\frac{\text{benefit-cost}}{\text{cost}})$ objective functions. Water allocations according to the $(\frac{\text{benefit-cost}}{\text{m}^3})$ objective functions yielded different results with both these models.

In both models water allocations differ in three sub-areas - all in the Groenberg area.

The extent of differences is larger with the long-term model which was subjected to less strict constraints. Since the $(\frac{\text{benefit-cost}}{\text{m}^3})$ criterion implicitly assumes water to be the only ultimate limiting source - certainly more limiting than capital - the realism of using it for water allocation should be questioned from an economic point of view. The other three criteria should be preferred. If real constraints had been placed on capital availability, the differences between this function and the other three would probably have been larger, depending on the constraint level.

It is remarkable that all the objective functions with the long-term model allocate water to large areas, and that generally, water allocations to such small areas as were the case with the other models did not occur. It can be ascribed to the fact that the long-term model does not accept as a prerequisite those small areas of a specific crop which at present are already under irrigation or which should according to the Department of Agriculture and Water Supply, in future be put under irrigation.

The short-term and long-term linear programming models yield considerably smaller allocations to the Berg River areas (Groenberg, Noord-Agter-Paarl and Perdeberg) and larger allocations to the Eerste River areas (Bottelary and Idas Valley).

CROPPING PATTERNS

Table 4 shows the differences in total irrigated areas under the three main crop groups according to the different allocation models.

It appears in the first place that the incremental benefit/cost method and the conditional linear programming model were based upon assumptions which involve considerably more cultivation of vineyards and other crops, and considerably less deciduous fruit production than the two models in which crop selection and water allocation are optimized simultaneously. With the latter two models, vineyards play a considerably more important role with maximization of the $(\frac{\text{benefit-cost}}{\text{m}^3})$ criterion than with the other economically more generally acceptable objective

TABLE 3 - Water allocation according to the long-term linear programming model with four objective functions

	Objective functions			
Distribution areas and sub-areas	**(i) Benefit-cost (ii) Benefit/cost (iii) $\frac{\text{Benefit-cost}}{\text{Cost}}$**		**$\frac{\text{Benefit-cost}}{\text{m}^3}$**	
	Hectares receiving water	**Allocation million m^3/year**	**Hectares receiving water**	**Allocation million m^3/year**
Idas Valley	1 013	2,43	1 013	2,43
Groenberg (Wellington)				
BR 11	1 060	2,43	1 060	2,43
Dal Josafat	260	0,46	260	0,46
BR 10	0	0	616	3,32
BR 9	747	4,56	1 858	5,70
Krom River	1 783	8,96	1 783	4,50
Groenberg	0	0	0	0
Noord-Agter-Paarl	0	0	0	0
Perdeberg	0	0	0	0
Bottelary				
B 1	2 275	14,69	2 275	14,69
B 2	768	4,26	768	4,26
B 3	0	0	0	0
B 4	0	0	0	0
B 5	598	4,31	598	4,31
Joostenberg Flats				
J 2	0	0	0	0
J 4	0	0	0	0
Riebeek-Kasteel	0	0	0	0
Total	**8 504**	**42,10**	**10 231**	**42,10**

functions. Where existing patterns are not included as conditional constraints (the long-term model), only deciduous fruit appear in the final solution.

These phenomena may be explained thereby that vineyards in particular have a lower water requirement per unit area and per unit value of gross margin, and that as more water becomes available, the optimum shifts from products with a high margin per m^3 of water to products which maximize financial yields per unit of other sources. This finding corresponds to those of Hancke and Groenewald (1972), Van Rooyen (1973) as well as Groenewald and Van Zyl (1986).

TABLE 4 - Cropping pattern with the different allocation models

Model and objective function	Vineyards	Deciduous fruit	Other	Total
	ha			
Incremental benefit-cost method and conditional linear programming:				
(i) Benefit-cost	8 883	1 535	398	10 816
(ii) $\frac{\text{Benefit-cost}}{\text{m}^3}$				
(iii) Benefit/cost	8 883	1 534	398	10 815
(iv) $\frac{\text{Benefit-cost}}{\text{Cost}}$				
Short-term linear programming:				
(i) Benefit-cost	2 398	6 871	73	9 342
(ii) Benefit/cost				
(iii) $\frac{\text{Benefit-cost}}{\text{Cost}}$				
(iv) $\frac{\text{Benefit-cost}}{\text{m}^3}$	4 670	5 649	73	10 392
Long-term linear programming:				
(i) Benefit-cost	0	8 504	0	8 504
(ii) Benefit/cost				
(iii) $\frac{\text{Benefit-cost}}{\text{Cost}}$				
(iv) $\frac{\text{Benefit-cost}}{\text{m}^3}$	3 641	6 590	0	10 231

It is also evident that irrigation water availability will lead to an optimal cropping pattern which will differ substantially from predetermined expectations of the agriculturalists involved therewith. It can also be expected that the long-term tendency will be to move in the direction of the optimum. These findings and expectations correspond to events in the Great Fish River Valley (Backeberg, 1984).

