A quality of life-based decision support model for the determination of water research priorities

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Abstract

A "value to the country and its peoples"-based decision support system for the assessment and funding of applied, low-risk water research is suggested, accentuating the fundamental quality of life and human needs of each individual citizen of the country. Appropriate research assessment models developed and in use, were investigated by means of literature surveys and personal communication. Multicriteria decision-making (MCDM) was selected, with the simple multi-attribute rating technique (SMART), as the specific method among the family of MCDM methods.

A set of "values to the individual person"-based assessment criteria was generated from an in-house exercise; as used by other institutions; from interviews with water managers; from basic human needs and quality of life-concepts; and from issues raised by stakeholders in water and sanitation. Weights for these criteria were elicited from technical managers, and socio-political groups in the Country, and a scoring system added. Finally, some ancillary management elements were added to the core research assessment method to complete the decision support model.

Introduction

Water is an important national resource and in some countries, also a scarce resource. Being a national resource it could be argued that water should, therefore, be utilised to the benefit of all of a country and its inhabitants.

From the above argument, and because research funding is generally limited and inadequate, it follows that research performed on all aspects of water should be instrumental in achieving this goal. Whereas criteria such as "the potential increase in water quantities" or "the potential improvement in water quality" could be used to assess priorities in water research, it is really the eventual benefits that the increase in water quantities, or the improvement in water quality, might potentially have for the country and its people that matter (Fig. 1). Therefore, a "value to the country and its peoples"-based decision support system was created, for the assessment and funding of applied, low-risk water research, accentuating the fundamental quality of life and human needs of every person in a country. The decision support system was developed, using the South African Water Research Commission (WRC) as case study.

The WRC is a parastatal institution, funding mostly applied, (OECD, 1987) relatively low-risk, ensured-outcome, water research and technology transfer projects from levies on all water sales in the country. Fifteen so-called research fields (convenient groupings of projects) are being funded, i.e. agricultural water utilisation; drinking water; membrane technology; hydrometeorology; rainfall stimulation; surface hydrology; developing communities; groundwater; mine water; water pollution; municipal effluents; industrial water and effluents; aquatic ecosystems; water resource management; and general.

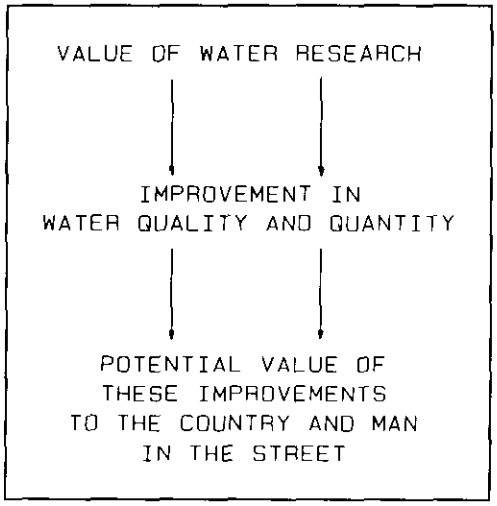

Figure 1
Extension of benefits from water research results to the fundamental elements of value

Review of research and development assessment methodology

General methods for the assessment of research and development (R&D)

Various researchers have summarised general R&D project selection and decision-making methodologies, such as Baker and Pound (1964); Gee (1971); Augood (1973); Souder (1978); Souder and Mandakovic (1986); Luukonen-Gronow (1987); and Danila (1989). Project selection methodology for the more "developmental" e.g. dam or process plant construction type of projects, may be found in works such as Dasgupta et al. (1972); Baum and Tolbert (1985); Lock (1987); and Sang (1988).

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A wide range of multicriteria (or multi-attribute) decision making (MCDM) techniques has been developed, mostly over the last 20 years. Refer to Von Winterfeldt and Edwards (1986), e.g., for a comprehensive historical review. In three recent publications, Teclé (1992) compares 15 multicriteria decision-making techniques (of the 70 he had previously identified) for watershed resources management. Harboe (1992) compares six such MCDM methods for optimal reservoir operation and Lahlou and Canter (1993) evaluate 14 MCDM techniques for environmental remediation projects assessment.

Various classifications of the more classic R&D evaluation methods have been attempted. Augood (1973) and Danila (1989) classified the methods according to the manner in which the results are obtained and presented. Lovelace's (1987) classification revolves around the planning direction and level of analysis whereas Souder and Mandakovic (1986) offer a classification based upon historical development and development in sophistication.

Some of these models can be combined (Danila, 1989) such as using the well-known peer review (Cole et al., 1981; Plevin, 1992) or the nominal-interacting/Q-sort process (Souder, 1978; Souder and Mandakovic, 1986), together with, for example, one of the "checklist" family of models. A listing of some of the general R&D decision-making methods is given in Offringa (1996).

In a survey of Fortune 500 industrial firms concerning the usage of techniques and methods for R&D project selection and resource allocation, Liberatore and Titus (1983) found that many R&D managers do not perceive that these techniques 'appreciably improved their decision-making'. However, Von Winterfeldt and Edwards (1986) cite a number of tests performed, showing that decomposed (e.g. criteria-based) models outperformed holistic judgement - thus putting forward a strong case for the use of correctly chosen and structured decision support models in the assessment of research and development.

