Assessing the Validity of Decision Support Systems: A Case Study from the Sustainable Management of the West Bank Aquifer

by

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ABSTRACT

Decision support systems (DSS) have been widely advocated as key tools for the integrated management of water resources, which emerged as a critical need for addressing the various technical, economic, social, environmental and politico-institutional challenges facing the management of water resources. This thesis aims at developing a framework for assessing the validity of DSS in application to water resources management, more particularly reviewing Multi-Criteria Analysis (MCA) and Cost-Benefit Analysis (CBA) as a basis for decision-making. This is critical at times of increasing demand for tools such as DSS, and therefore the increasing importance of overcoming a major DSS limitation, which is validity. The proposed framework consists of two complementary approaches: (1) assessing intra-model validity (MCA), an approach which consists of studying the level of confidence in the comprehensiveness of management options (MO) and basic indicators (BI), analysing uncertainty in the performance values and weights assigned to BI, undertaking a sensitivity analysis of MO ranking to BI performance values and weights, and, based on results, generating as well as evaluating strategy alternatives; (2) assessing DSS inter-model validity, an approach which consists of comparing models (MCA and CBA). The application of the framework to the Sustainable Management of the West Bank Aquifer (SUSMAQ) generates results very much consistent with literature findings: importance of sensitivity analysis as a practical alternative to uncertainty analysis, sensitivity of MO ranking to BI performance values more than to BI weights, importance of accounting for indirect benefits and for the choice of discount rate in CBA, complementarity if not equivalence of MCA and CBA, etc. Although the aim of the thesis is methodological, the application uses validity assessment results to test various strategies for the management of water resources in the West Bank, as an illustrative example only.

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LIST OF ABBREVIATIONS

BI:	Basic Indicator
BIPV:	Basic Indicator Performance Value
BIW:	Basic Indicator Weight
CBA:	Cost Benefit Analysis
CEA:	Cost Effectiveness Analysis
CM:	Cubic metres
CS:	Current Scenario
DPSIR:	Demand-Pressure-State-Impact-Response
DSS:	Decision Support System
DST:	Decision Support Toolkit
EC:	Economic
EN:	Environmental
FS:	Future Scenario
IRR:	Internal Rate of Return
L/cap/day:	Litres per capita per day
L/sq.m./yr:	Litres per square metre per year
LTPA:	Long Term Policy Analysis
MCA:	Multi Criteria Analysis
MCDM:	Multi Criteria Decision-Making
MCM:	Million Cubic Meters
MO:	Management Option
NWB:	North West Basin
PV:	Performance Value
SO:	Socio-economic
Sq.km.:	Square kilometres
Sq.m.:	Square metres
SUSMAQ:	Sustainable Management of the West Bank and Gaza Aquifers
USD:	United States Dollars
W:	Weight
Yr:	Year

1 INTRODUCTION

1.1 Background

"Improving the quality of life": a very noble objective yet faced with long lasting and increasing challenges, such as securing the "right to water". While the solution to this particular challenge might sound obvious a priori, its true complex nature is revealed when the spatial and temporal dimensions are taken into account: i.e. securing the "right to water" to all living creatures, humans and non-humans, present and future, starting by attempting to define what is the "right to water". This therefore calls the need for a sustainable management of water resources: a management that would integrate the various challenges facing the water sector for the purpose of sustainably reducing the demand-supply gap. These challenges can be divided into technical, economic, social, environmental, and politico-institutional:

Technically, resources have been deployed and continue to be deployed for increasing the supply of good quality water while limiting the associated risks. To this end, various sources of supply have been experimented at various levels of sophistication: surface and groundwater development, rainwater harvesting, aquifer recharge, desalination, wastewater reuse, etc. Studies and projects for the protection of water quality, by both prevention and remediation, were also undertaken. Parallel to that, modelling techniques and other information technology tools were developed, and continuously improved, for both determining and monitoring the quantity and quality of water available. These techniques studied also the uncertainty factor, and looked at means for enhancing the reliability and reversibility of the various systems put in place, as well as reducing their vulnerability.

Economically, increasing efforts are being spent to maximise the financial viability of water policies, plans, programmes and projects, by including all costs incurred and all benefits generated. Costs would then include not only the direct costs -investment, operation and maintenance- but also the indirect ones, or externalities. Benefits are also divided into direct and indirect ones, where the latter include benefits of the environmental and social type. Internalising the externalities has led to the birth of the environmental valuation science, with all its complexities. Such studies help calculating the true value of water, or what is often referred to as the "shadow value" of water, which in turn allows more enhanced demand-price elasticity studies and therefore more realistic tariffs systems. This implies sharper economic assessment studies and therefore better strategy formulation.

Socially, attempts are still being made to answer the following questions: who has a "right to water", and if there is no "right to water", who are the "demanders" or the users? Is there any priority among users (citizens, industrialists, farmers, etc.)? What is a "reasonable" water demand per user per day? Should future generations be included? In summary, how can social and temporal equity be insured, especially with increasing human aspirations? No matter what the replies are, strategies have started to be developed to better manage demand in an attempt to reduce its value, and therefore reduce the demand-supply gap. Examples of management options vary from traditional approaches, such as reducing leakage, or changing crop planting patterns to more efficient water crops, to more modern approaches such as trading water, or what is referred to as "water banks", and related water concepts such as "virtual water", its application and limitations.

Environment has been lately identified as an additional water user, and as such an additional entity with a "right to water" in both quantity and quality: water for biodiversity (fauna and flora), water for air, water for land and water for water (surface and ground). Water for environment is also, both directly and indirectly, water for people, for people use the environment as a commodity: direct use of natural resources (water, air, land and biodiversity) for living and for developing the various economic sectors (construction, industry, agriculture, energy, tourism, etc.). People also use the environment as a disposal facility: natural resources become then waste recipients and cleaners.

At the politico-institutional level, several challenges also face the water sector: how to deal with shared water resources? How to ensure effective management at the aquifer/basin level? How to draft adequate legislation that tackles the various aspects of water and how to ensure proper implementation? How to enhance institutional capacities for better management? How to involve all stakeholders, starting with the public and civil society, in developing water policies and implementing them? What are the best approaches for effective participation: top-down or bottom-up? How to best benefit from the private sector? How to bring on board all disciplines, yet alleviate communication barriers between them? How to plan for the long-term? How to make decisions with gaps in information?...And many other questions that adequate water policies need to address.

1.2 Decision Support Systems in Water Resources Management

Reviewing the various challenges facing water resources and outlined above – technical, economic, social, environmental and politico-institutional – points out the need for an integrated management of water resources. The means to reach such an objective is less straightforward though. Decision support tools (DSS) have emerged as an integrated management tool, with several associated benefits: power of integration, transparency, objectivism, stakeholders' involvement, etc. At the same time, various challenges face the application and use of DSS, primarily how to assess their validity, and hence improve DSS in view of identifying the "best" solution - presuming that "best" solutions actually exist. "Valid" decision support systems then become tools where the decision process, or methodology, is clearly separated from the decision quality, i.e. the result.

Literature reveals a number of DSS related to water resources management: Water-Ware, AQUATOOL, NELUP, DSSIPM, MULINO, and many others. All applications have contributed to the enhancement of knowledge related to integrated water resources management, with of course a number of limitations as further detailed in section 2.2.2.

1.3 The SUSMAQ Project

One of the decision support tools that have been recently developed in application to water resources management is the decision support tool established in the context of the SUSMAQ project. SUSMAQ, or "Sustainable Management of the West Bank and Gaza Aquifers", is a project executed between 1999 and 2005 in partnership between the Palestinian Water Authority and the University of Newcastle upon Tyne, with funding from the United Kingdom Government's Department for International Development (DFID).

The aim of the SUSMAQ project is to "increase understanding of the sustainable yield of the West Bank and Gaza aquifers under a range of future economic, demographic and land use scenarios, and to evaluate alternative water management options". The project has been implemented with the hope to provide support to decision-making at all levels in relation to the sustainable yield of the West Bank and Gaza aquifers. The interdisciplinary approach has prevailed during project execution, by bringing together hydro-geologists and groundwater modellers with economists and policy experts. "In this way, hydro-geological understanding could inform, and be informed by, insights from the social sciences" (SUSMAQ, 2005a).

SUSMAQ DSS evaluates a number of water management options, under different scenarios, based on various economic, environmental and socio-economic indicators. SUSMAQ DSS lacks however an analysis about its validity, a major challenge associated with DSS, as discussed in section 1.2.

1.4 Thesis Aims and Objectives

This thesis aims at developing a framework for assessing the validity of decision support systems in application to water resources management, more particularly reviewing multi-criteria analysis (MCA) and cost benefit analysis (CBA) as a basis for decision-making.

Assessing DSS validity requires studying the uncertainty associated with its parameters, as well as with parameters' intra and inter relationships. DSS parameters include: scenarios, alternatives or management options, as well as criteria or indicators. Intra and inter relationships include (1) weights or coefficients associated with the respective indicators, including who decides about the value of these weights; (2) indicators' performance values – how they are calculated, what the level of uncertainty is, etc.; and (3) aggregation of indicators and weights – what method to choose, why, etc. Apart from studying uncertainty associated with the parameters and parameters' relationships, sensitivity of results to parameters can be assessed to answer questions such as: which parameter or relation influences the results most? Do different methods – where other methods range from other aggregation techniques to completely different decision-making tools, such as optimisation, cost benefit analysis studies, etc. - lead to different results? Do different users using the same method end up with different results?

Different methods have been developed to assess the validity of DSS. Examples include: framework tools, questionnaires, comparison between different methods, and others. The proposed framework however presents an integrated approach examining validity both intra-model and inter-model. Analysis intra-model involves studying the various parameters of the DSS – a Multi Criteria Analysis model in the case of this research (comprehensiveness of management options and basic indicators, as well as uncertainty analysis related to BI performance values (BIPV) and weights (BIW) and inter-relations between these parameters (sensitivity analysis of MO ranking to BIPV and BIW, generation of strategies, evaluation of strategies, etc.). Analysis inter-model requires the application of another model (the one selected in this research is Cost Benefit Analysis) and inter-comparison between models.

This integrated framework is applied to the SUSMAQ project – North West Bank, current and future scenarios. It demonstrates how to make a step forward in the use of DSS from management options assessors to strategy builders.

1.5 Main Contribution to Knowledge Claimed

This research comes at a time when it is widely believed that DSS will thrive in the next decade (Carlsson & Turban, 2002), thus making it important to account for the various lessons learned in the development of future DSS. Amongst the most important lessons is the need to find ways to overcome the various technical limitations encountered so far intra and inter DSS such as validity concerns arising from ranking assignment and method selection (Bell at al., 2001).

By developing a methodology for assessing validity of DSS both intra-model (intra MCA: comprehensiveness of management options and basic indicators, uncertainty analysis of MO and BI, sensitivity of MO ranking to BI performance values and weights, generation of strategies and evaluation) and inter-model (comparison of MCA results and CBA results), this research would have contributed to overcoming some of the technical limitations associated with DSS which are related to validity issues thus enhancing DSS performance. This would make the use of DSS as strategy recommenders more reliable, at times of increasing demand for tools such as DSS, as presented by Carlsson and Turban who reported that "as dynamics of global markets increase, the need for accurate, more diverse and immediate information will continue to grow" (Carlsson & Turban, 2002).

1.6 Thesis Structure

Chapter 2 reviews literature to define the basis for the methodology outlined in chapter 3. It starts with a background on the sustainable management of water resources (demand aspect, politico-institutional aspect, economic aspect, social aspect, quality management and techniques for assessing sustainability), to then introduce decision support systems in water resources management and related validity issues (emergence of DSS as integrated management tools, examples of water related DSS, DSS and indicators, frameworks for DSS evaluation, weaknesses of DSS, strengths of DSS and DSS outlook). It then reviews other decision tools for sustainable water resources management, mainly cost benefit analysis (CBA) (background and evolution, approaching the true economic value of water in CBA, application to water resources management, limitations and CBA vs. other decision-making tools). The literature review chapter briefly discusses long-term policy analysis before ending with some conclusions linking to the chosen methodology.

The proposed methodology is presented in chapter 3. It starts with an overview of the methods with some illustrative examples. The conceptual framework for assessing DSS validity intra-model (MCA) and inter-model (MCA and CBA) is then detailed. The chapter concludes with a discussion about the limitations associated with the methodology.

Application of the conceptual framework to the SUSMAQ project is detailed in chapter 4. The chapter starts with an overview of the West Bank aquifer status, followed by an overview of existing policy and management options. SUSMAQ decision support tool is then presented, with emphasis on the region (North West Bank). and scenarios (current and future) of application. The chapter ends with application limitations.

Application results are outlined in chapter 5. The chapter starts with results of methodology application to the SUSMAQ North West Bank – current scenario. It details results related to both intra-model validity and inter-model validity. The chapter exposes how the results are evaluated (evaluation of management options ranking) to build strategies, which are in turn assessed for their sustainability, cost and demand-supply gap reduction. Another section is then dedicated for a brief overview of results related to methodology application to the North West Bank – Future Scenario (intra-model validity only).

Chapter 6 addresses the general applicability of the proposed framework by proposing a set of guidelines to develop a user-interface and its associated user manual. It is expected that these outputs will facilitate both the use of the proposed validity assessment framework in the context of the SUSMAQ project and its replication to other projects of similar or different natures in various regions.

Chapter 7 discusses results and concludes. It first reviews the methodology proposed for assessing the validity of DSS, or more particularly the MCA and CBA methods as a basis for decision-making, highlighting the contribution of this thesis to the field of research. It particularly discusses the level of information (and the associated time and cost) needed to implement a robust DSS. The chapter then discusses the SUSMAQ/West Bank application, reviewing management options and derivative strategies, as well as evaluating strategies' implications for the West Bank.

2 LITERATURE REVIEW

2.1 Sustainable Management of Water Resources

The subject of water resources management was awarded particular attention at both United Nations Summits for Sustainable Development (United Nations, 1992, Agenda 21; and United Nations, 2002, World Summit for Sustainable Development Plan of Implementation) whereby emphasis was put on the need to have an integrated approach in managing water resources and develop "policies related to protecting and managing the natural resource base of economic and social development". The Global Water Partnership (GWP) has issued the following definition of Integrated Water Resources Management (IWRM): "IWRM is a process that promotes the coordinated development and management of water, land and related resources in order to maximise the resulting economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

The United Nations Educational, Scientific and Cultural Organization (UNESCO) has been playing a key role in the sustainable management of water resources in the World and specifically in the Arab World, through its various programmes, namely the International Hydrological Programme (IHP) (Al-Weshah, 2002) which entered its seventh phase in 2008 (UNESCO (IHP), 2006). The United Nations Environment Programme (UNEP) devoted a special issue of its "Industry and Environment" paper to the water subject (UNEP, 2004). Recognising the need to give the management dimension of groundwater resources the appropriate attention, the World Bank established a Groundwater Management Advisory Team (World Bank, GW MATE), "a core group of experienced specialists in the multidisciplinary and multifaceted subject of groundwater management". GW MATE aims at supporting and strengthening the groundwater components of World Bank financed projects and Global Water Partnership action at country or regional level.

General issues related to water policies, whether at the international or national level, have been tackled by several authors (Abu-Zeid, 1998; Van Wilgen & Cowling, 1998; Krol et al., 2001; Chaturvedi, 2001; Deason et al., 2001; Lenzen & Foran, 2001; Varis & Vakkilainen, 2001; Piegay et al., 2002; etc.). Saleth and Dinar noted common features or trends across countries in what relates to water: a move towards decentralisation and privatisation, towards integrated water resources management and towards financial viability and physical sustainability (Saleth & Dinar, 2000). Biswas further elaborated on the sustainability issue in various publications, namely in "Sustainable water resources development: some personal thoughts" (Biswas, 1994) and "Water policies in the 21st century" (UNEP, 2004). The author identified the following sustainability issues: (1) short-term versus long-term considerations and the attribution of "short-termism" to lack of knowledge or understanding of the long term impacts, but also to obligation for survival; (2) difficulties in internalising externalities for the following considerations: methodological, political, time and ineffective/expensive regulations; and (3) risks and uncertainties.

As for the 21st century water policies, according to the author (Biswas), they must take into account changes that have occurred in the last decade (trend towards decentralisation, expanded roles for the private sector and NGOs) and need to address diverse social interests and agendas, rapid changes in technology, globalisation, relentless economic competition, lack of political certainty, and steadily increasing human aspirations. The author specifies that an objective, comprehensive review of the latest and foreseeable trends indicates that the world of water management will change more during the next 20 years than it did in the previous 2000. Many of the important drivers of this change will come from outside the water sector and, unlike recent and past experience, the water profession will have limited or no control over them. Hence water professionals will have to react to these changes very quickly, while taking into account public participation: how to formulate future water policies in consultation with multiple stakeholders having multiple interests, conflicting views and differing priorities? Biswas concludes by specifying that while the current emphasis is on technical and economic issues, the water problems of the future are likely to have greater social, environmental and political components, the consideration of which entails value judgment, which differs depending upon the analysts and the stakeholders concerned.

Literature specific to the demand aspect of water resources is reviewed in section 2.1.1, the institutional and political aspect in section 2.1.2, the economic aspect in section 2.1.3 and the social aspect in section 2.1.4. Section 2.1.5 focuses on the management of water quality. Techniques for the sustainability assessment of water resources management options are reviewed in section 2.1.6.

2.1.1 Demand Aspect of Water Resources:

Preference for water demand management over supply based management techniques has been internationally recognised. Haddad and Lindner explored water demand as well as water supply management options for the case of Palestine (Haddad & Lindner, 2001). Mohamed and Savenije argued that water demand management strategies would not face socio-political opposition if compensation were provided (Mohamed & Savenije, 2000). Projecting water demand is not straightforward if all factors- political, social, economic, etc. - are to be taken into account. The Environment Agency of the United Kingdom suggested four demand scenarios in its water resources strategy for England and Whales, based on societal values and governance (United Kingdom/ Environment Agency, 2001).

Agriculture is a major consumer of water. The impacts of groundwater management strategies on irrigated agriculture were reviewed by Masiyandima et al. who concluded that changing the irrigated crops to less water consuming ones is not enough and that limiting the irrigation area proportionally to a safe yield is a must (Masiyandima et al., 2002). A review of the types of irrigation systems and their suitability for using non-conventional waters was carried out by Pereira et al. (Pereira et al., 2002). The various agricultural related challenges facing water policies were reviewed by Haddadin (Haddadin, 2002).

Water demand figures in the Middle East, and other water scarce regions, can be easily decreased if only municipal water is accounted for, i.e. if industrial and agricultural demand for water is considered as virtual water which can be easily traded. The concept of virtual water was praised by Wichelns and Allan (Wichelns, 2001; Allan, 2002). Details about virtual water flows between nations were provided by Hoekstra and Hung (Hoekstra & Hung, 2002).

Environment has been lately introduced as a fourth water demander (i.e. in addition to the municipal, industrial and agricultural) and the concept of "environmental flow" was introduced as "the water regime within a river, wetland or coastal zone that maintains ecosystems and their benefits where there are competing water uses, and where flows are regulated" (UNEP, 2004).

2.1.2 Institutional and Political Aspect of Water Resources:

Diversities of institutional complexities represent a constraint for the integrated management of water resources and so do the behaviour changes through social processes (Pollard, 2002).

Kumar noted that groundwater management should be carried out at three levels: from village level to watershed level to aquifer level. He also noted that local user group organisations should be promoted and rights over groundwater need to be recognised, pointing out the need to establish tradable private property rights (Kumar, 2000). The property right issue was also tackled by Narain and Narain et al. who outlined the importance of access to information (Narain, 1998; Narain et al., 1998).

The political aspect of shared groundwater resources was addressed by Haddad and Feitelson, both taking Palestine as a case study (Haddad, 1998; Feitelson, 2002). The role of fresh water in the Israeli-Palestinian conflict was tackled by Lonergan and Brooks (Lonergan & Brooks, 1994). Other examples of water resources related conflicts include India-Bangladesh, Egypt-Sudan and others.

2.1.3 Economic Aspect of Water Resources:

Economic factors that affect the system design of water resources projects were reviewed by Maass et al (Maass et al, 1962). Hall and Dracup analysed the water cost breakdown from source of supply to end user including an analysis of the chosen interest rate (Hall & Dracup, 1970). Loaiciga and Leipnik studied the relation between market price of groundwater, cost of groundwater extraction, aquifer storage, institutional and environmental regulations and discount rate (Loaiciga & Leipnik, 2001).

The shadow value of water along with water market related issues as well as equity and efficiency were discussed by Dinar and Loehman (Dinar & Loehman, 1995). Grimble reviewed some economic instruments for improving water use efficiency (Grimble, 1999).

Policy implications from water pricing were analysed by Dinar and Subramanian (Dinar & Subramanian, 1998) as well as Zekri and Dinar (Zekri and Dinar, 2003). This brings up the issue of elasticity where the quite large literature on the price elasticity of water demand shows that, in developing and developed countries alike, the price elasticity is significantly negative, meaning that users react to price increases by reducing demand. A second important point is that the price elasticity is related to the price level – the higher the price, the greater the elasticity (Briscoe, 2005).

A study done for the United Nations Environment Program on the "Environmental Impacts of Trade Liberalisation and Policies for the Sustainable Management of Natural Resources – a Case Study on Romania's Water Sector" concluded that water tariffs do not reflect actual costs and thus an increase in water price has a negligible effect on exports (UNEP, 1999). However, water would be a controllable cost for industry if pricing were introduced (UNEP, 2004) that:

- accurately reflected scarcity and the cost of water supply and waste water treatment;

- incorporated such environmental externalities as the loss of ecosystem function;

- was linked to the volume consumed, taking into account the possibility of trading systems or water banks (Hatem-Moussallem et al., 1999), which typically involve a cap on allowable water use among a group of companies or in a geographical area, or even for a water retailer.

2.1.4 Social Aspect of Water Resources:

A major aspect of water resources sustainability is the social one (Roseland, 2000, Scott et al., 2000; Pollard, 2002;). In this respect, several criteria need to be considered: ensuring the participation of all stakeholders (Dube & Swatuk, 2002; Welp, 2001); engaging women (Kansiime, 2002); ensuring equity (Kansiime, 2002); facilitating a bottom-top approach (Kansiime, 2002) and anticipating farmers' reactions (Kijne, 2001; Feuillette et al., 2003; Rinaudo, 2002). Feuillette et al. developed a model for farmers' behaviour (Feuillette et al., 2003) and Rinaudo analysed the factors that lead the farmers to engage in corruption activities (Rinaudo, 2002). Centner analysed the agricultural nuisances vs. the "right to farm", basing his argumentation on relevant United States legislation (Centner, 2002).

Pahl-Wostl et al. (2007) discussed how water management in most European countries is not yet based on a participatory approach but on expert knowledge guiding management decisions – involvement and co-decision-making is far from being realised in practice which is a certain impediment to implementing new water policies. He outlined the elements of social learning for river basin management (building up shared problem perception, trust for self-reflection, recognition of mutual dependencies and interactions, reflections about dynamics and cause-effect relationships in the basin, reflections on subjective valuation schemes, engaging in collective learning and decision processes).

To overcome this, the importance of "Good advice" is praised by Anh and Abbott (n.d.) who argue that only when sufficient knowledge can be mobilised, can the water sector be better managed. This has been made possible thanks to the rapid development of the conceptual apparatus that brings the developments on the social side and those on the technological side together (Jonoski, 2002). Jonoski and Harvey (2004) propose a restructuring of the decision-making, whereby instead of assuming a prior knowledge of the various interests of all stakeholders, a process of collaborative learning and negotiation towards a decision is envisaged. This is done by knowledge circulation through network distributed decision support systems of three major functional components: the fact engine, the judgement engine, and a collaboration and negotiation platform.

Abbott & Jonoski (2001) stress the importance of water professionals providing knowledge to the population, because this knowledge "must then serve the interests of the population as a whole, empowering the individuals, families, and other social groups within this population as general stakeholders in water resources, while also enhancing their awareness of their environmental responsibilities". In the opinion of the authors, this will lead to more sustainable and equitable distributions and uses of water. This requires the application of knowledge management systems to be introduced by ways of prototypes, which require new institutional structures. It also implies some understanding of the actions and judgements of others, towards reaching a stage of change of attitude towards the "others" in a society.

This concept of sociotechnology has been extensively reviewed in a number of publications in the Journal of Hydroinformatics – where hydroinformatics is defined as "a cross-disciplinary field of study that combines technological, human sociological and more general environmental interests, including an ethical perspective. It covers the application of information technology in the widest sense to problems of the aquatic environment and of water resources management. It aims to equip professionals, engineers, managers and decision makers working in water related arenas, with available information and technology, to make rapid and robust decisions as they address the increasing challenges of ensuring a sustainable water environment and adequate water resources for generations to come" (International Association of Hydraulics Engineering and Research, n.d.). Abbott (1999) sees in hydroinformatics an opportunity to meet the challenges of mankind in relation to water, specifying that the extent of success implies a success in changing the nature of societies by the very way they think and behave about "the worlds of the waters".

2.1.5 Management of Water Quality:

The engineering aspect of groundwater management, both quantity and quality, has been the subject of many books (Bear, 1979; Hamill & Bell, 1986; Grigg, 1996; Biswas, 1997; etc.). Various techniques for managing water quality and reducing pollution were proposed by several authors (Van Steenbergen & Oliemans, 2002; Plagnes & Bakalowicz, 2002; Unami & Kawachi, 2003; Hiscock & Grischeck, 2002; Ferrier & Edwards, 2002; Mahmood et al., 2001; Falconer & Hodge, 2001; Zalewski, 2000). It is now accepted that source control is the best way to prevent contamination of water with pathogens and pollutants. Methods of isolating and treating such contaminants at source are often available and cost-effective (UNEP, 2004).

A detailed review of the sources of groundwater contamination, the mechanism of contamination as well as its movement was carried out by Barcelona et al. (Barcelona et al., 1988). In the same document "Handbook of Groundwater Protection", the authors examined the restoration of groundwater quality, the design and construction of monitoring wells as well as the use of models in managing groundwater protection programmes.

Groundwater protection programmes or management options are many and include identification of protection zones, restriction of certain land uses, addition/ replacement of certain wells, increase of public awareness and enactment and enforcement of pertinent legislation (UNESCO, 2001). While some of the options focus on pollution treatment, others focus on pollution prevention. The topic of groundwater pollution prevention was addressed at an international conference on protecting groundwater in Birmingham, UK "Protecting Groundwater: An International Conference on Applying Policies and Decision-Making Tools to Land-Use Planning" (Phillips, 2001). It was noted that whereas pollution prevention is a cost on farmers, pollution treatment is a cost on citizens. Catchment abstraction management strategies (CAMS) were introduced and a methodology for wellhead protection areas was outlined.

Developing groundwater protection/ pollution prevention guidelines requires a combination of two factors: pollution potential from land-use types and recharge potential or groundwater vulnerability (UNESCO, 2001; Collin & Melloul 2001, 2003; Melloul & Wollman, 2003). The Committee on Techniques for Assessing Groundwater Vulnerability (National Research Centre/ Water Science and Technology Board, 1993) reviewed three methods for assessing groundwater vulnerability, which are overlay and index, process-based simulation models, and statistical methods. Daly et al. reviewed the main concepts of the European approach to karst-groundwater-vulnerability assessment and mapping and proposed a method for assessing the vulnerability of a resource based on four factors: overlying factors, precipitation, karst network and concentration (Daly et al., 2002).

2.1.6 Techniques for the Sustainability Assessment of Water Resources Management Options:

The complexities of the sustainability concept make the planning for it a learning process (Meppem & Gill, 1998). Several indicators have been suggested as a way to assessing sustainability. However, before evaluating water management options, attention should be given to the formulation of "right" scenarios/ management options, since not all scenarios are plausible ones (Schreider & Mostovaia, 2001). Both scenarios and sustainability criteria and weights have to be chosen in close consultation with the stakeholders (Brown et al., 2001). Sensitivity analysis ought to be carried out to determine the most important input for every model output (Francos et al., 2003). Multi-criteria analysis models, like any other model, need validation; expert judgment is a good method (Qureshi et al., 1999). Scenarios, management options, criteria, and related analysis are further discussed in section 2.2.

Safe yield has always been considered a major constraint in groundwater development for ensuring the physical sustainability of the water resources systems (Dottridge & Abu Jaber, 1999). For Sophocleous, a fixed sustainable yield cannot be determined; the sustainable yield should vary over time (Sophocleous, 2000).

To that end, sustainability has very often been associated with optimisation, for which several techniques have been proposed in water resources development. Linear programming, one of the most famous methods, has been heavily used for optimum well placing, optimum pumping pattern, water allocation policies, etc. (Buras, 1972; Biswas, 1976; Karanth, 1987; Willis and Yeh, 1987; De Juan et al., 1999; Wichelns, 2002; Shangguan et al., 2002; etc.). In order to reduce computational effort in water resources optimisation, Croley suggested modifying the optimisation technique rather than limiting the development of the system model (Croley, 1974). Other optimisation techniques that have been explored include dynamic programming and genetic algorithms (Buras, 1972; Cai et al., 2001). Ahlfeld and Mulligan developed MODOFC Modflow Optimal Flow Control and tested it on subsidence control, wetland protection from dewatering, etc. (Ahlfeld and Mulligan, 2000). In 1985, Van der Heidje et al. reviewed the various groundwater –quantity and quality – management models (Van der Heidje et al., 1985). Wurbs, in 1995, reviewed water management models including optimisation and simulation software, with a reference to international centres for groundwater modelling such as the "International Groundwater Modeling Center and National Research Center on Groundwater Modeling" (Wurbs, 1995).

Whereas various methods and tools have been developed to provide rational insights to systems' behaviour (environmental, societal and economic), achieving sustainable development remains challenged by two main issues:

1- *Integration*: as understanding of the natural resource base has improved, the need for integrated approaches to management has been increasingly widely appreciated (Brooksbank, 2001) and political opinion has been moving in the direction of integrating environmental issues in the decision-making processes of other sectors, not only at the end of a policy process, but already at the start of it – green accounting (Luiten, 1999). But integration remains a difficult issue (Feas et al., n.d.), as a consequence, decision-making has become a more complex process.
2- *Communication*: communication between science and politics is always difficult as there is quite often a dramatic gap between those who analyse and provide disciplinary expertise and those who decide, in knowledge, aims and way of thinking and language (Luiten, 1999; Feas et al., n.d.). Therefore, sound and adequate cooperation between the two is a must.

Several tools have been developed to address the challenges mentioned above such as DPSIR, MCA and DSS:

- The European Environment Agency (EEA) uses a chain of linkages between the driving forces within society (D), the pressure on the environment (P), the state of the environment itself (S), the impact on people and nature (I) and the desirable response (R). This approach is called the DPSIR chain (Luiten, 1999). According to Mysiak, the DPSIR is particularly useful because of its ability to represent cause-effect relationships between interacting components of complex social, economic and environmental systems and to organise the flow of information between their parts. It provides a conceptual model that gives the assessor an overview of the problem. It hence structures the assessor's thinking, helping to provide a good understanding of the system's dynamics.

- MCA, or Multi-Criteria Analysis: for Mysiak (n.d.), MCA permits the multiple impacts of alternative actions to be assessed with respect to multiple criteria. This allows (1) the expansion and augmentation of the decision makers' learning ability and ability to define and formulate their values; and (2) the helping of other actors' preferences, goals, criteria, intentions and beliefs to be better understood by examining the trade-offs between conflicting criteria/ objectives pushed by one or more decision-makers or stakeholders. Literature reveals several MCA techniques such as (1) ZAPROS-LM, a method to aid in qualitative evaluation of multi-attribute alternatives without resort to quantitative judgments or scaling of qualitative ones (Larichev & Moshkovich, 1995); (2) SMARTS and SMARTER (Edwards & Barron, 1994); etc. Olson compared three multi-criteria methods to predict known outcomes (SMART, PROMETHEE and a centroid method) (Olson, 2001): PROMETHEE and SMART proved to be very similar in accuracy. Prato discussed multiple attribute decision analysis for ecosystem management (Prato, 1999); it is an alternative conceptual framework for evaluating and selecting land and water resources management systems for individual properties that alleviates several of the limitations of contingent valuation and cost benefit analysis. The UNESCO, through its International Hydrology Programme (IHP), developed methodological guidelines for the integrated environmental evaluation of water resources development. Three levels of indicators were identified, with the third level consisting of ecology and socio-economy. Indicators were calculated for every water resources management option and integration from one level of indicators to the other was done by assigning weights to the respective indicators. The best management option was identified using multi-criteria decision-making and it was evaluated through a thorough sensitivity analysis (UNESCO, 1987). Other examples of MCA in application to water resources management include: analysis of water privatisation scenarios in Korea (Choi & Park, 2001); resources and flow alternatives in the Glen Canyon Dam (Flug et al., 2000); etc. Chebaane et al. proposed combining scientific analysis with a participatory approach in the Amman Zarqa Basin groundwater management as a prototype to be used in the management of other groundwater basins in Jordan, which would also be useful in other parts of the world that are experiencing similar groundwater over-exploitation problems (Chebaane et al., 2004). Al-Kloub et al. (1997) ranked major water projects in Jordan utilising a multi-criteria decision aid method, including a weights sensitivity analysis where the weighting method selection is discussed: the trade-off method by Keeney and Raiffa, 1976 and the Analytical Hierarchy Process AHP by Saaty, 1994. Similar multi-criteria decision-making approaches have been developed/ used for other areas partly related to water resources such as environmental impact studies (Bose & Chakrabarti, 2003).

- For Kersten et al. (1999), information technology can help a great deal in achieving sustainable development by providing well-designed and useful tools for decision-makers and one such tool is the decision support system, or DSS.

2.2 Sustainable Water Resources Management & Decision Support Systems:

2.2.1 Emergence of DSS as an Integrated Natural Resources Management Tool

Construction of Decision Support Systems is a popular and interdisciplinary research and development domain. As reported by Mysiak et al. (n.d.), the concept of DSS emerged in the 1960s and was proposed for computerised systems assisting to deal with semi-structured or unstructured problems. Later, DSS application spread to natural resources management issues. According to Jamieson and Fedra (1996a, b), the introduction of DSS techniques for water-resources planning dates back to the 1980s, without however encompassing the wide range of considerations normally associated with integrated natural resources management.

Emergence of DSS technology was accompanied with a series of expectations, as reported by Carlsson and Turban (2002); these expectations included:

- decision-makers could, more effectively than before, deal with unstructured or semi-structured difficult problems;

- decision-makers could make better and more reasoned decisions without using optimisation tools and without mastering advanced modelling; and
- decision-makers could start making systematic use of their knowledge and experience in interactive problem solving processes.

Moreover, DSS main strength stems from their capability of combining various modelling and management tools, as the vast literature related to water related DSS presents it.

2.2.2 Examples of Water Related DSS

2.2.2.1 Water-Ware (Jamieson & Fedra, 1996a, b; Fedra & Jamieson, 1996):

Waterware is the outcome of Eureka EU 487, a collaborative research programme which had the objective of assisting government agencies, river-basin commissions, etc., in decision-making related to water resources management. Reaching this objective was through developing a comprehensive, easy-to-use DSS for river-basin planning and management, capable of addressing a wide spectrum of issues such as the following: determining the limits of sustainable development; evaluating the impact of new environmental legislation; deciding what, where and when new resources should be developed; assessing the environmental impact of water-related developments; as well as formulating strategies for river and groundwater pollution-control programmes. By combining the capabilities of geographical information systems, database technology, modelling techniques, optimisation procedures and expert systems, the aim is to improve the quality of decision-making in what is becoming an increasingly complex area. The study concludes that, notwithstanding the effort required, the benefits of adopting a comprehensive, integrated approach to river-basin planning rather than considering the basin in a fragmented, piecemeal fashion, far outweigh the initial investment, and therefore use of the system can be justified easily.

2.2.2.2 AQUATOOL (Andreu et al., 1996):

AQUATOOL, a generalised DSS, was originally designed for the planning stage of decision-making for complex basins, including multiple reservoirs, aquifers and demand centres. Subsequently, it has been expanded to incorporate modules for the operational management stage of decision-making. The modular structure provides a high level of flexibility in the design, implementation and operation of the system. Computer-assisted design modules of the DSS facilitate the graphical definition of a complex of water-resource systems, which is the key to geographically referenced databases and knowledge bases. The modelling capacity includes basin simulation and optimisation modules, an aquifer flow-modelling module and two modules for risk assessment. The usefulness of this DSS is demonstrated by the fact that, in 1996, it was already being used by two River Basin agencies in Spain as a standard tool not only to develop their Basin Hydrological Plans but also to manage the resource efficiently in the short to medium term. In the complex cases presented, the DSS has been recognised as a valuable tool for screening alternatives, obtaining operating guidelines, gaining a better appreciation of the basin as a whole, estimating changes in reliability following structural modifications and assessing risks involved with management decisions. Furthermore, AQUATOOL has proved useful in providing a framework for discussion when conflicts have arisen in the system, including water allocation, modifications to water rights or agreements, surface-water-groundwater interactions, etc.

2.2.2.3 NELUP (Dunn et al., 1996):

The NELUP decision-support system has been developed to provide a quantitative description of the main economic and environmental impacts arising out of rural land-use change at the river basin scale. The system integrates models of economics, ecology and hydrology with relational and spatial databases, thereby permitting interactive evaluation of different future scenarios through a graphical user interface.

2.2.2.4 DSSIPM (Mira da Silva et al., 2001a,b):

DSSIPM is a decision support system that was developed to improve planning and management for the large irrigation schemes in the Alentejo region of Portugal. The system was designed to help in the analysis and evaluation of the crops and crop systems that can potentially be cultivated, together with the identification of limitations affecting crop selection and crop yields. It integrates socio-economic and biophysical data at the field level to analyse the performance of an irrigation scheme in terms of the adoption of irrigation by farmers and farmers' income. The final output is given in the form of specific actions and policies for irrigated areas. The final framework of the DSSIPM is generic in nature, being suitable for planning and policy evaluation in other large irrigation schemes.