A sensitivity test was executed on the linear programming models. Solutions for the short and long-term models were found to exhibit a high degree of stability with respect to unit gross margins. This was not the case with the conditional linear programming model. With the latter the validity found of certain area activities was at the lowest level. This implies that it was only the built-in prescribed cropping patterns which enabled certain areas to qualify for their allocated irrigation water.

ECONOMIC IMPLICATIONS

Tables 1 to 3 show relatively small differences in physical water allocations while Table 4 reflects considerable differences in cropping patterns. The question is whether these differences are of appreciable economic importance. This will firstly be measured by comparing the total annual (benefit-cost) values obtained with the different models. In this comparison, solutions obtained with the (benefit-cost) objective functions are used in the case of linear programming models. The comparison appears in Table 5.

TABLE 5 - (Benefit-cost) values as obtained from different allocation models

Model	Annual realized (benefit-cost) R million	Rates: Incremental benefit/cost model/IBC*
Incremental benefit/cost	3,6	1,00
Conditional model	3,6	1,00
Short-term model	9,5	2,64
Long-term model	10,6	2,94

*IBC = Incremental benefit/cost method

It appears that total annual net benefits yielded by the short-term and long-term models that simultaneously optimize crop selection and water allocation exceed those based upon predetermined cropping patterns two to threefold. These differences are accentuated that when dual values were calculated, it amounted to 4,5 cents per m^3 of water in the case of the conditional linear programming model compared to 11,6 cents in the case of the long-term and short-term models. Thus, further additional allocations as distributed by the latter two models will yield a marginal value product approximately 2,6 times that from models with a fixed cropping pattern. This does therefore indicate that models which optimize water allocations and crop patterns simultaneously lead to considerably more beneficial use of irrigation water.

A discount rate of 6% per annum and an economic life span of 45 years which were accepted following the Department of Water Affairs' project analysis criteria, result in a discount factor of 15,456 for a series of annual discounted amounts. The respective capitalized net benefits as yielded by the short and long-term linear programming models (Table 5) will exceed those from the other models by R91 million and R108 million respectively. Even if it is taken into account that the gross margins were based on 1981 data and that gross margins have since declined, these figures still appear to be reasonably realistic in the light of the fairly pessimistic discounting criteria (6% over 45 years). In his comprehensive study on irrigation planning on the Makatini Flats, Van Rooyen (1983) used a discount rate of 2,5% per annum and an economic life span of 30 years, and he stated that those criteria could be regarded as realistic for the evaluation of projects which will be financed from public funds. If the latter criteria were used, the discount factor for a series of annually discounted amounts would be 20,930. Under these circumstances the additional net benefits of R91 million and R108 million would increase to R123 million and R146 million respectively.

CONCLUSION

Nowadays it is generally accepted that an improvement in the effectiveness and efficiency of State expenditure is vitally important for future economic welfare in South Africa. This also implies that State expenditure on capital works should be incurred in such a manner as to lead to the highest possible economic benefit. In water development decisions, this requirement will involve that optimization models which optimize irrigation crop selection simultaneously with water allocation should be preferred to models based upon rigid cropping patterns. The results of this study, as well as those of Backeberg (1984) and Van Rooyen (1983) strongly illustrate the importance thereof.

It also appears that the policy often followed, namely to satisfy upstream water requirements up to a certain point before considering allocations further downstream, may in many cases be very expensive and lead to suboptimal allocations.

Analogous to this water allocation study involving different crops, it can be stated in a more global sense that for multi-purpose State water schemes, mathematical or operational research models should be utilized to optimize social benefit-cost for the allocation of water among the different target sectors such as agriculture, urban water supply, hydro-electric power generation, etc. In order to achieve this, however, considerably more research is needed for the construction and utilization of such models. If the multi-purpose water resource studies in the northern parts of the country are borne in mind, such mathematical models may be of inestimable value, for example, water for the PWV region (in addition to what already exists), may in the future originate from Lesotho, the Tugela and even the Usutu or Crocodile River systems. All these sources have potentials for multi-purpose application. An orderly operational research model that can create such a water plan, can be of great value to the Republic - particularly if stochastic elements such as frequencies of drought and flood are incorporated therein.

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