These methods surveyed, although not by any means complete, already provide for a whole range of possible methods for the assessment of R&D. However, since many methods reported on in the literature have seldom if ever been used in practice (e.g. Danila, 1989; Teclé, 1992), and before an evaluation could be made of the suitability of these models for the assessment of water research, it was necessary to add a practical dimension and investigate what methodologies were currently being employed by real-life R&D institutions.

Research assessment methods followed by some research institutions

To establish which methods were actually being used under practical conditions, a survey was made of the *ex ante*, i.e. before execution, project assessment methodologies employed by some organisations performing, funding and managing research. (Although simple "round table" discussions may strictly-speaking also be classified as a model, this was regarded as the default and organisations practising this model were not included).

The survey included some basic research-oriented organisations, as well as organisations more related to infrastructure development, in order to provide a somewhat wider perspective to research project assessment and selection. Information was gathered using correspondence by mail, telephone and telefax, personal visits and extraction from the rather limited amount of literature freely available. Of the 103 institutions surveyed (Offringa, 1996) the *ex ante* project assessment models and methods employed for 29 institutions who do practice some structured evaluation system, were extracted and analysed further for possible adaptation and use by the WRC.

From this survey it was noted that some form of external or internal peer review of research and some variation of criteria-based, checklist models were the dominant models for projects worth assessment. Some institutions, such as the Australian CSIRO (CSIRO, 1991; CSIRO, 1993) and the South African Department of Transport (Van der Walt, 1994) made use of a more modern variety of the checklist model, namely a multiple (conflicting) criteria model. As expected, the banks and money-lending institutions made use of, *inter alia*, ratio (indices) models, but it is interesting to note that three non-lending, research funding institutions did make use of benefit/cost ratios (both in money terms) where they believed that the potential benefits and costs could be quantified. One research funding institution (CONACYT), stated (Corcuera, 1994) that they attempted using benefit/cost ratios (CONACYT, 1994) but eventually discarded it as being impractical.

Selection of method

A category of research assessment method, namely MCDM was selected firstly. The selection was done using the criteria of Teclé (1992) and Lahlou and Canter (1993), as well as the general Organisation for Economic Co-operation and Development guidelines (OECD, 1987). Details of the selection process are described in Offringa (1996). For some of the textbooks on MCDM-oriented decision-making, the reader is referred to, for example, Keeney and Raiffa (1976); Zeleny (1977); Goicoechea et al. (1982); Chankong and Haimes (1983); French (1986); Steuer (1986); Szidarovszky et al. (1986); Von Winterfeldt and Edwards (1986); Watson and Buede (1987); Bana e Costa (1990); Bogetoft and Pruzan (1991); Goodwin and Wright (1991); and Vincke (1992). A number of methods have been presented in software format (e.g. Zionts and Lofti, 1989; Buede, 1992; Vincke, 1992) or could be implemented on spreadsheets (Stewart, 1989). Stewart (1992a) provides a critical survey of some of the methods more generally used.

A specific method among the family of MCDM methods, namely the simple multi-attribute rating technique (SMART) (Von Winterfeldt and Edwards, 1986; Belton and Vickers, 1990; Goodwin and Wright 1991) was subsequently selected, as suiting the requirements of WRC best (Offringa, 1996). The main steps in the SMART method are summarised from Von Winterfeldt and Edwards (1986) as:

- Identification of the decision-maker.
- Identification of the alternatives (e.g. courses of action).
- Identification of the relevant attributes (to be used as criteria).
- Assigning of values to measure the performance of each alternative on each criterion.
- Weighting of the criteria.
- Aggregation of performance values on criteria and weights for each alternative, using the weighted additive value function where possible.
- Provisionally choosing the alternative that maximises the overall value.
- Performing of sensitivity analyses to determine robustness of the method, especially to the weights selected.

Experimental methodology

The steps of the SMART method were followed, except that weighting had to be done before scoring, since weighting of

criteria external to the WRC was regarded as important for acceptance and transparency of the eventual assessment method.

Generation of quality of life-based criteria

As the main focus of the core water research assessment method, a set of criteria was generated, following general guidelines (Keency and Raiffa, 1976; Von Winterfeldt and Edwards, 1986; Keeney et al., 1987; Keeney et al., 1990). The criteria were generated in the following ways:

From the criteria employed by other institutions surveyed

Relevant criteria, that could serve as a pool for potential use by the WRC, were extracted and categorised into generic criteria, from the survey of organisations performing, funding and managing research, as described in Offringa (1996).

Criteria from an in-house WRC exercise

An independent in-house exercise was conducted by senior WRC managers, during which a list of attributes and sub-attributes was generated, following a bottom-up approach (Von Winterfeldt and Edwards, 1986).

Criteria from basic human quality of life needs and values

In this exercise, it was attempted to incorporate the basic human needs and quality of life concepts, as they impact upon water and water research project assessment, as part of the "value of water to the ordinary citizen" concept. Since basic human needs, motivating human behaviour, and the quality of life requirements have been well studied in general (e.g. Dalkey et al., 1972; Andrews and Withey, 1976; UNESCO, 1978; OECD, 1985; Callahan et al., 1986; Mukherjee, 1989), and also in South Africa (Ellis, 1980; Ellis and Erlank, 1983; Möller et al., 1987) it was felt that information on actual human needs could be obtained from the vast literature available, rather than attempting an own study or eliciting information from the various peoples and groups in South Africa.