2.2.2.5 MULINO (Mysiak et al., n.d.; Feas et al., n.d.):

The 5th Framework Programme (FP5) of the European Commission has dedicated a key action under the "Energy Environment and Sustainable Development Programme" to water related issues with an action line targeted to DSS developments. Within that context, the project MULINO (MUlti-sectoral, INtegrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale) was financed to contribute to scientific developments and applications in the field of DSS for water resource management and decision-making, with a specific policy reference to the Water Framework Directive. The MULINO project has focused on connecting environmental tools and decision support methods, by combining the DPSIR approach with multi-criteria analysis methods in a decision support system called mDSS. From a practical viewpoint, mDSS manages social, economic and environmental criteria, by formalising them as D, P, or S indicators and then by considering them as decision factors within the Analysis Matrix. Early end users' involvement, development of several evolutionary prototypes, designing a specific user interface adopted for environmental applications and variety of implemented models and decision support tools have been the main factors intended to guarantee the system success. The conceptual framework presented by the MULINO approach may contribute to provide methodological support to cope with the general problem of Integrated Water Resources Management implementation, by supporting in particular:

- the management of the complexity of decision contexts typical of Integrated Water Resources Management;
- the management of large amounts of multi-sectoral and multidisciplinary information; and
- the communication between the scientific and the policy sector and between decision-makers and the involved stakeholders.

2.2.2.6 SFCP (Simonovic & Nirupama, 2005):

A new technique called Spatial Fuzzy Compromise Programming (SFCP) was developed to enhance ability to address different uncertainties in spatial water resources decision-making. A general fuzzy compromise programming technique, when made spatially distributed, proved to be a powerful and flexible addition to the list of techniques available for decision-making where multiple criteria are used to evaluate multiple alternatives.

2.2.2.7 Other Examples:

Gasparino et al. (2006) developed a methodology in the framework of the OPTIMA (Optimisation for Sustainable Water Management) project, financed by the European Commission (6th Framework Programme of Research, INCO-MPC). The author concluded that the identification of a set of "consistent", "independent", "bottom-up" and "shared" synthetic indicators (aggregated indices) could be strongly facilitated by the interpretation of the dimensions of the emerging "underlying structure" – a methodology more typical of "soft" social sciences, which promotes bottom-up as opposed to top-down approach.

McKinney et al. described every component of integrated water resources management outlining key authors and models for each component and denoted the importance of geographical information system based decision support system (McKinney et al., 1999). Cai et al. (2002) introduced a framework for sustainability analysis in water resources management with an application to the Syr Darya Basin. The sustainability criteria included risk criteria (reliability-frequency of system failure-, reversibility – time required for a system to return from failure-, and vulnerability – severity of system failure), environmental criteria (control of surface and groundwater salinity and soil salinity), equity criteria (temporal and social) and economic acceptability criteria (benefit vs. investment). The authors concluded that to bring this tool from research to practice, additional work should include verifying some important parameters for sustainability analysis such as the discount rate, screening alternative weights for competitive sustainability criteria, testing other forms of sustainability measurement, and developing an innovative methodology to incorporate uncertainty analysis, especially regarding the stochastic hydrologic patterns, into the modelling framework. Cai et al. also developed a model for assessing the sustainability of irrigation water management options, along with a trade-off analysis between various objectives and economic instruments to cut down pollution levels (Cai et al., 2003).

Levy et al. (2000) proposed the use of sustainable development indicators to improve multiple-objective environmental decision-making under conditions of unknown variability. The authors concluded that under high levels of uncertainty, the art of the feasible (satisficing) is likely to be more helpful than the art of the ultimate (optimisation).

De Santa Olalla Manas et al. developed a methodology using modelling, geographical information system and decision support system for assessing the most appropriate irrigation method (De Santa Olalla Manas et al., 1999). Hoffman developed the RESPECT model (Research, Education, Sustainability, Participatory decision-making, Equity, Communication and Trust) for analysing water management options (Hofmann & Mitchell, 1998). Booty et al. designed the RAISON model, an environmental decision-support system that combines database, geographical information system, simulation modelling, uncertainty analysis, neural network, expert system, optimisation and visualisation, for assessing the impact of toxic chemicals on a certain water resource system (Booty et al., 2001). Several other authors suggested techniques for assessing the sustainability of management options such as Nijkamp & Vreeker, 2000; Jacks et al., 2000; Young et al., 2000; and O'Looney, 2001.

2.2.3 Decision Support Systems and Indicators:

2.2.3.1 Definition:

An indicator can be defined as "a parameter, or a value derived from a set of parameters, that points to, provides information about and/or describes the state of a phenomenon. It has a significance beyond that directly associated with the parameter value" (European Commission, 2003).

A water related environmental indicator is "a number that is meant to indicate the state of the development of important aspects of water related environment (an indicator without a unit of measurement is an index, which is often constructed from several indicators weighted together to include the total effect on the state of the environment)" (Statistical Commission and Economic Commission for Europe, 2001).

2.2.3.2 Criteria:

Several international organisations and countries have developed a list of criteria for selecting indicators. In the United Kingdom for instance, the criteria of the sustainable development indicators set were based on the requirements that they should (European Commission, 2003):

- be representative;
- be scientifically valid;
- be simple and easy to interpret;
- show trends over time;
- give early warning about irreversible trends where possible;
- be sensitive to the changes they are meant to indicate;
- be based on readily available data or be available at reasonable cost;
- be based on data adequately documented and of known quality;
- be capable of being updated at regular intervals; and
- have a target level or guideline against which to compare them.

Indicators' selection is very often accompanied by major public consultation/ awareness raising exercises. In some cases, innovative Internet-based discussion portals have been developed (European Commission, 2003).

According to Ott (Ott, 1978), there are 21 characteristics that an ideal water quality index should possess:

1- be developed from a logical scientific rationale or procedure;
2- strike a reasonable balance between oversimplification and technical complexity;
3- be sensitive to small changes in water quality;
4- avoid eclipsing;
5- avoid ambiguity;
6- avoid nonlinearity in the aggregation process;
7- be dimensionless;
8- employ a clearly defined range;
9- impart an understanding of the significance of the data;
10- be relatively easy to apply;
11- easily accommodate new variables;
12- permit probabilistic interpretations to be made;
13- include variables that are widely and routinely used;
14- include toxic substances;
15- include variables that have clear effects on aquatic life, recreational use, or both;
16- be tested in a number of geographical areas;
17- show reasonable agreement with expert opinion;
18- show reasonable agreement with biological measures of water quality;
19- be compatible with water quality standards;
20- include guidance on how to handle missing values; and
21- clearly document the limitations.

2.2.3.3 Functions:

Originally, environmental indicators were closely linked to environmental conditions and provided a yardstick with which to judge the efficacy of environmental regulatory programs. By the 1990s the emphasis had changed to decision-making and to setting objectives. Indicator functions are more closely focused on the interaction between the natural environment and socio-economic decision-making (Rogers et al., 1997).

Literature shows that indicators have been developed or proposed for each of the following purposes (Ott, 1978):

- Resource allocation;
- Ranking of locations;
- Enforcement of standards;
- Trend analysis;
- Public information; and
- Scientific research

Indicators can be the means of increasing awareness and communication, as presented by the European Commission 2003 study "EU Member State Experiences with Sustainable Development Indicators" (European Commission, 2003).

Water related environmental indicators could be used for the following aims (Statistical Commission and Economic Commission for Europe, 2001):

- support priority setting, by determining factors that cause pressure on the water related environment;
- supply policy-makers with information on the state of water related environment; and
- control the impacts of policy responses of water management.

2.2.3.4 Users and Audience:

Literature shows that is necessary to identify the user of the indicators (Rogers et al., 1997). Scientists, administrators, elected officials and general public cannot be satisfied by the same measure. "The administrator needs to see the resource allocation implications and the scientist needs to see the cause-effect implications."

2.2.3.5 Types:

Indicators of sustainable development are usually of three major classes: environmental, social and economic. Some organisations (including the European Union) add institutional indicators as a separate class. In addition to these classes, some indicators are further categorised based on "whether the factor being indicated is a pressure on the natural environment, is indicative of the state or condition of the environment and whether it measures the extent of social responses to pressures and social conditions". This Pressure-State-Response framework (PSR) is a variation of the DPSIR framework (European Commission, 2003).

2.2.3.6 Trade-Offs:

There are several trade-offs involved with the formulation and use of Sustainable Development Indicators (SDI) (European Commission, 2003). One relates to the issue of whether the SDI set is policy driven (closely mirroring sustainable development policy) or statistics driven (designed to ensure the highest availability and quality of data). Another important trade-off is that of stability (i.e. a stable set of indicators) (which allows to accurately measure progress against a baseline) versus change (i.e. a changing set of indicators) (which reflects the dynamic concept of sustainable development, i.e. changing circumstances, pressures and opportunities).

2.2.3.7 Data Sheets:

Several organisations and/or countries have developed a data sheet for the indicators they have selected. For example, Waller-Hunter, who has developed, for the United Nations Division of Sustainable Development, "Indicators of Sustainable Development", has produced an indicator sheet that contains the following information: (1) indicator (name, brief definition, unit of measurement); (2) placement in the framework (Agenda 21; type of indicator -driving force, or state, etc.); (3) significance (policy relevance) (purpose, relevance to sustainable/ unsustainable development, linkages to other indicators, targets, international conventions and agreements); (4) methodological description and underlying definitions (underlying definitions and concepts, measurement methods, the indicator in the DSR framework, limitations of the indicator, alternative definitions); (5) assessment of the availability of data from international and national sources (data needed to compile the indicator, data availability, data sources); (6) agencies involved in the development of the indicator; (7) further information (Waller-Hunter, 1996).

Hanley et al. suggested 7 indicators (green net national product, genuine savings, ecological footprint, environmental space, net primary productivity, the index of sustainable economic welfare and the genuine progress indicators) pointing out that no single measure is sufficient (Hanley et al., 1999). Loucks and Gladwell suggested three types of indicators to assess the sustainability of water resources systems, which are: reliability, resilience and vulnerability (Loucks & Gladwell, 1999). This methodology was applied by Fowler et al. for assessing the impacts of climate change on a water resource system (Fowler et al., 2003).

The UNESCO/ International Hydrology Programme suggested a long list of hydro-environmental and socio-economic indicators for assessing the state of water resources systems (UNESCO, 1987). Several authors developed a series of indicators in relation to particular water systems. As an example, Lundin and Morrison (2002) developed environmental sustainability indicators for urban water systems, Kondratyev et al. (2002) used sustainable development indicators (pressure, state, response) along with new indicators (external and critical loads, sediments, etc.) in assessing the state of the water resources of a lake.

Other examples of water related indicators/ data sheets include:

- Waller-Hunter/ Indicators of Sustainable Development/ Water: protection of the quality and supply of fresh water resources (Waller-Hunter, 1996)
- World Development Indicators (World Bank, 1997) - fresh water: future water resources (CM/cap); annual freshwater withdrawals (MCM, % of total resources, % agriculture, % industry, % domestic); access to safe water (urban % of population; rural % of population)
- Blue Plan Water Related Indicators (UNEP/MAP/Blue Plan, 1999)
- Water Related Indicators from “Measuring Environmental Quality in Asia” (Rogers et al., 1997): OECD; Hammond et al; Canadian Index – Inhaber 1976; Green Index/ Hall and Kerr, 1991; Environmental Diamonds.
- Water Quality Indices from “Environmental Indices: Theory and Practice” (Ott, 1978), where several water quality indices were reviewed:
    - General water quality indices (Horton “Quality Index”; Brown et al. “Water Quality Index”, Prati et al. “Implicit Index of Pollution”, McDuffie and Haney “River Pollution Index”, Dinius “Social Accounting System”)

  - Specific-Use Water Quality Indices (O'Connor "Fish and Wildlife Index", O'Connor "Public Water Supply Index", Deininger and Landwehr "Index for Public Water Supply", Walski and Parker "Index for Recreation", Stoner "Index for Dual Water Uses", Nemerow and Sumitomo "Index for Three Water Uses")
  - Planning Indices (Truett et al. "Prevalence Duration Intensity Index", Truett et al. "National Planning Priority Index", Truett et al. "Priority Action Index", Dee et al. "Environmental Evaluation System", Inhaber "Canadian National Index", Zoeteman "Potential Pollution Index", Johanson and Johnson "Pollution Index")
  - Statistical Approaches (Shoji et al. "Composite Pollution Index", Joung et al. "Index of Partial Nutrients", Joung et al. "Index of Total Nutrients", Coughlin et al. "Principal Component Analysis", Harkins "Harkin's Index", Schaeffer and Janardan "Beta Function Index")
- Water related indicators from the Lebanese Environment and Development Observatory – Lebanon (Lebanese Environment and Development Observatory, 2001).

2.2.3.8 Reduction:

According to the European Commission 2003 study referenced above (European Commission, 2003), there has been a tendency in several Member States to initially produce a very large set of Sustainable Development Indicators and then reduce the number on the grounds of both relevance to the national situation and data availability.

Reducing the number of sustainable development indicators (SDI) or environmental quality indicators (EQI) is also a must to avoid redundancy. Since environment is multi-dimensional, the development of EQI involves data simplification and reduction of effective dimensionality (Ott, 1978). One such dimensionality reduction technique is Principal Component Analysis (PCA); PCA transforms correlated original variables into a new set of uncorrelated variables (Flury and Riedwyl, 1988). For PCA to provide stable solutions, a rule of thumb is that the observation-to-variable ratio is three to one (Yu et al, 1998).

2.2.3.9 Aggregation:

Indicators can be presented individually or they can be mathematically aggregated to form indices. Aggregation of indicators into indices can proceed using a range of different aggregation methods and mathematical functions (summation, multiplication, etc.) (Rogers et al., 1997). Rogers et al. (1997) review the flow of information, in a pyramid form, from "primary measurement data" to "analysed processed data", to "indicators" and finally "indices".

It is important to distinguish between two general environmental index forms (Ott, 1978):

- those in which the index numbers increase with increasing environmental pollution "increasing scale"; and
- those in which the index numbers decrease with increasing environmental pollution "decreasing scale".

Two problems can be faced in aggregating indicators (Ott, 1978):

- Ambiguity: when the index is greater than a certain target whereas the indicators or sub-indices are all below the respective targets. In such cases – e.g.: linear sum aggregation-, "the problem is exaggerated".
- Eclipsing: when extremely poor environmental quality exists for at least one pollutant variable, but the overall index foes not reflect this fact. In such cases – e.g.: weighted linear sum aggregation-; "the problem is underestimated".

The table below presents some aggregation functions and their respective characteristics:

Table 2.1: Aggregation of Indicators

Aggregation Function	Increasing Scale Indices	Decreasing Scale Indices
Additive Forms		
Linear Sum	Ambiguity; no eclipsing	Eclipsing; no ambiguity
Weighted Sum	Eclipsing; no ambiguity	Eclipsing; no ambiguity
Maximum Operator	No eclipsing; no ambiguity	Not applicable
Multiplicative Forms		
Weighted Product	Not applicable	No eclipsing; no ambiguity
Minimum Operator	Not applicable	No eclipsing; no ambiguity

Weighting, obviously, presents a major challenge; weights should be justified on scientific and/or socio-economic grounds (Rogers et al., 1997). Weighting is further discussed in section 2.2.5.

2.2.3.10 Uniformity:

The European Commission, 2003 study noted that whilst indicators were to provide the basis to help develop national indicators, countries involved realised that a good indicator system should ideally, to a certain extent, be harmonised internationally. The same issue was addressed by Ott (Ott, 1978) regarding the desirability of a uniform water quality index.

2.2.3.11 Overview of Available Environmental Quality Indices:

In his book "Measuring Environmental Quality in Asia", Rogers (Rogers et al., 1997) reviewed several approaches that have been developed at the international level for the formulation of environmental indices. These include: the Netherlands Approach, World Resources Study, Organisation for Economic Cooperation and Development Indices, National Center for Economic Alternatives Index, the Green Index, the UNDP Human Development Index, the World Bank's Wealth of Nations Index, etc.

2.2.3.12 New Measures of Environmental Quality:

There has been a growing interest in using environmental clean up costs as an index of environmental degradation, or what is known as "the Cost of Remediation" approach (Rogers et al., 1997). The costs are based on the idea that there are three major ways to meet standards: process change, prevention and clean up after the fact. Estimation of costs for process changes and prevention suffers from a number of difficulties, one is lack of such data; the other is "joint costs", i.e. costs associated with process changes bring about multiple benefits simultaneously. So focus was rather on "clean up costs" after the fact. Economic valuation of environment is further discussed in section 2.3.

The World Bank has developed "Environmental Diamonds" for comparative assessment of environmental performance of countries. The first step is to select the appropriate variables or indicators, the second is to standardise these variables/ indicators, the third is to aggregate the scores into four components (water, air, land and ecosystem) and the last is to draw the diamonds (Rogers et al., 1997).

A third measure of environmental quality is known as "environmental elasticity" (Rogers et al., 1997). It is defined as the percentage change in an environmental aggregate as a function of a 1 percent change in an economic aggregate. The Map of Environmental Elasticity is a 4-quadrant map:

- quadrant of positive environmental change relative to positive economic change;
- quadrant of positive environmental change relative to negative economic change;
- quadrant of negative environmental change relative to positive economic change;
- quadrant of negative environmental change relative to negative economic change.

2.2.3.13 Recommendations:

The Hungarian experience of water related international indicators showed that (Statistical Commission and Economic Commission for Europe, 2001) further efforts should be made to:

- improve the quality and compatibility of existing data;
- further develop concepts and estimation methods;
- cover also the sectoral water related indicators (industry, energy, agriculture and tourism);
- force the cooperation of national institutions in the developing work ("a focal point for sustainable development indicators needs to be placed in every federal ministry as the Federal Plan for Sustainable Development demands", European Commission, 2003); and
- link the indicators more closely to national goals and international commitments.

2.2.4 Evaluation of DSS: Evaluation Definition, Frameworks and Methodologies

This proliferation of DSS applications, in water related issues and others, raises a question on the validity of this technique as a reliable decision-making tool, bearing in mind the importance of distinguishing between the decision quality and the decision process. As Mysiak (n.d.) points it out, normally, the quality of a decision is considered with regard to either the decision process (and its appropriateness) or/and the characteristics of the choice. Evaluating the decision process and the decision outcomes separately may omit some important aspects of the decision. An "excellent" decision process (built upon consistent and transparent preference modelling) may end up with a "wrong" decision, while a rather inconsistent decision process may lead to a "right" decision. The decisions made under uncertainty integrate the decision maker's attitude towards negative decision outcomes. The decision outcomes in such a case depend on the future conditions, which may prove to be less favourable for the decision-maker.

In this respect, literature reveals a good amount of methodologies for assessing the effectiveness of DSS in various fields. Methodologies range from framework tools to questionnaires (simple and pre-post test questionnaires) to comparison between various methods, etc.

Finlay and Wilson (1997) define validation as the process of checking the extent to which the DSS developed to allow experimentation on a surrogate world is appropriate to the task in hand. They propose a simple, operationalisable validity framework that is suitable by both system builders and users. This framework is intended to provide the basis for the development of a practical validation methodology, one contingent on the context in which the system will be built and used. This framework differentiates between:

- Validity of the logic model: logical validity (analytical validity, theoretical validity);
- Validity of the data model: data validity (accuracy, precision, theoretical validity);
- Validity of the computer-human interface: interface validity (usability, information validity, precision, theoretical validity);

- General validity (conceptual validity, experimental validity, replicative validity, verification); and
- Internal validity (clarity, reliability, operational validity, robustness, face validity).

Kanungo et al. (2001) studied whether specific DSS affected the effectiveness of credit decision-making at the State Bank of India by undertaking an experiment consisting of measurements that were taken as pre- and post- tests; an experimental intervention was applied between the pre-tests and the post-tests. The major research question addressed in the experiment was whether the use of the DSS improved the quality of decision-making pertaining to credit. It consisted of 8 subsidiary questions related to time, learning, perceived confidence, credit appraisal capabilities, etc.

Zapatero et al. (1997) empirically assessed the differences in the perceived usefulness of five multiple attribute decisions support systems versus a basic spreadsheet. A questionnaire was developed to assess user-friendliness of the software, confidence in the procedure implemented by the software, and users' confidence in their results when employing the decision aids. Time to reach a decision was also measured. Significant differences were found in the overall way users ranked these aids, in the perceived user-friendliness and the confidence in procedure among aids, and in the time it took to arrive at a result. The study concluded that while the assistance provided by a DSS should be assessed in terms of the improvement in the quality of decisions, the problem lies in the fact that there is not one right answer to measuring the quality of decisions, as, in multiple-attribute problems, the most preferred result is a matter of subjective, individual preference.

Brooksbank (2001) developed an assessment framework of the DSS tool that consists of ten criteria including context, objectives, principles and assumptions, equipping, organising, communicating, performance indicators, observing, system practice and creating. Bell et al. (2001) evaluated the usefulness of multi - criteria methods in integrated assessment of climate policy by organising a workshop in which climate change experts and policy-makers applied several methods in the context of a hypothetical greenhouse gas policy decision.

The European Union funded HarmoniRiB project (Harmonised Techniques and Representative River Basin Data for Assessment and Use of Uncertainty Information in Integrated Water Management) has several objectives (Harmonirib newsletters). One of these objectives is to establish a practical methodology and a set of tools for assessing and describing uncertainty originating from data and models used in decision-making processes for the production of integrated water management plans. As an example of uncertainty in socio-economic assessments three different methods (Cost Effective Analysis, Cost Benefit Analysis and Multi Criteria Analysis) have been compared.

Mysiak (n.d.) describes the Marie Curie project that analyses water-related conflicts and evaluates different approaches to decision-making aid regarding their ability to integrate conflicting objectives and communicate uncertainty. Based on the characteristics of decision methodologies and the cognitive predisposition of decision-makers, the project tries to determine how suitable the decision methods are for catchment-based water management under the conditions created by the implementation of the Water Framework Directive. The work is being conducted in conjunction with two EU funded research and development projects: MULINO and HarmoniRiB.

The Marie Curie project tests hypotheses regarding whether:

- a set of methods can be specified which are more suitable for a specific situation, without taking into account the decision-makers dealing with the problem;
- a set of methods exists which is preferably applied in a successive manner when exploring a given problem; and
- how much the usefulness of a method as perceived by decision-makers depends on their understanding of the analytical algorithm underlying the method.

2.2.5 Evaluation of DSS: Weaknesses of DSS

Newman et al. (1999) report the findings of a study by OSAIG (Organizational Aspects of Information Technology Special Interest Group) on the performance of information technology and the role of human and organisational factors. Results show that 80 to 90% of systems do not meet their performance goals, 80% are delivered late and/or over budget, and between 10 and 20% meet all their success criteria. According to Mysiak (n.d.), despite the variety of scientific papers dealing with theoretical aspects of the now vast array of decision methods available, the solution of real-world problems in water resource management has still not been satisfactorily reported; and Bell et al. (2001) found that none of the multi-criteria development methods had high predictive validity.

Why? Literature reveals that throughout the years, several issues have challenged the development and adoption of DSS.

2.2.5.1 DSS Validity Related Challenges:

Beneficiary's distrust of the usefulness of the DSS and their ability to improve consistency or confidence (Newman et al., 1999; Bell et al., 2001) is a key challenge, which seems to be common to all types of models, as demonstrated by Lu et al. (2001). The fact that different methods often lead to different conclusions when applied to the same decision problem is probably at the heart of people's distrust of DSS. According to Mysiak (n.d.), the variation of results obtained when two or more decision methods are used by a decision-maker may be as large as the variation of rank orders obtained when different people use the same decision method. Selecting the best decision method becomes a decision problem itself which, to be solved, presumes that a best decision method exists or is known, which obviously is not true since preferences elicited by a decision technique/tool are of a subjective nature and based on the decision-maker's value system: in order to aggregate multiple decision outcomes, subjective preferences and risk attitudes have to be built in. The quality of a decision in such a case can only be assessed with respect to the values and preferences stated by the decision-maker.

The fact that DSS are surrounded with considerable uncertainties that stem from natural randomness, uncertainty in data, models and parameters, and uncertainty about measures and scenarios is another major challenge facing DSS validity and adoption. Uncertainty is discussed in the next section.

Inadequate end users' involvement in the development of DSS hinders adoption of DSS; examples include unclear definition of the beneficiaries/users at the development stage, lack of user involvement from the early stages of DSS development and mismatch of the DSS output with the decision-making style of the decision-maker because the decision-maker's conceptual models are excluded (Newman et al., 1999).

Lack of field testing and failure of DSS to keep pace with the needs of the various users – who once they interacted and learned from the system, no longer required its use for decision-making (Newman et al., 1999)- constitute also important challenges. Mysiak also addressed the risk of decision support systems failing to be up to the challenge of real world problems despite undeniable benefits stemming from their usage as well as the popularity and number of developed decision support systems. This is due to the fact that the majority of decision support systems have been developed in an academic environment, which implies limited scope to continue customising the systems and adapting them to changing conditions once the corresponding research project has been completed (Mysiak, n.d.). Newman et al. (1999) reached a very similar conclusion and stressed on the perceived conflict between achieving a research career and achieving real impact in industry. Pertaining to the development of DSS, most successful impacts in industry have been achieved by those who chose to forgo an optimal scientific and (or) academic career path. Often, researchers get rewarded for new product development but not actually for delivering benefits to industry (Newman et al., 1999).

2.2.5.2 DSS Uncertainty and Sensitivity Related Challenges:

Literature reveals a good amount of research on uncertainty associated with MCA and DSS, which, as discussed above, stems from uncertainty in parameters (variability, imprecision, inherent randomness, subjective judgments, assumptions, lack of knowledge), in models (choices, assumptions, lack of knowledge), weights, and uncertainty about measures and scenarios. Below a few examples of parameters and weights related uncertainty:

Mateos et al. (2006) introduced an approach based on Monte Carlo simulation techniques for aggregating decision-makers preferences, where information is incomplete. Basson & Petrie (2007) discussed an integrated approach for the consideration of uncertainty in decision-making supported by Life Cycle Assessment. Yeh & al (1999) presented a new fuzzy MCA model to handle the multi-criteria selection problem with imprecise judgments; a particular feature of the model is that criteria weights are determined by fuzzy rules, which reduces the uncertainty associated with the criteria weighting process.

In order to support water resources policy makers to make a strategic selection between different measures in a DSS while taking uncertainty into account, de Kort and Booij (n.d.) developed a methodology for the ranking of measures. The methodology was applied to a pilot DSS for flood control in the Red River Basin in Vietnam and China. It consists of a Monte Carlo uncertainty analysis employing Latin Hypercube Sampling and a ranking procedure based on the significance of the difference between output distribution for different measures. Two aspects are discussed namely the type of uncertainty to be investigated – selected on the basis of a first-order uncertainty analysis - and the choice of the uncertainty analysis method – chosen based on a multi criteria analysis.

Yu et al. (2001) examined the uncertainty of a rainfall runoff model output caused by model calibration parameters. Four methods, the Monte Carlo simulation (MCS), Latin Hypercube Simulation (LHS), Rosenblueth's point estimation method (RPEM), and Harr's point estimation method (HPEM), were utilised to build uncertainty bounds on an estimated hydrograph. The study concluded that LHS only needs 10% of the number of MCS parameters to achieve similar performance. However the analysis results from RPEM (which requires 2^p parameter sets) and HPEM (which requires 2p parameter sets) differ markedly from those of MCS due to the very small number of model parameters.

Sensitivity analysis (SA) is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation. Originally, it was created to deal simply with uncertainties in the input variables and model parameters. Over the course of time, the ideas have been extended to incorporate model conceptual uncertainty, i.e. uncertainty in model structures, assumptions and specifications. As a whole, SA is used to increase the confidence in the model and its predictions, by providing an understanding of how the model response variables respond to changes in the inputs, be they data used to calibrate it, model structures, or factors, i.e. the model independent variables. SA is thus closely linked to uncertainty analysis (UA), which aims to quantify the overall uncertainty associated with the response as a result of uncertainties in the model input.

Kleijnen (1995) carried out a survey of statistical techniques for sensitivity analysis and related analyses. Wolters and Mareschal discussed three types of sensitivity analysis for additive multi-criteria decision-making (MCDM) methods: 1) sensitivity of a ranking to specific changes in the evaluations of all alternatives on certain criteria; 2) the influence of specific changes in certain scores of an alternative; and 3) the minimum modification of the weights required to make an alternative ranked first (Wolters & Mareschal, 1995). Lin and Wen (2003) carried out a sensitivity analysis of the optimal assignment; they investigated the range in which the current optimal assignment remains optimal and determined those values of assignment model parameters for which the rate of change of optimal value function remains constant.

Satelli (2004) introduced global sensitivity analysis as "the study of how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input", specifying that "global could be an unnecessary specification here, were it not for the fact that most analysis met in the literature are local or one-factor at a time".

Since one of the primary tasks in the application of MCA is the assignment of weights to the objectives or measures so that component scores can be aggregated, Butler et al. (1997) presented a simulation approach for high dimensional sensitivity analysis of the weights of multi-criteria decision models. The approach allows simultaneous changes of the weights and generates results that can easily be analysed statistically to provide insights into multi-criteria model recommendations. The study stresses the importance of this approach as opposed to single attribute approach – whereby when performing one-dimensional analysis on a given weight, the ratios among the other weights are held constant- since the single attribute approach can be misleading as it ignores the potential interaction that can result from simultaneous manipulations of multiple weights. Three cases are considered:

- random weighting: requires no weight assessments and yet may aid the decision-maker both before and after assessing the weights;
- random rank-order weights: requires an importance ranking which may be easier to elicit from a decision- maker than numerical weights;
- weight assessments are required but the approach recognises that these assessed weights may be subject to response error.

The first two simulation approaches can be applied before a numerical assessment of the weights has been completed. In some cases, the use of these two approaches may result in the identification of a single, most preferred alternative and make further weight assessment unnecessary. The random weights model was useful in that it helped the decision maker(s) focus on the alternatives that were superior regardless of the relative importance attached to the attributes. The importance rank order models also proved useful when testing a partial ordering of the weights.

For Hobbs et al., rating, the most applied weight selection method, is likely to lead to weights that fail to represent the trade-offs that users are willing to make among criteria; decisions are more sensitive to the method used as to which person applies it (Hobbs et al, 1992). According to Moshkovich et al., differences in attribute weights, as well as the method used, influence the results less than evaluation of alternative scores on attributes; attribute weighs and scores of alternatives over these attributes are not independent: if an attribute is considered to be very important, raters tend to give lower scores over these attributes. On the other hand, if attributes are considered minor, raters tend to give high scores to all alternatives (Moshkovich et al., 1998).

2.2.5.3 Information Technology Related Challenges:

These include limited computer ownership among decision-makers (Newman et al., 1999), unfriendliness of graphical user interfaces (Newman et al, 1999; Mysiak, n.d.), as well as DSS complexity and possibly considerable data input (Newman et al., 1999) versus problems of data availability (Mysiak, n.d.).

2.2.5.4 Human Resources – End Users– Related Challenges:

These include cognitive obstacles, such as an aversion among senior executives to DSS technology (Carlsson & Turban, 2002; Mysiak, n.d.). Cognitive obstacles, however, seem to vary across the types of models (Lu et al., 2001). Moreover, users often see no reason for changing current management methods and distrust the output of a DSS because they do not understand the underlying theories of the models (Newman et al., 1999). According to Carlsson and Turban (2002), people do not really understand the support they get and disregard it in favour of past experience and visions, they cannot really handle large amounts of information and knowledge, they are frustrated by theories they do not really understand and they believe they get more support by talking to other people. Users are also often subject to classic weighting biases, as demonstrated by Bell et al. (2001) by testing if weights are chosen by both hierarchical and non-hierarchical methods.

2.2.2.5 Other Challenges:

Other challenges include:

- lack of general consensus regarding what constitutes decision quality and, correspondingly, how it should be evaluated. Moreover, the way a decision situation is structured may be the cause of further disagreements (Mysiak, n.d.); and
- DSS use increases the time needed to take a decision (Kanungo et al., 2001).

2.2.6 Evaluation of DSS: Strengths of DSS

DSS suitability to various management cases, particularly integrated natural resources management, has been reported by many, as DSS offer integrated technical capabilities, allow for transparent decision-making processes, bridge the gaps between experts and non-experts and are cost effective on the long term:

- According to Mysiak et al. (n.d.), important functions of environmental DSS include understanding of problem's origins and complex cause-effect relationships, which determine current environment state of catchments.

- For Feas et al.(n.d.), a DSS is ideally suited to answering questions arising from policy changes on water resources by providing the understanding of the processes involved, evaluating the consequences and delivering advice.

- Brooksbank (2001) stressed how DSS contributed to the development of (1) effective access to the broad range of technical data, knowledge and process information that might be relevant to decision-making, (2) new ways of analysing potential strategies for resource use and their implications, and development of tools or methods that "package" these new approaches to make them accessible to the resource manager.

- Jamieson et Fedra (1996a,b) stated that openness about how decisions are reached is greatly facilitated through the use of a DSS in which the effects of alternative development policies can be explained and their impacts assessed in a form which can be comprehended by the non-expert. They added that the use of a single integrated modelling-decision-analysis framework, although possibly more expensive at the outset, can achieve considerable cost savings and organisational benefits in the longer term, apart from the benefits to be gained from improved planning and management.

DSS role in capacity building has been emphasised by many: Brooksbank (2001) talked about building the capacity of managers and their advisers to bring advances into existing and evolving decision-making processes. According to Kanungo et al. (2001), DSS is effective: it helps organise the structure of thoughts in the manager's mind when trying to assess a proposal; it changes the focus of the manager from a subjective to an objective outlook and increases the learning of the manager. Bell et al. (2001) demonstrated that participants gained insights from using the MCA methods, and although none of the MCA methods had high predictive validity, nevertheless, insights gained from using MCA methods were evidenced by differences between holistic rankings completed before and after applying the MCA methods and reviewing the results.

2.2.7 DSS: Outlook

In their paper "DSS: Directions for the Next Decade", Carlsson and Turban (2002) analysed most visible changes relevant to DSS, assessed how much expectations related to DSS were actually met and pointed out some directions for the future.

According to Carlsson and Turban (2002), the term DSS itself is seen less and less frequently both in the trade journals and the vendors' websites; terms such as business intelligence are becoming very popular and these practically eliminated the term executive information systems. The same authors mention that DSS promises did not fully come true mainly because key DSS challenges never appear to be technology related but they are "people problems". Nevertheless, they believe that DSS, regardless of what name(s) they are going to appear under, will actually thrive in the next decade mainly because most of the challenges of DSS are still valid, and development will be facilitated by the remarkable changes taking place at the individual, company, and market level:

1- larger groups of senior executives are becoming comfortable with IT;
2- modern cooperations and their strategic business units will continue to lose their hierarchical organisation structures – this has been implemented as reductions in staff and middle management personnel; and
3- as dynamics of global markets increase, the need for accurate, more diverse and immediate information will continue to grow.

2.2.7.1 Lessons Learned:

Proper development of DSS in the future should take into account the various lessons learned as outlined below, bearing in mind that although several attempts have been undertaken to facilitate the choice of a "best" method for a decision situation, there is no set of agreed criteria allowing to choose an appropriate MCA method for a given decision situation (Mysiak et al., n.d.). Lu et al. (2001) emphasised that the purposes of DSS design are not only to increase the decision quality, but also to increase the willingness to use DSS. To that end, Lu et al. (2001) stressed on the importance of the process of building the model, rather than the completion of the model, as DSS is meant as a supplement, rather than as a substitute for intuition. Enhancing the DSS development process can be achieved by taking the following lessons learned into account:

Users' Involvement

There is a strong need for end users' involvement and participatory approach in the development of the DSS as well as a need for confidence in, and agreement with, the system as prerequisite for user acceptance, even though the purpose of the system is to make available expertise beyond that of the user (Newman et al, 1999). Andreu et al. (1996) reported the experience gained during the development and implementation of AQUATOOL, which indicates that a main prerequisite to ensure users' expectations are realised is the close communication between the DSS developers and the technicians who will use it in the Agency. This guarantees that the final product will address the real problems. For Mysiak et al. (n.d.), an environmental DSS which claims for more effective and transparent decision making has to integrate knowledge from different sectors and disciplines and has to support group collaboration process with a large number of stakeholders having different perspective on the problem.

Transparency

Feas et al. (n.d.) state that in the field of environmental decision-making, one of the main issues is the need, sometimes the obligation imposed by the legislation, to communicate the decision process and make it more comprehensible and transparent to all those who have a meaningful role in the final decision: decision-makers, people and groups affected, and analysts. In water related issues, public participation, although challenged by institutional, financial and time constraints, remains a must for various legal, social and technical reasons, as outlined by Feas et al. (n.d.):

1- It is required by legislation.
2- It is somewhat a must because of the capital role that water plays in society as an important primary good, closely related to social and economic development.
3- It complements decision-makers' little experience in sustainable water management and the uncertainty inherent to decision problems thus sharing part of the responsibility and trying to find compromise solutions that facilitate acceptance.
4- It helps identifying the main relevant criteria and their societal targets in the decision process, as well as selecting the aggregation procedure and assessing weights.

Ease of Use

According to Lu et al. (2001), the willingness to use computerised models appears to rely heavily on preferences and perceived usefulness. Although the perceived ease of using computerised models has no direct effect on either preference or willingness, removing barriers that would allow people to believe that using DSS is easy would however have direct effect on its perceived usefulness and subsequent indirect effects on people's preferences and willingness to use DSS. Jamieson and Fedra (1996a,b) also stressed the importance of a DSS being both comprehensive and easy to use, with all the complexity being hidden from the user. Andreu et al. (1996) recommended that complete documentation of the tools developed be available; this documentation includes user's manuals for the DSS as a whole and for each mathematical model separately, as well as technical manuals and worked examples.

Performance and Performance Limitations

New generation of intelligent DSS should be both the screening/filtering of a growing overwhelming flow of data and support of an effective and productive use of information systems (Carlsson and Turban, 2002). Andreu et al. (1996) recommended adopting an approach that does not try to solve all the problems at once, but progresses from simple questions to more complex ones. In this way, the development of tools in the DSS responds to the priorities of the final users, rather than becoming an academic exercise.

DSS developers need also to find ways to overcome the various technical limitations encountered so far intra and inter DSS such as:

- Subjectivity pertaining to weight and ranking assignment in DSS and MCA: who assesses the weights and which method is used both have a significant impact on weights; both who applies the ranking method and which method is used can strongly impact results (Bell et al., 2001).
- Users' preferences to apply several MCA methods to increase confidence and insight: according to Bell et al. (2001), users themselves recommended such multi-method approaches for policy making. Yet they preferred the freedom of unaided decision-making most of all, challenging the MCA community to create transparent methods that permit maximum user control.

Maintenance and Update

Newman et al. (1999) emphasized the need for long-term commitment: support and availability for planning, maintenance and evaluation of the software necessary to demonstrate its benefits to industry. Kanungo et al. (2001) called for a continuous refinement and enhancement of the system; otherwise the DSS may lose its utility and may have to be replaced by another system.

Marketing and Replication

Newman et al. (1999) recommended a business plan for marketing the DSS. For Jamieson and Fedra (1996a,b), it is apparent that the successful application of a DSS in one complex basin encourages other agencies to adopt its use. Therefore, the DSS has to be capable of coping with a wide range of possibilities rather than a specific, pre-set configuration, a pre-requisite for it to be viewed as a generic DSS. .

Poon and Wagner (2001) tried to test the "Critical Success Factors (CSF)" for Executive Information Systems, as developed by Rockart and DeLong in 1988, which are: (1) committed and informed executive sponsor; (2) operating sponsor; (3) appropriate IT staff; (4) appropriate technology; (5) management of data; (6) clear link to business objectives; (7) management of organisational resistance; (8) management of system evolution and spread; (9) evolutionary development methodology; and (10) carefully defined information and system requirements. The study shows an interesting pattern, namely that companies either "get it right" and essentially succeed on all CSFs, or "get it completely wrong", that is, fall short on each of the CSFs. The dichotomy between success and failure cases suggests the existence of an even smaller set of "meta-success" factors. Based on the authors' findings, they speculate that these "meta-success" factors are "championship" (executive and operating sponsors), "availability of resources" (human, technology, financial), and "link to organization objectives". Authors stress that companies that believe they can solve their problems with an information system will likely fail whereas those that translate business goals into corresponding information needs and then into a well-managed system will likely succeed.

2.2.7.2 Complementarity of Approaches:

As mentioned previously, one of DSS main strengths stems from their capability of combining various modelling and management tools. While these tools are complementary, they sometimes lack the economic component in terms of monetarisation of externalities.

According to Mysiak (n.d.), the multiple criteria decision approach (MCA) forms a complement to economic approaches such as Cost Effectiveness Analysis (CEA) or Cost Benefit Analysis (CBA) to monetarising externalities and other impacts. While the main advantage of using MCA is the fact that it does not require ecological services to be expressed in monetary terms, thus neatly sidestepping the problems encountered in CEA/CBA, neither monetarisation nor MCA is unambiguously superior to the other; indeed, the two approaches have complementary strengths.

Whether the two approaches lead to the same results is therefore important to be researched; CBA is further discussed in section 2.3.

2.3 Sustainable Water Resources Management and Cost Benefit Analysis

2.3.1 Cost Benefit Analysis and Water Resources Management: Background & Evolution

The first Cost-Benefit Analysis (CBA) application to water resources management dates back to the 1930s in the USA; the theory of CBA is however much older and dates back to the 1840s in the writings of a French engineer and economist (Brouwer & Pearce, 2005). This might be due to the fact that economic development and environmental sustainability in many countries depend on considering water as a scarce resource, and therefore using economic principles for its management (Briscoe, 2005).

With time, CBA evolved to become as applicable to water quality as it is to water quantity, where water quality goes beyond drinking water standards to include ecosystem services (recreation, fisheries, biodiversity and general amenity), and the considerable advance in economic valuation techniques has largely contributed to that (Brouwer & Pearce, 2005). Griffin reviewed the fundamental principles of cost benefit analysis (Griffin, 1998), and analysed them as follows:

1. Projects are deemed economically acceptable "...if the benefits to whomsoever they accrue are in excess of the estimated costs...". This introduces the possibility of inequities in the distribution of project benefits or costs.
2. Welfare changes pertain to differences between with-and without- project scenarios
3. Cost measurement is founded on social opportunity costs
4. Producer benefits are to be measured as producer surplus changes
5. Consumer benefits are to be measured as consumer surplus changes
6. Zero-sum transfers of benefits or costs are to be ignored
7. Temporal aggregation employs discounting
8. Unmonetarised welfare changes are to be disclosed: the existence of both incommensurables (a project result that cannot be valued using reasonable techniques but can be physically measured) and intangibles (a project impact that can be neither counted nor economically valued) means that some project impacts will not be monetarised. The author's advice for CBA analysts in these situations

is to abandon full reliance on a benefit-cost criterion, as there is concern about how to correctly monetarise environmental welfare changes. Contemporary environmental evaluation techniques will not always be suitable or will be too expensive to employ in some circumstances. It is therefore unlikely that all environmental influences will be evaluated. Therefore meritorious decision-making must contemplate more than a single economic index because all welfare changes could not be reduced to this index.

The true economic value of water that needs to be reflected in CBA is discussed in section 2.3.2, and applications presented in section 2.3.3. CBA limitations are outlined in section 2.3.4. Section 2.3.5 compares CBA to other decision-making tools such as multi-criteria analysis.

2.3.2 Approaching the True Economic Value of Water in CBA:

2.3.2.1 Definition of the True Economic Value of Water:

Approaching the "economic value" of water implies adding to the direct cost of water, which includes the capital cost, operation & maintenance, treatment, storage and delivery (often referred to as user cost), the indirect cost composed of externalities, third party effects and environmental costs, which constitute the true economic cost of water. As Van der Lee and Gill point it out, the environment as a water user is now entitled as are all other water users to receive an allocation of water, as a measure to mitigate the riverine degradation (Van der Lee & Gill, 1999).
A direct consequence is the evolution of the science of ecological economics. Ecological economics seeks to recognise what traditional economics often ignores; that the economy is embedded in wider social and biophysical systems (Dodds, 1997).

In calculating the true cost of water, the cost is divided into use cost and opportunity cost, where in discussing "use costs", three concepts are defined: (1) the concept of "historical costs", (2) the concept of "replacement cost pricing", and (3) the concept of marginal cost, and opportunity costs reflect the value of water in its best practical alternative use (Briscoe, 2005).

As for the benefits, Bergstrom et al. (Bergstrom et al., 2001a) presented the major economic services supported by clean water: drinking water for human consumption; drinking water for livestock consumption and agricultural crop production to a lesser degree; industrial processes including food product processing; healthy aquatic ecosystems, flood control, erosion control, recreational fishing, recreational hunting/ trapping, commercial fishing, commercial hunting/trapping, on-site nature observation and study (bird watching) and off-site nature observation and study (viewing wildlife photos), pointing out that water quality may also support non-use or passive use services. Young (2005) discussed four types of water benefits: (1) commodity; (2) water for recreation, aesthetics, and fish and wildlife habitat; (3) waste disposal; and (4) dis-values (damage or negative benefits). They reported that most resource economists have concluded that non-use values should be added to use values so as to more accurately measure total environmental value. Therefore, CBA should take into account direct, indirect and secondary effects.

2.3.2.2 Water as a Human Right:

Discussing the true value of water brings up the issue of whether water can be a considered a human right. There have been both express and implied references to a right to water in public international law (conventions and declarations, customary international law and judicial decisions); however, the human right to water is not yet explicitly recognised (Scanlon et al., 2004).

Scanlon et al. (2004) attribute the link between water and human rights to the following factors:

- Drastically changing environmental and social factors make the issue of water as a human right become more significant;
- Water has not been clearly stated as a human right though it sits at the very essence of the right to life and other fundamental human rights;
- The establishment of a right to water in international human rights law would safeguard already accepted human rights and environmental principles;
- Recognising water as a human right would provide more effective protection;

- A human right to water would impose obligations on states, as human rights need to be translated into specific national legal obligations and responsibilities; .
- Acknowledging a human right to water would help focus attention to resolve conflicts over the use of shared watercourses;
- A human right to water can help set priorities for water policy to ensure that no person may be deprived of enough, good-quality water to satisfy basic needs; and
- Global problems need global solutions: the water crisis requires a major shift in policies in order to eradicate poverty and to enhance sustainable development.

2.3.2.3 Introduction to Water Valuation Techniques:

Bergstrom et al. (Bergstrom et al., 2001a) outlined the water quality valuation process as follows: water quality monitoring to assess the current water quality; assessment of factors affecting water quality "without action" and assessment of factors affecting water quality "with action"; setting of reference water quality (Q0) and probability (PROB0), and subsequent water quality (Q1) and probability (PROB1) and calculation of change in water quality (Q1-Q0) and probability (PROB1-PROB0) and associated change in water services DS=S1-S0, and finally determination of change in economic value.

Bergstrom et al. (Bergstrom et al., 2001a) discussed the various valuation tools or techniques for implementing the process outlined above: water market demand function, cost functions, averting or defensive expenditures, damages avoided, changes in production costs, hedonic price method, stated preference method (contingent valuation method or conjoint analysis), travel cost method; specifying that the choice of tool depends on many factors: theoretical appropriateness, estimation robustness, ease of data collection, time and budget constraints and professional judgment and preference.

Contingent valuation methods are being extensively used in water quality valuation, despite the limitations associated with such methods, discussed in section 2.3.4. As presented by Briscoe (2005), the value of water to a user is the maximum amount the user would be willing to pay for the use of the resource. In the US, values of water have been calculated for irrigated agriculture, hydropower, household purposes, industrial purposes and environmental purposes (Briscoe, 2005).

Shabman & Stephenson (2000) discussed environmental valuation and its economic critics and concluded that the debate over the "value of valuation" in water resources will not subside, because this debate is part of a wider intellectual dialogue regarding the role of analysts and quantification in the making of public policy.

2.3.2.4 Benefits Transfer and Contingent Valuation Methods:

The necessity for low cost and timely non-market valuation research has renewed academic and policy interest in transferring the findings of primary non-market valuation research conducted in one location to other locations, otherwise known as benefits transfer (Vanderberg et al, 2001).

Delavan and Epp (2001) explained that transfer to the policy site may take one of two forms:

- a direct transfer of the mean willingness to pay (WTP) value obtained from the study site; and
- a transfer of the estimated benefit function at the study site to the policy site population characteristics.

The prevailing presumption in the applied economics literature is that the transfer of the benefits function to the conditions at the policy site is preferred and more closely predicts WTP than the direct transfer. This is understandable as WTP generally increases with subjective perceptions of past contamination, number of contamination sources, likelihood of future contamination, interest in community issues and perceptions that water sources were not safe. Therefore, benefit function transfers tend to dominate direct transfers in terms of accuracy.

Vanderberg et al. (2001) revealed two other findings related to WTP: (1) respondents with higher incomes and education have higher WTP values on average, as do respondents who have a greater aversion to voluntary risks and a greater trust in ability to protect public water supplies; (2) study town aggregation plays an important role in the relative accuracy of transfers, a point that benefit transfer practitioners need to recognize in future research.

Delavan and Epp (2001) explained that one of the driving forces behind the increased number of benefits studies and better transfer estimates in the USA was legislation (Executive Order 12290), which mandated cost-benefit analysis for major regulations. Executive Order 12290 was, by many accounts, a political manoeuvre meant to reduce the burden on businesses by making it more difficult to enact environmental and other regulatory legislation. Ironically, the order led to a proliferation of focused, carefully constructed benefits studies which have supported the promulgation of regulations in the long run. The continued refinement of methods and the proliferation of benefits estimation studies have led to frequent use of benefits transfers in legal proceedings and government policy analyses where timely benefits estimates must rely on existing data.

Delavan and Epp (2001) specified that since benefit estimates for environmental goods are scarce in public policy (relative to cost estimates), any available number is often deemed best. Policy makers need estimates of benefits, even if they are imperfect. The costs of not having benefits information when making a decision must be weighted against the costs of possibly inaccurate or misleading benefits transfer work, for a wrong decision made with defective information also imposes costs. The ultimate test is whether the expected cost of doing the transfer, including the costs of making the wrong decision, outweighs the cost of doing a complete benefits study (which is also susceptible to error) (Delavan & Epp, 2001).

Boyle et al. (2001) concluded that the validity of water valuation estimates needs to be investigated and that while there is no need for more water valuation studies, especially with respect to potable water supplies, more research is needed on when credible benefits transfer will work as acceptable proxies for an original study.

2.3.3 Application of CBA to Water Resources Management:

Brouwer and Pierce (2005) reviewed the application of CBA to water resources management in several countries as summarised below:

2.3.3.1 Application Overview & Lessons Learned:

In Sweden, although the legislation states that economics is one of the aspects to be considered when ensuring a long-term management of resources, an explicit requirement to perform CBA is nowhere found (Frykblom et al., 2005). In a study aiming at over viewing the use of CBA by Swedish government agencies and non-governmental organisations (a total of 38) during the period 1997-2001, one-third reported having used CBA either because it is an agency's requirements or because the nature of the environmental effects or the project dictate so. The respondents who did not use CBA during this period do not foresee any future use within their agency either because the method is perceived as being insufficient for their type of problems or their sector does not have any significant environmental impact, or because CBA is outside the realm of what they normally do and the organisation lacks the competence to conduct such an analysis. The authors of the study outline the need for an integrated approach to management, which requires cooperation between specialists of various disciplines, which in turn requires a careful balancing between the research project's policy relevance and scientific relevance.

In appraising flood control investments in the UK, authors conclude that benefit-cost (B/C) ratios based on property damage alone may understate "true" benefits (Pearce and Smale, 2005). To overcome this, a number of additional factors need to be included which are: infrastructure damage; loss of environmental assets; distress, trauma and morbidity; non-use values; and damages associated with climate change. The authors also discuss a CBA learning effect, whereby the later the CBA, the more likely it is to be based on improved information about risks and assets at risk.

Maestu et al. reported that the Spanish government considers it important to include the valuation on non-market benefits in CBA, and that decisions affecting the water environment need to include an analysis of the environmental costs and benefits involved. The authors mentioned that in some cases, CBA of major water projects has evolved into a more complex multi-criteria analysis, including stakeholder consultation about the weights attached to different costs and benefits. The authors concluded that careful attention has to be paid in CBA to the development of future water demand, especially agricultural and urban water use, the associated pressures and impact on water quality and ecological status, as well as the assessment of environmental costs and benefits associated with different alternative options to simulate sustainable water use and good ecological status, and more effort needs to be put into that (Maestu et al., 2005).

Economic benefits of improved bathing water quality in the United Kingdom as a result of the European bathing water directive were estimated using a contingent valuation study. The survey questionnaire contained questions related to six categories: views of nature, personal characteristics, self-efficacy, expectations, values, knowledge and experience. The study revealed that the benefits outweigh the costs even allowing for any sources of imprecision in their estimation. The authors outlined the need for policy-makers to not only be informed about the economic costs and benefits, but also about the reasons why people will or will not pay, and how much they pay, as the reasons involve a consideration of the various beliefs, attitudes and values that individuals hold about themselves, society, institutions and the environment, and how these all operate in relation to one another (Georgiou et al., 2005).

Griffiths and Wheeler discussed benefit-cost analysis of regulations affecting surface water quality in the United States. They described how benefits and costs have been revisited in general to include not only compliance costs but also social costs associated with overall changes in consumer and producer surplus, opportunity costs associated with government regulatory activity, transitional social costs associated with unemployment and firm closing, and indirect effects on other industries, productivity, investment, and foreign trade; and environmental benefits including human health, amenities of the environment, ecological benefits, and materials damage. But the authors do specify that improvement needs to be made in the monetization of ecosystem services and non-use benefits. The authors also specified that although valuation of improved water quality and justification of public funding in public goods is required by law, there is no clear cut indication that net benefits be positive (Griffiths & Wheeler, 2005).

2.3.3.2 Some Numbers:

Dupont and Renzetti discussed the absence of any effort to compare the costs and benefits of projects related to the remedial action plan to improve water quality in the Great Lakes in Canada, presenting this as a major shortcoming of the decision-making process, as the CBA revealed that the benefits, which included a valuation of both use and no-use values, do not exceed 30% of the costs (Dupont & Renzetti, 2005).

In discussing the flood control policy in The Netherlands, the authors demonstrated that while the CBA of the proposed managed realignment measures compared to the "do nothing" baseline resulted in a net welfare loss of 2.2 billion Euro, the CBA which took into account the non-priced socio-economic benefits (public safety, biodiversity and landscape amenities) resulted in a net welfare gain of almost 1 billion Euro (Brouwer & Kind, 2005).

According to the authors of the CBA analysis of river restoration in Denmark (Dubgaard et al., 2005), the Danish government has set an explicit objective to get "value for money" spent on environmental protection. CBA seems then to be highly encouraged even if it has to rely on benefits transfer, on the basis of any number is better than no number. In an example related to the Skjern river project, an economic valuation is carried out for a number of environmental benefits including: better land allocation, reduction of nitrogen and phosphorous, improved hunting and fishing opportunities, outdoor recreation, non-use value of biodiversity, etc. An interesting conclusion is related to the major influence the discount rate value has on the CBA results, with the project highly beneficial at low discount rates (3%) and neutral at higher discount rates (7%). The authors attribute this discrepancy or intra-generational discounting to the characteristics of nature restoration projects, as discussed in section 2.3.4.

In discussing CBA of implementing the European urban wastewater directive in Greece, the authors reported that the use of CBA in Greek public administration is practically non-existent, though the idea of balancing environmental and economic trade-offs is gaining a momentum in Greek courts (Kontogianni et al., 2005). The estimation of the economic benefits of improved water quality in the Thermaikos Gulf was based on a contingent valuation survey, which revealed that the willingness to pay (WTP) is very much influenced by the status of individuals: while being a member of an environmental protection organisation helps giving a positive response, being unemployed or a student is most likely to result, on average, in a negative reply. CBA results proved a net benefit estimate of ~ 26 million Euros. Implementing CBA in Greece revealed a "conflict of constitutional rights", that is a conflict between free enterprise versus environmental protection.

To study the benefits of a revised European bathing water directive in The Netherlands, Brouwer and Bronda used a contingent valuation method asking households their willingness to pay to improve water quality. Aggregation of WTP estimates resulted in a total economic value of 170 million Euros per year (Brouwer & Bronda, 2005).

Rinaudo & Loubier reported that CBA of water quality projects in France, if carried out, have focused, until recently, on financial costs, i.e. direct expenditures associated with the implementation of the projects and direct expenditures avoided (benefits), while other non-monetised costs caused by the often diffuse effects of pollution, are generally not considered. In a case study on groundwater remediation in the Rhine valley, the authors considered 4 types of avoided costs: costs born by economic agents using water as input in their production process, costs born by agents using water as a final consumption good, costs born by indirect groundwater users, reduction of the non-use value of groundwater when it is polluted. Benefits are extended to include benefits accruing to agriculture (corrosion damage cost, crop quality and yield, etc.), and to environmental non-use benefits. The study resulted in non-use benefits representing approximately 70 to 80% of the total benefits (Rinaudo & Loubier, 2005).

In CBA and efficient water allocation in Cyprus, the authors reported the key objectives of public policy in the allocation of resources that are efficiency, equity, and environmental sustainability, pointing out that an economically efficient allocation need not necessarily be an equitable or sustainable one (Groom et al., 2005). They estimated non-use values using the contingent valuation method, which revealed a positive WTP for the provision of local water to the endangered species of 10 pounds per household per year, with an increased WTP of 10 pounds plus an extra 5 pounds per household per year for the local allocation of water to the endangered species if other states along the migratory route make similar choices (the co-operative scenario). The authors concluded that the optimal allocation of the scare water resources in Cyprus, which requires a careful balancing of the various values of water, is through the development of a uniform water pricing scheme where each water user is charged the same price.

Soto Montes de Oca and Bateman reported that the fact that international organisations have defined water as a basic right and that it is difficult to value benefits of improved water supplies in both physical and monetary terms resulted in insufficient analysis of benefits. To study benefits of urban water supply in Mexico City, the contingent valuation method was adopted and WTP results revealed that even low-income households would be prepared to pay higher water charges in return for an improved service, as averting measures to cope with the service unreliability constitute important costs to households with poor service standards. While one of the key local decision-makers said that the information provided by the WTP study injected a new perspective and should form the basis of future discussions between relevant water decision-making bodies, others showed some scepticism about whether actual WTP would correspond to stated amounts. The authors concluded that WTP and CBA information has allowed for the observation of the existence of economic and policy opportunities to give water a more realistic value (Soto Montes de Oca & Bateman, 2005).

In a study to estimate the loss of value of water resources due to pesticide contamination in the Mekong Delta, Vietnam, the authors (Phuong & Gopalakrishnan, 2003) used the contingent valuation method which proved that the household mean WTP for improvement in water quality is US$8 per year, which is 0.1% of the household income. Based on the total number of households and a discount rate of 10%, the authors estimated that the total value of rural water resources lost by pesticide pollution in the Mekong Delta is US$251 million.

Poe et al. (2001) argued that water valuation studies, despite their limitations, are not producing random noise. Studies are reflecting systematic differences in water, and particularly groundwater, values. For example, private and public well users are not valuing the same commodity in the sense that private well owners do not pay water bills, are not protected by drinking water standards, and may have a more intimate knowledge of their water supply. The private well users were willing to pay more than the city/county water users.

2.3.4 CBA Limitations:

Notwithstanding the various benefits of CBA application to water resources management outlined above, and the additional side benefits such as the ones presented by Brouwer and Pearce (2005) and Brouwer and Kind (2005)[1], CBA is challenged by a number of limitations analysed below, noting that for Rinaudo and Loubier (2005), despite all caveats, CBA is a very useful and valuable tool when preparing and informing water resources policy and decision-making.

According to Saleth (2004), it is true that an integrated approach can help in resolving the ecological conflicts of economic activities. Yet there are limits to this approach as only a weak integration of the economic and ecological aspects is feasible as the usual approach to integration involves the use of economic values as a common

[1] Beside offering an economic tool to manage a scarce resource, there is a number of advantages associated with CBA:

- introducing "cost-benefit thinking";
- introducing a powerful communication tool and facilitator of decision-making processes, especially when CBA is set up in an interactive or participatory –bottom-up- way;
- asking decision-makers to think about the relevant baseline scenario; and
- stimulating scientific thinking about environmental accidents such as floods.

denominator. However, these values have problems in reflecting the real ecological and social values of the resources, especially when interdependence, externalities, and intergenerational issues distort the process of evaluation and tradeoffs.

2.3.4.1 Environmental Valuation Limitations:

Several limitations are associated with one of the major environmental valuation tools, that is the contingent valuation method: comprehensiveness of variables and risk variables, availability of information to support results, sensitivity of results to questionnaires' wording and design, aggregation issues, choice of discount rate, and conceptual issues.

Bergstrom et al. (2001b) warned about the possibility of omitting a risk assessment variable from a water quality option price equation leading to biased option price results, as option price estimates which are biased upwards or downwards can lead to flawed water policy and management decisions. Because of the sensitivity of welfare estimates to research methods, water policy decisions and outcomes based on economic valuations may turn on subjective decisions that a researcher makes with respect to data collection and analysis.

Information is an important input in value formation and the distribution of estimated contingent values. Both specific information about personal exposure levels based on actual well tests and general information about sources of contaminants, health effects, water quality standards and opportunities for mitigation are needed to support contingent valuation programs affecting risks (Poe & Bishop, 2001).

Epp and Delavan (2001) reported that some respondents indicated that values will differ when a valuation question is worded differently and that the object to be valued is different. Another significant finding is the importance of the respondent's subjective perception of the effectiveness of a given program. Questionnaire design can significantly influence willingness to pay (WTP) responses in contingent valuation method studies.

Literature on valuation of multi-component programmes is replete with empirical reports that WTP for a multi-component program is less than the sum of WTP for its components evaluated independently (Randall et al., 2001). Some decisions about appropriate aggregation strategies must precede policy pronouncements.

The choice of the discount rate is an important determinant of the economic efficiency of water related projects (Rinaudo & Loubier, 2005). Intra-generational discounting is a major characteristic of nature restoration projects, where costs are incurred at an initial stage and benefits expected to continue indefinitely.

Rinaudo and Loubier reported that the contingent valuation approach (WTP) can be perceived by some as if the polluters own certain pollution rights, which is considered contrary to the polluters pay principle (Rinaudo & Loubier, 2005).

2.3.4.2 Other Limitations:

Other limitations are related to the subject of water resources management in general and benefit cost analysis in particular: accuracy of data and related uncertainty and sensitivity techniques, long-term effect of water/environmental policies, as well as public participation.

Water resources management requires forecasting the behaviour of a number of economic, technical/ environmental and social variables, where no full accuracy is expected, which calls the need for recognising uncertainty. Uncertainty techniques being too expensive in terms of resources required to perform them, sensitivity analysis is used as a practical alternative (Young, 2005). This highlights the importance of uncertainty surrounding environmental modelling.

A key issue in water management is the concern over the effects of current policy decisions on future generations. This is intensified by the presence of suspected irreversibilities. The uncertainty about future population growth and ecosystem resilience, combined with the exponential discounting process, may result in very low weights being placed on the benefits of protecting the aquifer (Xepapadeas & Koundouri, 2004).

Rinaudo and Loubier (2005) stressed the need for a multi-disciplinary and participatory approach in water resources management. The main problem with cost benefit analysis is that it does not provide a methodology to guide the inclusion of community consultation into the decision process (Van der Lee & Gill, 1999). The author promoted the use of an integrated trans-disciplinary decision-making process for water resources management as a way of achieving sustainable economic, ecological and social outcomes for water resources. He stressed the distinction between inter-disciplinary and trans-disciplinary; where the former implies the maintenance of a disciplinary perspective, though involves the participation of individuals representing different disciplinary backgrounds and trans-disciplinary, on the other hand, implies a completely open, learning oriented framework where the prospective synergies available from this kind of cooperation, have a much greater possibility of being realised.

2.3.5 CBA vs. Other Decision-Making Tools:

CBA benefits and limitations are further discussed through comparison to other decision-making tools such as the public trust doctrine, multi-criteria analysis, etc.

2.3.5.1 CBA vs. Public Trust Doctrine:

Brouwer and Pearce present a major procedure used for making public investment and policy decisions that is the public trust doctrine which started in the USA and moved also to the European Union (Brouwer & Pearce, 2005). The public trust doctrine arose in the context of environmental damage liability, and implies that some "pre-damage" situation must be reinstated; it can take one of two forms: either that the specific natural environment is restored to its "pre-damage" situation; or that, if the specific asset cannot be restored, another "like" asset must be created so as to compensate for the loss of the first asset.

Hence, as far as compensation is concerned, CBA and public trust approaches converge, as far as benefits are concerned, if and only if "making the environment whole" is the same as "making people whole". CBA will diverge from the public trust approach because it will compare the (hypothetical) compensation with the costs of restoring the pre-damage situation.

2.3.5.2 CBA vs. Multi-Criteria Analysis:

Joubert et al. (Joubert et al, 1997) presented 4 primary strengths of multi criteria analysis (MCA) vs. CBA in public sector project appraisal:

1- Public participation: CBA can assist in this, provided sensitivity analysis is well designed; however the outcome of a CBA is almost entirely in the hands of the analysts and those who inform them on appropriate distributional weightings.
2- The second reason relates to the ethical, theoretical and practical shortcomings of CBA and the valuation tools it requires.
3- The third reason follows from the second: even assuming that the valuation tools used within CBA could perform the tasks they purport to, it can be argued that placing a monetary value on certain environmental features, risks or externalities may be a questionable exercise.
4- The fourth reason concerns the nature of the decisions taken in the appraisal of public sector projects. These generally involve a multiplicity of criteria and objectives. CBA addresses this complexity by reduction of the issues to a single net present value.

Giorgetti and Petch (2006) argued that since CBA is a quantitative tool, both market and non market values are required to complete it. Hence, CBA is limited by the availability and quality of data provided in non-market valuations. Where time, budget and information are limited for undertaking a full CBA, the MCA provides a comprehensive framework for community to weigh up qualitatively trade-offs of complex management decisions. The CBA is most useful for internal information purposes (such as sustainability, funding, equity considerations) and in Court, whereas the MCA is a tool which facilitates consultation with the community, allowing the community to attach different weightings to identified impacts according to their own values and preferences.

CBA has some limitations in water related projects as many complex ecological functions of water bodies are not easily comprehended; hence it is very difficult to identify willingness-to-pay values for them. In addition to this, many authors have challenged the reliability and consistency of answers in willingness-to-pay studies. However the most important weakness lies in its reliance on a sole criterion which is efficiency; therefore policy effects that cannot be included in the efficiency framework- for example, equity issues, macroeconomics effects or sustainability effects- are neglected (Messner, 2006). While use of MCA overcomes the limitations mentioned above, it raises other questions such as: which MCA method to use? Who should determine the criteria? How is double counting prevented? Who decides on the weighting? Who is to be included in the participation process?...

In a workshop on the selection and prioritisation of adaptation measures in 2003, a diagram titled "what method to use when?" is presented: it allows identification of the most suitable prioritization technique between the following three: MCA, CBA and cost effectiveness analysis (CEA). Whenever criteria, which cannot be easily accommodated in CBA (such as institutional, sociological or cultural aspects), are important or when benefits cannot be quantified and valued (e.g. preserving biodiversity), one has to resort to MCA (Selection and Prioritisation of Adaptation Measures, Workshop 2003).

2.3.5.3 Combining CBA and MCA: Towards Total CBA

Salling et al. (n.d.) presented a new decision support system that examines socio-economic feasibility risks involved in the implementation of transport infrastructure projects. The model makes use of conventionally cost-benefit analysis embedded within a wider multi-criteria analysis. Weights are assigned to both CBA and MCA, 70% and 30% respectively as an illustrative example. Results show that while CBA application gives a highest B/C ratio of 3.5 for a certain alternative x, TRR (total rate of returns), which combines weighted CBA and MCA, gives a highest B/C ratio of 5 for another alternative y. Three direct consequences stem from that:

1- including non-monetary criteria changes the ranking;
2- including non-monetary criteria increases the benefits by ~ 40%; and
3- combining CBA and MCA lead to something similar to "total CBA" –i.e. CBA that takes into account environmental externalities- presented and discussed in sections 2.3.2 and 2.3.3.

2.4 Outlook: Towards Long Term Policy Analysis

Multi-criteria analysis, decision support systems, and cost benefit analysis are all tools that decision-makers use in an attempt to identify best, or most sustainable, policies, or what is known as "long term policy analysis (LTPA)", with very often limited knowledge, or what is known as info-gap.

Ben-Haim (2006) introduced the info-gap decision theory, where the central emphasis is that decisions under severe uncertainty must not demand more information, or at least not much more, than the decision-maker can reliably supply, and that is not much in the conditions under which the decision must be made. The author explained how in employing an approximate model, the user is acknowledging a large information gap between what is known and what needs to be known. Info-gap theory addresses the two contrasting consequences of uncertainty (threat of failure and possibility of un-imagined success) with 2 functions:

- robustness function assesses the immunity to failure
- opportuneness function assesses the immunity to windfall

Both these functions are quantitative, but numbers are not enough. The decision-maker must make value judgments. A key feature of this theory is that uncertainty can be quantified without using distribution functions.

The subject of LTPA has been the subject of a book by Lempert et al. (2003) where LTPA is presented as an important example of a class of problems requiring decision-making under conditions of deep uncertainty – that is where analysts do not know, or the parties to a decision cannot agree on:

1- the appropriate conceptual models that describe the relationships among the key driving forces that will shape the long-term future;

2- the probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models; and/or
3- how to value the desirability of alternative outcomes.

The book proposes four key elements of successful LTPA:

- consider large ensembles (hundreds to millions) of scenarios;
- seek robust, not optimal, strategies;
- achieve robustness with adaptivity; and
- design analysis for interactive exploration of the multiplicity of plausible futures.

For that purpose, a "XLRM" framework is used, supported by the Wonderland model which tracks changes in the economy, demographics and environment:

- L: policy levers or near-term actions that, in various combinations, comprise the alternative strategies decision-makers want to explore
- X: exogenous uncertainties or factors outside the control of decision-makers that may nonetheless prove important in determining the success of their strategies
- M: measures or performance standards that decision-makers and other interested communities would use to rank the desirability of various scenarios
- R: relationships or potential ways in which the future, and in particular those attributes addressed by the measures, evolve over time based on the decision-makers' choice of levers and the manifestation of the uncertainties. A particular choice of Rs and Xs represents future state of the world.

Rather than assume away uncertainties by either dropping poorly understood factors from consideration or assigning them arbitrary values, the authors propose to retain them and explore them over their full plausible range. They propose to reframe the question from "what is the long-term future?" to "how can we shape it to our liking?" They conclude by stating that computers can help humans create and consider a very large number of plausible long-term futures. Humans can then use the computer to assess which near-term actions perform well, compared to the alternatives, over all these futures using a wide range of values. Humans and computers then search for plausible futures that "break" the chosen strategy. If they cannot break it, the resulting strategy should support a consensus for successful action.

2.5 Some Conclusions

Literature reveals the importance of DSS as one of the key tools for the sustainable management of water resources; a tool that would analyze in an integrated approach the various aspects related to water management: demand, institutional and political, economic, social, quality, etc. This is demonstrated by the large number of water related DSS.

While various benefits are associated with DSS, DSS continue to face a number of challenges, mostly related to validity concerns, particularly raised by uncertainty in the values of the parameters used and sensitivity of results to both parameters' values and chosen methods of evaluation.

Overcoming these challenges is necessary, especially that experts predict a proliferation in the use of DSS. This implies that further research needs to be carried out for the purpose of assessing the validity of DSS, validity being amongst the most important challenge associated with DSS.

Assessing the validity of DSS requires first investigation of validity intra-model. This implies a thorough study of the DSS parameters (management options, indicators, and indicators performance values and weights) and the relationships between DSS parameters (sensitivity analysis etc.) for better formulation and evaluation of strategies.

Assessing validity of DSS requires also comparison with other decision-making tools, particularly those tools that are frequently used in decision-making related to water resources management, such as cost benefit analysis. Several advantages are attributed to CBA and literature reveals a good number of CBA applications to water resources management. At the same time, CBA faces some limitations too, thus the importance of cross-comparison with DSS. This would constitute the second aspect of DSS validity analysis: inter-model validity.

All these tools and related analysis serve successful long-term policy analysis often constrained by data limitation, particularly in the field of water resources management.

3 CONCEPTUAL FRAMEWORK

To assess the validity of decision-making using decision support systems (DSS), one of the most important challenges facing DSS and aim of this research, a two-approach methodology is proposed: (1) an intra-model approach that consists of analysing uncertainty and sensitivity factors associated with the DSS used; and (2) an inter-model approach that consists of testing other decision-making tools, of the cost based type, and comparing results.

Intra-model validity aims at checking how much the model results are influenced by any change inside the model. This change can stem from various levels in the model itself, starting with (1) the level of comprehensiveness of management options (MO) and basic indicators (BI), to (2) the level of confidence in the BI performance values and the level of consensus in the BI weights, to (3) the level of sensitivity of MO ranking to BI weights and performance values. Different methods, quantitative and qualitative, are used for studying the impacts of the various changes outlined above. Strategies are then generated out of various combinations of MO, as per uncertainty and sensitivity results. Validity of strategies is subsequently assessed based on sustainability, cost and reduction in the water demand-supply gap (subject of the application of this framework).

Inter-model validity aims at comparing model results with the outputs of another model. The first being a multi-criteria model, the second is selected from the cost-based models. While MO ranking results are compared across models, strategies generated from MO combinations are also cross-checked.

While the proposed framework relies in some of its steps, step 3 (section 3.1) and CBA calculation (step 3.2), on existing methods, the integrated & comprehensive approach it offers presents an innovative way of addressing validity issues. This is particularly important given the forecasted proliferation in the use of DSS (Carlsson and Turban, 2002) yet the performance limitations associated with DSS (Carlsson and Turban, 2002; Bell et al., 2001).

Section 3.1 discusses details of the intra-model validity approach, while section 3.2 discusses details of the inter-model validity approach. Limitations of the proposed methodology are presented in section 3.3.

3.1 Intra-Model Validity

As can be concluded from the vast literature on decision support systems discussed in chapter 2, validity of decision-support systems is a function of:

- the input data (management options, indicators and indicators weights and performance values), i.e. uncertainty associated with the input data. This consists of the level of comprehensiveness of management options/alternatives, the level of comprehensiveness of indicators, the level of confidence in the assignment of indicators' performance values, as well as the degree of consensus on the weights elicited for indicators.
- the processing of the input data, i.e. the uncertainty associated with the technique used for processing the input data.

Based on the above, a 5-step approach, sketched in figure 3.1, is proposed to assess validity intra-model:

1. *Step 1*: study the level of comprehensiveness of management options (MO) and basic indicators (BI), by reviewing the methodology used for identifying and consolidating the MO and BI. If the level of comprehensiveness of MO or BI turns out to be low, further stakeholder consultation and/or literature review is recommended. This could include the use of sociotechnology techniques, such as the ones reviewed in chapter 2 (section 2.1.4)[2]. If the level of comprehensiveness proves to be high, the analysis is directly taken to the second level.

2. *Step 2*: study the uncertainty associated with the performance values and weights assigned to the BI, by assessing the level of confidence in assigning performance values (PV) and the degree of consensus in eliciting weights (W). The level of confidence in assigning BIPV is assessed based on a matrix of

[2] For the sake of the application study related to this thesis, and as can be noticed from chapters 4 and 5, these sociotechnology techniques have not been reviewed and/or used. Retrospectively however, the approach adopted does not appear to be inconsistent with the concepts praised by Abbott and Jonoski (section 2.1.4); further recommendations are outlined in chapter 7.

criteria which includes the methodology used, its application (model and data), the assumptions made, along with the details of calculation of the best and worst value, which in many cases influence the calculation of the performance value of the indicator under consideration. Each criterion is given a score ranging from low to high; similarly the estimated level of confidence is then given a score ranging from low to high (as illustrated in chapter 5). The degree of consensus in eliciting the weights is assessed based on the level of stakeholder involvement, i.e. the degree of elicitation of stakeholders' preferences for objectives. If the uncertainty level is low, the analysis is directly taken to the third level. If the uncertainty level is high, either further stakeholder consultation and/or literature/calculation review is undertaken if feasible, otherwise the analysis is taken to the third level.

3. *Step 3*: analyse the sensitivity of MO ranking to PV and W. The sensitivity of MO ranking to BIPV is carried out using the distance-based uncertainty analysis method. The purpose of the distance-based uncertainty method is to determine the minimum modification of PV required to achieve rank equivalence between two MO (Hyde & Maier, 2005; Hyde et al., 2005). This is done by translating the problem into an optimisation problem and exploring the feasible PV range. The objective function minimises a distance metric (Euclidian distance), which provides a numerical value to the amount of dissimilarity between the original PV and the optimized one for both MO, where the optimized PV refer to the sets of PV that are the smallest distance from the original sets of PV, such that when the optimized PV are used, the total values of the two MO being assessed are equal (this is illustrated with specific examples in chapter 5).