Theories on human needs within social and work context, such as Maslow's Need Hierarchy, and the ERG, Herzberg Two-factor, McLelland and Equity theories (e.g. Callahan et al., 1986) were included, as were some fundamental needs from project planning and execution (Grover, 1983) and the needs pertaining to clean air and water (Kneese, 1984).

Criteria from managers in water research

An attempt was made to map the decision-making skills and "gut-feel" of five of the few people in South Africa approaching the required overall, encompassing background of the full scope of water research as funded by WRC, into criteria for the decision support system. They were asked to rank four research fields (i.e. categories of water research) by "importance", and then had to expand on the reasons for their judgement, i.e. to describe their inner feelings on why they regarded certain fields as more (or less) important than other fields. In addition, descriptive sentences were elicited on what they regarded as the value of water for the country and its people.

Criteria from strategy-planning exercises

As part of its mission and brief, the WRC compiles strategic research plans in a number of research fields and speciality research areas. The objective here was to obtain some additional criteria from the values, requirements, issues and concerns raised by stakeholders in the water and sanitation fields at a number of these strategy-planning exercises. From these, a consolidated list of potential criteria was compiled. The brunt of the input came from the research community itself, but also from the relevant Government Departments and other Government, non-Government and private institutions in the water and sanitation fields. Of these strategic plans, two included some issues raised around the developing communities (Mitchell and Offringa, 1991; Offringa, 1992). In addition, some issues were extracted from a strategy-planning workshop held by the "Water and Sanitation 2000" action group (W&S, 1991), and from a Department of Water Affairs and Forestry document on water supply and sanitation for developing communities (DWA, 1991).

Checking and pruning of the criteria

Following the guidelines and principles for the compilation, checking and pruning of a value tree (Keeney and Raiffa, 1976; Von Winterfeldt and Edwards, 1986), the five lists of criteria generated, were consolidated and categorised into a number of main criteria and a number of subcriteria - one set of criteria for assessing the lower hierarchy research **projects**, and one set of criteria for the higher hierarchy research **fields'** assessment.

Using these guidelines, a compromise had to be made between the requirements for "completeness" and to be "decomposable", and the requirements of "minimum size" and "non-redundancy" (see, for example, Von Winterfeldt and Edwards, 1986). The philosophy followed was to keep it as simple as possible, i.e. limit the levels and numbers of criteria as far as possible, and force preferential independence as far as possible in order to use the additive value function if and where possible (Von Winterfeldt and Edwards, 1986). It was decided not to decompose the tree too many levels down, but rather to use the subcriteria to better define, and as descriptors of, the higher level criteria - again for the reasons of simplicity, to avoid interdependence problems, and for ease of weighting elicitation, and eventual routine use. Some depth and accuracy of decision-maker preferences would, of necessity, be sacrificed in this way. With regard to the number of criteria in each level, it was also attempted to adhere as closely as possible to "the magical number 7" of Miller (1956).

Choice of aggregation rule

The aggregation rule for the aggregation of weights and performance assessments against criteria should already be decided upon at this stage, taking into account the requirements for using the various rules, such as the additive, multiplicative and multilinear rules (Keeney and Raiffa, 1976; Von Winterfeldt and Edwards, 1986).

The simple additive aggregation model:

$$V(\underline{x}) = \sum_{i=1}^{p} w_i v_i (x_i) \qquad (1)$$

where $V(\underline{x})$ is the aggregated value over p criteria; w_i is the criterion weight; and $v_i(x_i)$ is regarded as a value of achievement associated with some level x_i on criterion i (Von Winterfeldt and Edwards, 1986); may strictly be used only under the rather strong

assumption of additive difference independence - although the additive aggregation rule has proved to be robust to minor violations of this assumption and little seems to be lost when using the additive rule under such conditions (Von Winterfeldt and Edwards, 1986; Stewart, 1992b). However, where serious doubts exist because of preferential dependence (Keeney and Raiffa, 1976) of some of the criteria, the multiplicative aggregation rule should be employed (Von Winterfeldt and Edwards, 1986).

If performance assessment is done using a ratio method, such as AHP (Saaty, 1980) or in the case of efficiency criteria, Lootsma (1991) suggests a multiplicative aggregation rule of the form:

$$V(\underline{x}) = \prod_{i=1}^{n} (v_i(x_i))^{w_i} \qquad (2)$$

Weighting of the criteria

To obtain an indication of the relative importance, or weights, of these criteria, as perceived by the main stakeholders of the WRC's research funding, it was necessary to elicit preferences from representative stakeholders. The main stakeholders were identified as being the public, the Government, the research community, the WRC Executive and the WRC research managers.

Criteria weights were elicited from the following groupings:

- The middle management technical group (research managers) at WRC, representing experience in their field of expertise in water and water research.
- The higher management technical group (Executive Director and deputies) at WRC, representing an overall view and experience in water and water research as funded by the WRC.
- An external, socio-political group, in an attempt to obtain some indication of the preferences of the people of the country which these groups represent. Nine different political and labour union groups provided their weighting preferences.
- An external, research management group, also having socio-political perspective, as some indication of the preferences of the research community. Eleven senior managers from universities and trade and industry were approached.

The weighting was done hierarchically, i.e. main criteria were weighted first, then subcriteria. In line with the philosophy to keep the decision support system (and the weight elicitation process with the groups external to the WRC) as simple as possible, only the main criteria and major subcriteria were weighted. The unweighted subcriteria would act as checklists to take into account when evaluating the alternatives against the higher levels of weighted criteria.

Both the Swing weighting method (which does away with the notion of importance altogether, see Von Winterfeldt and Edwards, 1986), and ratio weighting were used for the first two (internal) groups. Once a good correlation between these two methods had been found, only the more user-friendly ratio weighting software package *Trade-Off* (Scholtz, 1991) was further employed for the external groups. Averages of the four groups' weighting outcomes were used (Von Winterfeldt and Edwards, 1986).

A measurement (scoring) system

Following the guidelines on measurement by Torgerson (1958), Von Winterfeldt and Edwards (1986) and Lootsma (1991), and taking the requirements of additive and multiplicative aggregation and the nature of the WRC research projects and groupings of projects (i.e. research fields) into account, the following scoring system was devised. For the higher hierarchy research fields, the scoring system is as depicted in Fig. 2, and for the lower hierarchy research projects, in Fig. 3. Generically, with some adaptations for certain criteria, the scale suggested for the assessment of research projects is:

0 - No/none
20 - Low/little/poor
40 - Fair/reasonable/moderate
60 - High/strong/large
80 - Very high/strong/large
100 - The "ideal" project; extreme/overwhelming etc.

The scoring of research fields differs from that of research projects, in that the field rated as highest on the criterion at issue, is arbitrarily set at 100 on the scale.

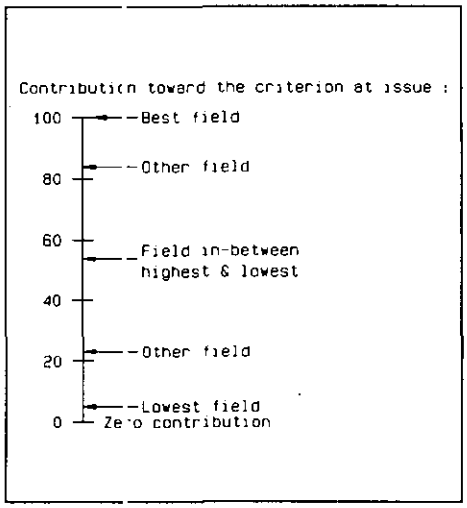

Figure 2
Scale for the single criterion assessment of research fields

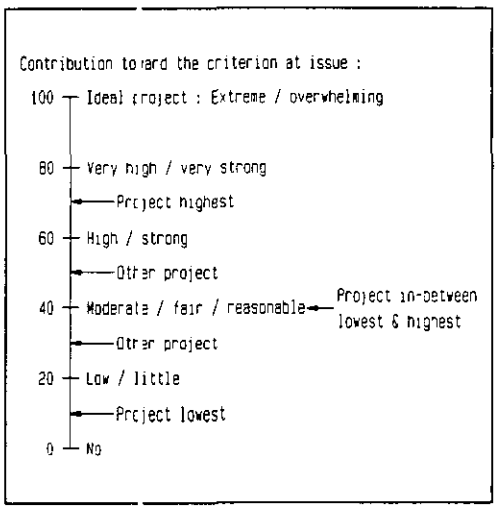

Figure 3
Scale for the single criterion assessment of research projects

Ancillary management elements

In the preceding sections the compilation methodology for a criteria-based research assessment method has been cursorily described. However, in the management of research in general, and project selection in particular, this core method is only a part of a more complete, overall, research assessment decision support model, system or framework (Goicoechea et al., 1982; Twiss, 1986; Sang, 1988). A number of appropriate (to WRC) "ancillary management elements" to complement the core assessment method were thus compiled from literature (Goicoechea et al., 1982: Twiss, 1986; OECD, 1987; Sang, 1988), from practical methodology followed by other institutions (Offringa, 1996), as well as from experience at the WRC.

- Management of the project proposal portfolio before any screening and assessment of individual projects can commence. (This could, for example, involve changing of the proposal, in conjunction with the project leader, within limits, to make it more suitable for assessment).
- System borders and constraints existing in terms of, for example, financial, policy, technical, political, social or other aspects.
- The use of screening methods to limit the original number of project applications to "workable" numbers, and arrive at some approximation of a Pareto optimal set of alternatives for final assessment. (e.g. Lahlou and Canter (1993) for a description of the various screening methods for the elimination of non-feasible and dominated sets of alternatives).
- The possible employment of external (peer and expert) review in the assessment exercises (Cole et al., 1981; National Research Council, 1987; Pouris, 1988; NSERC, 1989; NIH, 1992).
- The eventual budget allocation after the initial assessment of relative importances has been made. Budget allocation aspects may be very organisation-dependent. Some budget allocation methods are discussed by, for example, Sugden and Williams (1978), Twiss (1986), Eilon and Williamsson (1988), Mishan (1988) and Sang (1988).
- Management of special and extraordinary situations. These might also be, to a large extent, organisation-dependent. Examples, as applicable to the WRC, include:
  - Only, or mainly, very weak project proposals in a research field
  - Only, or mainly, extremely strong (important) project proposals in a research field, their total costs exceeding the available budget
  - Projects impacting upon two or more fields
  - Projects complementing each other
  - Political and other uncontrollable issues ("state variables", Von Winterfeldt and Edwards, 1986).

Results

Criteria sets generated

Being not a trivial task, criteria sets were generated from the five different methods of criteria generation followed and described. The consolidated lists of criteria are presented in an unpruned (Keeney and Raiffa, 1976) format.

Consolidated criteria used by other institutions

Criteria of potential use for the assessment of water research, were categorised (Offringa, 1996), and are summarised in Table 1.