   The objective function is:

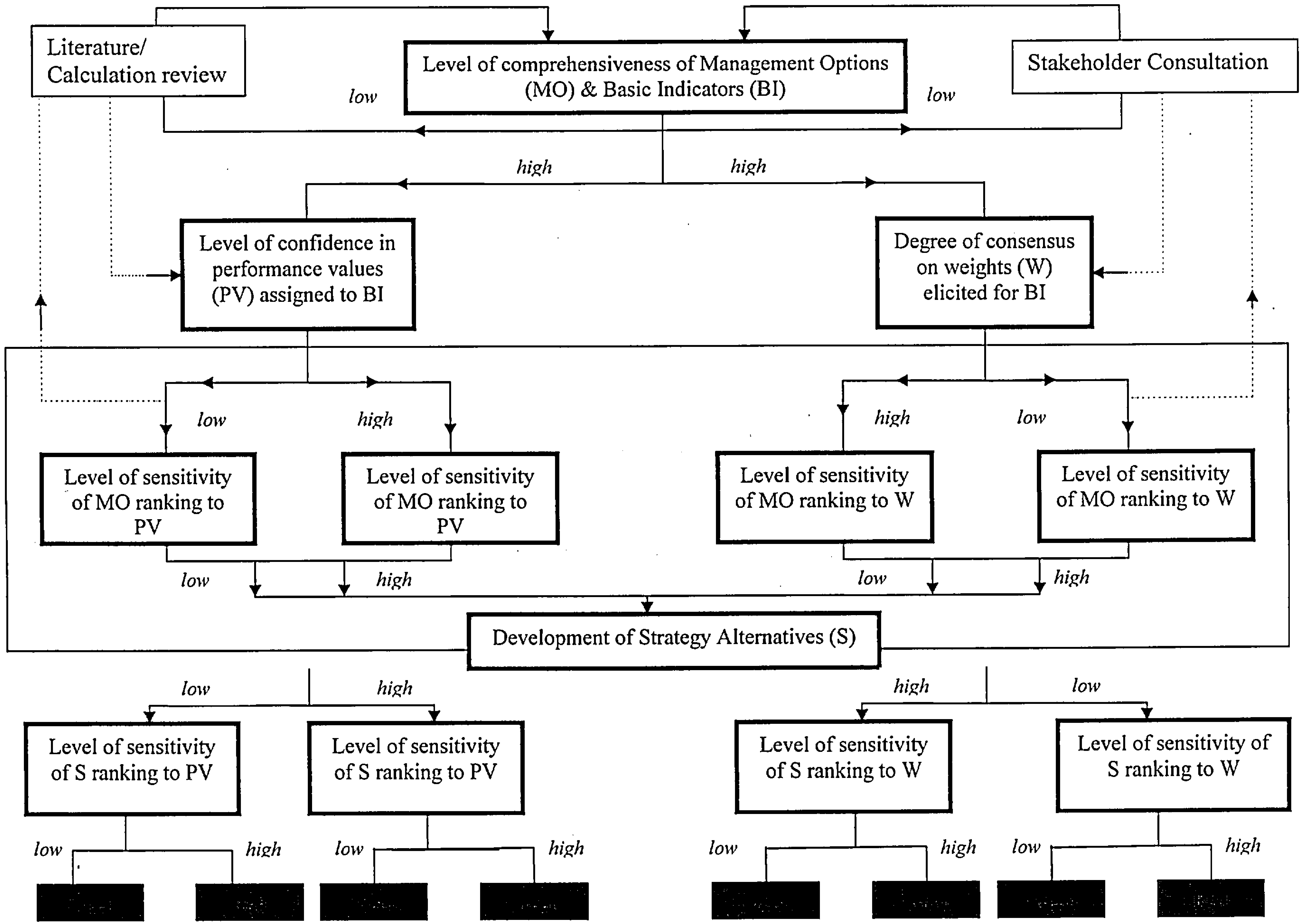
   Minimise $d_e = \sqrt{\sum_{m=1}^{M}((BIPV_{mi(y)} - BIPV_{mo(y)})^2 + (BIPV_{mi(x)} - BIPV_{mo(x)})^2)}$

   Subject to the following constraints: $V(MO_y)opt = V(MO_x)opt$

   $LL_{BIPV} \leq BIPV_{mo} \leq UL_{BIPV}$

   for m=1 to M

Figure 3.1: DSS Intra-Model Validity



Green: Appropriate to make a reccmmendation
Red: Not appropriate to make a recommendation

Where:

- $BIPV_{mi(y)}$ is the initial PV of BI m for MOy
- $BIPV_{mo(y)}$ is the optimised PV of BI m for MOy
- $BIPV_{mi(x)}$ is the initial PV of BI m for MOx
- $BIPV_{mo(x)}$ is the optimised PV of BI m for MOx
- M is the total number of BI
- $V(MO_y)opt$ is the modified total value for the BI of the initially lower ranked MO (say MOy)
- $V(MO_x)opt$ is the modified total value for the BI of the initially higher ranked MO (say MOx)
- LL_{BIPV} and UL_{BIPV} are the lower and upper limits, respectively, of each of the BI

The optimisation problem is solved using the Generalized Reduced Gradient (GRG2) non-linear optimisation method. The output is the minimum Euclidian distance (d_e) for each pair of MO, which can be summarised in a matrix:

- A large Euclidian distance between two MO means that the ranking of the two MO is robust; i.e. one MO will always dominate the other, irrespective of the PV of the BI.
- A small Euclidian distance means that the ranking of the two MO is very sensitive to the BIPV; i.e. slight changes in the PV of the BI will result in rank equivalence between the two MO. The most critical BI can also be identified by examining the relative and absolute change Δ in the BIPV:

  - Absolute $\Delta BIPV_m = BIPV_{mo} - BIPV_{mi}$
  - Relative $\Delta BIPV_m = \dfrac{BIPV_{mo} - BIPV_{mi}}{BIPV_{mi}} \times 100$

The sensitivity of MO ranking to BI weights is carried out using 3 methods: the distance-based uncertainty analysis method as well as two other methods to cross-check results (robustness measure method and sensitivity analysis method), where the three methods are summarised in table 3.1:

Table 3.1: Summary of the 3 Methods for Assessing Sensitivity to the Elicitation of BI Weights

	Robustness Measure (r)	Sensitivity Analysis (δ)	Distance Based (d_e)
Requirements	changing all weights at the same time by the same value	changing 1weight at a time by different values	changing all weights at the same time by different values
Interpretation of Results	a value ~ 0 implies indifference; a value ~ 1 implies robustness	a value ~ 0 implies indifference	a value ~ 0 implies indifference

A robustness measure is proposed to allow the decision-maker to determine the robustness of the preference between two MO, which is defined as the proportion by which the decision-maker must modify the basic indicators' weights to change the ranking between two MO (Guillen et al, 1998). The robustness measure can be calculated for each pair of MO using the following equation:

$$r(MO_1, MO_2) = \frac{w_1 \times (PV_{1,1} - PV_{1,2}) + ... + w_m \times (PV_{m,1} - PV_{m,2})}{w_1 \times |(PV_{1,1} - PV_{1,2})| + ... + w_m \times |(PV_{m,1} - PV_{m,2})|}$$

Where:

- $r(MO_1, MO_2)$ is the robustness between MO1 and MO2; r(MO1,MO2) takes its value in the interval (-1,1) and MO1 dominates MO2 on all BI when r(MO1,MO2) = 1
- w_m is the weight applied to BIm,
- $PV_{m,1}$ is the PV of BI m of MO1

The weights required to reverse the ranking between a pair of MO (modified weights) (w^*)) can be calculated using the following equation:

$w_1^* = w_1 - w_1 \times r(MO_1, MO_2)$ if $PV_{1,1} > PV_{1,2}$

$w_1^* = w_1 + w_1 \times r(MO_1, MO_2)$ if $PV_{1,1} < PV_{1,2}$

The total values for the BI of the pair of MO being assessed are then determined using the modified weight (w^*) and should be equal if the method has been undertaken correctly.

Some limitations are associated with this method, such as:

- critical weights are not identified as all weights are adjusted by an equal proportion, dependent on the initial value; and
- following the adjustment mentioned above, the sum of the modified weights is not equal to the sum of the initial weights.

The sensitivity analysis method, (Triantaphyllou & Sanchez, 1997), consists of calculating for each pair of MO (x) and (y) for each BI (m) the minimum quantity δ that a weight needs to be changed by, to reverse the ranking:

$$\delta_{m,x,y} = \frac{V(MO_x) - V(MO_y)}{PV_{x,m} - PV_{y,m}}$$

Where:

- $V(MO_x)$ and $V(MO_y)$ are the total values for the BI of MO x and y, respectively
- $PV_{x,m}$ is the PV of BI m for MOx
- $PV_{y,m}$ is the PVof BI m for MOy

For the modified weight to be feasible, the following condition must be satisfied: $\delta_{m,x,y} \leq w_m$, where w_m is the weight elicited for BI_m.

When a feasible solution is possible, the modified weight (w_m^*) is calculated as follows:

$$w_m^* = w_m - \delta_{m,x,y}$$

The percentage change in the weight is evaluated by:

$$\%w_m = \frac{w_m^*}{w_m} \times 100$$

The total values of the pair of MO being assessed are then determined using the modified weights and should be equal if the method has been undertaken correctly.

An advantage of this method over the robustness method is that it allows the identification of critical weights as the weights that require the smallest relative change in the weights to change the ranking of any pair of MO. Some limitations are associated with this method, mainly that weights' sensitivity is assessed independently and only one weight is varied at a time.

The purpose of the distance-based uncertainty method, as stated above, is to determine the minimum modification of weights required to achieve rank equivalence between two MO (Hyde & Maier, 2005; Hyde et al., 2005). This is done by translating the problem into an optimisation problem and exploring the feasible weight range. The objective function minimizes a distance metric (Euclidian distance), which provides a numerical value to the amount of dissimilarity between the original weights and the optimised weights, where the optimised weights refer to the set of weights that is the smallest distance from the original set of weights, such that when the optimized weights are used, the total values of the two MO being assessed are equal.

The objective function is: Minimise $d_e = \sqrt{\sum_{m=1}^{M} (w_{mi} - w_{mo})^2}$

Subject to the following constraints: $\sum_{m=1}^{M} w_{mi} = \sum_{m=1}^{M} w_{mo}$

$$V(MO_y)opt = V(MO_x)opt$$

$$LL_w \leq w_{mo} \leq UL_w$$

for m=1 to M and for factor i and $LL_w > 0$

Where

- w_{mi} is the initial weight of BI m
- w_{mo} is the optimised weight of BI m

- M is the total number of BI
- $V(MO_y)opt$ is the modified total value for the BI of the initially lower ranked MO
- $V(MO_x)opt$ is the modified total value for the BI of the initially higher ranked MO
- LL_w and UL_w are the lower and upper limits, respectively, of each of the MO weights

The weight ranges can be defined by either the decision-makers or actors, or, alternatively, actual ranges of the available data can be utilised (i.e. the minimum and maximum values of the BI weights elicited from a range of actors involved in the decision analysis process) (Hyde et al., 2005).

The optimisation problem is solved using the Generalized Reduced Gradient (GRG2) non-linear optimisation method. The output is the minimum Euclidian distance (d_e) for each pair of MO, which can be summarised in a matrix:

- A large Euclidian distance between two MO means that the ranking of the two MO is robust; i.e. one MO will always dominate the other, irrespective of the value of the BI weights.

- A small Euclidian distance means that the ranking of the two MO is very sensitive to the BI weights; i.e. slight changes in the BI weights will result in rank equivalence between the two MO. The most critical BI can also be identified by examining the relative and absolute change Δ in the BI weights:
  - Absolute $\Delta w_m = w_{mo} - w_{mi}$
  - Relative $\Delta w_m = \frac{w_{mo} - w_{mi}}{w_{mi}} \times 100$

In summary, the outcome of the sensitivity analysis exercise would be one of the following:

- MO ranking is highly sensitive to both BI performance values and weights;
- MO ranking is neither sensitive to BI performance values, nor to BI weights;
- MO ranking is highly sensitive to BI performance values, but not to BI weights;
- MO ranking is highly sensitive to BI weights, but not to BI performance values.

4. *Step 4:* develop strategy alternatives based on MO and BI uncertainty and sensitivity analysis results. Various MO combinations are proposed taking into account uncertainty and sensitivity analysis results; i.e. MO which demonstrate robust high ranking results (that is irrespective of the uncertainty associated with the BI performance values and weights), or MO with un-robust high ranking results but based on low uncertainty parameters (BI performance values and weights) are favoured over MO with low ranking results or MO with un-robust high ranking results based on high uncertainty parameters (BI performance values and weights). The various strategies are then evaluated based on three criteria:

   a. Sustainability: sustainability is calculated based on the weighted sum of the BIPV, which are generated from the BIPV of the various MO multiplied by the respective coefficients as per MO combination (illustrative examples are provided in chapter 5);

   b. Demand-supply gap: gap is calculated as per the equation below:

$$G_x = (D - DR_x) - S_x$$

Where:

G_x is the gap between the supply offered by strategy x and the demand
D is the total demand

DR_x is the total demand reduction insured by strategy x:

$$DR_x = BDR + DR_{MOy} * C_{y(x)(n)}$$

BDR is the baseline demand reduction

DR_{MOy} is the demand reduction ensured by MOy (where MOy is the MO that refers to demand reduction, in case it exists)

$C_{y(x)(n)}$ is the coefficient of MOy for strategy x (i.e. the percentage of use of MOy in stratgey x) normalised as follows:

$$C_{y(x)(n)} = \frac{C_{y(x)}}{C_{\max(x)}}$$

where $C_{y(x)}$ is the coefficient of MOy for strategy x

$C_{max(x)}$ is the highest MO coefficient in strategy x

S_x is the total quantity of supply offered by strategy x:

$$S_x = BS + \sum_i S_{MOi} * C_{i(x)(n)}$$

BS is the baseline supply

S_{MOi} is the additional supply offered by management option i

$C_{i(x)(n)}$ is the coefficient of MOi for strategy x (i.e. the percentage of use of MOi in stratgey x) normalized as follows:

$$C_{i(x)(n)} = \frac{C_{i(x)}}{C_{\max(x)}}$$

where $C_{i(x)}$ is the coefficient of MOi for strategy x

$C_{max(x)}$ is the highest MO coefficient in strategy x

i can take the following values 1, 2, 3, …m (where m is the total number of MOs)

c. Cost: the cost associated with each strategy is calculated based on the costs of the different MOs (capital cost as well as operation and maintenance cost), weighted with the respective normalised MO coefficients

5. *Step 5:* analyze the sensitivity of strategy alternatives to BI performance values and weights following the methodology presented in step 3. Sensitivity analysis results could then be:

- strategy ranking is highly sensitive to both BIPV and BIW;
- strategy ranking is neither sensitive to BIPV, nor to BIW;

- strategy ranking is highly sensitive to BIPV, but not to BIW;
- strategy ranking is highly sensitive to BIW, but not to BIPV.

The overall outcome of the intra-model validity approach is that either it is appropriate that a recommendation for decision-making be made (signalled in green) or not (signalled in red), based on the following uncertainty/sensitivity results combinations:

It is appropriate to make a recommendation for decision-making in each of the following cases:

- low uncertainty in BIW and low sensitivity of strategy ranking to BIW;
- low uncertainty in BIW and high sensitivity of strategy ranking to BIW;
- high uncertainty in BIW and low sensitivity of strategy ranking to BIW;
- low uncertainty in BIPV and low sensitivity of strategy ranking to BIPV;
- low uncertainty in BIPV and high sensitivity of strategy ranking to BIPV;
- high uncertainty in BIPV and low sensitivity of strategy ranking to BIPV.

It is not appropriate to make a recommendation for decision-making in any of the following cases:

- high uncertainty in BIW and high sensitivity of strategy ranking to BIW;
- high uncertainty in BIPV and high sensitivity of strategy ranking to BIPV.

3.2 Inter-Model Validity

A complementary method to the intra-model validity approach is the inter-model validity approach whereby another decision-making tool is explored and results cross-checked. The initial method under study being a multi-criteria analysis method (MCA), it is judged appropriate to test a cost-based method (internal rate of return (IRR) or cost-benefit analysis (CBA)), as CBA methods have been widely used as the primary means for assessing water resources development options, but normally rely on economic considerations only.

The internal rate of return (percentage rate that causes the discounted percent value of the benefits in a cash flow to be equal to the discounted present value of the costs) of each management option is calculated based on:

(1) the overall costs of each MO (direct and indirect costs) and the direct benefits only (IRR(Direct Benefits Only)); and
(2) the overall costs and benefits of each MO (IRR)

Both results are compared, and then cross-checked against MCA results. Strategies are then generated and IRR and IRR(Direct Benefits Only) calculated.

Later, the benefit cost ratio of each management option is calculated with and without indirect benefits (CBA(Direct Benefits Only)). CBA is carried out for various discount rates (3%, 5%, 7% and 10%) and results intra and inter compared. This allows testing the impact of the choice of discount rate on CBA results. Again, strategies are then generated based on the results and CBA and CBA(Direct Benefits Only) computed.

The question of whether CBA inclusive of indirect benefits is equivalent to MCA is then addressed by combining CBA and MCA results, where:

- for CBA, only direct benefits are taken into account to limit redundancy;

- for MCA, only indirect benefits are considered to limit redundancy – where indirect benefits refer to the social and environmental ones, and where aggregation of indirect benefits needs to be carefully studied; and

- a weight of 70% and 30% is used for CBA and MCA respectively, as an illustrative example ony as proposed by Salling et al. (n.d.) for transport projects.

Results are then compared to CBA(Direct Benefits Only), CBA (i.e. CBA inclusive of indirect benefits), and MCA.

This approach allows addressing the following issues:

- impact of indirect benefits on CBA analysis;
- impact of the choice of discount rate on CBA analysis;
- comparison of CBA and MCA; and
- comparison of CBA&MCA combination to CBA and MCA.

3.3 Limitations

The proposed methodology is challenged by two types of limitations: conceptual type and application type.

At the conceptual level, the methodology, particularly step 3 of the validity intra-model, relies on existing methods to study sensitivity, such as the robustness measure method and the sensitivity analysis method which are constrained by some limitations, as discussed in section 3.1, but overcome by the distance-based uncertainty method applied for assessing sensitivity to both BI weights and performance values.

Application of selected steps of the methodology is based on secondary data; this is further discussed in chapter 4. Examples include:

- Steps 1 and 2 of the intra-model validity: level of comprehensiveness of MO and BI, level of confidence in assigning BI performance values, degree of consensus in eliciting BI weights, all assessed based on data presented in the various SUSMAQ reports, many of which are or rely on secondary data.

- Step 4 of the intra-model validity: limitations associated with the method used for calculating the evaluation criteria for the various strategies (sustainability and demand-supply gap criteria) which is based on MO related data.

- Inter-model validity: assumptions that indirect benefits used in IRR and CBA are the same indirect benefits used in MCA analysis. An attempt to overcome this constraint is through the comparison carried out between the combination of CBA&MCA and CBA and MCA separately.

4 APPLICATION

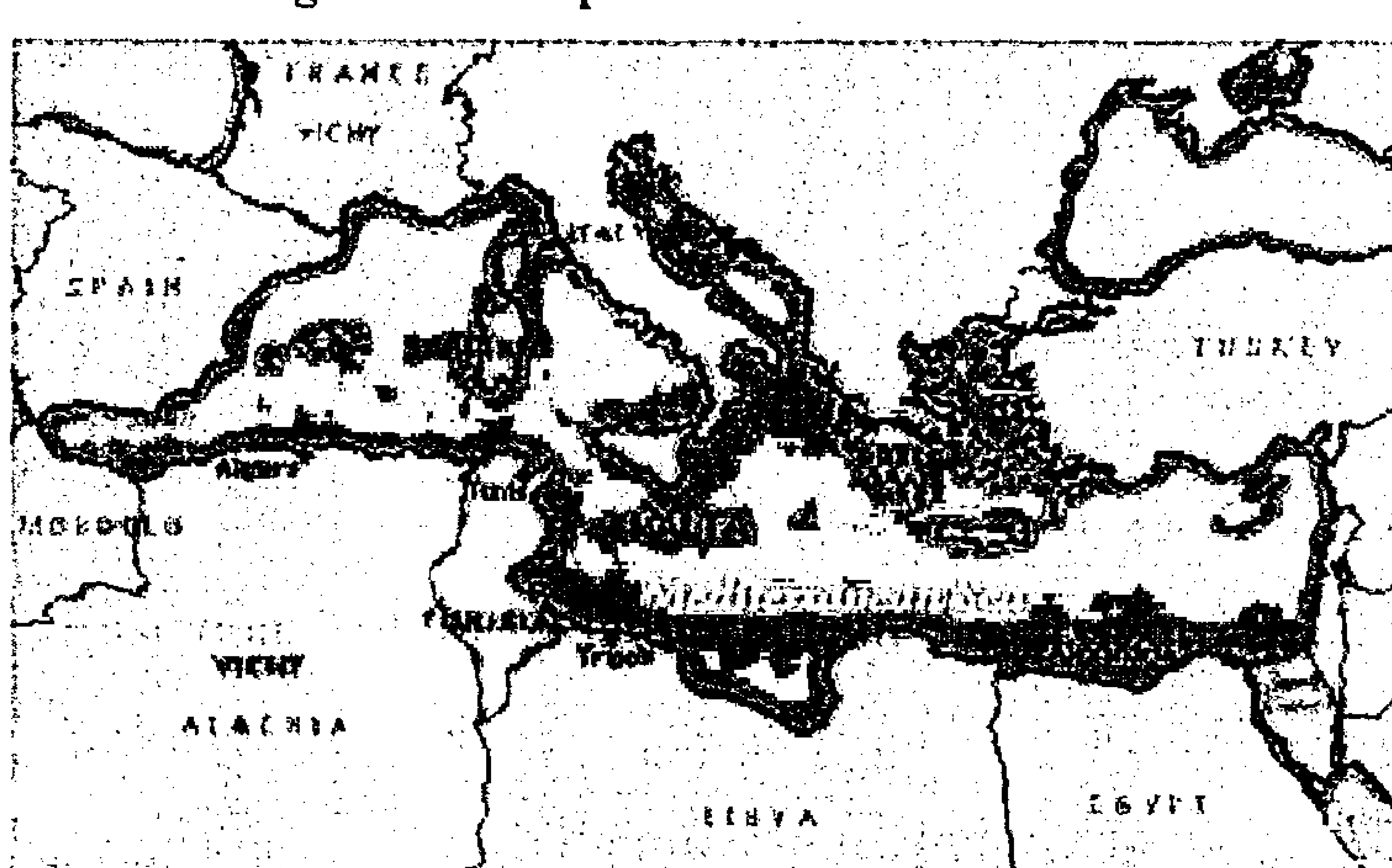
The conceptual framework for assessing the validity of decision support systems (DSS), as outlined in chapter 3, is applied to a water resources management case study: the sustainable management of the West Bank aquifer. An overview of the West Bank Aquifer status is presented in section 4.1. While existing policy and management activities are presented in section 4.2, the Decision Support Tool developed in the context of the Sustainable Management of the West Bank and Gaza Aquifers (SUSMAQ) project[3] and application details are discussed in sections 4.3 and application limitations in section 4.4.

4.1 Overview of the West Bank Aquifer Status

4.1.1 Background:

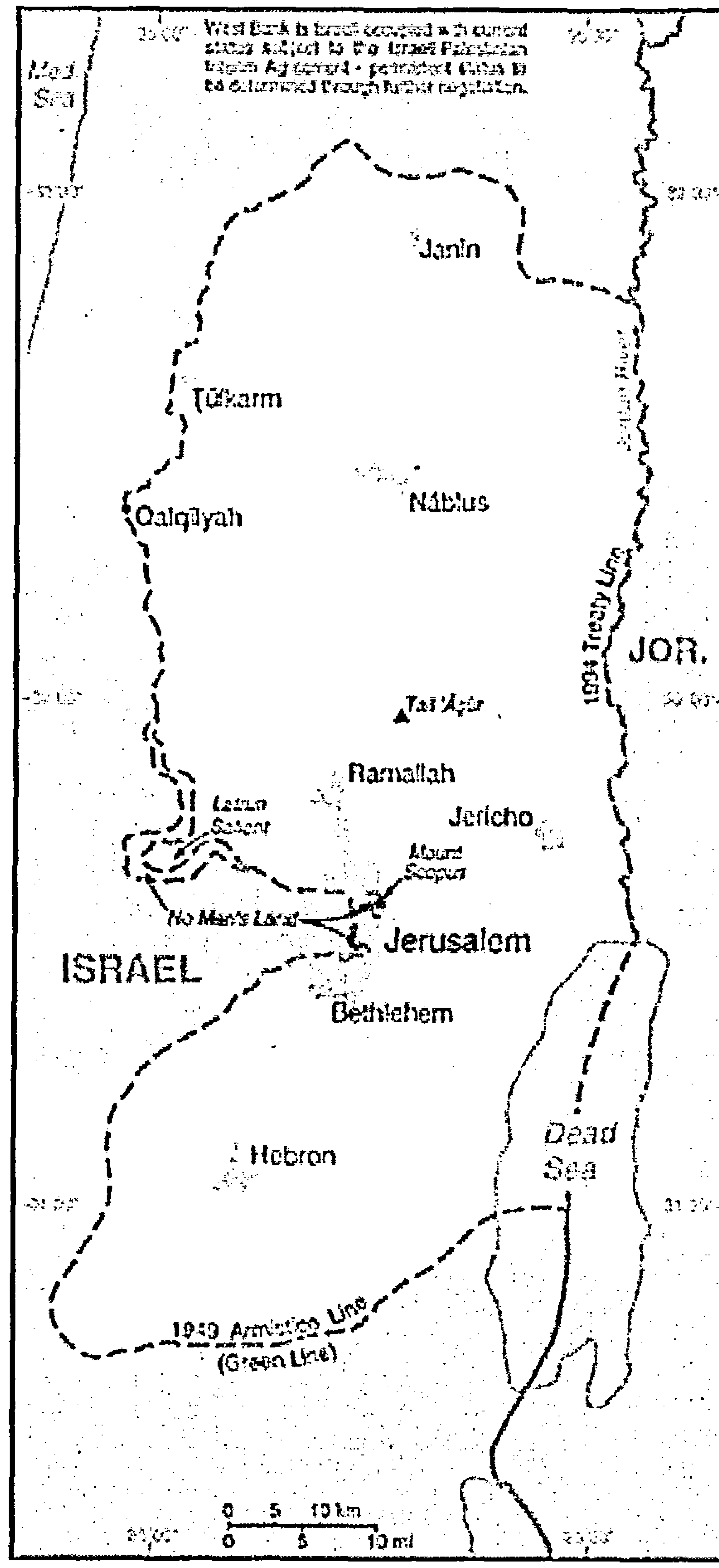
Located on the East coast of the Mediterranean Sea (figure 4.1), the West Bank (figure 4.2) spreads over an area of 5,600 km^2 and accounts for about two million inhabitants (Aliewi et al., 2005). The temperature and precipitation vary with altitude (highest point at 1,022 m), with warm to hot summers and mild to cool winters.

Figure 4.1: Map of the Mediterranean Sea



[3] The aim of the SUSMAQ project is to increase understanding of the sustainable yield of the West Bank and Gaza aquifers under a range of future economic, demographic and land use scenarios, and to evaluate alternative groundwater management options. The project is interdisciplinary, bringing together hydro-geologists and groundwater modellers with economists and policy experts. In this way, hydro-geological understanding can inform, and be informed by, insights from the social sciences. The results of the study will provide support to decision-making at all levels in relation to the sustainable yield of the West Bank and Gaza aquifers. The project runs from November 1999 to October 2004, and is a partnership between the Palestinian Water Authority, the University of Newcastle upon Tyne. The project is funded by the United Kingdom Government's Department for International Development (DFID).

Figure 4.2: Map of the West Bank

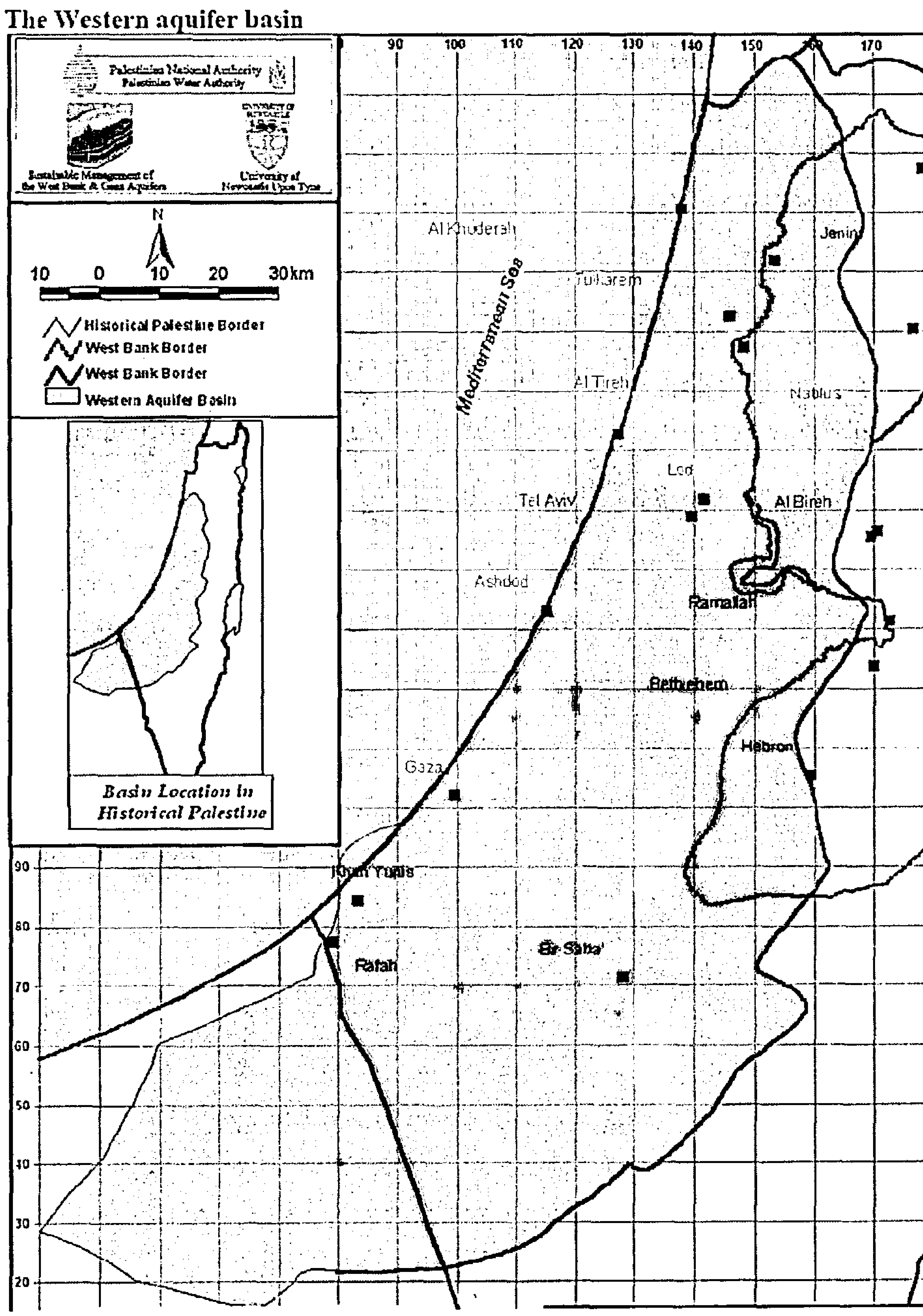


4.1.2 Sources of Water:

Groundwater is the primary source of water for the Palestinians in the West Bank and Gaza Strip. The groundwater resources of Palestine are extracted from wells and springs. The Israelis and Palestinians jointly use a number of aquifer basins, including the Western Aquifer Basin (other aquifer basins include: the Coastal Aquifer Basin, the North-Eastern Aquifer Basin and the Eastern Aquifer Basin).

The Western Aquifer Basin (WAB) (figure 4.3) is the largest of all groundwater basins in Historical Palestine. It includes the western part of the West Bank mountains and extends to the coastal areas of Historical Palestine, and from the North central mountains area to the Hebron mountain in the South. Two main aquifers are present in this basin: the upper and the lower aquifer. The average thickness of these aquifers ranges between 600-900 metres (Aliewi et al., 2005). Based on the findings of the SUSMAQ project, the average annual natural recharge for the WAB is around 400-440 MCM/yr, and the main recharge source are the mountains of the West Bank.

Figure 4.3: Map of the Western Aquifer Basin (WAB)



The Northern region, which the application section of this thesis is based on, comprises Nablus, Tulkarem and Jenin (516 km^2, around 900,000 inhabitants).

The surface water in Palestine is mainly from numerous seasonal wadis, as well as the Jordan River, which is currently controlled and used exclusively by the Israelis (SUSMAQ, 2005a).

4.1.3 Supply and Demand:

Palestine is among the countries with the scarcest renewable water resources per capita due to both natural and artificial constraints, amounting to only 100 cubic metres per capita per year. This amount is far below the per capita water resources available in other countries in the Middle East and the World (SUSMAQ, 2005a).

At present, water demand exceeds the available water supply. In the North West Bank for example, subject of this research, where the current population is about 900,000, the total demand currently amounts to ~ 146 MCM/yr (Aliewi et al., 2005), whereas the available supply does not exceed 68 MCM/yr, including efforts for demand reduction (SUSMAQ, 2005f).

The gap between water supply and water demand is growing due to population growth, higher standard of living, and the need to expand irrigated agriculture and industrialisation. Bridging the growing gap will be totally dependent on the development options and the action plans to be implemented, as discussed in section 4.3. In order to minimise both economic and environmental consequences, strategies for the future must involve significant improvement of demand management measures, utilisation of alternative lower quality sources, recycled water and wastewater re-use and intensive analysis of sector reallocation whenever this is practical.

The figure is even more misleading in relation to water quality since, particularly in Gaza but also in many parts of the West Bank, the water available to consumers is far below internationally acceptable potable standards (SUSMAQ, 2005a).

4.1.4 The Hydro-Political Challenge:

The issue of sustainable water resources development in Palestine is complex. This is because the development of additional water sources is restricted and based on the approval of the Israelis, since Palestinian water rights are still a subject to be determined and defined within the results of the Final Status Negotiations. In addition to the scarcity of water resources under the existing political constraints, the protection of the water resource environment is another constraint that makes it difficult to develop sustainable demand/supply scenarios for Palestine which has an unclear socio-economic future (SUSMAQ, 2003).

4.2 Existing Policy and Management Activities

4.2.1 Planning and Legislation:

An assessment of the overall water related sector shows that the policies, strategies and plans have progressed significantly in recent years including the creation of the National Water Plan of 2000; the Palestinian Development Plan, 1999-2003; the National Environmental Strategy, 2000-2010; and the National Environment Action Plan of 2000. Legislation has at the same time been developed and/or updated to keep pace with these new plans with the most significant for the sector being the new Water Law of 2002. Of critical significance the new law established that all water resources are public property and the Palestinian Water Authority (PWA) was given the full responsibility for managing water resources and wastewater but that these functions would be separated from service delivery which would be transferred to water authorities. Unfortunately implementation of these policies, strategies and plans have been severely curtailed by the impacts of the Intifida although both sector authorities and donor agencies have persevered in maintaining whatever progress was possible during the period (SUSMAQ, 2005a).

4.2.2 Institutional Setting:

Progress has also been achieved in the recent period with regard to institutional restructuring within the sector. The establishment of the National Water Council, ratified as part of the new Water Law, was an important step to broaden the accessibility of water sector planning to a wider group of stakeholders represented as members of the Council and raise the status and authority of the sector by appointment of the Chairman of the Palestinian Authority (later the Prime Minister) as the Chairman of the Council. In recent months (years), the PWA has also been restructured to report through the Ministry of Agriculture in order to provide a direct access to the Cabinet of Ministers (SUSMAQ, 2005a).

The structure of operation of the PWA is also under change in accordance with the new Water Law, with service delivery coming under three regional authorities in the West Bank and a separate one in Gaza. These regional authorities will coordinate their activities with the local government network and there is provision for the establishment of Joint Service Councils to ensure that the interests of smaller communities are effectively fed back through the system. A separate bulk authority is also planned which will take responsibility for the development, collection and transportation of bulk supplies to, from and between the various regional authorities. PWA will maintain the critical roles of strategic planning and coordination, policy and planning, integrated resource management, establishment of standards and regulations (SUSMAQ, 2005a).

4.2.3 Key Studies:

The most relevant studies, and which have been used by the SUSMAQ decision support tool described in section 4.3, are the National Water Plan, adopted as an official document by PWA; a study on Palestinian Water Demand carried out by PWA; a study on the Eastern and North-Eastern Aquifers and a resultant management tool developed by CH2MHill but not yet officially adopted, the West Bank Integrated Water Resources Management Plan and the West Bank Water Management Analysis Tool (CH2MHILL, 2002)[4]; and the Coastal Aquifer Management Plan, financed by

[4] The West Bank Water Management Analysis Tool (WBWMAT) was developed as part of the West Bank Integrated Water Resources Management Plan, developed by CH2MHILL in 2002, with a

USAID; in addition to the technical work and information available on the Western Aquifer from the SUSMAQ project. Other key information and statistics are available within Palestine from PWA, the Palestinian Central Bureau of Statistics, the Ministries of Planning and International Cooperation, Agriculture, Health, Industry, among others (SUSMAQ, 2005a).

4.3 SUSMAQ Decision Support Tool

4.3.1 DST in Brief:

The Decision Support Tool (DST) for the SUSMAQ Project was designed to help the PWA in the selection of the best Management Options according to socio-economic/hydro-political and climatic drivers at a regional or national scale. The DST was developed in Microsoft Excel and Visual Basic for Applications (SUSMAQ, 2005g). The structure of the DST is divided in three blocks. The first block is the Database Manager, the second block is the Model setting and finally the third block is the Multi-Criteria Analysis Tool (MCAT) (figure 4.4):

- The Database Manager allows the user to access five databases: Scenario, Region, Package (a database which describes the planned water sector investment projects), Management Options and Basic Indicators databases. In each of these databases, the user will be able to create, delete and modify items.
- The Model setting allows the user to create a model based on the data stored in the different databases. During this process the user will have to select a particular Scenario, a Region, set a list of relevant Management Options, Packages and Basic Indicators. The software will guide the user in this task.
- The MCAT allows the user to rank the Management Options. The MCAT is divided in three simple steps: calculate the Basic Indicator values, assign weights and rank the Management Options.