Criteria generated from an in-house exercise

The following, preliminary, set of potential research assessment criteria was generated in this exercise:

Impact of the research on the water household
Impact on water quantities
Economic implications
Impact on water quality improvement
Protection of the environment
Health implications

Application potential
Commercialisation potential
Nature and development level of target group

State of the art of the research
Need for an increase in knowledge
Need for the establishment of local expertise

Chances of successful research
Track record of the research team
Scientific and technological complexity of the research
Availability of the required infrastructure

Planning
Conceptual planning of the research
Scientific merit

Criteria from basic human quality of life needs and values

It could only be attempted to compile a list of attributes for use as potential criteria for the assessment of the worth of water research projects from the these basic human needs and values studies. The consolidated attributes, already pruned to some extent, are listed as:

- Need for safety and security, where security is defined as freedom from threat (no danger from floods, fear of water shortages); stability; peace of mind
- Need for belonging, life compared with others (e.g. same water quality, sanitation, clean lake, etc. as for "the Joneses")
- Provision of self-esteem, sense of personal worth, status (e.g. job-creation, good water and sanitation systems)
- Equity, fairness, social justice (same standards and treatment as for others)
- Personal hygiene (adequate water quantities and quality)
- Adequate free time for resting, sleeping, fun, play, recreation (by, for example, having a tap in or close to the home instead of having to fetch water from far away)
- Health (sickness and morbidity)
- Creature comforts beyond subsistence (good water quality, satisfaction with food, sanitation, play, fun, recreation, sensual pleasures, aesthetics of, for example, clean potable water and surface water bodies)
- Income and prosperity, cost of living
- Employment, opportunities for finding work
- Education and training and opportunities therefore; improvement of skills and expertise
- Stability, development and growth of the social system
- Culture, traditions, (the "deeper") cultural values
- Power, empowerment, control, role of women, independence, freedom, possession.

TABLE 1
CATEGORISED CRITERIA USED BY SOME RESEARCH AND FUNDING INSTITUTIONS FOR THE ASSESSMENT AND SELECTION OF RESEARCH AND DEVELOPMENT PROJECTS

Categorised criterion	Institution making use of the categorised criterion																									
	AFRC	AIDAB	ARS	AWWARF	BSF	CIDA	CDC	CEC	CSIRO	CONACYT	DOT	EIB	EPA	Eskom	FRST	IDB	LWRRDC	NCTR	NERC	NIH	NSERC	NSF	PtWT	STA	USAID	VTT
Excellence of researchers & research institution/chances to achieve objectives	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Impact/benefits/relevance of the research	✓	✓	✓					✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Scientific merit/excellence	✓		✓	✓	✓					✓			✓					✓	✓			✓	✓	✓	✓	
Benefit/cost & financial ratios		✓				✓						✓				✓	✓									
Budget appropriateness/reliability				✓	✓					✓			✓					✓		✓	✓		✓		✓	
Soundness of research approach/proposal			✓							✓			✓				✓			✓	✓	✓	✓		✓	
Application potential/probability of implementation	✓			✓			✓		✓		✓				✓		✓		✓					✓		
Timeliness/time frame of realisation	✓	✓							✓						✓				✓							✓
Innovativeness				✓	✓			✓					✓							✓	✓			✓	✓	
Urgency											✓												✓	✓		
Involvement of other institutions/ cooperative research		✓		✓	✓					✓								✓							✓	✓
Fit with the mission & priorities of the organisation/country						✓		✓				✓			✓	✓	✓		✓					✓		
Need for funds/other funding available																					✓					
Need for increase in knowledge/ similar research already performed			✓						✓														✓	✓		

Legend for Table 1

AFRC	-	Agricultural and Food Research Council - UK
AIDAB	-	Australian International Development Assistance Bureau
ARS	-	Agricultural Research Service - USA
AWWARF	-	American Water Works Association Research Foundation - USA
BSF	-	Binational Science Foundation - Israel
CIDA	-	Canadian International Development Agency - Canada
CDC	-	Commonwealth Development Corporation - UK
CEC	-	Commission of the European Communities - Belgium
CSIRO	-	CSIRO Australia
DOT	-	Department of Transport - South Africa
EIB	-	European Investment Bank - Luxembourg
EPA	-	Environmental Protection Agency - USA
Eskom	-	Eskom - South Africa
FRST	-	Foundation for Research, Science and Technology - New Zealand
IDB	-	Inter American Development Bank - USA
LWRRDC	-	Land and Water Resources Research and Development Corporation - Australia
NCTR	-	National Committee for Technological Research - Italy
NERC	-	*Natural Environment Research Council* - UK
NIH	-	National Institutes of Health - USA
NSERC	-	National Science and Engineering Research Council - Canada
NSF	-	National Science Foundation - USA
PtWT	-	Project Agency for Water Technology and Sludge Treatment - Germany
STA	-	Science and Technology Agency - Japan
USAID	-	US Agency for International Development - USA
VTT	-	Technical Research Centre of Finland - Finland

Additional criteria from managers in water research

Additional criteria generated in this fashion, over and above those obtained from the first two exercises include aspects such as political impact; international influences; uniqueness to South Africa; and the maintaining of research momentum. The calmness, pleasing and deeper social and positive effects of clean water were again stressed.