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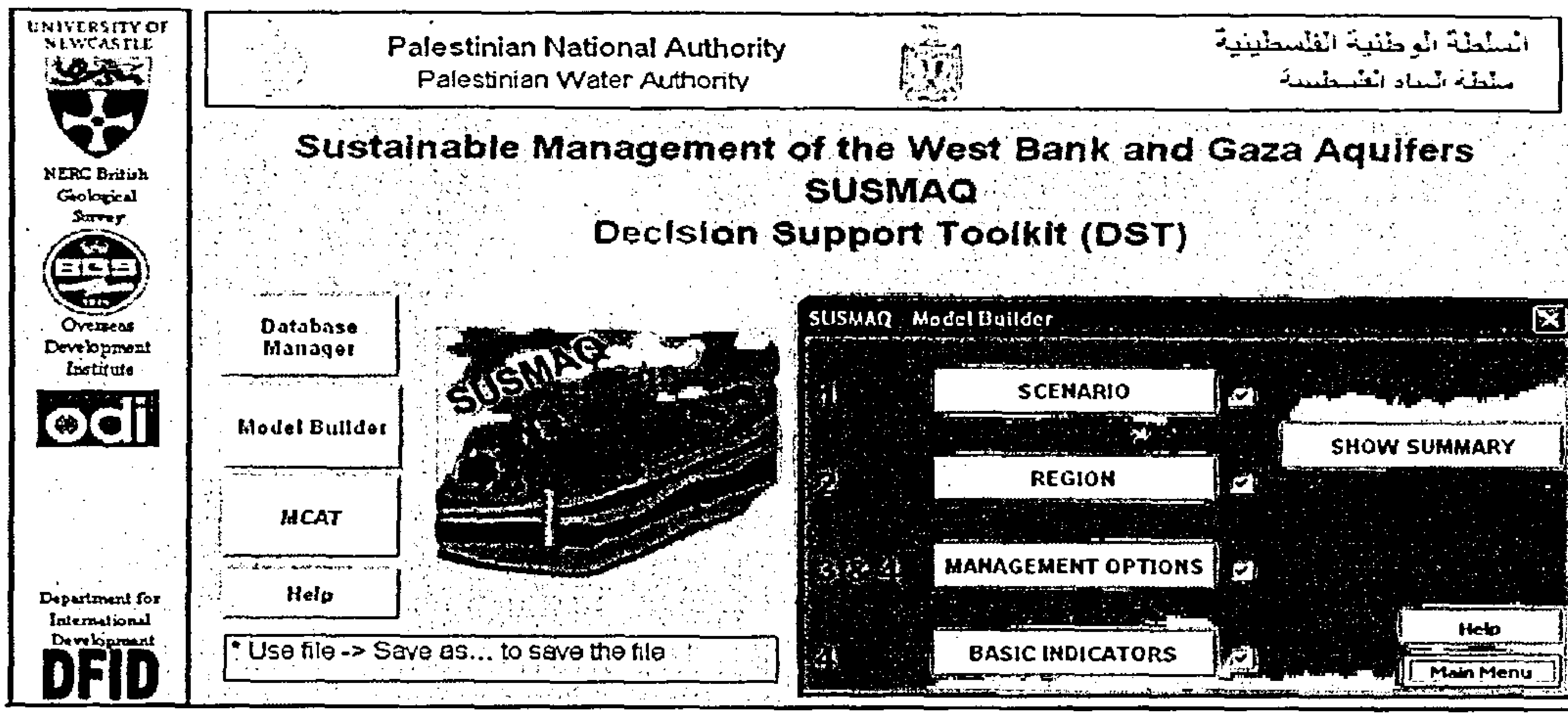
funding from the United States Agency for International Development. The purpose of WBWMAT is to provide a flexible, user-friendly analytical method to develop and evaluate options for water management in the West Bank. The WBWMAT has been designed as a screening tool for the user to compare the impact of different management options on projected water supply and demand. Generic economic analysis is also performed to permit cost-based comparisons between options. The user provides input on the types of actions planned, either to decrease demand, or increase supply. The WBWMAT compares this input to reasonable engineering limits of resources extractions, graphically presents the resulting supply and demand projection, and calculates the total cost of option implementation based on a library of unit costs.

Figure 4.4: SUSMAQ DST Software



4.3.2 *MCAT in Brief:*

The MCAT is based on two complementary frameworks:

- The Pressure-State-Response framework (PSR)
- The Composite Programming technique

4.3.2.1 The Pressure-State-Response Framework:

The PSR framework is based on the use of indicators which can measure the economic, social and environmental performance of a country, sector or system in terms of sustainability. In the PSR context, three categories of indicators can be identified: <u>Pressure Indicators</u>, which focus on changes in the main drivers which create pressure on water resources; <u>State Indicators</u>, which focus on describing the state of the system in economic, environmental and social terms; and <u>Response Indicators</u>, which measure the actions taken to improve the state of the system, and the resulting impacts (SUSMAQ, 2005f).

In the SUSMAQ project, the <u>pressures</u> on Palestinian water resources are described in terms of socio-economic/hydro-political and climatic <u>scenarios</u> (current, consolidating and future). Socio-economic pressures relate to the development from subsistence and internal economic markets towards a more industrial and service based economy based on international trading. Hydro-political pressures concern international water allocations and political constraints such as access and control over water infrastructure, and the influence of the separation wall. Climatic pressures relate mainly to the effect of future climatic variability including climate change on groundwater recharge. The state of the system is described by social, environmental and economic indicators. These can include the impacts on livelihoods in terms of water usage and expenditure on water, on aquifer water levels and quality, and investment efficiencies and costs. The responses (Management Options) can then be assessed using these indicators to achieve sustainable abstraction regimes. The Management Options can include structural measures such as wells, water transfers, desalination, while non-structural measures include virtual water, regulation (environmental and economic), etc.

4.3.2.2 The Composite Programming Technique:

The United Nations Educational, Scientific and Cultural Organisation has carried out an extensive study in which an MCA technique (Composite Programming) was applied to the integrated environmental evaluation of water resources development projects (SUSMAQ, 2005f). This approach has been developed further for the SUSMAQ project. In this approach, the indicators, termed Basic Indicators (BI), are defined and evaluated to measure the impacts of each of a set of Management Options (MO).

MO and BI are quantified based on detailed analyses which were made of the groundwater systems in the Palestinian West Bank, focusing on the Western Aquifer Basin and the Eocene aquifer of the North-East Aquifer basin, and of the environmental influences affecting sustainable management of these aquifers. This work was built around numerical groundwater flow and transport models of the aquifers, which were based on field, data analysis and modelling studies of geology, hydro-stratigraphy, pollution sources and groundwater quality, and of the rainfall distributions under current and future climates, and how these affect groundwater recharge. The social and economic aspects of water management were studied through a series of institutional analyses, household surveys, village level case studies and local stakeholder workshops (SUSMAQ, 2005f).

The indicator values are calculated in different units, and converted to a set of normalised values (on a range of zero to one) based on the ideal and worst values of each indicator. This allows inter-comparison between different types of measurement of impacts (for example, comparison between economic returns and groundwater quality). The ideal and worst values can be defined either in relation to just the scenario being assessed, or across a range of scenarios. The BI's are then combined mathematically, through an additive weighting approach, into 2nd and 3rd level indicators. The implications of this approach, namely potential eclipsing as discussed in chapter 2, are overcome as much as possible by the use of numerical weights which reflect stakeholder preferences as part of the balancing of conflicting objectives[5]. The purpose of this structure is to provide a systematic way to represent and evaluate the trade-offs between different conflicting objectives.

4.3.3 SUSMAQ Scenarios, Management Options and Basic Indicators

SUSMAQ scenarios are the quantified descriptions of alternative possible futures for the West Bank and Gaza. They represent different stages in the development of Palestine, and its relationship with socio-economic development priorities (from survival to security to development and diversification) (SUSMAQ, 2005f). Identification of possible futures and related constraints and conditions was carried out following a participatory approach with the various stakeholders. This resulted in the following three scenarios, with no specific time scale assigned to them:

- Current: the existing socio-economic environment;
- Consolidating: transition between the current and the future scenarios; and
- Future: the scenario which would pertain in the long-term once all artificial and political constraints were lifted.

The prevailing macro socio-economic environment was set for each scenario, along with the constraints/ assumed conditions and objectives. Scenario details are presented in Annex A.

[5] The detailed sensitivity analysis of MO ranking to BIW (sections 5.1.3) is also critical at limiting the implications of potential eclipsing.

SUSMAQ management options (MO) are the generic potential water management solutions under each of the scenarios, identified based on brainstorming sessions followed by consolidation of results leading to a total of 14 management options:

- Groundwater supply development (including associated infrastructure)
- Rainwater harvesting
- Tanker supply
- Direct connection to Mekerot (the Israeli State Water Supply Company)
- Desalination (including associated infrastructure)
- Demand management
- Environmental protection/ conservation
- Wastewater reuse
- Sectoral reallocation
- Changes to agricultural policy
- Water transfer
- Administrative and institutional structures
- Surface water development
- Importation

Ceiling values for each MO were evaluated; they represent the maximum resources available under the scenario limitations. Ceiling values applicable to each of the MOs, regions and scenarios were based on the scenario constraints as defined by Palestinian National Authority (PNA) and Palestinian Water Authority (PWA) policies and the availability of water resources.The evaluation of ceiling values was carried out using the Palestinian National Water Plan (NWP) database developed by the PWA, which contains information on planned water sector projects, incorporating SUSMAQ Project statistics as necessary. The ceiling values were determined in close cooperation with relevant PWA staff taking into account SUSMAQ project modelling outputs (SUSMAQ, 2005f). The allocation of ceiling values of water availability are summarised in Annex B.

SUSMAQ indicators are identified to measure the state of water resources in the West Bank and Gaza, in economic, environmental and social terms in response to the Management Options (SUSMAQ, 2005f). The primary purpose is to allow objective comparison between the different MO. SUSMAQ indicators are further detailed below:

- Economic indicators: a total of 5 divided into two groups: investment efficiency (internal rate of return, agricultural water production cost, public network production cost) and social versus productive benefit (public network production cost per beneficiary, industrial/ agricultural water productivity).
- Environmental indicators: a total of 7 indicators divided into three groups: aquifer state-quantity (aquifer water level, reliability of supply from aquifer, yield of major aquifer springs), aquifer state-quality (aquifer water quality), and pollutant pressures (wastewater discharge, agricultural pesticide use, industrial effluent).
- Socio-economic indicators: a total of 7 divided into two groups: household water (water connection, water quality, water usage), household livelihoods (agricultural jobs creation, industrial jobs creation, source yield and livelihoods, expenditure on water).

The relative effect of the MOs on BI values varies according to the extent to which they impact on the social, environmental or economic situation. In the sustainability assessment methodology, the BIs are designed such that they measure the impact of a range of MOs, and thereby provide a means for comparison of their relative impacts. However, in some cases there are no direct mechanisms (linkages) for a particular MO to affect some of the BI values (this is irrespective of whether or not appropriate data are available). Annex C shows which of the indicators do not directly measure the impacts of each MO. For those BIs which do not measure the impact of an MO, the DST automatically assigns a normalised indicator value of 0.5 (i.e a default value that is neutral, and does not bias the final result either positively or negatively).

The evaluation of indicators is based on existing studies (section 4.2.3) as well as SUSMAQ various reports, including detailed spatial databases on hydrogeology, groundwater pollution, and from socio-economic surveys. The central source of information is the SUSMAQ Package Database (section 4.3.1). The calculation of SUSMAQ basic indicators (BI) requires not only that sufficient numbers of packages are available to represent the full estimated total of the MO for each scenario, but also that the relevant information to calculate the BI value is included in the package database (SUSMAQ, 2005f). Data needed for the calculation of the BI is presented in Annex D. The case studies presented in the following sections and analysed in chapter 5 (North West Bank – Current Scenario and Future Scenario) have considered only the management options for which there are sufficient data on which to base an assessment.

4.3.4 SUSMAQ DST Results for the SUSMAQ North West Bank – Current Scenario

SUSMAQ DST application to the North West Bank – current scenario evaluates 5 alternatives (Management Options = MO) against 18 weighted criteria (Basic Indicators = BI), as presented in table 4.1.

Table 4.1: SUSMAQ DST NWB/CS -Management Options (MO), Basic Indicators (BI) &Weights (W)

Basic Indicators (BI)	Groundwater Supply Development (MO1=GW)	Rainwater Harvesting (MO2=RW)	Direct Connection to Mekerot (MO3-ME)	Demand Management (MO4=DM)	Waste Water Reuse (DM5=RE)	W	2nd Level Indicators	W	3rd Level Indicators	W
Internal Rate of Return (EC1) (%)						0.33	Investment Efficiency	0.5	Economic	0.25
Agricultural Water Production Cost (EC2) ($/m3)						0.33				
Public Network Production Cost (EC3)($/m3)						0.34				
Public Network Production Cost per Beneficiary (EC4)($/person)						0.5	Social vs. Productive Benefit	0.5		
Industrial/ Agricultural Water Productivity (EC5) (MCM)						0.5				
Aquifer Water Level (EN1) (m)						0.5	Aquifer State - Quantity	0.33	Enviro-nmental	0.25
Reliability of Supply from Aquifer (EN2) (-)						0.5				
Aquifer Water Quality (EN3) (mg/l)						1	Aquifer State - Quality	0.34		
Wastewater Discharge (EN4) (ton/annum)						0.33	Pollutant Pressures	0.33		
Agricultural Pesticide Use (EN5) (ton/annum)						0.33				
Industrial Effluent (EN6) (ton/annum)						0.34				
Water Connection (SO1) (-)						0.33	Household Water	0.5	Social	0.5
Water Quality (SO2) (-)						0.33				
Water Usage (SO3) (-)						0.33				
Agricultural Jobs Creation (SO4) (-)						0.25	Household Livelihoods	0.5		
Industrial Jobs Creation (SO5) (-)						0.25				
Source Yield and Livelihoods (SO6) (-)						0.25				
Expenditure on Water (SO7) (-)						0.25				

The five MO are:

- Groundwater supply development: development of new wells and springs, rehabilitation, optimisation of management of aquifers and springs, artificial recharge, etc.
- Rainwater harvesting: urban storm water collection and storage and household level schemes with cisterns

- Direct connection to Mekerot: in accordance with the prevailing agreements and national policy
- Demand management: network rehabilitation, metering, pressure control, tariffs and irrigation efficiency
- Wastewater reuse: the further treatment and utilisation of wastewater from both large and small scale systems and recycling in industry

Detailed results are presented in the tables below (SUSMAQ, 2005f):

- Table 4.2: first level indicators
- Table 4.3: first level indicators (normalised from zero to one)
- Table 4.4: second level indicators
- Table 4.5: third level indicators

Table 4.2: SUSMAQ DST NWB/CS – First Level Indicators

	Best	Worst	Groundwater Supply Development (including associated infrastructure)	Rainwater Harvesting	Direct Connection to MEKEROT	Demand Management	Reuse
Internal rate of return IRR (%)	28.80	-9.40	11.60	-9.40	4.70	18.70	10.20
Agricultural water production cost ($/m3)	0.00	4.00	1.50	1.50	1.50	1.50	3.00
Public network production cost ($/m3)	1.60	84.90	8.30	1.60	5.00	7.70	5.00
Public network production cost per beneficiary ($/person)	0.00	32,519.10	774.60	47.90	404.90	35.20	404.90
Industrial/agricultural water productivity (MCM)	105.10	-631.30	26.10	0.00	-302.60	12.80	-631.30
Aquifer water level (m)	3.80	27.70	5.00	3.80	3.80	3.80	3.80
Reliability of supply from aquifer (-)	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Aquifer water quality (mg/l)	43.00	327.00	89.00	67.00	68.00	67.00	65.00
Wastewater discharge (ton/annum)	7,560.00	12,500.00	9,250.00	8,620.00	8,670.00	8,635.00	8,550.00
Agricultural pesticide use (ton/annum)	107.00	562.00	244.00	215.00	217.00	216.00	215.00
Industrial effluent (ton/annum)	40.90	110.00	50.60	45.10	45.40	45.40	45.10
Water connection (-)	4.00	2.00	2.70	2.00	2.30	2.30	2.00
Water quality (-)	3.30	2.30	3.00	2.30	2.70	2.70	3.00
Water usage (-)	3.30	2.66	3.30	3.00	3.30	3.30	3.00
Agricultural jobs creation (-)	3.70	0.00	1.00	1.00	1.00	1.00	1.00
Industrial jobs creation (-)	4.00	2.66	3.00	2.70	3.00	3.00	3.30
Source yield and livelihoods (-)	3.30	1.66	3.00	3.00	2.70	2.70	3.30
Expenditure on water (-)	1.70	3.00	3.00	2.70	2.30	2.30	2.30

Note: data to be considered as draft estimates only "the BI need to be recalculated using comprehensive and verified data" (SUSMAQ, 2005f)

Table 4.3: SUSMAQ DST NWB/CS – First Level Indicators (Normalised)

	Groundwater Supply Development (including associated infrastructure)	Rainwater Harvesting	Direct Connection to MEKEROT	Demand Management	Reuse
Internal rate of return IRR	0.55	0.00	0.37	0.74	0.51
Agricultural water production cost	0.63	0.63	0.63	0.63	0.25
Public network production cost	0.92	1.00	0.96	0.93	0.96
Public network production cost per beneficiary	0.98	1.00	0.99	1.00	0.99
Industrial/agricultural water productivity	0.89	0.86	0.45	0.87	0.00
Aquifer water level	0.95	1.00	1.00	1.00	1.00
Reliability of supply from aquifer	1.00	1.00	1.00	1.00	1.00
Aquifer water quality	0.84	0.92	0.91	0.92	0.92
Wastewater discharge	0.66	0.79	0.78	0.78	0.80
Agricultural pesticide use	0.70	0.76	0.76	0.76	0.76
Industrial effluent	0.86	0.94	0.93	0.93	0.94
Water connection	0.35	0.00	0.15	0.15	0.00
Water quality	0.70	0.00	0.40	0.40	0.70
Water usage	1.00	0.53	1.00	1.00	0.53
Agricultural jobs creation	0.27	0.27	0.27	0.27	0.27
Industrial jobs creation	0.25	0.03	0.25	0.25	0.48
Source yield and livelihoods	0.82	0.82	0.63	0.63	1.00
Expenditure on water	0.00	0.23	0.54	0.54	0.54

Table 4.4: SUSMAQ DST NWB/CS – Second Level Indicators

	Groundwater Supply Development (including associated infrastructure)	Rainwater Harvesting	Direct Connection to MEKEROT	Demand Management	Reuse
Investment efficiency	0.70	0.55	0.65	0.76	0.58
Social vs productive benfit	0.93	0.93	0.72	0.94	0.49
Aquifer state - quantity	0.97	1.00	1.00	1.00	1.00
Aquifer state - quality	0.84	0.92	0.91	0.92	0.92
Pollutant pressures	0.74	0.83	0.82	0.83	0.83
Household water	0.68	0.18	0.51	0.51	0.41
Household livelihoods	0.34	0.34	0.42	0.42	0.57

Table 4.5: SUSMAQ DST NWB/CS – Third Level Indicators

	Groundwater Supply Development (including associated infrastructure)	Rainwater Harvesting	Direct connection to MEKEROT	Demand Management	Reuse
Economic	0.82	0.74	0.69	0.85	0.54
Environmental	0.85	0.92	0.91	0.91	0.92
Social	0.51	0.26	0.47	0.47	0.49
Overall	0.67	0.54	0.63	0.68	0.61

4.3.5 SUSMAQ DST Results for the SUSMAQ North West Bank – Future Scenario

SUSMAQ DST application to the North West Bank – future scenario (NWB/FS) evaluates the same 5 alternatives (Management Options = MO) against the same 18 weighted criteria (Basic Indicators = BI), as presented in tables 4.6, 4.7, 4.8 and 4.9.

Table 4.6: SUSMAQ DST NWB/FS – First Level Indicators

	Best	Worst	Groundwater Supply Development (including associated infrastructure)	Rainwater Harvesting	Direct Connection to MEKEROT	Demand Management	Reuse
Internal rate of return IRR (%)	28.80	-9.40	28.20	-9.40	9.70	28.80	9.40
Agricultural water production cost ($/m3)	0.00	4.00	2.00	2.00	2.00	2.00	4.00
Public network production cost ($/m3)	1.60	84.90	4.10	1.80	2.60	5.20	2.60
Public network production cost per beneficiary ($/person)	0.00	32,519.10	32,519.10	57.30	16,259.60	37.80	16,259.60
Industrial/agricultural water productivity (MCM)	105.10	-631.30	93.40	0.00	-186.40	26.50	-466.20
Aquifer water level (m)	3.80	27.70	27.70	8.80	8.80	8.80	8.80
Reliability of supply from aquifer (-)	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Aquifer water quality (mg/l)	43.00	327.00	327.00	75.00	47.00	80.00	43.00
Wastewater discharge (ton/annum)	7,560.00	12,500.00	12,500.00	8,735.00	8,320.00	8,800.00	7,560.00
Agricultural pesticide use (ton/annum)	107.00	562.00	562.00	226.00	189.00	232.00	245.00
Industrial effluent (ton/annum)	40.90	110.00	110.00	46.50	42.00	49.50	48.80
Water connection (-)	4.00	2.00	4.00	3.00	3.70	3.70	3.70
Water quality (-)	3.30	2.30	3.30	2.70	3.00	2.70	3.00
Water usage (-)	3.30	2.66	3.30	3.30	3.00	3.30	3.30
Agricultural jobs creation (-)	3.70	0.00	3.00	3.00	3.00	3.00	3.00
Industrial jobs creation (-)	4.00	2.66	4.00	3.00	3.70	3.00	4.00
Source yield and livelihoods (-)	3.30	1.66	2.30	1.70	2.00	2.00	2.30
Expenditure on water (-)	1.70	3.00	2.00	1.70	2.00	2.30	2.30

Note: data to be considered as draft estimates only "the BI need to be recalculated using comprehensive and verified data" (SUSMAQ, 2005f)

Table 4.7: SUSMAQ DST NWB/FS – First Level Indicators (Normalised)

	Groundwater Supply Development (including associated infrastructure)	Rainwater Harvesting	Direct Connection to MEKEROT	Demand Management	Reuse
Internal rate of return IRR	0.98	0.00	0.50	1.00	0.49
Agricultural water production cost	0.50	0.50	0.50	0.50	0.00
Public network production cost	0.97	1.00	0.99	0.96	0.99
Public network production cost per beneficiary	0.00	1.00	0.50	1.00	0.50
Industrial/agricultural water productivity	0.98	0.86	0.60	0.89	0.22
Aquifer water level	0.00	0.79	0.79	0.79	0.79
Reliability of supply from aquifer	1.00	1.00	1.00	1.00	1.00
Aquifer water quality	0.00	0.89	0.99	0.87	1.00
Wastewater discharge	0.00	0.76	0.85	0.75	1.00
Agricultural pesticide use	0.00	0.74	0.82	0.73	0.70
Industrial effluent	0.00	0.92	0.98	0.88	0.89
Water connection	1.00	0.50	0.85	0.85	0.85
Water quality	1.00	0.40	0.70	0.40	0.70
Water usage	1.00	1.00	0.53	1.00	1.00
Agricultural jobs creation	0.81	0.81	0.81	0.81	0.81
Industrial jobs creation	1.00	0.25	0.78	0.25	1.00
Source yield and livelihoods	0.39	0.02	0.21	0.21	0.39
Expenditure on water	0.77	1.00	0.77	0.54	0.54

Table 4.8: SUSMAQ DST NWB/FS – Second Level Indicators

	Groundwater Supply Development (including associated infrastructure)	Rainwater Harvesting	Direct Connection to MEKEROT	Demand Management	Reuse
Investment efficiency	0.82	0.50	0.67	0.82	0.50
Social vs productive benfit	0.49	0.93	0.55	0.95	0.36
Aquifer state - quantity	0.50	0.90	0.90	0.90	0.90
Aquifer state - quality	0.00	0.89	0.99	0.87	1.00
Pollutant pressures	0.00	0.81	0.88	0.78	0.86
Household water	0.99	0.63	0.69	0.74	0.84
Household livelihoods	0.74	0.52	0.64	0.45	0.68

Table 4.9: SUSMAQ DST NWB/FS – Third Level Indicators

	Groundwater Supply Development (including associated infrastructure)	Rainwater Harvesting	Direct connection to MEKEROT	Demand Management	Reuse
Economic	0.66	0.72	0.61	0.88	0.43
Environmental	0.17	0.86	0.92	0.85	0.92
Social	0.87	0.57	0.66	0.60	0.76
Overall	0.64	0.68	0.71	0.73	0.72

4.4 Limitations of Application

As discussed in section 3.3, application of the conceptual framework outlined in chapter 3 faces some limitations, mainly related to lack of data. As mentioned in the various SUSMAQ reports, although demonstration case studies are based on the best available information, some databases were incomplete, particularly relating to the proposed water development projects under the direction of the Palestinian Water Authority. Examples of secondary data include data used for implementing steps 1 and 2 of the intra-model validity framework (level of comprehensiveness of MO and BI, level of confidence in assigning BI performance values and degree of consensus in eliciting BI weights).

Data limitation restricted the detailed application of the conceptual framework to the North West Bank, SUSMAQ current scenario only, with partial application to the North West Bank, SUSMAQ future scenario. Extension of the application to other regions, and/or other scenarios can help enriching results discussion and analysis, and therefore refine both the methodology and the results – and related conclusions and recommendations.

5 RESULTS

Results of the application of the conceptual framework for assessing the validity of decision support systems (DSS) intra and inter-model to the SUSMAQ – North West Bank/. current scenario (NWB/CS) are presented in sections 5.1 and 5.2 of this chapter. As mentioned in chapter 4, this application evaluates 5 management options (MO) against 18 weighted basic indicators (BI). While section 5.1 discusses the intra-model validity, inter-model validity is discussed in section 5.2. Section 5.3 investigates application to the North West Bank/ future scenario (NWB/FS) (intra-model validity). Section 5.4 concludes with a summary of the various strategies.

5.1 SUSMAQ – DST NWB/CS: Validity Intra-Model

The various steps of the conceptual framework for assessing intra-model validity are discussed in this section: the level of comprehensiveness of MO and BI in section 5.1.1, the uncertainty associated with BI performance values and weights in section 5.1.2, the sensitivity of MO ranking to BI performance values and weights in section 5.1.3 and strategies development and evaluation in section 5.1.4.

5.1.1 Level of Comprehensiveness of Management Options and Basic Indicators:

The 3-step methodology which has been adopted for identifying SUSMAQ MO (SUSMAQ, 2005f), as outlined below, demonstrates a relatively high level of comprehensiveness in the list of management options:

- Generation of a wide and diverse range of options - often duplicated or overlapping- (implementation, strategic, policy, institutional development, etc.), based on open brainstorming during the course of several workshops in Cyprus and the West Bank which grouped various stakeholders;
- Consolidation of the initial list by excluding duplicates/overlaps, assessing according to stakeholders' priorities, grouping into six different types of MO (policy and regulation, institutional development, supply expansion and water transfer, demand management, environmental protection and conservation, and sectoral reallocation), and separation of these MO into three scenarios;

- Further analysis of the consolidated lists into lists which are both appropriate to the constraints, conditions and objectives of the three scenarios, and measurable.

Based on the methodology and criteria adopted for identifying SUSMAQ BI (SUSMAQ, 2005f), as outlined below, it can be concluded that the list of BI is exhaustive:

- Literature review that covered BI definition, purpose, aggregation, criteria for selection, data sheets, etc.;
- Generation of initial lists of BI based on a participatory approach that grouped various stakeholders in the course of workshops in Cyprus and Ramallah;
- Consolidation of initial lists based on the following criteria: that the BI be directly related to water, can be evaluated using existing SUSMAQ data and is calculable using methods/models available in the SUSMAQ project. The final number of indicators selected was then based on a judgment about the balance between the need for a comprehensive set of indicators, the perceived complexity of the system for decision makers, and the practical consideration of the time and resources needed to carry out quantified assessments.

5.1.2 Uncertainty Analysis Related to the Performance Values and Weights Assigned to Basic Indicators

5.1.2.1 Level of Confidence in the Performance Values Assigned to Basic Indicators:

As mentioned in chapter 3, the level of confidence in assigning basic indicators' performance values is assessed based on a matrix of criteria which include the methodology used, its application (model and data), the assumptions made, along with the details of calculation of the best and worst value, which in many cases influence the calculation of the performance value of the indicator under consideration. Each criterion is given a score ranging from low to high, based on data availability, quality, etc., as detailed in the footnotes of tables 5.1, 5.2 and 5.3. with the same type of scoring attributed to the estimated level of confidence. Results, generated based on information presented in SUSMAQ reports (SUSMAQ, 2005b, c, d, e), are presented in tables 5.1, 5.2, 5.3 for the economic, environmental and socio-economic basic indicators respectively.

While the level of confidence is demonstrated to be high or medium to high for all economic indicators, the level of confidence is high for some of the environmental indicators (aquifer state quantity) and medium for the remaining environmental indicators (aquifer water quality and pollutant pressures). Most of the socio-economic indicators are assigned a performance value with a medium to high level of confidence, while two of them (Source Yield and Livelihoods; Expenditure on Water) with a medium level of confidence.

5.1.2.2 Degree of Consensus on the Weights Elicited for Basic Indicators:

Elicitation of stakeholders' preferences for objectives, which are later translated into weights associated with the various indicators and groups of indicators, was undertaken only for the current scenario for the North West Bank in a participatory workshop (SUSMAQ, 2005f). Time constraints made it difficult to generate similar weights (participatory weightings) for the remaining scenarios and regions, which led to the use of default weightings (i.e. equal weightings for each BI within a group at each level[6]). Table 5.4 presents the participatory and the default weightings for the various indicators and groups of indicators.

For the purpose of this case study, given the absence of data related to consensus on the weights elicited for basic indicators, the following is assumed as an illustrative example :

- the level of consensus on the weights generated from stakeholder consultation (participatory weighting) is high;
- whenever the default weighting is equal, plus or minus 20%, to the participatory weighting, then the degree of consensus on this weight is high; otherwise, the degree of consensus is low.

Based on the above, the degree of consensus appears to be high for three indicators only: the Agricultural Water Production Cost (EC2), the Reliability of Supply from Aquifer (EN2) and the Aquifer Water Quality (EN3).

[6] With the exception of the third level, where more weight was attributed to the social third-level indicator (50%)

Table 5.1: Confidence Level in Assessing the Performance Values of the Economic Basic Indicators

	Methodology(1)	Application		Assumptions(4)	BEST (5)	WORST (6)	Remarks(7)	Estimated Confidence Level(8)
		Model(2)	Data(3)					
EC1 – Internal Rate of Return	Very High	-	High		Medium (not properly defined)			High
EC2 – Agricultural Production Cost	Very High	-	High		Medium (not properly defined)			High
EC3 – Public Network Production Cost	Very High	-	Medium		Medium (not properly defined)			Medium to High
EC4 – Public Network Production Cost per Beneficiary	Very High	-	Medium		Medium (not properly defined)			Medium to High
EC5 – Industrial/ Agricultural Water Productivity	Very High	-	Medium	Constant representing the differential productivity of water in industry compared to agriculture per cubic metre set to 40	Medium (not properly defined)			Medium to High

(1) **Methodology:** assessment takes into account the presence of a well defined/structured methodology
(2) **Model:** assessment takes into account the type of model as well as its accuracy
(3) **Data:** assessment takes into account the reliability of the source, the spatial dimension (regional or local), the time dimension (recent or old), etc.
Based on tables 2.1 and 3.1 of SUSMAQ – SUS#52V1.1 (SUSMAQ, 2005c): <35% (low); 35%-70% (medium); 70%-90% (high); >90% (very high)
(4) **Assumptions:** are the assumptions, if any, conservative?
(5) **Best:** assessment takes into account if the best value is properly defined
(6) **Worst:** assessment takes into account if the worst value is properly defined
(7) **Remarks:** are there any other remarks which would affect the assessment?
(8) **Estimated Confidence Level:** is defined as follows (the result of the assessment can range from Very High to High to Medium to Low)
Average of (Methodology assessment, Model assessment, Data assessment, Best/Worst value assessment) taking into account assumptions made

Table 5.2: Confidence Level in Assessing the Performance Values of the Environmental Basic Indicators

	Metho-dology[(1)]	Application		Assumptions[(4)]	BEST [(5)]	WORST [(6)]	Remarks[(7)]	Estimated Confidence Level[(8)]
		Model[(2)]	Data[(3)]					
EN1 – Aquifer water level	V. High	High (steady state, transient, rainfall)	Medium (SUSMAQ database based on PNWPP – some data at governorate level)	Conservative: - additional abstraction from Western Aquifer only - low emission rainfall scenario	High (steady state model, saturation thickness)			High
EN2 – Reliability of supply from aquifer	V. High				High			High
Yield of major aquifer springs	V. High	High (EN1)	Medium (EN1 + spring discharge database)	Conservative	High			High
EN3 – Aquifer water quality	V. High	High (pollution model)	Low: - few available published surveys - data at regional scale - EN3: load distributed across model - EN6: lack of comprehensive and accurate data	Not conservative (no hydro chemical processes considered)	Medium (not properly defined)		Hypothetical boreholes -Chloride proxy	Medium
EN4 – Wastewater discharge	V. High	-		Conservative (600 mg/l BOD)	Medium (not properly defined)			Medium
EN5 – Agricultural pesticide use	V. High	-		Conservative (pesticide usage same rate; only intensive agriculture considered)	Medium (not properly defined)			Medium
EN6 – Industrial effluent	V. High	-		Not conservative (rely on heavy metals; solid waste sites not included)	Medium (not properly defined)			Medium

(1) **Methodology:** assessment takes into account the presence of a well defined/structured methodology
(2) **Model:** assessment takes into account the type of model as well as its accuracy
(3) **Data:** assessment takes into account the reliability of the source, the spatial dimension (regional or local), the time dimension (recent or old), etc.
(4) **Assumptions:** are the assumptions, if any, conservative?
(5) **Best:** assessment takes into account if the best value is properly defined
(6) **Worst:** assessment takes into account if the worst value is properly defined
(7) **Remarks:** are there any other remarks which would affect the assessment?
(8) **Estimated Confidence Level:** is defined as follows (the result of the assessment can range from Very High to High to Medium to Low)
Average of (Methodology assessment, Model assessment, Data assessment, Best/Worst value assessment) taking into account assumptions made

Table 5.3: Confidence Level in Assessing the Performance Values of the Socio-Economic Basic Indicators

	Methodology[1]	Application		Assumptions[4]	BEST[5]	WORST[6]	Remarks[7]	Estimated Confidence Level[8]
		Model[2]	Data[3]					
S01 – Water connections	High (quantitative approach + qualitative approach)	-	Medium: some data missing for quantitative analysis		Medium (not properly defined)			Medium - High
S02 – Water quality		-			Medium (not properly defined)			
S03 – Water usage		-			Medium (not properly defined)			
S04 – Agricultural jobs		-			Medium (not properly defined)			
S05 – Jobs in industry		-			Medium (not properly defined)			
S06 - Small source yield	Medium (qualitative approach)	-			Medium (not properly defined)			Medium
S07 - Expenditure on water as percentage of total household expenditure		-			Medium (not properly defined)			

(1) **Methodology:** assessment takes into account the presence of a well defined/structured methodology
(2) **Model:** assessment takes into account the type of model as well as its accuracy
(3) **Data:** assessment takes into account the reliability of the source, the spatial dimension (regional or local), the time dimension (recent or old), etc.
(4) **Assumptions:** are the assumptions, if any, conservative?
(5) **Best:** assessment takes into account if the best value is properly defined
(6) **Worst:** assessment takes into account if the worst value is properly defined
(7) **Remarks:** are there any other remarks which would affect the assessment?
(8) **Estimated Confidence Level:** is defined as follows (the result of the assessment can range from Very High to High to Medium to Low)
Average of (Methodology assessment, Model assessment, Data assessment, Best/Worst value assessment) taking into account assumptions made

Table 5.4: Degree of Consensus on the Weights Elicited for Basic Indicators

Basic Indicators	Default CW	Participatory CW	1st Level Aggregation	Default CW	Participatory CW	2nd Level Aggregation	CW[1]	Participatory CW	Overall Default W	Overall Participatory CW	Relative Difference (%)	Degree of Consensus
Internal Rate of Return	0.33	0.05	Investment Efficiency	0.5	0.5	Economic	0.25	0.3	0.041250	0.007500	450	low
Agricultural Water Production Cost	0.33	0.25							0.041250	0.037500	10	high
Public Network Production Cost	0.34	0.7							0.042500	0.105000	60	low
Public Network Production Cost per Beneficiary	0.5	0.8	Social vs. Productive Benefit	0.5	0.5				0.062500	0.120000	48	low
Industrial/ Agricultural Water Productivity	0.5	0.2							0.062500	0.030000	108	low
Aquifer Water Level	0.5	0.7	Aquifer State - Quantity	0.33	0.4	Enviro-nmental	0.25	0.3	0.041250	0.084000	51	low
Reliability of Supply from Aquifer	0.5	0.3							0.041250	0.036000	15	high
Aquifer Water Quality	1	1	Aquifer State-Quality	0.34	0.3				0.085000	0.090000	6	high
Wastewater Discharge	0.33	0.2	Pollutant Pressures	0.33	0.3				0.027225	0.018000	51	low
Agricultural Pesticide Use	0.33	0.7							0.027225	0.063000	57	low
Industrial Effluent	0.34	0.1							0.028050	0.009000	212	low
Water Connection	0.33	0.7	Household Water	0.5	0.7	Social	0.5	0.4	0.082500	0.196000	58	low
Water Quality	0.33	0.1							0.082500	0.028000	195	low
Water Usage	0.33	0.2							0.082500	0.056000	47	low
Agricultural Jobs Creation	0.25	0.25	Household Livelihoods	0.5	0.3				0.062500	0.030000	108	low
Industrial Jobs Creation	0.25	0.25							0.062500	0.030000	108	low
Source Yield and Livelihoods	0.25	0.25							0.062500	0.030000	108	low
Expenditure on Water	0.25	0.25							0.062500	0.030000	108	low

[1]Based on the value used in SUSMAQ DST

5.1.3 Sensitivity Analysis of Management Options Ranking to Basic Indicators Performance Values and Weights:

Table 5.5 presents the ranking of the various MO based on table 4.5: overall ranking and ranking with respect to the third level of indicators.

Table 5.5: Ranking of SUSMAQ DST NWB/CS Management Options

	MO1= Groundwater Development	MO2= Rainwater Harvesting	MO3= Direct Connection to Mekerot	MO4= Demand Management	MO5= Reuse
Overall	2	5	3	1	4
Economic	2	3	4	1	5
Environmental	3	1	2	2	1
Socio-economic	1	4	3	3	2

While Demand Management appears to be the most sustainable option, a preliminary analysis indicates a relatively low level of robustness based on the factors below:

- a difference of 1% only between the first rank (MO4 - Demand management) and the second (MO1 – Groundwater supply development) (table 4.5), which means that any slight change in any of the BI weights or performance values would cause a reversal of ranking;

- the first rank MO (MO4) ranks first for one of the three third level indicators (economic), while it ranks second for the environmental indicator and third for the socio-economic one – a rank quite similar for the #2 MO (MO1) which ranks first for the socio-economic indicator, second for the economic one and third for the environmental; which means that there is no absolute dominance for the first rank (MO4).

To further assess the robustness of MO ranking, a sensitivity analysis is carried out with respect to:

- the performance values assigned to the various BI (BIPV); and
- the weights elicited for the respective BI (BIW)

5.1.3.1 Sensitivity of Management Options' Ranking to the Assignment of Basic Indicators Performance Values (BIPV):

To assess the sensitivity of the MO ranking to the performance values assigned to the 18 basic indicators (BIPV), the distance-based uncertainty method is applied, as detailed in chapter 3.

Table 5.6 is the Euclidian Distance matrix; while tables 5.7-5.16 present the changes in the basic indicators performance values that would cause a reversal of ranking between MO1 and MO2 (table 5.7), MO1 and MO3 (table 5.8), MO1 and MO4 (table 5.9), MO1 and MO5 (table 5.10), MO2 and MO3 (table 5.11), MO2 and MO4 (table 5.12), MO2 and MO5 (table 5.13), MO3 and MO4 (table 5.14), MO3 and MO5 (table 5.15) and MO4 and MO5 (table 5.16).

Table 5.6: SUSMAQ DST NWB/CS – Euclidian Distance (BIPV)

	MO1 (Groundwater Supply GW)	MO2 (Rainwater Harvesting RW)	MO3 (Connection to Mekerot ME)	MO4 (Demand Management DM)	MO5 (Wastewater Reuse RE)
$d_e(MO_1,...)$		**0.387**	0.111	**0.015**	0.185
$d_e(MO_2,...)$			0.271	**0.395**	0.208
$d_e(MO_3,...)$				0.124	0.073
$d_e(MO_4,...)$					0.197

It is clear from table 5.6 that there is almost indifference between MO1 (Groundwater Supply Development) and MO4 (Demand Management) due to the small value of the Euclidian distance (0.015); while the ranking of MO1/MO2 (Groundwater Supply Development/ Rainwater Harvesting) and MO2/MO4 (Rainwater Harvesting/ Demand Management) seem more robust due to the relatively high value of the Euclidian distance (0.387 and 0.395 respectively). It is to be noted that the same conclusion can be drawn by looking at the third level indicators presented in table 4.5; this method however provides evidence for critical BIs which affect the robustness of the outcome. The associated changes in BI performance values are further discussed below.

Table 5.7 indicates that a reversal in ranking between MO1 (Groundwater Supply Development) and MO2 (Rainwater Harvesting) is rather improbable given the high change required in the PV of SO5 (Industrial Jobs Creation).

Table 5.7: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO1 and MO2

Basic Indicator	MO1 (GW) = 0.67*	MO2 (RW) = 0.54*	MO1=MO2=0.60 (d_c=0.387)			
			MO1 PV_o	MO1 (% Δ)	MO2 PV_o	MO2 (% Δ)
Internal Rate of Return (EC1)	0.55	0.00	0.50	-8.80	0.05	(0.05)
Agricultural Water Production Cost (EC2)	0.63	0.63	0.58	-7.74	0.67	7.74
Public Network Production Cost (EC3)	0.92	1.00	0.87	-5.42	1.00	0.00
Public Network Production Cost/ Benef. (EC4)	0.98	1.00	0.90	-7.51	1.00	0.15
Industrial/ Agric.Water Productivity (EC5)	0.89	0.86	0.82	-8.21	0.93	8.55
Aquifer Water Level (EN1)	0.95	1.00	0.90	-5.09	1.00	0.00
Reliability of Supply from Aquifer (EN2)	1.00	1.00	0.95	-4.84	1.00	0.00
Aquifer Water Quality (EN3)	0.84	0.92	0.74	-11.89	1.00	9.23
Wastewater Discharge (EN4)	0.66	0.79	0.63	-4.85	0.82	4.06
Agricultural Pesticide Use (EN5)	0.70	0.76	0.67	-4.57	0.79	4.19
Industrial Effluent (EN6)	0.86	0.94	0.83	-3.83	0.97	3.50
Water Connection (SO1)	0.35	0.00	0.25	-27.64	0.10	(0.10)
Water Quality (SO2)	0.70	0.00	0.60	-13.82	0.10	(0.10)
Water Usage (SO3)	1.00	0.53	0.90	-9.67	0.63	18.21
Agricultural Jobs Creation (SO4)	0.27	0.27	0.20	-27.12	0.34	27.12
Industrial Jobs Creation (SO5)	0.25	0.03	0.18	-28.88	0.10	245.51
Source Yield and Livelihoods (SO6)	0.82	0.82	0.74	-8.97	0.89	8.97
Expenditure on Water (SO7)	0.00	0.23	0.00	(0.00)	0.30	31.76

*Third level indicators (table 4.5)

Table 5.8: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO 1 and MO3

Basic Indicator	MO1 (GW) = 0.67	MO3 (ME) = 0.63	MO1=MO3=0.65 (d_c=0.111)			
			MO1 PV_o	MO1 (% Δ)	MO3 PV_o	MO3 (% Δ)
Internal Rate of Return (EC1)	0.55	0.37	0.54	-2.55	0.38	3.79
Agricultural Water Production Cost (EC2)	0.63	0.63	0.61	-2.24	0.64	2.24
Public Network Production Cost (EC3)	0.92	0.96	0.91	-1.57	0.97	1.50
Public Network Production Cost/ Beneficiary (EC4)	0.98	0.99	0.95	-2.17	1.00	1.26
Industrial/ Agricultural Water Productivity (EC5)	0.89	0.45	0.87	-2.38	0.47	4.75
Aquifer Water Level (EN1)	0.95	1.00	0.94	-1.47	1.00	0.00
Reliability of Supply from Aquifer (EN2)	1.00	1.00	0.99	-1.40	1.00	0.00
Aquifer Water Quality (EN3)	0.84	0.91	0.81	-3.44	0.94	3.16
Wastewater Discharge (EN4)	0.66	0.78	0.65	-1.40	0.78	1.19
Agricultural Pesticide Use (EN5)	0.70	0.76	0.69	-1.32	0.77	1.22
Industrial Effluent (EN6)	0.86	0.93	0.85	-1.11	0.94	1.02
Water Connection (SO1)	0.35	0.15	0.32	-8.00	0.18	18.66
Water Quality (SO2)	0.70	0.40	0.67	-4.00	0.43	7.00
Water Usage (SO3)	1.00	1.00	0.97	-2.80	1.00	0.00
Agricultural Jobs Creation (SO4)	0.27	0.27	0.25	-7.84	0.29	7.84
Industrial Jobs Creation (SO5)	0.25	0.25	0.23	-8.36	0.27	8.36
Source Yield and Livelihoods (SO6)	0.82	0.63	0.80	-2.59	0.66	3.34
Expenditure on Water (SO7)	0.00	0.54	0.00	(0.00)	0.56	3.94

Table 5.8 indicates that a reversal in ranking between MO1 (Groundwater Supply Development) and MO3 (Direct Connection to Mekerot) is possible based on changes in BIPV not exceeding 19% (SO1 – Water Connection). Table 5.9 demonstrates that a reversal of ranking between MO1 (Groundwater Supply Development) and MO4 (Demand Management) is possible with changes in basic indicators performance values, not exceeding 2-3%. This is a clear sign of indifference between the two options.

Table 5.9: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV– Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO1 and MO4

Basic Indicator	MO1 (GW) = 0.67	MO4 (DM) = 0.68	MO1=MO4=0.67 (d_c=0.015)			
			MO1 PV_0	MO1 (% Δ)	MO4 PV_0	MO4 (% Δ)
Internal Rate of Return (EC1)	0.55	0.74	0.55	0.33	0.73	-0.25
Agricultural Water Production Cost (EC2)	0.63	0.63	0.63	0.29	0.62	-0.29
Public Network Production Cost (EC3)	0.92	0.93	0.92	0.20	0.92	-0.20
Public Network Production Cost/ Beneficiary (EC4)	0.98	1.00	0.98	0.28	1.00	-0.27
Industrial/ Agricultural Water Productivity (EC5)	0.89	0.87	0.90	0.31	0.87	-0.31
Aquifer Water Level (EN1)	0.95	1.00	0.95	0.19	1.00	-0.18
Reliability of Supply from Aquifer (EN2)	1.00	1.00	1.00	0.00	1.00	-0.18
Aquifer Water Quality (EN3)	0.84	0.92	0.84	0.45	0.91	-0.41
Wastewater Discharge (EN4)	0.66	0.78	0.66	0.18	0.78	-0.15
Agricultural Pesticide Use (EN5)	0.70	0.76	0.70	0.17	0.76	-0.16
Industrial Effluent (EN6)	0.86	0.93	0.86	0.14	0.93	-0.13
Water Connection (SO1)	0.35	0.15	0.35	1.03	0.15	-2.41
Water Quality (SO2)	0.70	0.40	0.70	0.52	0.40	-0.91
Water Usage (SO3)	1.00	1.00	1.00	0.00	1.00	-0.36
Agricultural Jobs Creation (SO4)	0.27	0.27	0.27	1.02	0.27	-1.02
Industrial Jobs Creation (SO5)	0.25	0.25	0.26	1.08	0.25	-1.08
Source Yield and Livelihoods (SO6)	0.82	0.63	0.82	0.34	0.63	-0.43
Expenditure on Water (SO7)	0.00	0.54	0.00	(0.00)	0.54	-0.51

Table 5.10 indicates that a reversal of ranking between MO1 (Groundwater Supply Development) and MO5 (Reuse) is possible based on changes in BIPV not exceeding 14% (SO1 – water connection, SO5 – Industrial jobs creation).

Table 5.10: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO1 and MO5

Basic Indicator	MO1 (GW) = 0.67	MO5 (RE) = 0.61	MO1=MO5=0.64 (d_c=0.185)			
			MO1 PV_0	MO1 (% Δ)	MO5 PV_0	MO5 (% Δ)
Internal Rate of Return (EC1)	0.55	0.51	0.53	-4.21	0.54	4.51
Agricultural Water Production Cost (EC2)	0.63	0.25	0.60	-3.70	0.27	9.25
Public Network Production Cost (EC3)	0.92	0.96	0.90	-2.59	0.98	2.48
Public Network Production Cost/ Beneficiary (EC4)	0.98	0.99	0.94	-3.59	1.00	1.26
Industrial/ Agricultural Water Productivity (EC5)	0.89	0.00	0.86	-3.92	0.04	(0.04)
Aquifer Water Level (EN1)	0.95	1.00	0.93	-2.43	1.00	0.00
Reliability of Supply from Aquifer (EN2)	1.00	1.00	0.98	-2.31	1.00	0.00
Aquifer Water Quality (EN3)	0.84	0.92	0.79	-5.69	0.97	5.16
Wastewater Discharge (EN4)	0.66	0.80	0.64	-2.32	0.81	1.91
Agricultural Pesticide Use (EN5)	0.70	0.76	0.68	-2.18	0.78	2.00
Industrial Effluent (EN6)	0.86	0.94	0.84	-1.83	0.95	1.67
Water Connection (SO1)	0.35	0.00	0.30	-13.21	0.05	(0.05)
Water Quality (SO2)	0.70	0.70	0.65	-6.61	0.75	6.61
Water Usage (SO3)	1.00	0.53	0.95	-4.62	0.58	8.70
Agricultural Jobs Creation (SO4)	0.27	0.27	0.24	-12.96	0.31	12.96
Industrial Jobs Creation (SO5)	0.25	0.48	0.22	-13.81	0.51	7.34
Source Yield and Livelihoods (SO6)	0.82	1.00	0.78	-4.29	1.00	0.00
Expenditure on Water (SO7)	0.00	0.54	0.00	(0.00)	0.57	6.51

Table 5.11 indicates that a reversal of ranking between MO2 (Rainwater Harvesting) and MO3 (Direct Connection to Mekerot) is rather improbable as requested changes in PV can reach 168% (SO5 – Industrial jobs creation).

Table 5.11: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO2 and MO3

Basic Indicator	MO2 (RW) = 0.54	MO3 (ME) = 0.63	MO2=MO3=0.58 (d_c=0.271)			
			MO2 PV_0	MO2 (% Δ)	MO3 PV_0	MO3 (% Δ)
Internal Rate of Return (EC1)	0.00	0.37	0.03	(0.03)	0.34	-8.96
Agricultural Water Production Cost (EC2)	0.63	0.63	0.66	5.29	0.59	-5.29
Public Network Production Cost (EC3)	1.00	0.96	1.00	0.00	0.93	-3.55
Public Network Production Cost/ Beneficiary (EC4)	1.00	0.99	1.00	0.15	0.94	-5.07
Industrial/ Agricultural Water Productivity (EC5)	0.86	0.45	0.91	5.85	0.40	-11.23
Aquifer Water Level (EN1)	1.00	1.00	1.00	0.00	0.97	-3.31
Reliability of Supply from Aquifer (EN2)	1.00	1.00	1.00	0.00	0.97	-3.31
Aquifer Water Quality (EN3)	0.92	0.91	0.98	7.44	0.84	-7.47
Wastewater Discharge (EN4)	0.79	0.78	0.81	2.78	0.75	-2.82
Agricultural Pesticide Use (EN5)	0.76	0.76	0.78	2.86	0.74	-2.88
Industrial Effluent (EN6)	0.94	0.93	0.96	2.39	0.91	-2.41
Water Connection (SO1)	0.00	0.15	0.07	(0.07)	0.08	-44.10
Water Quality (SO2)	0.00	0.40	0.07	(0.07)	0.33	-16.54
Water Usage (SO3)	0.53	1.00	0.60	12.45	0.93	-6.61
Agricultural Jobs Creation (SO4)	0.27	0.27	0.32	18.54	0.22	-18.54
Industrial Jobs Creation (SO5)	0.03	0.25	0.08	167.87	0.20	-19.75
Source Yield and Livelihoods (SO6)	0.82	0.63	0.87	6.13	0.58	-7.90
Expenditure on Water (SO7)	0.23	0.54	0.28	21.72	0.49	-9.31

Table 5.12 indicates that changes of the order of 247% (SO5 – Industrial jobs creation) are needed to cause a reversal of ranking between MO2 (Rainwater Harvesting) and MO4 (Demand Management); which demonstrates a robust ranking between the two options.

Table 5.12: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO2 and MO4

Basic Indicator	MO2 (RW) = 0.54	MO4 (ME) = 0.68	MO2=MO4=0.60 (d_c=0.395)			
			MO2 PV_0	MO2 (% Δ)	MO4 PV_0	MO4 (% Δ)
Internal Rate of Return (EC1)	0.00	0.74	0.05	(0.05)	0.69	-6.60
Agricultural Water Production Cost (EC2)	0.63	0.63	0.67	7.77	0.58	-7.77
Public Network Production Cost (EC3)	1.00	0.93	1.00	0.00	0.88	-5.40
Public Network Production Cost/ Beneficiary (EC4)	1.00	1.00	1.00	0.15	0.93	-7.36
Industrial/ Agricultural Water Productivity (EC5)	0.86	0.87	0.93	8.58	0.80	-8.41
Aquifer Water Level (EN1)	1.00	1.00	1.00	0.00	0.95	-4.86
Reliability of Supply from Aquifer (EN2)	1.00	1.00	1.00	0.00	0.95	-4.86
Aquifer Water Quality (EN3)	0.92	0.92	1.00	9.23	0.82	-10.93
Wastewater Discharge (EN4)	0.79	0.78	0.82	4.08	0.75	-4.10
Agricultural Pesticide Use (EN5)	0.76	0.76	0.79	4.20	0.73	-4.21
Industrial Effluent (EN6)	0.94	0.93	0.97	3.52	0.90	-3.53
Water Connection (SO1)	0.00	0.15	0.10	(0.10)	0.05	-64.74
Water Quality (SO2)	0.00	0.40	0.10	(0.10)	0.30	-24.28
Water Usage (SO3)	0.53	1.00	0.63	18.28	0.90	-9.71
Agricultural Jobs Creation (SO4)	0.27	0.27	0.34	27.22	0.20	-27.22
Industrial Jobs Creation (SO5)	0.03	0.25	0.10	246.46	0.18	-29.00
Source Yield and Livelihoods (SO6)	0.82	0.63	0.89	9.00	0.56	-11.60
Expenditure on Water (SO7)	0.23	0.54	0.30	31.88	0.46	-13.66

Table 5.13 indicates that changes of the order of 135% (SO5 – Industrial jobs creation) in the BIPV are needed to cause a reversal of ranking between MO2 (Rainwater Harvesting) and MO5 (Reuse); which demonstrates a robustness in the ranking.

Table 5.13: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators that Would Cause Ranking Reversal between MO2 and MO5

Basic Indicator	MO2 (RW) = 0.54	MO5 (RE) = 0.61	MO2=MO5=0.58 (d_c=0.208)			
			MO2 PV_o	MO2 (% Δ)	MO5 PV_o	MO5 (% Δ)
Internal Rate of Return (EC1)	0.00	0.51	0.03	(0.03)	0.49	-5.17
Agricultural Water Production Cost (EC2)	0.63	0.25	0.65	4.25	0.22	-10.62
Public Network Production Cost (EC3)	1.00	0.96	1.00	0.00	0.93	-2.85
Public Network Production Cost/ Beneficiary (EC4)	1.00	0.99	1.00	0.15	0.95	-4.07
Industrial/ Agricultural Water Productivity (EC5)	0.86	0.00	0.90	4.69	0.00	(0.00)
Aquifer Water Level (EN1)	1.00	1.00	1.00	0.00	0.97	-2.65
Reliability of Supply from Aquifer (EN2)	1.00	1.00	1.00	0.00	0.97	-2.65
Aquifer Water Quality (EN3)	0.92	0.92	0.97	5.97	0.87	-5.93
Wastewater Discharge (EN4)	0.79	0.80	0.80	2.23	0.78	-2.19
Agricultural Pesticide Use (EN5)	0.76	0.76	0.78	2.30	0.75	-2.30
Industrial Effluent (EN6)	0.94	0.94	0.96	1.92	0.92	-1.92
Water Connection (SO1)	0.00	0.00	0.05	(0.05)	0.00	(0.00)
Water Quality (SO2)	0.00	0.70	0.05	(0.05)	0.65	-7.58
Water Usage (SO3)	0.53	0.53	0.58	9.99	0.48	-9.99
Agricultural Jobs Creation (SO4)	0.27	0.27	0.31	14.88	0.23	-14.88
Industrial Jobs Creation (SO5)	0.03	0.48	0.07	134.73	0.44	-8.42
Source Yield and Livelihoods (SO6)	0.82	1.00	0.86	4.92	0.96	-4.02
Expenditure on Water (SO7)	0.23	0.54	0.27	17.43	0.50	-7.47

Based on table 5.14, a reversal of ranking between MO3 (Direct Connection to Mekerot) and MO4 (Demand Management) requires a change in the BIPV not exceeding 21% (SO1 – Water connection).

Table 5.14: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO3 and MO4

Basic Indicator	MO3 (ME) = 0.63	MO4 (DM) = 0.68	MO3=MO4=0.65 (d_c=0.124)			
			MO3 PV_o	MO3 (% Δ)	MO4 PV_o	MO4 (% Δ)
Internal Rate of Return (EC1)	0.37	0.74	0.38	4.17	0.72	-2.09
Agricultural Water Production Cost (EC2)	0.63	0.63	0.64	2.46	0.61	-2.46
Public Network Production Cost (EC3)	0.96	0.93	0.98	1.65	0.91	-1.71
Public Network Production Cost/ Beneficiary (EC4)	0.99	1.00	1.00	1.26	0.98	-2.34
Industrial/ Agricultural Water Productivity (EC5)	0.45	0.87	0.47	5.23	0.85	-2.67
Aquifer Water Level (EN1)	1.00	1.00	1.00	0.00	0.98	-1.54
Reliability of Supply from Aquifer (EN2)	1.00	1.00	1.00	0.00	0.98	-1.54
Aquifer Water Quality (EN3)	0.91	0.92	0.94	3.48	0.88	-3.47
Wastewater Discharge (EN4)	0.78	0.78	0.79	1.31	0.77	-1.30
Agricultural Pesticide Use (EN5)	0.76	0.76	0.77	1.34	0.75	-1.34
Industrial Effluent (EN6)	0.93	0.93	0.95	1.12	0.92	-1.12
Water Connection (SO1)	0.15	0.15	0.18	20.53	0.12	-20.53
Water Quality (SO2)	0.40	0.40	0.43	7.70	0.37	-7.70
Water Usage (SO3)	1.00	1.00	1.00	0.00	0.97	-3.08
Agricultural Jobs Creation (SO4)	0.27	0.27	0.29	8.63	0.25	-8.63
Industrial Jobs Creation (SO5)	0.25	0.25	0.28	9.20	0.23	-9.20
Source Yield and Livelihoods (SO6)	0.63	0.63	0.66	3.68	0.61	-3.68
Expenditure on Water (SO7)	0.54	0.54	0.56	4.33	0.52	-4.33

Table 5.15 indicates that changes in the BIPV not exceeding 12% (SO1 – water connection) would cause a reversal of ranking between MO3 (Direct Connection to Mekerot) and MO5 (Reuse).

Table 5.15: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO3 and MO5

Basic Indicator	MO3 (ME) = 0.63	MO5 (RE) = 0.61	MO3=MO5=0.62 (d_c=0.073)			
			MO3 PV_o	MO3 (% Δ)	MO5 PV_o	MO5 (% Δ)
Internal Rate of Return (EC1)	0.37	0.51	0.36	-2.41	0.52	1.73
Agricultural Water Production Cost (EC2)	0.63	0.25	0.62	-1.42	0.26	3.56
Public Network Production Cost (EC3)	0.96	0.96	0.95	-0.95	0.97	0.95
Public Network Production Cost/ Beneficiary (EC4)	0.99	0.99	0.97	-1.36	1.00	1.26
Industrial/ Agricultural Water Productivity (EC5)	0.45	0.00	0.43	-3.02	0.01	(0.01)
Aquifer Water Level (EN1)	1.00	1.00	0.99	-0.89	1.00	0.00
Reliability of Supply from Aquifer (EN2)	1.00	1.00	0.99	-0.89	1.00	0.00
Aquifer Water Quality (EN3)	0.91	0.92	0.89	-2.01	0.94	1.99
Wastewater Discharge (EN4)	0.78	0.80	0.77	-0.76	0.81	0.73
Agricultural Pesticide Use (EN5)	0.76	0.76	0.75	-0.77	0.77	0.77
Industrial Effluent (EN6)	0.93	0.94	0.93	-0.65	0.95	0.64
Water Connection (SO1)	0.15	0.00	0.13	-11.85	0.02	(0.02)
Water Quality (SO2)	0.40	0.70	0.38	-4.44	0.72	2.54
Water Usage (SO3)	1.00	0.53	0.98	-1.78	0.55	3.35
Agricultural Jobs Creation (SO4)	0.27	0.27	0.26	-4.98	0.28	4.98
Industrial Jobs Creation (SO5)	0.25	0.48	0.24	-5.31	0.49	2.82
Source Yield and Livelihoods (SO6)	0.63	1.00	0.62	-2.12	1.00	0.00
Expenditure on Water (SO7)	0.54	0.54	0.52	-2.50	0.55	2.50

Table 5.16 indicates that a reversal of ranking between MO4 (Demand Management) and MO5 (Reuse) would require a change in the BIPV less than 33% (SO1 – water connection).

Table 5.16: SUSMAQ DST NWB/CS - Distance Based Uncertainty Analysis on Basic Indicators PV – Changes in Basic Indicators PV that Would Cause Ranking Reversal between MO4 and MO5

Basic Indicator	MO4 (DM) = 0.68	MO5 (RE) = 0.61	MO4=MO5=0.64 (d_c=0.197)			
			MO4 PV_o	MO4 (% Δ)	MO5 PV_o	MO5 (% Δ)
Internal Rate of Return (EC1)	0.74	0.51	0.71	-3.29	0.54	4.71
Agricultural Water Production Cost (EC2)	0.63	0.25	0.60	-3.87	0.27	9.67
Public Network Production Cost (EC3)	0.93	0.96	0.90	-2.69	0.98	2.60
Public Network Production Cost/ Beneficiary (EC4)	1.00	0.99	0.96	-3.67	1.00	1.26
Industrial/ Agricultural Water Productivity (EC5)	0.87	0.00	0.84	-4.19	0.04	(0.04)
Aquifer Water Level (EN1)	1.00	1.00	0.98	-2.42	1.00	0.00
Reliability of Supply from Aquifer (EN2)	1.00	1.00	0.98	-2.42	1.00	0.00
Aquifer Water Quality (EN3)	0.92	0.92	0.87	-5.44	0.97	5.40
Wastewater Discharge (EN4)	0.78	0.80	0.77	-2.04	0.82	2.00
Agricultural Pesticide Use (EN5)	0.76	0.76	0.74	-2.10	0.78	2.09
Industrial Effluent (EN6)	0.93	0.94	0.92	-1.76	0.96	1.75
Water Connection (SO1)	0.15	0.00	0.10	-32.23	0.05	(0.05)
Water Quality (SO2)	0.40	0.70	0.35	-12.09	0.75	6.91
Water Usage (SO3)	1.00	0.53	0.95	-4.84	0.58	9.10
Agricultural Jobs Creation (SO4)	0.27	0.27	0.23	-13.55	0.31	13.55
Industrial Jobs Creation (SO5)	0.25	0.48	0.22	-14.44	0.51	7.67
Source Yield and Livelihoods (SO6)	0.63	1.00	0.60	-5.78	1.00	0.00
Expenditure on Water (SO7)	0.54	0.54	0.50	-6.80	0.58	6.80

A summary of results related to distance based uncertainty analysis on basic indicators PV is presented in table 5.17.

Table 5.17: SUSMAQ – DST - Summary of Distance Based Uncertainty Analysis on the BIPV

	Sensitivity Results	Critical BI(*)
MO1- MO2	Low (Robustness)	-
MO1- MO3	Medium	SO1 (19%)
MO1- MO4	High (Indifference)	-
MO1- MO5	Medium	SO1, SO5 (14%)
MO2- MO3	Low (Robustness)	-
MO2- MO4	Low (Robustness)	-
MO2- MO5	Low (Robustness)	-
MO3- MO4	Medium	SO1 (21%)
MO3- MO5	Medium	SO1 (12%)
MO4- MO5	Medium	SO1 (33%)

(*) For the purpose of this table, critical BI refer to the basic indicators which the ranking is the least sensitive to

Results summarised in table 5.17 indicate the following:

- a high sensitive ranking for MO1-MO4: 1 pair out of 10
- a low sensitive ranking for the following pairs (MO1-MO2; MO2-MO3; MO2-MO4; MO2-MO5): 4 pairs out of 10 – with all MO robustly ranked compared to MO2
- a medium sensitive ranking for MO1-MO3, MO1-MO5, MO3-MO4, MO3-MO5, MO4-MO5: 5 pairs out of 10

Based on the above, it can be concluded that the ranking of the various management options (MO) in the context of SUSMAQ DST North West Basin/ Current Scenario is sensitive to the performance values of the various basic indicators. Although these conclusions can be directly drawn by looking at the third-level indicators presented in table 4.5, this method provides evidence for critical BIs.

5.1.3.2 Sensitivity of Management Options' Ranking to the Elicitation of Basic Indicators Weights (BIW):

To assess the sensitivity of MO ranking to the elicitation of basic indicators weights, three methods are tested, as detailed in chapter 3; which allows better validation of results through cross comparison of results:

5.1.3.2.1 Robustness Measure:

Application of the robustness measure to the SUSMAQ DST NWB/CS generates the results presented in table 5.18.

Table 5.18: SUSMAQ DST NWB/CS – BIW - Robustness Index

	MO1 (Groundwater Supply GW)	MO2 (Rainwater Harvesting RW)	MO3 (Connection to Mekerot ME)	MO4 (Demand Management DM)	MO5 (Wastewater Reuse RE)
$r(a_1,...)$		0.645	0.263	-0.045	0.282
$r(a_2,...)$			-0.533	-0.819	-0.319
$r(a_3,...)$				-0.938	0.153
$r(a_4,...)$					0.342

From the values presented in table 5.18, it is clear that there is almost indifference between MO1 and MO4, due to the small value of r(MO1,MO4)= - 0.045, and dominance of MO4 over MO3 since r(MO3,MO4)= - 0.938.

Table 5.19 presents the modified weights which correspond to the two above-mentioned cases. The sum of modified weights required for MO1=MO4 is equal to 0.98; the performance value of MO1 is then equal to the performance value of MO4, equal to 0.66 – initially, MO1=0.67 and MO4=0.68, whereas for MO3=MO4, the sum of modified weights required is 0.14 (<<1), and MO3=MO4=0.12; a clearly infeasible scenario, as demonstrated by the high value of the robustenss index.

Table 5.195: SUSMAQ DST NWB/CS – Modified BI Weights for Reversal of Ranking between Selected Management Options

Basic Indicator	Initial Weight	Modified Weight for MO1=MO4 (r=-0.045)	Modified Weight for MO3=MO4 (r=-0.938)
Internal Rate of Return (EC1)	0.33*0.5*0.25=0.041	0.039	0.002
Agricultural Water Production Cost (EC2)	0.33*0.5*0.25=0.041	0.039	0.002
Public Network Production Cost (EC3)	0.34*0.5*0.25=0.042	0.040	0.082
Public Network Production Cost/ Beneficiary (EC4)	0.5*0.5*0.25=0.062	0.059	0.003
Industrial/ Agricultural Water Productivity (EC5)	0.5*0.5*0.25=0.062	0.065	0.003
Aquifer Water Level (EN1)	0.5*0.33*0.25=0.041	0.039	0.002
Reliability of Supply from Aquifer (EN2)	0.5*0.33*0.25=0.041	0.039	0.002
Aquifer Water Quality (EN3)	1*0.34*0.25=0.085	0.081	0.005
Wastewater Discharge (EN4)	0.33*0.33*0.25=0.027	0.026	0.001
Agricultural Pesticide Use (EN5)	0.33*0.33*0.25=0.027	0.026	0.001
Industrial Effluent (EN6)	0.34*0.33*0.25=0.028	0.026	0.001
Water Connection (SO1)	0.33*0.5*0.5=0.082	0.086	0.005
Water Quality (SO2)	0.33*0.5*0.5=0.082	0.086	0.005
Water Usage (SO3)	0.33*0.5*0.5=0.082	0.078	0.005
Agricultural Jobs Creation (SO4)	0.25*0.5*0.5=0.062	0.059	0.003
Industrial Jobs Creation (SO5)	0.25*0.5*0.5=0.062	0.059	0.003
Source Yield and Livelihoods (SO6)	0.25*0.5*0.5=0.062	0.065	0.003
Expenditure on Water (SO7)	0.25*0.5*0.5=0.062	0.059	0.003
Sum	0.997	0.978	0.141
MO	MO1=0.67 MO3=0.63 MO4=0.68	0.66 (modified MO1 = modified MO4)	0.12 (modified MO3 = modified MO4)

5.1.3.2.2 Sensitivity Analysis:

Application of the sensitivity analysis method to SUSMAQ DST generates the results outlined in the following tables. Results related to the potential reversal of ranking between MO1 (Groundwater Supply Development) and MO2, MO3, MO4, MO5 are presented in table 5.20 (modified weights) and 5.21 (percentage change in weight); MO2 vs. MO3, MO4, MO5 (tables 5.22, 5.23); MO3 vs. MO4, MO5 (table 5.24); and MO4 vs. MO5 (table 5.25).

Table 5.20: SUSMAQ DST NWB/CS – Sensitivity Analysis of BIW – Modified BIW Required for Reversal of Ranking between MO1 and MO2,3,4,5

Basic Indicator	MO1= MO2 (RW)	MO1= MO3 (ME)	MO1= MO4 (DM)	MO1= MO5 (RE)
Internal Rate of Return (EC1)	not feasible	not feasible	0.01	not feasible
Agricultural Water Production Cost (EC2)	not feasible	not feasible	not feasible	not feasible
Public Network Production Cost (EC3)	1.64	0.97	not feasible	1.60
Public Network Production Cost/ Beneficiary (EC4)	5.83	3.29	not feasible	5.49
Industrial/ Agricultural Water Productivity (EC5)	not feasible	not feasible	0.34	not feasible
Aquifer Water Level (EN1)	2.61	0.77	not feasible	1.27
Reliability of Supply from Aquifer (EN2)	not feasible	not feasible	not feasible	not feasible
Aquifer Water Quality (EN3)	1.75	0.58	0.02	0.81
Wastewater Discharge (EN4)	1.04	0.34	not feasible	0.46
Agricultural Pesticide Use (EN5)	2.05	0.64	not feasible	0.99
Industrial Effluent (EN6)	1.65	0.51	not feasible	0.80
Water Connection (SO1)	not feasible	not feasible	0.11	not feasible
Water Quality (SO2)	not feasible	not feasible	0.09	not feasible
Water Usage (SO3)	not feasible	not feasible	not feasible	not feasible
Agricultural Jobs Creation (SO4)	not feasible	not feasible	not feasible	not feasible
Industrial Jobs Creation (SO5)	not feasible	not feasible	not feasible	0.34
Source Yield and Livelihoods (SO6)	not feasible	not feasible	0.09	0.40
Expenditure on Water (SO7)	0.62	0.13	0.05	0.18

Table 5.20 presents three categories of results:

- $w_{m,x,y}$[7] = not feasible: no modification of weight for basic indicator m can reverse the ranking of management options x and y
- $w_{m,x,y} > 0.34$ (shaded result): this result is to be disregarded as there is a total of 18 basic indicators, corresponding weights of which (after aggregation into 7 second level indicators and 3 third level indicators) summing up to 1; no one indicator (1 of 18) can be assigned a weight higher than 1/3 of the total weight without nullifying a third level indicator and/or a second level indicator
- $w_{m,x,y} \leq 0.34$: there is a possibility to modify the weight of basic indicator m to cause ranking reversal between management options x and y. The corresponding percentage change is presented in table 5.21 which separates

[7] Modified weight of BI m to cause reversal of ranking between MO x and MO y

between changes >100% (which are rather improbable) and changes < 100% (more probable).

It is clear from the results displayed in table 5.21 that ranking of MO1 (Groundwater Supply Development) and MO4 (Demand Management) can be reversed by changing any of the weights associated with EC1 (Internal Rate of Return), or EN3 (Aquifer Water Quality), or SO1 (Water Connection), or SO2 (Water Quality), or SO6 (Source Yield and Livelihoods) or SO7 (Expenditure on Water), by 34%, 23%, 131%, 120%, 144%, and 85% respectively. Obviously weight assigned to EN3 is the most critical, followed by the one associated with EC1 and SO7 respectively - noting that the analysis deals with changing one weight at a time only; changing more than one weight at a time is discussed in section 5.1.3.2.3.

Table 5.21 presents a potential reversal of rankings between MO1 and MO3 (Direct Connection to Mekerot) by changing the weight assigned to SO7 (Expenditure on Water), however by a percentage change of 209%, which is rather improbable. The same applies to the reversal of ranking between MO1 and MO5 (Wastewater Reuse) by changing the weight assigned to SO7 by a percentage change of 284%, again rather improbable.

Table 5.21: SUSMAQ DST NWB/CS – *Sensitivity Analysis of BIW* – Percentage Change in BIW Required for Reversal of Ranking between MO1 and MO 2,3,4,5

Basic Indicator	MO1= MO2 (RW)	MO1= MO3 (ME)	MO1= MO4 (DM)	MO1= MO5 (RE)
Internal Rate of Return (EC1)	not feasible	not feasible	*33.90*	not feasible
Agricultural Water Production Cost (EC2)	not feasible	not feasible	not feasible	not feasible
Public Network Production Cost (EC3)	3,869	2,280	not feasible	3,768
Public Network Production Cost/ Beneficiary (EC4)	9,325	5,265	not feasible	8,793
Industrial/ Agricultural Water Productivity (EC5)	not feasible	not feasible	548	not feasible
Aquifer Water Level (EN1)	6,321	1,872	not feasible	3,082
Reliability of Supply from Aquifer (EN2)	not feasible	not feasible	not feasible	not feasible
Aquifer Water Quality (EN3)	2,056	683	*23.04*	959
Wastewater Discharge (EN4)	3,811	1,248	not feasible	1,701
Agricultural Pesticide Use (EN5)	7,525	2,371	not feasible	3,659
Industrial Effluent (EN6)	5,871	1,838	not feasible	2,866
Water Connection (SO1)	not feasible	not feasible	**130.71**	not feasible
Water Quality (SO2)	not feasible	not feasible	**120.47**	not feasible
Water Usage (SO3)	not feasible	not feasible	not feasible	not feasible
Agricultural Jobs Creation (SO4)	not feasible	not feasible	not feasible	not feasible
Industrial Jobs Creation (SO5)	not feasible	not feasible	not feasible	541
Source Yield and Livelihoods (SO6)	not feasible	not feasible	**144.32**	640
Expenditure on Water (SO7)	993	209	*84.94*	284

Results related to the potential reversal of ranking between MO2 (Rainwater Harvesting) and MO3, MO4, MO5 are presented in table 5.22 (modified weights) and 5.23 (percentage change in weight).