Additional criteria from strategy-planning exercises

Additional criteria, over and above those listed previously, obtained from the issues and concerns raised by stakeholders in the water and sanitation field during strategy-planning exercises are summarised as follows:

- Involvement of a "champion"
- Involvement of the community receiving the research results (also in research project execution); use of local skills and unemployed people
- Development of infrastructure
- Acceptance of research results by user communities (ability and willingness to pay, experience, skills and knowledge levels, ignorance, ability to manage)
- Commitment and contribution to democracy
- Conforming to, and integration with local institutional policies
- Reliability, appropriateness and sustainability of research products
- Political and social stability of receivers of research results
- Existence and influence of pressure groups; public awareness.

Aggregation of weight and score

Taking cognisance of the requirements mentioned under **Choice of aggregation rule**, and requirements of the WRC, the simple additive aggregation model (Eq. 1) was selected for the seven subcriteria of **Benefits to the country and its people**. However, because the evaluation of scores on each of the five main criteria is not additively independent, and because others were efficiency criteria, the multiplicative aggregation rule of Lootsma's (1991) (see Eq. 2) was selected for their aggregation.

A scoring matrix of weighted criteria

The final set of criteria, after performing the quality of criteria assessment checks (Von Winterfeldt and Edwards, 1986), is presented in value tree format (Fig. 4). Adding the average weights obtained from the four groups used in the weight elicitations, the complete set of criteria and subcriteria for the assessment of water research is summarised as a scoring matrix in Table 2.

For the assessment of research fields (groupings of projects), only the two main criteria listed in Table 2 viz. **Benefits to the country and its people** and **The need for further knowledge** are applicable. Weights for these two main criteria were normalised accordingly to 0.63 and 0.37 respectively.

It must be stressed that this scoring matrix should only be employed as **one** of the decision-making tools in the overall decision-making process. Special (e.g. political) circumstances might require further, executive, decision-making inputs.

The decision support system

By adding the WRC specific and required management elements discussed in Offringa (1996), a value to the ordinary citizen of the country-based decision support system for the *ex ante* assessment of low-risk, applied research projects and groupings of projects, was arrived at. The model is depicted in Fig. 5.

Because of constantly changing conditions, a model such as this would require maintenance (and improvement) in terms of the following:

The criteria set upon which the model is based, will require periodical review. External input could enhance the value of these exercises. Equally, the importance weights and aspects of the ancillary management elements will require updating at regular intervals. In addition, further evaluation and development of the budget allocation system will be advisable.

Conclusions

A simple, criteria-based model has been synthesised for the determination of low-risk, applied water research priorities, accentuating the fundamental human needs and quality of life requirements of each individual person in the country.