Table 5.23 presents a potential reversal of ranking between MO2 (Rainwater Harvesting) and MO3 (Direct Connection to Mekerot) by changing the weight assigned to EC5 (Industrial/ Agricultural Water Productivity) by 459% (rather improbable), as well as a reversal of ranking between MO2 and MO5 by changing the weight assigned to EC2 (Agricultural Water Production Cost) or EC5 by 534% and 225% respectively – both rather improbable.

Table 5.22: SUSMAQ DST NWB/CS– Sensitivity Analysis of BIW – Modified BIW Required for Reversal of Ranking between MO2 and MO 3,4, 5

Basic Indicator	MO2= MO3 (ME)	MO2= MO4 (DM)	MO2= MO5 (RE)
Internal Rate of Return (EC1)	not feasible	not feasible	not feasible
Agricultural Water Production Cost (EC2)	not feasible	not feasible	0.22
Public Network Production Cost (EC3)	2.30	1.87	1.68
Public Network Production Cost/Beneficiary (EC4)	8.45	not feasible	6.17
Industrial/ Agricultural Water Productivity (EC5)	0.29	not feasible	0.14
Aquifer Water Level (EN1)	not feasible	not feasible	not feasible
Reliability of Supply from Aquifer (EN2)	not feasible	not feasible	not feasible
Aquifer Water Quality (EN3)	26.25	not feasible	not feasible
Wastewater Discharge (EN4)	9.13	44.13	not feasible
Agricultural Pesticide Use (EN5)	20.99	60.96	not feasible
Industrial Effluent (EN6)	21.25	30.87	not feasible
Water Connection (SO1)	not feasible	not feasible	not feasible
Water Quality (SO2)	not feasible	not feasible	not feasible
Water Usage (SO3)	not feasible	not feasible	not feasible
Agricultural Jobs Creation (SO4)	not feasible	not feasible	not feasible
Industrial Jobs Creation (SO5)	not feasible	not feasible	not feasible
Source Yield and Livelihoods (SO6)	0.57	0.79	not feasible
Expenditure on Water (SO7)	not feasible	not feasible	not feasible

It is clear from table 5.24 that no reversal of rankings can occur between MO3 (Direct Connection to Mekerot) and MO4 (Demand Management) based on a change in the weight associated with any of the basic indicators. Reversal of ranking between MO3 and MO5 (Wastewater Reuse) can occur if the weight associated with EC5 (Industrial/ Agricultural Water Productivity), or the weight associated with SO3 (Water Usage) is changed by 10.15% and 35.19% respectively, or if the weight associated with SO2 (Water Quality), or SO5 (Industrial Jobs Creation) or SO6 (Source Yield and Livelihoods) is changed by 201%, 279% and 209% respectively, which is improbable.

Table 5.23: SUSMAQ DST NWB/CS – Sensitivity Analysis of BIW – Percentage Change in BIW Required for Reversal of Ranking between MO2 and MO 3,4,5

Basic Indicator	MO2= MO3 (ME)	MO2= MO4 (DM)	MO2= MO5 (RE)
Internal Rate of Return (EC1)	not feasible	not feasible	not feasible
Agricultural Water Production Cost (EC2)	not feasible	not feasible	534
Public Network Production Cost (EC3)	5,411	4,402	3,966
Public Network Production Cost per Beneficiary (EC4)	13,529	not feasible	9,876
Industrial/ Agricultural Water Productivity (EC5)	459	not feasible	225
Aquifer Water Level (EN1)	not feasible	not feasible	not feasible
Reliability of Supply from Aquifer (EN2)	not feasible	not feasible	not feasible
Aquifer Water Quality (EN3)	30,886	not feasible	not feasible
Wastewater Discharge (EN4)	33,539	162,093	not feasible
Agricultural Pesticide Use (EN5)	77,097	223,906	not feasible
Industrial Effluent (EN6)	75,763	110,064	not feasible
Water Connection (SO1)	not feasible	not feasible	not feasible
Water Quality (SO2)	not feasible	not feasible	not feasible
Water Usage (SO3)	not feasible	not feasible	not feasible
Agricultural Jobs Creation (SO4)	not feasible	not feasible	not feasible
Industrial Jobs Creation (SO5)	not feasible	not feasible	not feasible
Source Yield and Livelihoods (SO6)	905	1,271	not feasible
Expenditure on Water (SO7)	not feasible	not feasible	not feasible

Table 5.24: SUSMAQ DST NWB/CS – Sensitivity Analysis of BIW – Modified BIW (and % Change in Weight) Required for Reversal of Ranking between MO3 and MO 4, 5

Basic Indicator	MO3= MO4 (DM)	MO3= MO4 (DM) (%)	MO3= MO5 (RE)	MO3= MO5 (RE) (%)
Internal Rate of Return (EC1)	not feasible	not feasible	0.21	522
Agricultural Water Production Cost (EC2)	not feasible	not feasible	not feasible	not feasible
Public Network Production Cost (EC3)	1.33	3,132	not feasible	not feasible
Public Network Production Cost/Beneficiary (EC4)	not feasible	not feasible	not feasible	not feasible
Industrial/ Agricultural Water Productivity (EC5)	not feasible	not feasible	**0.006**	***10.15***
Aquifer Water Level (EN1)	not feasible	not feasible	not feasible	not feasible
Reliability of Supply from Aquifer (EN2)	not feasible	not feasible	not feasible	not feasible
Aquifer Water Quality (EN3)	not feasible	not feasible	2.46	2,891
Wastewater Discharge (EN4)	not feasible	not feasible	1.06	3,890
Agricultural Pesticide Use (EN5)	not feasible	not feasible	5.73	21,045
Industrial Effluent (EN6)	not feasible	not feasible	5.80	20,682
Water Connection (SO1)	not feasible	not feasible	not feasible	not feasible
Water Quality (SO2)	not feasible	not feasible	**0.17**	**201**
Water Usage (SO3)	not feasible	not feasible	**0.03**	***35.19***
Agricultural Jobs Creation (SO4)	not feasible	not feasible	not feasible	not feasible
Industrial Jobs Creation (SO5)	not feasible	not feasible	**0.17**	**279**
Source Yield and Livelihoods (SO6)	not feasible	not feasible	**0.13**	**209**
Expenditure on Water (SO7)	not feasible	not feasible	not feasible	not feasible

Based on table 5.25, it is highly improbable that a reversal of rankings occurs between MO4 (Demand Management) and MO5 (Wastewater Reuse) as the changes required in critical weights (weights associated with SO2 and SO6, Water Quality, Source Yield and Livelihoods,) are about 370% and 392% respectively.

Table 5.25: SUSMAQ DST NWB/CS – Sensitivity Analysis of BIW – Modified BIW (and % Change in Weight) Required for Reversal of Ranking between MO4 and MO5

Basic Indicator	MO4=MO5 (RE)	MO4=MO5 (RE) (%)
Internal Rate of Return (EC1)	not feasible	not feasible
Agricultural Water Production Cost (EC2)	not feasible	not feasible
Public Network Production Cost (EC3)	2.10	4,951
Public Network Production Cost per Beneficiary (EC4)	not feasible	not feasible
Industrial/ Agricultural Water Productivity (EC5)	not feasible	not feasible
Aquifer Water Level (EN1)	not feasible	not feasible
Reliability of Supply from Aquifer (EN2)	not feasible	not feasible
Aquifer Water Quality (EN3)	9.57	11,265
Wastewater Discharge (EN4)	3.91	14,367
Agricultural Pesticide Use (EN5)	30.44	111,801
Industrial Effluent (EN6)	15.42	54,982
Water Connection (SO1)	not feasible	not feasible
Water Quality (SO2)	**0.30**	**370**
Water Usage (SO3)	not feasible	not feasible
Agricultural Jobs Creation (SO4)	not feasible	not feasible
Industrial Jobs Creation (SO5)	0.36	577
Source Yield and Livelihoods (SO6)	**0.24**	**392**
Expenditure on Water (SO7)	not feasible	not feasible

5.1.3.2.3 Distance-Based Uncertainty Analysis Method:

Application of the Distance Based Uncertainty Analysis method to the SUSMAQ-DST generates the following results:

Table 5.26 is the Euclidian Distance matrix; while tables 5.27, 5.28, 5.29, 5.30 present the relative changes in the basic indicators that would cause a reversal of ranking between MO1 and MO2, MO3, MO4, MO5 (table 5.27), between MO2 and MO3, MO4, MO5 (table 5.28), between MO3 and MO4, MO5 (table 5.29) and between MO4 and MO5 (table 5.30).

Table 5.26: SUSMAQ DST NWB/CS– BIW- Euclidian Distance

	MO1 (Groundwater Supply GW)	MO2 (Rainwater Harvesting RW)	MO3 (Connection to Mekerot ME)	MO4 (Demand Management DM)	MO5 (Wastewater Reuse RE)
$d_e(a_1,\ldots)$		0.121	0.043	**0.007**	0.048
$d_e(a_2,\ldots)$			0.103	**0.159**	0.048
$d_e(a_3,\ldots)$				0.079	0.027
$d_e(a_4,\ldots)$					0.055

It is clear from table 5.26 that there is almost indifference between MO1 (Groundwater Supply Development) and MO4 (Demand Management) due to the small value of the Euclidian distance (0.007). The relative change in the respective BI weights is in the order of -8% to +4%, as appears in table 5.27, with the lowest relative change in weights (in absolute values) associated with the following BI: EC4 – Public Network Production Cost/ Beneficiary (0%), SO3 – Water Usage (0.3%), SO4 – Agricultural Jobs Creation (0.4%), SO5 – Industrial Jobs Creation (0.4%), EC3 – Public Network Production Cost (0.4%).

The ranking of MO2 (Rainwater Harvesting) vs. MO4 (Demand Management) seems to be robust due to the relatively high value of the Euclidian distance (0.159). Requested relative changes in the respective BI weights vary between -100% and 95%, with two BI requiring a -100% change in weights to cause reversal of ranking (EC1–Internal Rate of Return and SO3–Water Usage) (table 5.28).

Table 5.27: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI Weights – Relative Changes in Weights (%) that Would Cause Reversal of Ranking between MO1 and MO 2,3,4,5

Basic Indicator	MO1= MO2 (RW)	MO1= MO3 (ME)	MO1= MO4 (DM)	MO1= MO5 (RE)
Internal Rate of Return (EC1)	-100.0	-20.2	-3.9	0.2
Agricultural Water Production Cost (EC2)	23.6	2.4	0.6	-30.1
Public Network Production Cost (EC3)	45.4	7.1	0.4	6.9
Public Network Production Cost/ Beneficiary (EC4)	19.8	2.5	0.0	3.0
Industrial/ Agricultural Water Productivity (EC5)	8.8	-35.3	0.7	-50.5
Aquifer Water Level (EN1)	38.1	8.7	-0.6	8.0
Reliability of Supply from Aquifer (EN2)	23.6	2.4	0.6	3.5
Aquifer Water Quality (EN3)	22.3	5.7	-0.6	5.4
Wastewater Discharge (EN4)	91.4	25.9	-3.6	24.6
Agricultural Pesticide Use (EN5)	63.6	14.8	-1.3	14.0
Industrial Effluent (EN6)	68.4	17.3	-1.8	15.7
Water Connection (SO1)	-38.6	-11.3	2.7	-13.9
Water Quality (SO2)	-89.1	-17.6	3.9	1.8
Water Usage (SO3)	-55.7	1.2	0.3	-19.3
Agricultural Jobs Creation (SO4)	15.6	1.6	0.4	2.3
Industrial Jobs Creation (SO5)	-27.0	1.6	0.4	15.6
Source Yield and Livelihoods (SO6)	15.6	-13.5	3.3	13.2
Expenditure on Water (SO7)	59.5	46.0	-8.1	34.2

Ranking of MO1 vs. MO2 is also relatively robust, with d_e = 0.12. The relative change in weights required to reverse ranking varies between -100% and 91%, with one BI requiring a 100% change in weight to cause ranking reversal (EC1 – Internal Rate of Return) (table 5.27). Same applies to MO2 vs. MO3, where d_e =0.10, and the relative change in weights required to reverse ranking varying between -84% (EC1 – Internal Rate of Return) and 88% (EC5 – Industrial/ Agricultural Water Productivity) (table 5.28).

Table 5.28: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI Weights – Relative Changes in Weights (%) that Would Cause Reversal of Ranking between MO2 and MO 3,4,5

Basic Indicator	MO2= MO3 (ME)	MO2= MO4 (DM)	MO2= MO5 (RE)
Internal Rate of Return (EC1)	-83.6	-100.0	-39.4
Agricultural Water Production Cost (EC2)	19.4	46.6	36.0
Public Network Production Cost (EC3)	29.9	83.3	7.4
Public Network Production Cost per Beneficiary (EC4)	14.8	30.6	3.4
Industrial/ Agricultural Water Productivity (EC5)	88.5	24.6	50.8
Aquifer Water Level (EN1)	19.4	46.6	4.2
Reliability of Supply from Aquifer (EN2)	19.4	46.6	4.2
Aquifer Water Quality (EN3)	9.9	22.6	1.7
Wastewater Discharge (EN4)	33.7	73.1	4.5
Agricultural Pesticide Use (EN5)	31.3	72.5	6.4
Industrial Effluent (EN6)	30.3	72.0	6.2
Water Connection (SO1)	-11.2	-16.8	2.1
Water Quality (SO2)	-46.1	-83.8	-27.6
Water Usage (SO3)	-55.7	-100.0	2.1
Agricultural Jobs Creation (SO4)	12.8	30.8	2.8
Industrial Jobs Creation (SO5)	-28.4	-48.3	-22.3
Source Yield and Livelihoods (SO6)	46.5	95.4	-7.5
Expenditure on Water (SO7)	-43.9	-78.0	-14.5

Table 5.29: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI Weights – Relative Changes in Weights (%) that Would Cause Reversal of Ranking between MO3 and MO 4, 5

Basic Indicator	MO3=MO4 (DM)	MO3=MO5 (RE)
Internal Rate of Return (EC1)	-100.0	11.5
Agricultural Water Production Cost (EC2)	15.3	-24.8
Public Network Production Cost (EC3)	27.1	1.4
Public Network Production Cost per Beneficiary (EC4)	7.3	0.9
Industrial/ Agricultural Water Productivity (EC5)	-98.6	-19.6
Aquifer Water Level (EN1)	15.4	1.4
Reliability of Supply from Aquifer (EN2)	15.4	1.4
Aquifer Water Quality (EN3)	6.8	1.0
Wastewater Discharge (EN4)	19.2	4.7
Agricultural Pesticide Use (EN5)	22.0	2.6
Industrial Effluent (EN6)	22.6	2.5
Water Connection (SO1)	7.7	-4.5
Water Quality (SO2)	7.7	11.2
Water Usage (SO3)	7.7	-15.7
Agricultural Jobs Creation (SO4)	10.2	0.9
Industrial Jobs Creation (SO5)	10.2	11.2
Source Yield and Livelihoods (SO6)	10.2	17.8
Expenditure on Water (SO7)	10.2	0.9

Another Euclidian distance value which is worthwhile mentioning is the one associated with the MO3 – MO4 pair, where d_e =0.079 (table 5.26). Despite the relatively average value of d_e, the ranking of the two management options seems to be robust, as the required relative change in weights to reverse ranking reaches a value of -100% (EC1 – Internal Rate of Return) and -99% (EC5 – Industrial/ Agricultural Water Productivity) (table 5.29).

Table 5.30: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI Weights (%) – Relative Changes in Weights that Would Cause Reversal of Ranking between MO4 and MO5

Basic Indicator	MO4= MO5 (RE)
Internal Rate of Return (EC1)	-22.2
Agricultural Water Production Cost (EC2)	-40.5
Public Network Production Cost (EC3)	8.2
Public Network Production Cost per Beneficiary (EC4)	2.1
Industrial/ Agricultural Water Productivity (EC5)	-66.3
Aquifer Water Level (EN1)	4.5
Reliability of Supply from Aquifer (EN2)	4.6
Aquifer Water Quality (EN3)	2.6
Wastewater Discharge (EN4)	10.0
Agricultural Pesticide Use (EN5)	7.2
Industrial Effluent (EN6)	7.4
Water Connection (SO1)	-6.7
Water Quality (SO2)	20.3
Water Usage (SO3)	2.3
Agricultural Jobs Creation (SO4)	3.0
Industrial Jobs Creation (SO5)	20.7
Source Yield and Livelihoods (SO6)	32.0
Expenditure on Water (SO7)	3.0

5.1.3.2.4 Comparison of Results:

Table 5.31 compares the 3 methods used for assessing sensitivity of MO ranking to the elicitation of basic indicators weights. An analysis of the results points out the following:

- Ranking of MO1 (Groundwater Supply Development) – MO4 (Demand Management) pair is very sensitive to the basic indicators weights; all three methods lead to the same conclusion, but with a divergence of results as to the most critical BI weights.
- Ranking of MO3 (Direct Connection to Mekerot) – MO4 (Demand Management) pair is robust, as concurred by the 3 methods.
- Both the sensitivity analysis method and the distance based method indicate a robust ranking for the following management options pairs: MO2-MO4; MO1-MO2. The robustness measure method does not contradict these results, based on the relatively high value of the robustness index.
- All three methods seem to indicate an indifference of ranking of the MO3-MO5 pair, as the robustness index is relatively low (0.15) and the required changes in weights are relatively on the low side too (10% and 35% for the sensitivity analysis method; and a range of -25% to 18% for the distance based method).
- The distance-based method seems to be the most appropriate as it overcomes the limitations associated with the robustness and the sensitivity methods.

Table 5.31: Comparison of 3 Methods for Assessing Sensitivity to the Elicitation of BI Weights

	Robustness Measure	Sensitivity Analysis	Distance Based
Requirements	changing all weights at the same time by the same value	changing 1weight at a time by different values	changing all weights at the same time by different values
Interpretation of Results	a value ~ 0 implies indifference; a value ~ 1 implies robustness	a value ~ 0 implies indifference	a value ~ 0 implies indifference
Limitations	• Σw ≠ 1 • Critical w cannot be pointed out	Impact of w simultaneous change cannot be identified	
Results			
MO1- MO2	r=0.64	RR(*) infeasible ⇒ robustness	E_d=0.12 ⇒ robustness
MO1- MO3	r=0.26	CW(**)=SO7 (209%)	E_d=0.04 WCR(***)=-35:46
MO1- MO4	r=-0.04 ⇒ indifference	CW=EC1 (34%) =EN3 (23%) =SO7 (85%) ⇒ indifference	E_d=0.007 CW=EC4 (0%) =SO3 (0.3%) =SO4 (0.4%) =SO5 (0.4%) =EC3 (0.4%) ⇒ indifference
MO1- MO5	r=0.28	CW=SO7 (284%)	E_d=0.05 WCR=-50:34
MO2- MO3	r=-0.53	CW=EC5 (459%)	E_d=0.10 ⇒ robustness
MO2- MO4	r=-0.82	RR infeasible ⇒ robustness	E_d=0.16 ⇒ robustness
MO2- MO5	r=-0.32	CW=EC2 (534%) =EC5 (225%)	E_d=0.05 WCR=-39:51
MO3- MO4	r=-0.94 ⇒ robustness	RR infeasible ⇒ robustness	E_d=0.08 ⇒ robustness
MO3- MO5	r=0.15	CW=EC5 (10%) = SO3 (35%) ⇒ indifference	E_d=0.03 WCR=-25:18
MO4- MO5	r=0.34	CW= SO2 (370%) = SO6 (392%)	E_d=0.05 WCR=-66:32

(*)RR=Ranking Reversal
(**)CW=Critical Weight
(***)WCR=Weight Change Range (%)

5.1.3.3 Sensitivity to Assignment of BIPV vs. Sensitivity to Elicitation of BIW:

Sections 5.1.3.1 and 5.1.3.2 have presented sensitivity analysis results related to the assignment of basic indicators performance values and to the elicitation of basic indicators weights in the SUSMAQ DST NWB/CS. The purpose of this section is to check which of the BIW and BIPV influences the result most, by:

- comparing results of sections 5.1.3.1 and 5.1.3.2; and
- studying the sensitivity of MO ranking to the simultaneous change of BIW and BIPV, using the distance based uncertainty method

Table 5.32: SUSMAQ DST NWB/CS- Comparison of Sensitivity to Assignment of BIPV and Sensitivity to Elicitation of BIW

	Basic Indicators Performance Values	**Basic Indicators Weights (Based on the 3 methods)**
MO1- MO2	robustness	~ robustness
MO1- MO3	medium sensitivity (SO1)	no direct conclusion can be made
MO1- MO4	indifference	indifference (EC1, EC3, EC4, EN3, SO3, SO4, SO5, SO7)
MO1- MO5	medium sensitivity (SO1, SO5)	no direct conclusion can be made
MO2- MO3	robustness	~ robustness
MO2- MO4	robustness	~ robustness
MO2- MO5	robustness	no direct conclusion can be made
MO3- MO4	medium sensitivity (SO1)	robustness
MO3- MO5	medium sensitivity (SO1)	~ indifference (EC5, SO3)
MO4- MO5	medium sensitivity (SO1)	no direct conclusion can be made

Table 5.32 summarises results of sections 5.1.3.1 and 5.1.3.2 with the following interpretations:

- Elicitation of basic indicators weights seems to have an influence in 6 out of 10 cases, based on 2 cases where sensitivity of results (i.e. indifference) was clearly demonstrated to depend on BIW, 4 cases where robustness was evident and 4 cases where no clear conclusion could be made. Assignment of basic indicators performance values has an influence in 6 out of the 10 cases, based on 1 case where results were found to be very highly sensitive to the BIPV, 5 cases where results were found to be medium sensitive to BIPV and 4 cases where results were found to be robust. Therefore, MO ranking seems to be more sensitive to BIPV than to BIW.

- Both BIW and BIPV are very critical for the ranking of MO1 (Groundwater Supply Development) – MO4 (Demand Management), and not critical for the ranking of MO1/MO2 (Groundwater Supply Development/ Rainwater Harvesting) nor for MO2/MO4 (Rainwater Harvesting/ Demand Management), nor for MO2/MO3 (Rainwater Harvesting/ Direct Connection to Mekerot).

Table 5.33 presents the ranking of SUSMAQ MO based on table 5.5 and discusses whether the ranking is sensitive to BIW and/or BIPV based on table 5.32. It is clear from table 5.33 that ranking of SUSMAQ management options is strongly influenced by either the elicitation of basic indicators weights or the assignment of basic indicators performance values.

Table 5.33: SUSMAQ DST NWB/CS – Influence of BIW and BIPV on MO Ranking

<table>
<tr><th>Ranking of SUSMAQ MO</th><th>Influence of BIW and/or BIPV</th></tr>
<tr><td>MO4 – Demand Management (0.68)</td><td rowspan="5">MO4-MO1 ranking is highly sensitive to both BIPV and BIW

MO1-MO3 ranking is medium sensitive to BIPV and BIW

MO3-MO5 ranking is highly sensitive to BIW & medium sensitive to BIPV

MO5-MO2 ranking might be sensitive to BIW</td></tr>
<tr><td>MO1 - Groundwater Supply Development (0.67)</td></tr>
<tr><td>MO3 – Direct Connection to Mekerot (0.63)</td></tr>
<tr><td>MO5- Wastewater Reuse (0.61)</td></tr>
<tr><td>MO2 – Rainwater Harvesting (0.54)</td></tr>
</table>

Tables 5.34-5.44 explore the sensitivity of MO ranking to the simultaneous change of BIPV and BIW, using the distance based uncertainty analysis method[8].

[8] The calculation is done using Solver, a Microsoft Excel Add-In Function, which is based upon the Generalised Reduced Gradient (GRG2) non-linear optimisation method, as mentioned in chapter 3. GRG2 works first by evaluating the function and its derivatives at a starting value of the decision vector and then iteratively searching for a better solution using a search direction suggested by the derivatives. The GRG2 optimisation method requires that starting values are specified for the decision variables, therefore, random numbers are generated using the Microsoft Excel RANDBETWEEN function between the specified input parameter ranges for the BIW and the BIPV to be used as the starting values for the optimisation (Stokes & Plummer, 2004 cited in Hyde & Maier, 2005) - the Solver tool is found on the tools menu; the objective function is entered in *Set Target Cell* and the decision variables in *By Changing Cells,* constraints are added by selecting the *Add* button.

Table 5.34 presents the Euclidian distance matrix; while tables 5.35-5.44 present the relative changes in the basic indicators PV and W that would cause a reversal of ranking between MO1 and MO2 (table 5.35), MO1 and MO3 (table 5.36), MO1 and MO4 (table 5.37), MO1 and MO5 (table 5.38), MO2 and MO3 (table 5.39), MO2 and MO4 (table 5.40), MO2 and MO5 (table 5.41), MO3 and MO4 (table 5.42), MO3 and MO5 (table 5.43), MO4 and MO5 (table 5.44).

Table 5.34: SUSMAQ DST NWB/CS – Euclidian Distance (BIPV, W)

	MO1 (Groundwater Supply GW)	MO2 (Rainwater Harvesting RW)	MO3 (Connection to Mekerot ME)	MO4 (Demand Management DM)	MO5 (Wastewater Reuse RE)
$d_e(MO_1,...)$		0.115	0.041	0.006	0.046
$d_e(MO_2,...)$			0.096	0.143	0.047
$d_e(MO_3,...)$				0.065	0.025
$d_e(MO_4,...)$					0.054

It is clear from table 5.34 that there is almost total indifference between MO1 (Groundwater supply development) and MO4 (Demand management) due to the very small value of the Euclidian distance (0.006); while the MO2/MO4 (Rainwater harvesting/Demand management) seems to be robust due to the relatively high value of the Euclidian distance (0.143)

Table 5.35 indicates a relatively robust MO1/MO2 (Groundwater supply development/ Rainwater harvesting) ranking since required changes in the BIW can reach 100% (EC1 – Internal rate of return). Required changes in the PV however do not exceed 17% (SO5 – Industrial jobs creation); which demonstrates a higher ranking sensitivity to BIPV than to BIW.

Table 5.35: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO1 and MO2

Basic Indicator	MO1=MO2=0.67 (d_c=0.115)					
	MO1 PV_0	MO1 (% Δ)	MO2 PV_0	MO2 (% Δ)	W_0	ΔW (%)
Internal Rate of Return (EC1)	0.55	0.00	0.00	(0.00)	0.00	-100.00
Agricultural Water Production Cost (EC2)	0.62	-0.85	0.63	0.85	0.05	21.70
Public Network Production Cost (EC3)	0.91	-0.68	1.00	0.00	0.06	40.01
Public Network Production Cost/ Beneficiary (EC4)	0.97	-0.80	1.00	0.15	0.07	17.88
Industrial/ Agricultural Water Productivity (EC5)	0.89	-0.81	0.86	0.84	0.07	8.96
Aquifer Water Level (EN1)	0.94	-0.61	1.00	0.00	0.06	33.35
Reliability of Supply from Aquifer (EN2)	0.99	-0.52	1.00	0.00	0.05	20.33
Aquifer Water Quality (EN3)	0.83	-1.30	0.93	1.19	0.10	21.57
Wastewater Discharge (EN4)	0.65	-0.80	0.79	0.67	0.05	82.37
Agricultural Pesticide Use (EN5)	0.69	-0.65	0.77	0.59	0.04	57.03
Industrial Effluent (EN6)	0.85	-0.56	0.94	0.51	0.05	61.54
Water Connection (SO1)	0.34	-1.65	0.01	(0.01)	0.05	-33.89
Water Quality (SO2)	0.70	-0.25	0.00	(0.00)	0.02	-79.77
Water Usage (SO3)	1.00	-0.44	0.54	0.83	0.04	-49.45
Agricultural Jobs Creation (SO4)	0.26	-2.81	0.28	2.81	0.07	15.10
Industrial Jobs Creation (SO5)	0.25	-1.99	0.03	16.90	0.05	-23.64
Source Yield and Livelihoods (SO6)	0.81	-0.93	0.82	0.93	0.07	15.10
Expenditure on Water (SO7)	0.00	(0.00)	0.24	4.39	0.10	53.28

Table 5.36 demonstrates that minor changes in BIPV (less than 3%) and more important changes in BIW (reaching more than 40% for SO7 – expenditure on water) can cause a reversal of ranking between MO1 (Groundwater supply development) and MO3 (Direct connection to Mekerot).

Table 5.36: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO1 and MO3

Basic Indicator	MO1=MO3=0.65 (d_c=0.041)					
	MO1 PV_0	MO1 (% Δ)	MO3 PV_0	MO3 (% Δ)	W_0	ΔW (%)
Internal Rate of Return (EC1)	0.55	-0.28	0.37	0.41	0.03	-17.76
Agricultural Water Production Cost (EC2)	0.62	-0.30	0.63	0.30	0.04	2.03
Public Network Production Cost (EC3)	0.92	-0.22	0.96	0.21	0.05	6.19
Public Network Production Cost/ Beneficiary (EC4)	0.97	-0.30	0.99	0.29	0.06	2.29
Industrial/ Agricultural Water Productivity (EC5)	0.89	-0.22	0.45	0.44	0.04	-30.80
Aquifer Water Level (EN1)	0.95	-0.21	1.00	0.00	0.04	7.30
Reliability of Supply from Aquifer (EN2)	1.00	-0.19	1.00	0.00	0.04	1.82
Aquifer Water Quality (EN3)	0.83	-0.48	0.92	0.44	0.09	5.13
Wastewater Discharge (EN4)	0.66	-0.23	0.78	0.19	0.03	22.35
Agricultural Pesticide Use (EN5)	0.70	-0.20	0.76	0.18	0.03	12.71
Industrial Effluent (EN6)	0.86	-0.17	0.94	0.16	0.03	14.91
Water Connection (SO1)	0.35	-0.96	0.15	2.23	0.07	-9.74
Water Quality (SO2)	0.70	-0.45	0.40	0.79	0.07	-15.21
Water Usage (SO3)	1.00	-0.37	1.00	0.00	0.08	1.01
Agricultural Jobs Creation (SO4)	0.27	-1.06	0.27	1.06	0.06	1.48
Industrial Jobs Creation (SO5)	0.25	-1.13	0.26	1.12	0.06	1.48
Source Yield and Livelihoods (SO6)	0.81	-0.30	0.64	0.39	0.06	-11.75
Expenditure on Water (SO7)	0.00	(0.00)	0.54	0.73	0.09	40.12

Table 5.37 indicates an indifference in ranking between MO1 (Groundwater supply development) and MO4 (Demand management) due to the very negligible change in BIPV (~0%) and small change in BIW (maximum of 7% for SO7-Water expenditure).

Table 5.37: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO1 and MO4

Basic Indicator	MO1=MO4=0.67 (d_c=0.006)					
	MO1 PV_o	MO1 (% Δ)	MO4 PV_o	MO4 (% Δ)	W_o	ΔW (%)
Internal Rate of Return (EC1)	0.55	0.06	0.74	-0.04	0.04	-3.16
Agricultural Water Production Cost (EC2)	0.63	0.05	0.62	-0.05	0.04	0.48
Public Network Production Cost (EC3)	0.92	0.04	0.93	-0.04	0.04	0.33
Public Network Production Cost/ Beneficiary (EC4)	0.98	0.05	1.00	-0.05	0.06	0.03
Industrial/ Agricultural Water Productivity (EC5)	0.89	0.06	0.87	-0.06	0.06	0.55
Aquifer Water Level (EN1)	0.95	0.03	1.00	-0.03	0.04	-0.50
Reliability of Supply from Aquifer (EN2)	1.00	0.00	1.00	-0.03	0.04	0.47
Aquifer Water Quality (EN3)	0.84	0.08	0.91	-0.07	0.08	-0.50
Wastewater Discharge (EN4)	0.66	0.03	0.78	-0.03	0.03	-2.98
Agricultural Pesticide Use (EN5)	0.70	0.03	0.76	-0.03	0.03	-1.11
Industrial Effluent (EN6)	0.86	0.03	0.93	-0.02	0.03	-1.47
Water Connection (SO1)	0.35	0.19	0.15	-0.46	0.08	2.20
Water Quality (SO2)	0.70	0.10	0.40	-0.17	0.09	3.18
Water Usage (SO3)	1.00	0.00	1.00	-0.07	0.08	0.24
Agricultural Jobs Creation (SO4)	0.27	0.19	0.27	-0.19	0.06	0.32
Industrial Jobs Creation (SO5)	0.25	0.20	0.25	-0.20	0.06	0.32
Source Yield and Livelihoods (SO6)	0.82	0.06	0.63	-0.08	0.06	2.68
Expenditure on Water (SO7)	0.00	(0.00)	0.54	-0.09	0.06	-6.63

Table 5.38 indicates that changes of the order of ~1% max in BIPV and 48% max in BIW (EC5 – Industrial/Agricultural Water Productivity) can cause a reversal of ranking between MO1 (Groundwater supply development) and MO5 (Demand management).

Table 5.38: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO1 and MO5

Basic Indicator	MO1=MO5=0.65 (d_c=0.046)					
	MO1 PV_o	MO1 (% Δ)	MO5 PV_o	MO5 (% Δ)	W_o	ΔW (%)
Internal Rate of Return (EC1)	0.55	-0.26	0.51	0.28	0.04	0.18
Agricultural Water Production Cost (EC2)	0.62	-0.16	0.25	0.41	0.03	-28.38
Public Network Production Cost (EC3)	0.92	-0.17	0.96	0.16	0.05	6.43
Public Network Production Cost/ Beneficiary (EC4)	0.97	-0.23	0.99	0.23	0.06	2.87
Industrial/ Agricultural Water Productivity (EC5)	0.89	-0.13	0.00	(0.00)	0.03	-47.50
Aquifer Water Level (EN1)	0.95	-0.16	1.00	0.00	0.04	7.38
Reliability of Supply from Aquifer (EN2)	1.00	-0.15	1.00	0.00	0.04	3.15
Aquifer Water Quality (EN3)	0.83	-0.37	0.93	0.34	0.09	5.17
Wastewater Discharge (EN4)	0.66	-0.18	0.80	0.15	0.03	22.96
Agricultural Pesticide Use (EN5)	0.70	-0.15	0.76	0.14	0.03	12.99
Industrial Effluent (EN6)	0.86	-0.13	0.94	0.12	0.03	14.58
Water Connection (SO1)	0.35	-0.71	0.00	(0.00)	0.07	-13.02
Water Quality (SO2)	0.70	-0.42	0.70	0.42	0.08	1.76
Water Usage (SO3)	1.00	-0.24	0.53	0.44	0.07	-18.03
Agricultural Jobs Creation (SO4)	0.27	-0.82	0.27	0.82	0.06	2.24
Industrial Jobs Creation (SO5)	0.25	-0.98	0.48	0.52	0.07	14.72
Source Yield and Livelihoods (SO6)	0.81	-0.30	1.00	0.00	0.07	12.30
Expenditure on Water (SO7)	0.00	(0.00)	0.54	0.53	0.08	32.08

Table 5.39 indicates that a relatively high change in BIW (78% for EC5 – Industrial/Agricultural Water Productivity) is required to cause a reversal of ranking between MO2 (Rainwater harvesting) and MO3 (Direct connection to Mekerot), accompanied with smaller changes in BIPV (<16%).

Table 5.39: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO2 and MO3

Basic Indicator	MO2=MO3=0.64 (d_c=0.096)					
	MO2 PV_o	MO2 (% Δ)	MO3 PV_o	MO3 (% Δ)	W_o	ΔW (%)
Internal Rate of Return (EC1)	0.00	(0.00)	0.37	-0.27	0.01	-73.78
Agricultural Water Production Cost (EC2)	0.63	0.77	0.62	-0.77	0.05	16.89
Public Network Production Cost (EC3)	1.00	0.00	0.95	-0.56	0.05	24.70
Public Network Production Cost/ Beneficiary (EC4)	1.00	0.15	0.98	-0.71	0.07	12.38
Industrial/ Agricultural Water Productivity (EC5)	0.87	1.30	0.44	-2.50	0.11	78.12
Aquifer Water Level (EN1)	1.00	0.00	1.00	-0.48	0.05	15.50
Reliability of Supply from Aquifer (EN2)	1.00	0.00	1.00	-0.47	0.05	15.28
Aquifer Water Quality (EN3)	0.92	1.01	0.90	-1.01	0.09	9.44
Wastewater Discharge (EN4)	0.79	0.44	0.77	-0.45	0.03	27.74
Agricultural Pesticide Use (EN5)	0.77	0.45	0.75	-0.45	0.03	25.73
Industrial Effluent (EN6)	0.94	0.37	0.93	-0.37	0.04	25.11
Water Connection (SO1)	0.01	(0.01)	0.14	-4.98	0.08	-9.01
Water Quality (SO2)	0.00	(0.00)	0.40	-1.24	0.05	-39.61
Water Usage (SO3)	0.54	0.79	1.00	-0.42	0.04	-48.06
Agricultural Jobs Creation (SO4)	0.28	2.57	0.26	-2.57	0.07	11.61
Industrial Jobs Creation (SO5)	0.03	15.57	0.25	-1.83	0.05	-24.62
Source Yield and Livelihoods (SO6)	0.83	1.08	0.63	-1.39	0.09	41.08
Expenditure on Water (SO7)	0.23	1.68	0.53	-0.70	0.04	-37.92

Table 5.40 demonstrates a relatively robust ranking of the MO2/MO4 (Rainwater Harvesting/Demand Management) since required changes in BIW reach 100% (EC1 – Internal Rate of Return), but changes in BIPV are smaller (<23%).

Table 5.40: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO2 and MO4

Basic Indicator	MO2=MO4=0.70 (d_c=0.143)					
	MO2 PV_o	MO2 (% Δ)	MO4 PV_o	MO4 (% Δ)	W_o	ΔW (%)
Internal Rate of Return (EC1)	0.00	(0.00)	0.74	0.00	0.00	-100.00
Agricultural Water Production Cost (EC2)	0.63	1.56	0.62	-1.56	0.06	38.39
Public Network Production Cost (EC3)	1.00	0.00	0.91	-1.28	0.07	63.62
Public Network Production Cost/ Beneficiary (EC4)	1.00	0.15	0.99	-1.33	0.08	23.93
Industrial/ Agricultural Water Productivity (EC5)	0.87	1.52	0.86	-1.49	0.08	22.38
Aquifer Water Level (EN1)	1.00	0.00	0.99	-0.95	0.06	34.24
Reliability of Supply from Aquifer (EN2)	1.00	0.00	0.99	-0.95	0.06	34.24
Aquifer Water Quality (EN3)	0.93	1.93	0.90	-1.93	0.10	21.84
Wastewater Discharge (EN4)	0.79	0.93	0.78	-0.93	0.04	57.05
Agricultural Pesticide Use (EN5)	0.77	0.95	0.75	-0.96	0.04	56.49
Industrial Effluent (EN6)	0.95	0.80	0.93	-0.80	0.04	56.40
Water Connection (SO1)	0.01	(0.01)	0.14	-8.39	0.07	-10.67
Water Quality (SO2)	0.00	(0.00)	0.40	-1.21	0.03	-65.62
Water Usage (SO3)	0.53	0.51	1.00	-0.27	0.02	-80.72
Agricultural Jobs Creation (SO4)	0.28	5.04	0.26	-5.04	0.08	27.47
Industrial Jobs Creation (SO5)	0.04	22.34	0.25	-2.63	0.04	-37.52
Source Yield and Livelihoods (SO6)	0.84	2.36	0.61	-3.04	0.11	80.56
Expenditure on Water (SO7)	0.23	1.76	0.53	-0.76	0.02	-61.84

Table 5.41 indicates that a reversal of ranking between MO2 (Rainwater harvesting) and MO5 (reuse) require a change of up to 49% (EC5 – Industrial Agricultural Water Productivity) in the BIW, with minor changes in BIPV (<6%).