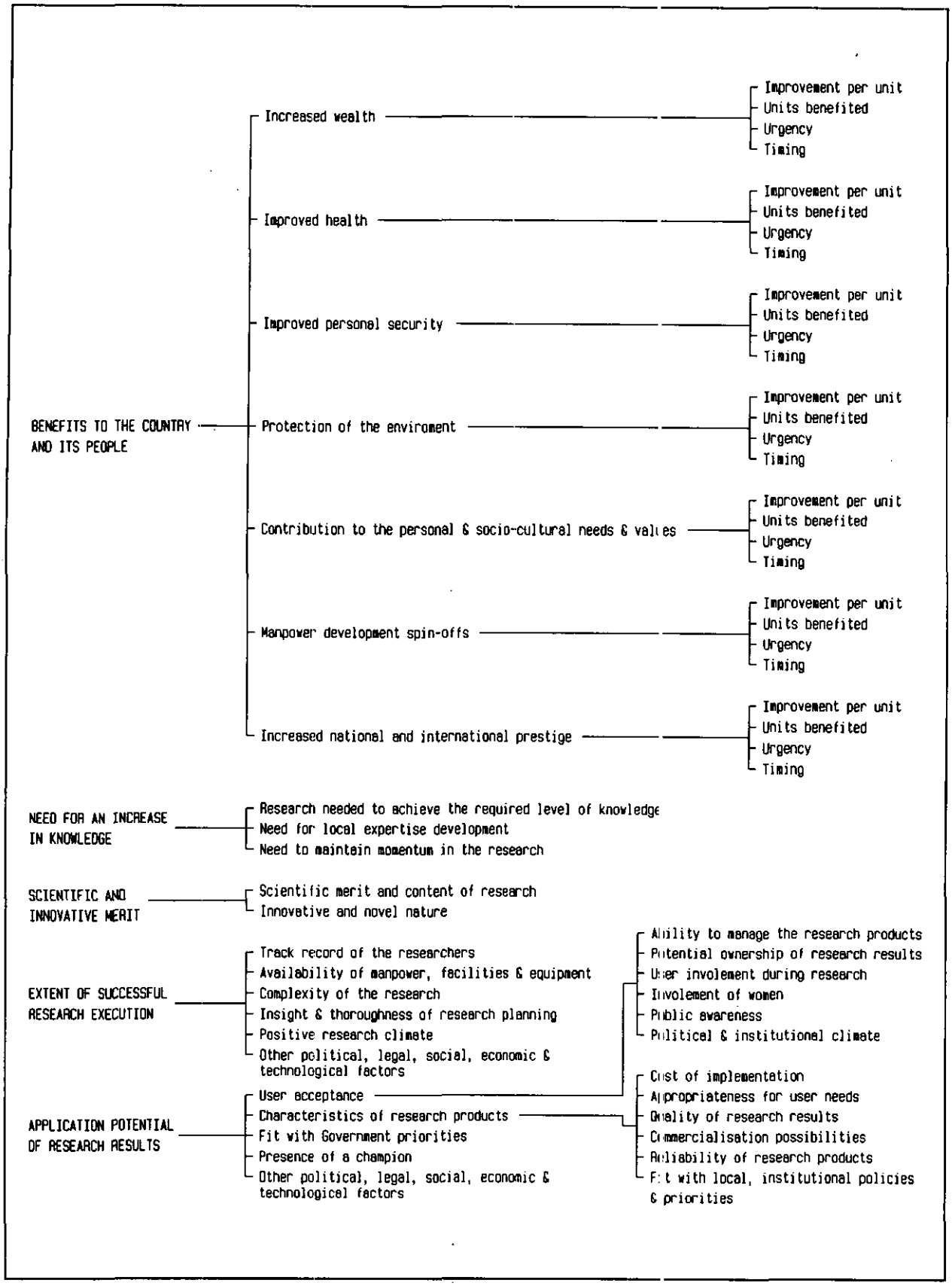

Figure 4

A value tree for the assessment of water research

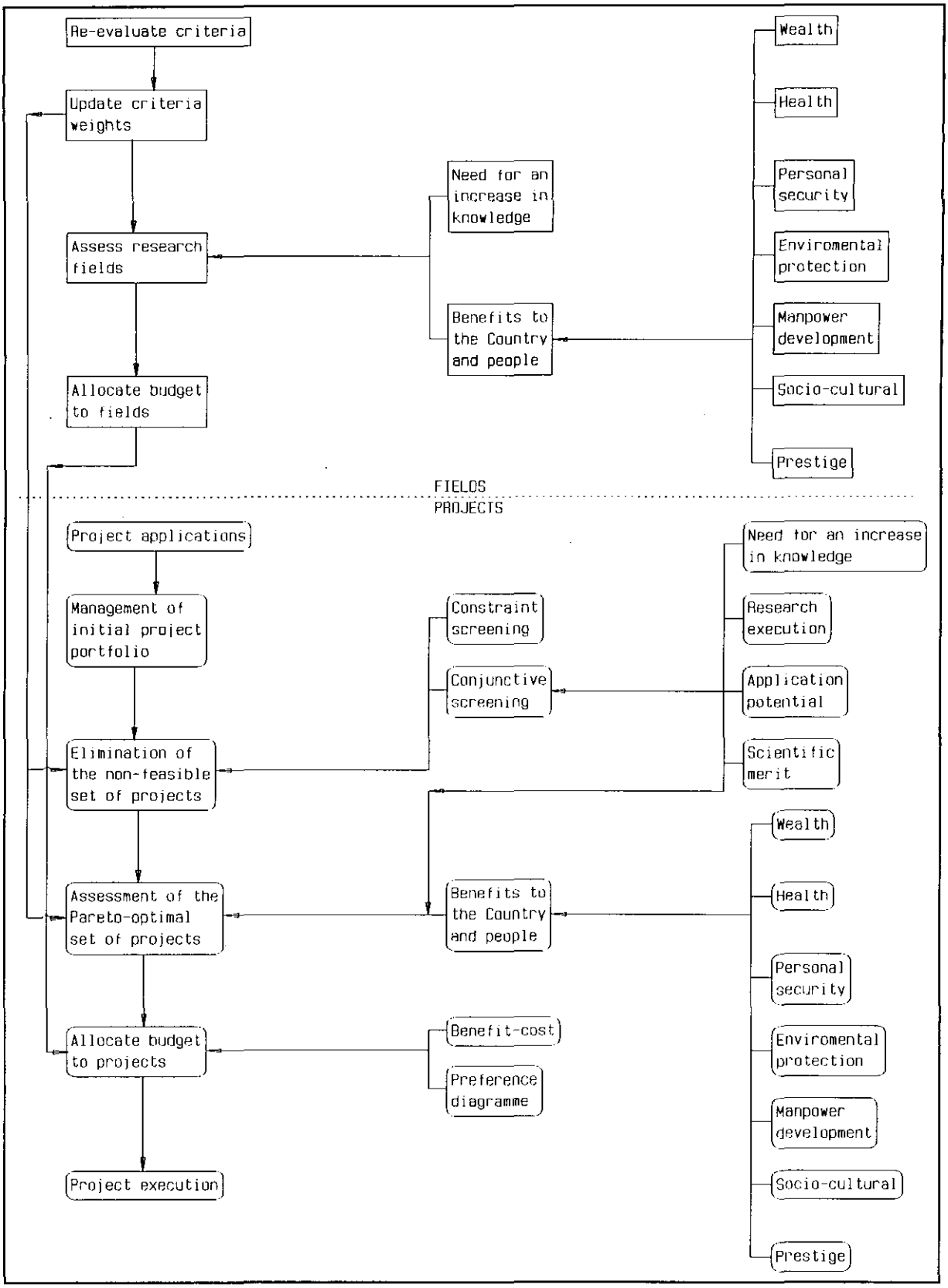

Figure 5

The value to the ordinary citizen-based decision support model

TABLE 2
A SUMMARISING SCORING MATRIX FOR THE ASSESSMENT OF APPLIED WATER RESEARCH PROJECTS

Criterion	Weight (w_i)	Score (v_i)	$W_i \times v_i$
1. Potential benefits of the research products to the country and its people	**0.30**		
Tertiary criteria for 1.1 to 1.7: • The **magnitude** of the benefit/problem • How **widely/generally applicable** is this benefit or problem • How **soon** will the benefit be realised • How **urgent** is it (e.g. a public issue) **Notes**: 1) Assume 100% successful research execution and transfer and implementation of results when evaluating on 1.1 to 1.7. 2) Keep criteria independent of each other when evaluating.			
1.1 Potential contribution to improved personal and national wealth • Increased personal income, i.e. additional money in the pocket from additional income, cost savings, employment creation, etc. • Increased income for communities, local and central Government • Increased sectoral income (agriculture, industry, etc.), leading to a larger gross national product • All aspects that can be expressed in money terms • All income-generating and cost-saving spin-offs from improving 1.2 to 1.7 (Includes, for example, income from tourism; or higher property values when improving 1.4; increasing capital and infrastructure value; increased income from improving 1.2, etc.).	**0.22**		
1.2 Potential contribution to improved personal health • Lowering of deaths resulting from sickness (i.e. excludes deaths from floods - see 1.3) • Less sickness and morbidity (includes chronic problems from bacteriological or chemical origin)	**0.20**		
1.3 Potential contribution to improved personal security • Security of life from natural and man-made disasters (deaths from floods, dam bursts, inclement weather conditions, toxic chemical spills; excludes deaths from sickness - see 1.2) • Avoidance of, or protection against, fear of and actual potentially injurious or dangerous conditions (include, for example, floods, water shortages, inclement weather conditions) • Self-sufficiency in water • Ensured availability of water; a feeling of security regarding future water supply	**0.17**		
1.4 Potential contribution to the protection of the environment • Protection and enhancement of animal, plant, insect and microbial species numbers and diversity • Improvement of aesthetic appeal and recreation possibilities (Excludes money aspects, e.g. income from tourism)	**0.14**		

1.5 Potential contribution to further manpower development • Increased qualifications • Increased knowledge, skills, entrepreneurship and efficiency • Increased training possibilities • Use and empowerment of unemployed people, and disadvantaged and local manpower (Includes any manpower development spin-offs from the research results)	**0.13**		
1.6 Potential contribution to the spiritual, socio-cultural needs and values • Aesthetic, sensual and artistic values, e.g. washing in clean and not muddy water; having good-looking and -tasting water (excludes aesthetic aspects of improving the environment, see 1.4) • Self-esteem and dignity (e.g. a toilet in the house) • Equity, social justice, belonging (e.g. having the same high water quality or sanitation system as others) • More leisure time for fun, and sleep (e.g. not having to walk long distances for water) • Stability, development and growth of the social system • Commitment and contribution to democracy	**0.11**		
1.7 Potential contribution to the national prestige of the water fraternity and the international prestige of the country Refers to e.g. prestigious projects; special national and international attention; potential breakthroughs, decorations, etc., both nationally and internationally	**0.03**		
Total	**1.00**	-	-
Score for criterion 1: $V_j = \sum_{i=1}^{7} (w_i \times v_i)$			

Criterion	Weight (w_i)	Score (v_i)	$(v_i)^{w_i}$
2. Need for an increase in knowledge	**0.18**		
• The amount of research still needed to achieve the required level of knowledge in the research area in question; the lack of local, and applicable foreign knowledge in this area of research • Need for the establishment of local research expertise • The need to maintain momentum in the research			
3. Scientific and innovative merit	**0.16**		
• Scientific merit and content of the research • Innovative and novel nature of the research			
4. The extent of successful research execution	**0.12**		
This refers to what extent or degree it is anticipated that the project objectives will be met: • Track record of the researchers • Availability and quality of manpower, equipment and facilities • Insight and thoroughness of the research planning • Scientific and technological complexity of the research • Positive research climate of the institution • Other political, social, economic, legal and technological factors enhancing or hampering successful project execution, should also be taken into account.			

5. Application potential of the research results	0.24		
This criterion measures whether research results can, and will, be implemented and used in practice. • Acceptance of research results by users (individuals, consultants, communities, sectors, authorities, etc.) - Ability to manage the products (experience, skills, knowledge levels, aptitude, attitude) - Potential ownership of the research results - Involvement of the user of the research results during research execution - Involvement of women - Public awareness, influence of the media - General political and institutional situation (e.g. stability) • Characteristics of the research results - Cost of implementation of the results - Appropriateness of research results for user needs - Quality of the research results - Commercialisation possibilities - Reliability of the research products - Conforming to, and integration with, local institutional policies and priorities • Presence of a "champion" of the research results • Fit with Government priorities • Other political, social, economic, legal and technological factors enhancing or hampering successful technology transfer, should also be taken into account			
Total	**1.00**	-	-
Total score $V = \prod_{i=1}^{5} (v_i)^{w_i}$			

Scoring: All the projects are scored against **one criterion at a time**. Generically:

0 - No/none
20 - Low/little/poor
40 - Fair/reasonable/moderate
60 - High/strong/large
80 - Very high/strong/large
100- The "ideal" project; Extreme/overwhelming/all/100%

Groupings of research projects (i.e. research fields) are only assessed on the first two criteria.

The model accommodates pre-assessment project proposals management, pre-screening of non-feasible and non-optimal projects, suggestions toward budget allocation, and the management of some special cases. The incorporation of outside expert and community opinion in both the development and use of the model, may enhance transparency and acceptance of the model and its outcome.

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