Table 5.41: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO2 and MO5

Basic Indicator	MO2=MO5=0.59 (d_c=0.047)					
	MO2 PV_0	MO2 (% Δ)	MO5 PV_0	MO5 (% Δ)	W_0	ΔW (%)
Internal Rate of Return (EC1)	0.00	(0.00)	0.51	-0.17	0.03	-37.47
Agricultural Water Production Cost (EC2)	0.63	0.29	0.25	-0.74	0.06	34.24
Public Network Production Cost (EC3)	1.00	0.00	0.96	-0.16	0.05	6.93
Public Network Production Cost/ Beneficiary (EC4)	1.00	0.15	0.99	-0.22	0.06	3.24
Industrial/ Agricultural Water Productivity (EC5)	0.86	0.36	0.00	(0.00)	0.09	48.21
Aquifer Water Level (EN1)	1.00	0.00	1.00	-0.14	0.04	3.84
Reliability of Supply from Aquifer (EN2)	1.00	0.00	1.00	-0.14	0.04	3.84
Aquifer Water Quality (EN3)	0.92	0.31	0.92	-0.31	0.09	1.76
Wastewater Discharge (EN4)	0.79	0.12	0.80	-0.12	0.03	4.15
Agricultural Pesticide Use (EN5)	0.76	0.13	0.76	-0.13	0.03	5.88
Industrial Effluent (EN6)	0.94	0.10	0.94	-0.10	0.03	5.72
Water Connection (SO1)	0.00	(0.00)	0.00	(0.00)	0.08	1.98
Water Quality (SO2)	0.00	(0.00)	0.70	-0.29	0.06	-26.17
Water Usage (SO3)	0.53	0.53	0.53	-0.53	0.08	2.09
Agricultural Jobs Creation (SO4)	0.27	0.79	0.27	-0.79	0.06	2.69
Industrial Jobs Creation (SO5)	0.03	5.48	0.48	-0.34	0.05	-21.17
Source Yield and Livelihoods (SO6)	0.82	0.24	1.00	-0.19	0.06	-7.06
Expenditure on Water (SO7)	0.23	0.78	0.54	-0.33	0.05	-13.71

Table 5.42 demonstrates a relatively robust ranking of the MO3/MO4 (Direct connection to Mekerot/ Demand management) pair due to a required change of up to 82% in BIW (EC1 – Internal rate of return), with minor changes in BIPV (<6%).

Table 5.42: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO3 and MO4

Basic Indicator	MO3=MO4=0.66 (d_c=0.065)					
	MO3 PV_0	MO3 (% Δ)	MO4 PV_0	MO4 (% Δ)	W_0	ΔW (%)
Internal Rate of Return (EC1)	0.37	0.21	0.73	-0.10	0.01	-81.94
Agricultural Water Production Cost (EC2)	0.63	0.74	0.62	-0.74	0.05	10.55
Public Network Production Cost (EC3)	0.96	0.53	0.92	-0.55	0.05	18.17
Public Network Production Cost/ Beneficiary (EC4)	0.99	0.68	0.99	-0.67	0.07	5.79
Industrial/ Agricultural Water Productivity (EC5)	0.45	0.52	0.87	-0.27	0.02	-63.63
Aquifer Water Level (EN1)	1.00	0.00	1.00	-0.46	0.05	9.39
Reliability of Supply from Aquifer (EN2)	1.00	0.00	1.00	-0.46	0.05	9.39
Aquifer Water Quality (EN3)	0.92	1.00	0.91	-1.00	0.09	5.78
Wastewater Discharge (EN4)	0.78	0.40	0.78	-0.40	0.03	12.20
Agricultural Pesticide Use (EN5)	0.76	0.42	0.76	-0.42	0.03	14.06
Industrial Effluent (EN6)	0.94	0.35	0.93	-0.35	0.03	14.53
Water Connection (SO1)	0.16	5.96	0.14	-5.95	0.09	6.33
Water Quality (SO2)	0.41	2.23	0.39	-2.23	0.09	6.34
Water Usage (SO3)	1.00	0.00	0.99	-0.88	0.09	5.22
Agricultural Jobs Creation (SO4)	0.28	2.54	0.26	-2.53	0.07	7.68
Industrial Jobs Creation (SO5)	0.26	2.70	0.25	-2.70	0.07	7.69
Source Yield and Livelihoods (SO6)	0.64	1.08	0.63	-1.08	0.07	7.70
Expenditure on Water (SO7)	0.55	1.27	0.53	-1.27	0.07	7.69

Based on table 5.43, there is almost indifference between MO3 (Direct connection to Mekerot) and MO5 (Reuse), since the changes required in BIW are less than 22% (EC2 – Agricultural Water Production Cost) and less than 6% in BIPV.

Table 5.43: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO3 and MO5

Basic Indicator	MO3=MO5=0.63 (d_c=0.025)					
	MO3 PV_0	MO3 (% Δ)	MO5 PV_0	MO5 (% Δ)	W_0	ΔW (%)
Internal Rate of Return (EC1)	0.37	0.05	0.51	0.22	0.05	10.10
Agricultural Water Production Cost (EC2)	0.62	0.03	0.25	0.33	0.03	-21.92
Public Network Production Cost (EC3)	0.96	0.04	0.96	0.11	0.04	1.18
Public Network Production Cost/ Beneficiary (EC4)	0.99	0.06	0.99	0.16	0.06	0.84
Industrial/ Agricultural Water Productivity (EC5)	0.45	0.05	0.00	(0.00)	0.05	-17.33
Aquifer Water Level (EN1)	1.00	0.04	1.00	0.00	0.04	1.15
Reliability of Supply from Aquifer (EN2)	1.00	0.04	1.00	0.00	0.04	1.15
Aquifer Water Quality (EN3)	0.91	0.09	0.92	0.24	0.09	0.97
Wastewater Discharge (EN4)	0.77	0.03	0.80	0.09	0.03	4.04
Agricultural Pesticide Use (EN5)	0.76	0.03	0.76	0.09	0.03	2.18
Industrial Effluent (EN6)	0.93	0.03	0.94	0.08	0.03	2.12
Water Connection (SO1)	0.15	0.08	0.00	(0.00)	0.08	-3.96
Water Quality (SO2)	0.40	0.09	0.70	0.33	0.09	9.92
Water Usage (SO3)	1.00	0.07	0.53	0.34	0.07	-13.79
Agricultural Jobs Creation (SO4)	0.27	0.06	0.27	0.59	0.06	0.84
Industrial Jobs Creation (SO5)	0.25	0.07	0.48	0.37	0.07	9.96
Source Yield and Livelihoods (SO6)	0.63	0.07	1.00	0.00	0.07	15.67
Expenditure on Water (SO7)	0.54	0.06	0.54	0.30	0.06	0.84

Table 5.44 indicates that a reversal of ranking between MO4 (Demand management) and MO5 (Reuse) requires a change of ~58% in BIW (EC5 – Industrial/Agricultural water productivity), and minor changes in the BIPV (<3%).

Table 5.44: SUSMAQ DST NWB/CS – Distance Based Uncertainty Analysis on BI PV and W - Changes in BIPV and BIW that Would Cause Reversal of Ranking between MO4 and MO5

Basic Indicator	MO4=MO5=0.66 (d_c=0.054)					
	MO4 PV_0	MO4 (% Δ)	MO5 PV_0	MO5 (% Δ)	W_0	ΔW (%)
Internal Rate of Return (EC1)	0.73	-0.20	0.51	0.29	0.03	-17.04
Agricultural Water Production Cost (EC2)	0.62	-0.19	0.25	0.48	0.03	-33.35
Public Network Production Cost (EC3)	0.92	-0.22	0.96	0.21	0.05	9.91
Public Network Production Cost/ Beneficiary (EC4)	1.00	-0.29	0.99	0.29	0.06	3.78
Industrial/ Agricultural Water Productivity (EC5)	0.87	-0.13	0.00	(0.00)	0.03	-57.15
Aquifer Water Level (EN1)	1.00	-0.19	1.00	0.00	0.04	6.53
Reliability of Supply from Aquifer (EN2)	1.00	-0.19	1.00	0.00	0.04	6.53
Aquifer Water Quality (EN3)	0.91	-0.42	0.93	0.42	0.09	3.83
Wastewater Discharge (EN4)	0.78	-0.17	0.80	0.17	0.03	12.80
Agricultural Pesticide Use (EN5)	0.76	-0.17	0.76	0.17	0.03	10.36
Industrial Effluent (EN6)	0.93	-0.15	0.94	0.14	0.03	10.41
Water Connection (SO1)	0.15	-2.31	0.00	(0.00)	0.08	-4.46
Water Quality (SO2)	0.40	-1.08	0.70	0.62	0.10	19.60
Water Usage (SO3)	1.00	-0.28	0.53	0.54	0.06	-21.50
Agricultural Jobs Creation (SO4)	0.27	-1.06	0.27	1.06	0.07	4.58
Industrial Jobs Creation (SO5)	0.25	-1.30	0.48	0.69	0.08	20.38
Source Yield and Livelihoods (SO6)	0.63	-0.56	1.00	0.00	0.08	30.14
Expenditure on Water (SO7)	0.54	-0.53	0.54	0.53	0.07	4.58

Results of the sensitivity analysis to the simultaneous change of BIPV and W indicate that ranking is more sensitive to BIPV than to BIW. A summary of all sensitivity analysis exercises is presented in table 5.45, with shaded rows corresponding to the SUSMAQ DST NWB/CS ranking (MO4-MO1-MO3-MO5-MO2). Table 5.45 indicates that simultaneous changes in BIPV and BIW generate results that are very consistent with separate changes in BIPV and BIW.

Table 5.45: SUSMAQ DST NWB/CS- Comparison of Sensitivity to Assignment of BIPV, Sensitivity to Elicitation of BIW, and Sensitivity to both BIPV and BIW

	Change in BI Performance Values	Change in BI Weights (Based on the 3 methods)	Simultaneous Change in BI PV and W
MO1- MO2	Low (Robustness)	Low (~ Robustness)	Low (Robustness)
MO1- MO3	Medium	no conclusion	Medium
MO1- MO4	High (Indifference)	High (Indifference) (EC1, EC3, EN3, SO3, SO4, SO5, SO7)	High (Indifference)
MO1- MO5	Medium	no conclusion	Medium
MO2- MO3	Low (Robustness)	Low (~Robustness)	Low (~ Robustness)
MO2- MO4	Low (Robustness)	Low (~ Robustness)	Low (Robustness)
MO2- MO5	Low (Robustness)	no conclusion	Medium
MO3- MO4	Medium	Low (robustness)	Low (~ Robustness)
MO3- MO5	Medium	High (~ Indifference) (EC5, SO3)	Medium – High (~ Indifference)
MO4- MO5	Medium	no conclusion	Medium

5.1.4 Strategy Development:

Ranking of management options (MO) related to the SUSMAQ DST NWB/CS seems to be sensitive to both the value of the weights assigned to the various basic indicators (BIW), and the performance value of these various BI (BIPV), with a higher sensitivity to BIPV. The impact of this sensitivity increases when there is no consensus on the assignment of the BIW, and/or when the level of confidence in BIPV is low or medium. This would mean for example that a conclusion such as a ranking of two MO is robust because reversal of ranking between the two MO requires a 100% change in the value of a BIW or a BIPV is not totally true, if there is no consensus on the assignment of the BIW or if the level of confidence in the elicitation of the BIPV is low. Therefore, it is difficult to automatically exclude any of the MO in developing strategy alternatives for water resources management in the West Bank.

5.1.4.1 Generation of Strategies:

Based on the sensitivity analysis of SUSMAQ DST NWB (North West Bank)/CS (Current Scenario) Management Options (MO) ranking to Basic Indicators (BI) performance values (BIPV) and weights (BIW), and uncertainties associated to these BIPV and BIW, five strategies are proposed which consist of a combination of MO that take into account MO ranking in relation to uncertainty in, and sensitivity to BIPV and BIW (table 5.46). ST1 for example consists of a full implementation of each MO - hence the 1,1,1,1,1 coefficients in table 5.50.

Table 5.46: SUSMAQ DST NWB/CS- Strategy Development

	ST1	ST2	ST3	ST4	ST5
MO1 (GW supply development)	1	1	1	1	1
MO2 (Rainwater harvesting)	1	0	0	0	0
MO3 (Direct connection to Mekerot)	1	2/3	1/4	0	0
MO4 (Demand management)	1	1	1	1	1
MO5 (Reuse)	1	2/3	1/4	1/2	0

- ST1 is based on the conservative interpretation of the uncertainty/ sensitivity exercise: indifference of ranking between all MO; therefore the strategy should take into account all MO equally
- ST2 is based on a less conservative interpretation of the uncertainty/ sensitivity exercise, which looks at common results between (1) sensitivity to changes in BIPV, (2) sensitivity to changes in BIW, and (3) sensitivity to simultaneous changes in BIPV and BIW: indifference between MO1 and MO4, superiority of MO1 & MO4 to MO2, and superiority of MO4 to MO3; which allows the elimination of MO2 (rainwater harvesting) and indicates a two-level ranking of MO: MO1 & MO4 > MO3 and MO5
- ST3 is similar to ST2, but with a higher percentage for the first level of MO (MO1 & MO4) with respect to the second level (MO3 and MO5) which better reflects the original difference in value between the two
- ST4 is similar to ST3 but excludes MO3 (direct connection to Mekerot) for being more difficult to implement politically/institutionally
- ST5 is similar to ST3 but excludes MO5 (reuse) for initial value scoring being less than MO1 and MO4.

5.1.4.2 Identification of Evaluation Criteria:

As detailed in chapter 3, strategies are evaluated based on (1) sustainability, (2) demand-supply gap and (3) cost.

5.1.4.2.1 Sustainability:

Sustainability is calculated based on the weighted sum of the BI performance values, which for the purpose of this exercise, are generated from the BIPV of the various management options multiplied by the respective coefficients outlined in table 5.46. Results are presented in table 5.47:

Table 5.47: SUSMAQ DST NWB/CS- Strategies Sustainability

	ST1	ST2	ST3	ST4	ST5
Economic sustainability	0.73	0.74	0.79	0.77	0.83
Environmental sustainability	0.90	0.90	0.89	0.89	0.88
Socio-economic sustainability	0.44	0.48	0.49	0.49	0.49
Overall sustainability	0.63	0.65	0.66	0.66	0.67

5.1.4.2.2 Demand-Supply Gap:

Although implicitly recognised in SUSMAQ BI, the demand-supply gap is calculated for every strategy as detailed in chapter 3, based on data from SUSMAQ 60 (SUSMAQ, 2005f) and Aliewi et al, 2005; results are outlined in table 5.48 - supply figures in table 5.48 are calculated based on values presented in Annex B.

Table 5.48: SUSMAQ DST NWB/CS- Strategies Demand-Supply Gap

	ST1	ST2	ST3	ST4	ST5
Supply (MCM)	76.3	75.37	74.7	74.45	74.3
Municipal					
Industrial					
Agricultural					
Demand Reduction/Management (MCM)	7.2	7.2	7.2	7.2	7.2
Municipal					
Industrial					
Agricultural					
Demand (MCM)	146.34				
Municipal	*60.75*				
Industrial	*4.95*				
Agricultural	*80.64*				
Demand-Supply Gap (MCM)	**62.84**	**63.77**	**64.44**	**64.69**	**64.84**

S1 = (61.8) + (12.5+0.4+1.3+0.3)
S2 = (61.8) + (12.5+2/3*1.3+2/3*0.3)
S3 = (61.8) + (12.5+1/4*1.3+1/4*0.3)
S4 = (61.8) + (12.5+1/2*0.3)
S5 = (61.8) + (12.5)
DR =(6.0) + 1.2 (constant for all strategies as all include a full exploitation of MO4)

Demand Municipal = Demand Municipal (West Bank)* %North (= Nablus + Tulkarem + Jenin)
= 135*(0.21+0.12+0.12)= 60.75

Demand Industrial = Demand Industrial (West Bank)* %North (= Nablus + Tulkarem + Jenin)
= 11 (8%*Municipal)*(0.21+0.12+0.12) = 4.95

Demand Agricultural = Demand Agricultural (West Bank)* %North (=Nablus+Tulkarem+Jenin)
= 168*(0.12+0.25+0.11)= 80.64

5.1.4.2.3 Cost:

As described in chapter 3, the cost associated with each strategy is calculated based on the costs of the different MOs as per the West Bank Water Management Analysis Tool (CH2MHILL, 2002), weighted with the respective normalised MO coefficients – as presented in tables 5.49 and 5.50:

Table 5.49: SUSMAQ DST NWB/CS- Management Options Cost

	Capital Unit Cost (USD/CM) (WBWMAT)(*)	O&M Unit Cost (USD/CM) (WBWMAT)(*)	Quantity of Water (MCM) (SUMSAQ 60)	MO Cost (MUSD)
MO1	0.41	0.52	12.5	11.625
MO2	0.7	0.21	0.4	0.364
MO3	Estimated at 0.93 (MO1)		1.3	1.209
MO4	0.3	0.115	1.2	0.498
MO5	0.17	0.76	0.3	0.279

(*) based on a library of unit costs as explained in footnote 3, chapter 4.

Table 5.50: SUSMAQ DST NWB/CS- Strategies Cost

	ST1	ST2	ST3	ST4	ST5
MO1	1	1	1	1	1
MO2	1	0	0	0	0
MO3	1	2/3	1/4	0	0
MO4	1	1	1	1	1
MO5	1	2/3	1/4	1/2	0
Cost (MUSD)	13.975	13.115	12.495	12.262	12.123

5.1.4.3 Evaluation of Strategies:

The various strategies are compared based on the three criteria outlined above (sustainability, supply-demand gap, cost); results are presented in figure 5.1 which ranks strategies according to:

- sustainability, based on the results presented in section 5.1.4.2.1
- demand-supply gap, where results presented in section 5.1.4.2.2 are normalised as follows:

$$G_{x(N)} = \frac{G_x - G_{min}}{G_{max} - G_{min}}$$

where G_{min} is zero

and G_{max} is the baseline gap = (D – BDR) - BS

= (146.34 – 6) - 61.8

= 78.54

- cost, where results presented in section 5.1.4.2.3 are normalised as follows:

$$C_{S(x)(N)} = \frac{C_{S(x)} - C_{min}}{C_{max} - C_{min}}$$

where C_{min} is zero

and C_{max} is the cost associated with a demand-supply gap of zero; i.e. the cost of 78.54MCM (by supply development and demand management/reduction). Based on the calculation of ST1 which reduces the gap by 15.7MCM at a cost of 13.975 million USD, C_{max} is estimated at almost 5 times C_{ST1}, i.e. ~ 70 million USD

Figure 5.1: SUSMAQ DST NWB/CS- Strategies Ranking

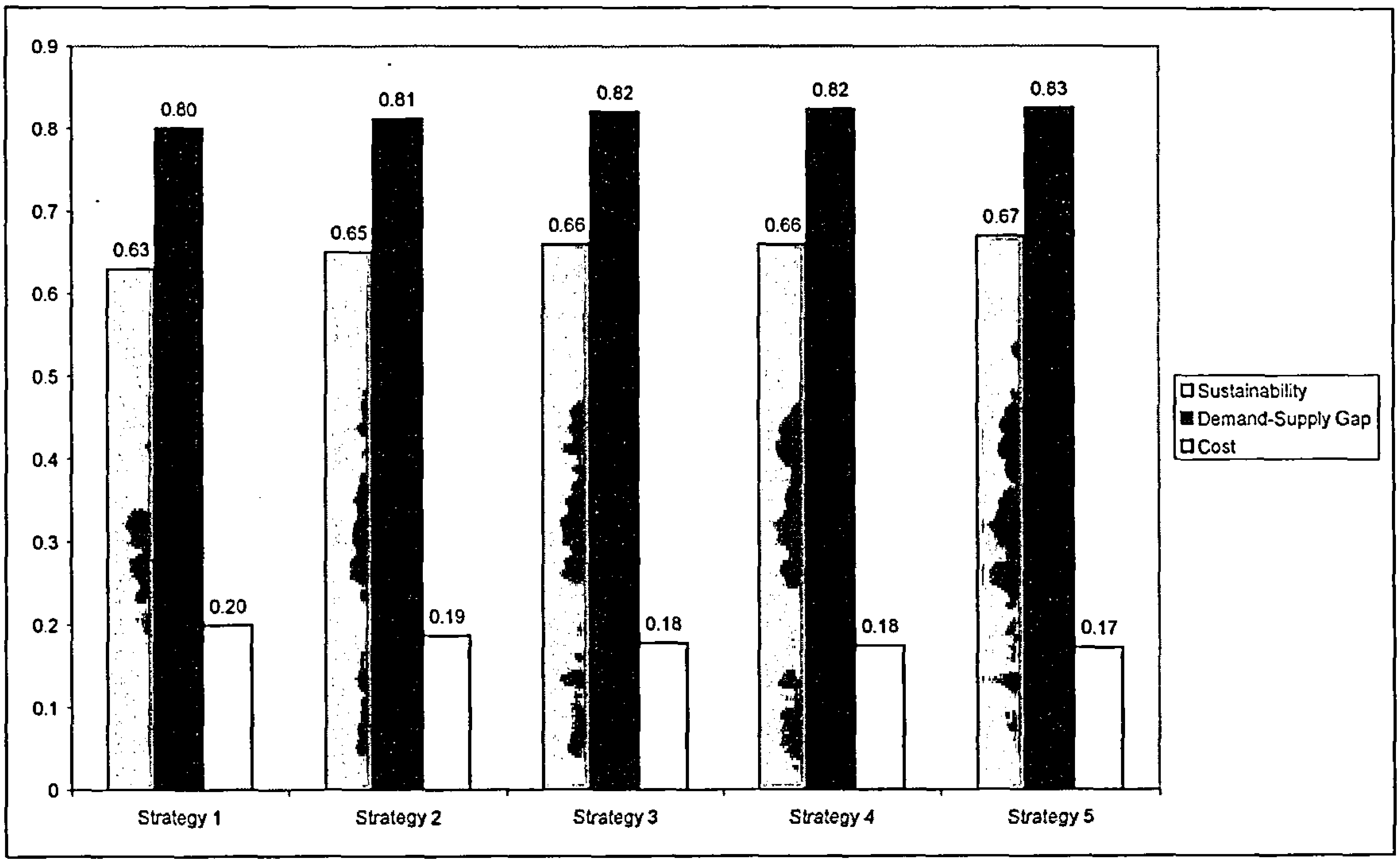


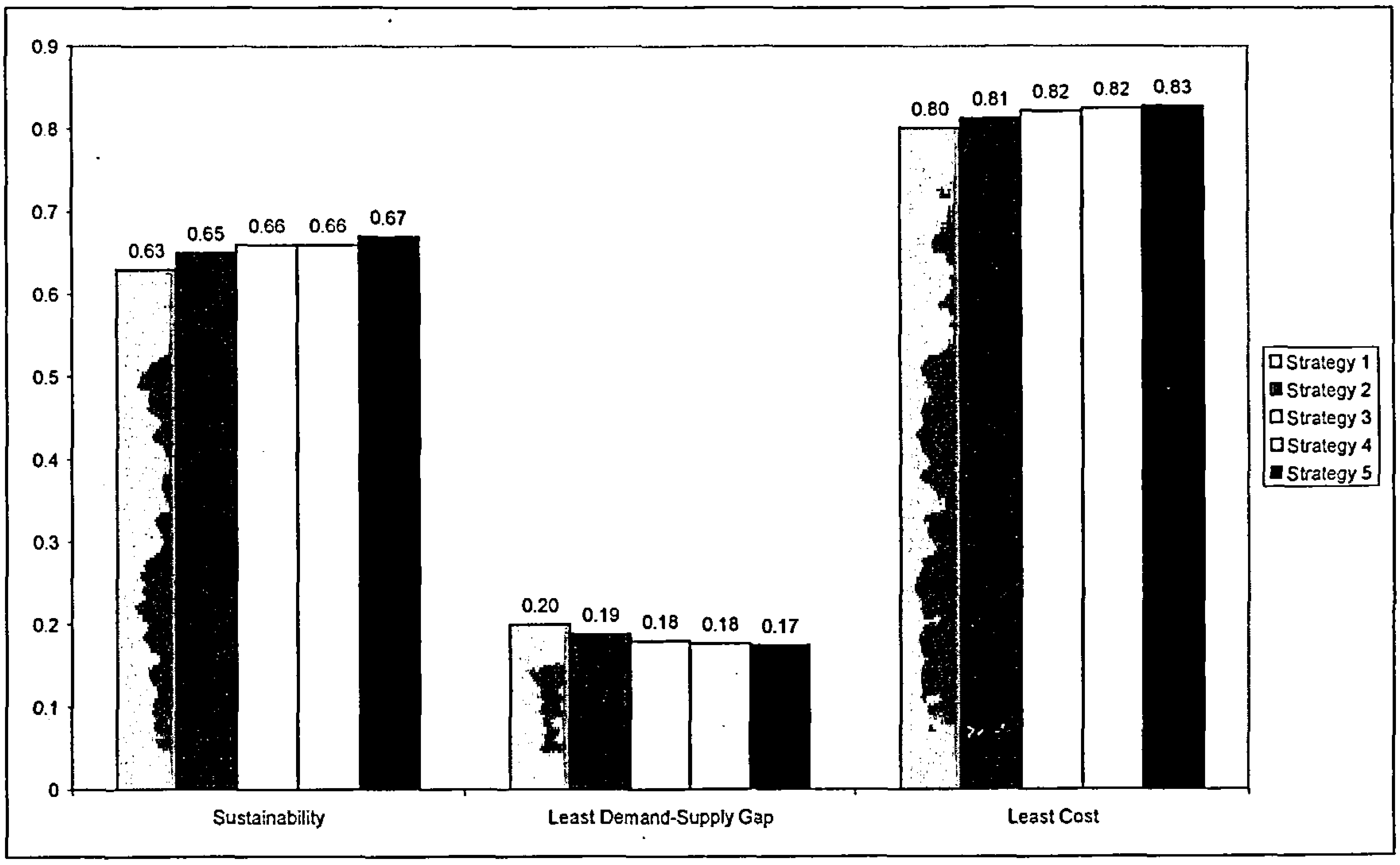
Figure 5.1 indicates the following:

- Strategy 1 ensures the highest demand-supply gap reduction (i.e. it has the lowest demand-supply gap index), but associated with the highest cost and the least sustainability index
- Strategy 5 is the most sustainable, at the least cost, but with the highest demand-supply gap
- This ranking (especially in terms of sustainability and demand-supply gap) does not appear to be very robust, given the small range of variability of scores (sustainability values varying from 0.63 to 0.67; supply demand gap varying from 0.80 to 0.83).

A normalisation of results (0 worst and 1 best) gives the results presented in figure 5.2

- sustainability results already normalised;
- demand-supply gap: complement values are calculated and referred to as least demand-supply gap;
- cost: complement values are calculated and referred to as least cost.

Figure 5.2: SUSMAQ DST NWB/CS- Strategies Ranking (Normalised Per Criterion)



It is clear from figure 5.2 that:

- strategy 5 scores best in terms of sustainability and least cost, while strategy 1 scores highest in terms of least demand-supply gap;
- all strategies score highest in terms of least cost (0.8-0.83), followed by sustainability (0.63-0.67), and finally least demand-supply gap (0.17-0.20);
- the range of variability of scores across strategies is very low for all criteria, this is demonstrated by standard deviation results (0.010 for least demand-supply gap, 0.015 for sustainability and 0.011 for least cost); and
- least demand-supply gap values are very low, which indicate that meeting demand in the North West Bank for the Current Scenario is difficult.

An overall value for each strategy is presented in table 5.51; it is computed based on weighted sum assigning an equal weight of 1/3 to each of the 3 criteria (sustainability, least demand-supply gap, and least cost). Results indicate that strategy 5 scores highest, although not very high (56% only) and that there is almost indifference in results (range of results is 0.54 to 0.56).

Table 5.51: SUSMAQ DST NWB/CS- Strategies Values (3 criteria)

	ST1	ST2	ST3	ST4	ST5
Sustainability	0.63	0.65	0.66	0.66	0.67
Demand-supply gap (Least)	0.20	0.19	0.18	0.18	0.17
Cost (Least)	0.80	0.81	0.82	0.82	0.83
Overall	**0.54**	**0.55**	**0.55**	**0.55**	**0.56**

Table 5.51 indicates the following:

- There is almost indifference between the five strategies, which means that there is no clear preference for a specific strategy/ MO combination. Strategy formulation can thus be based on other criteria of politico-institutional or technical nature.
- The indifference in ranking between strategies makes further sensitivity analysis at the strategy level (i.e. step 5 of the validity intra-model methodology outlined in chapter 3) of rather little use.
- No strategy will succeed at closing the demand-supply gap for the current scenario at the North West Bank; which means that the proposed MOs ought to be re-studied to increase supply and reduce demand.
- Sustainability and Least Demand-supply gap seem to be inversely proportional. This is more clearly pointed out by figure 5.3

Figure 5.3: SUSMAQ DST NWB/CS- Strategies Sustainability & Least Demand-Supply Gap (Eq.)

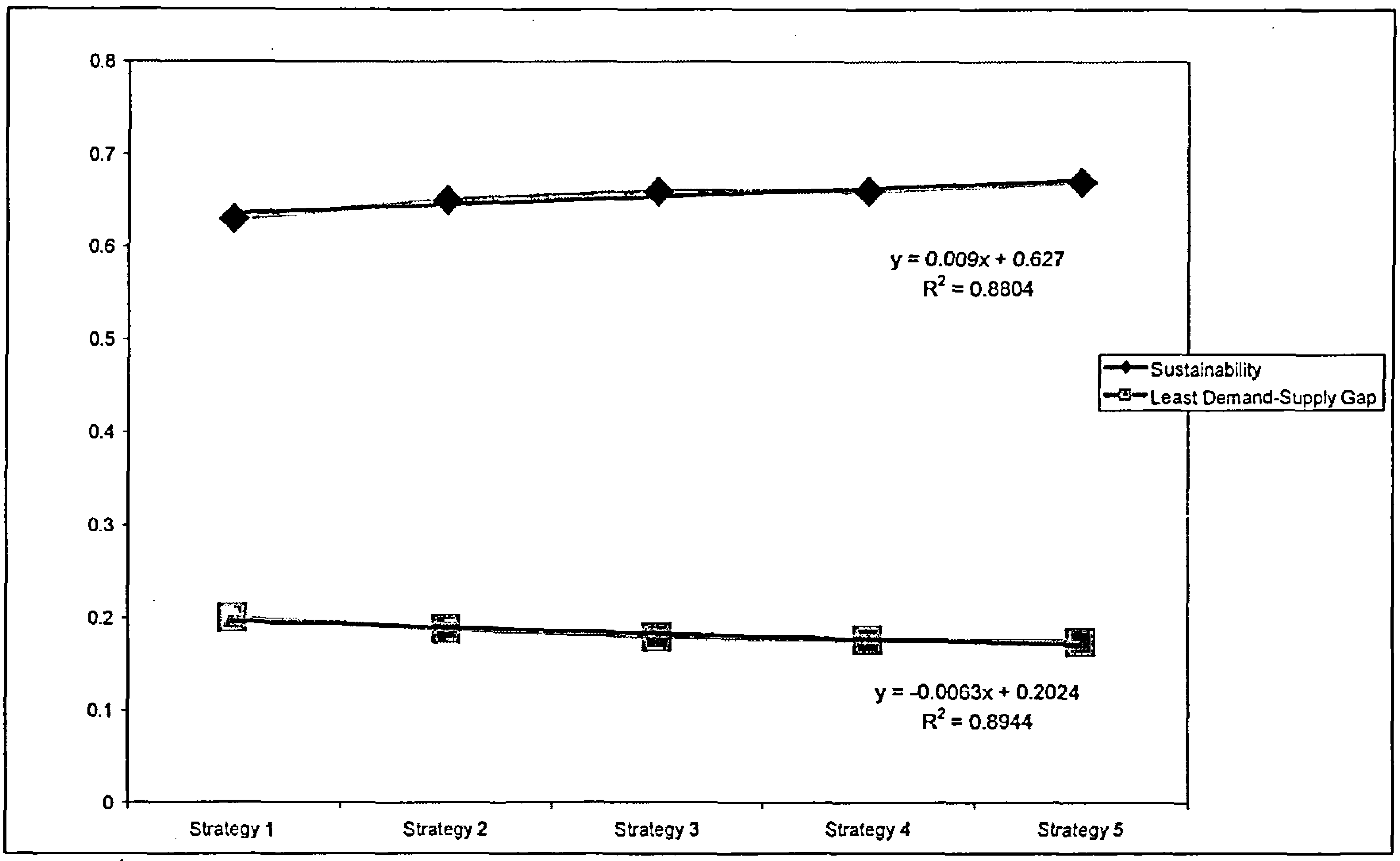


Figure 5.3 associates sustainability with a linear equation of slope equal to 0.009, and least demand-supply gap with a linear equation of slope equal to -0.0063; which implies that sustainability is inversely proportional to least demand-supply gap by 1.5, meaning that for every additional unit gained on least demand-supply gap, by supply enhancement, a unit and a half is lost on sustainability. This relation is presented in figure 5.4. Had additional data been available, it would have been interesting to study the complementary side of this relation, i.e. the variation of sustainability in relation to least demand-supply gap, but through demand management. On the other hand, and as pointed out in figure 5.5 below, more sustainable management options are cheaper. For every additional unit of sustainability, the cost is reduced by 0.7 units.

Figure 5.4: SUSMAQ DST NWB/CS- Sustainability vs. Least Demand-Supply Gap (through supply enhancement)

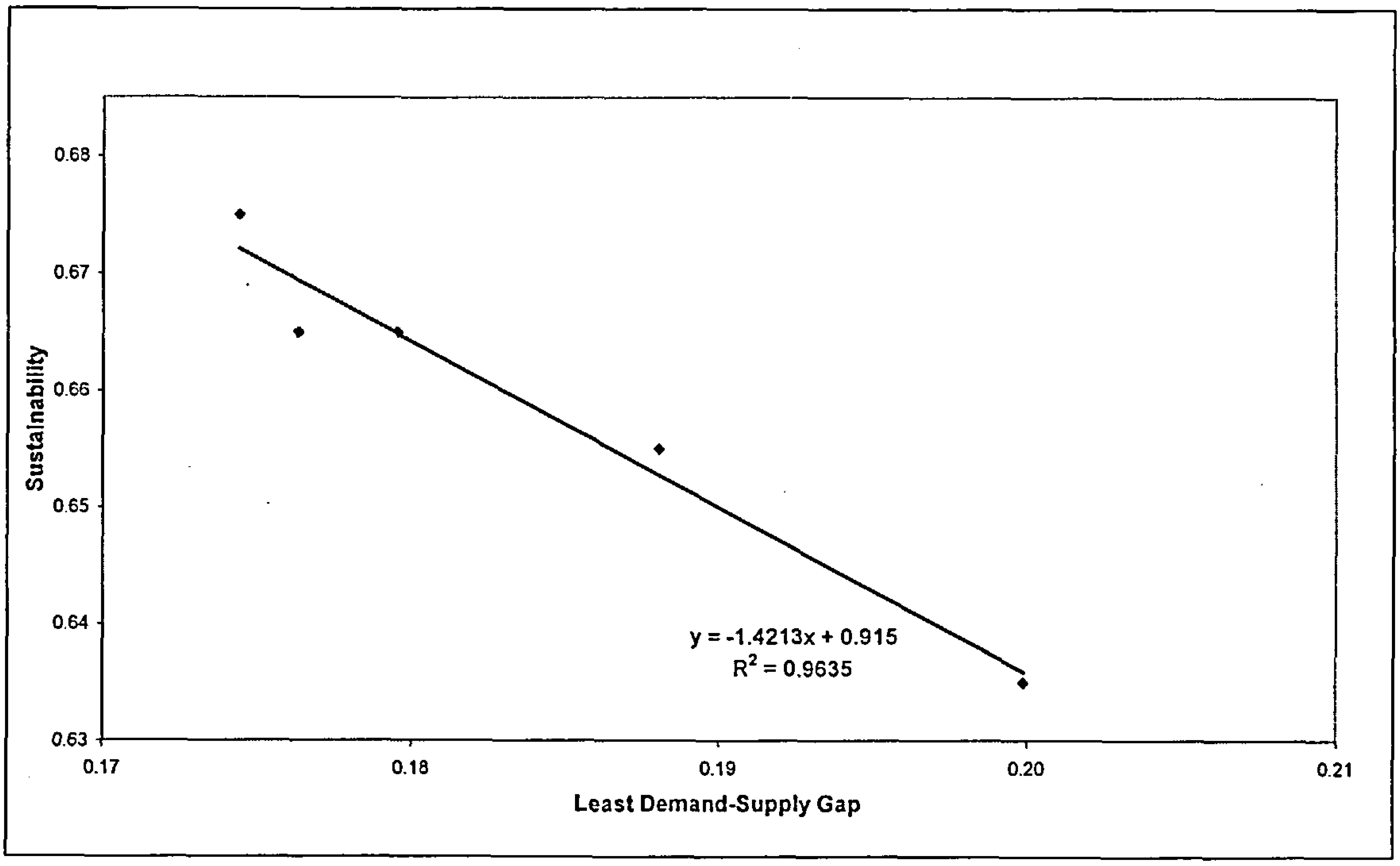
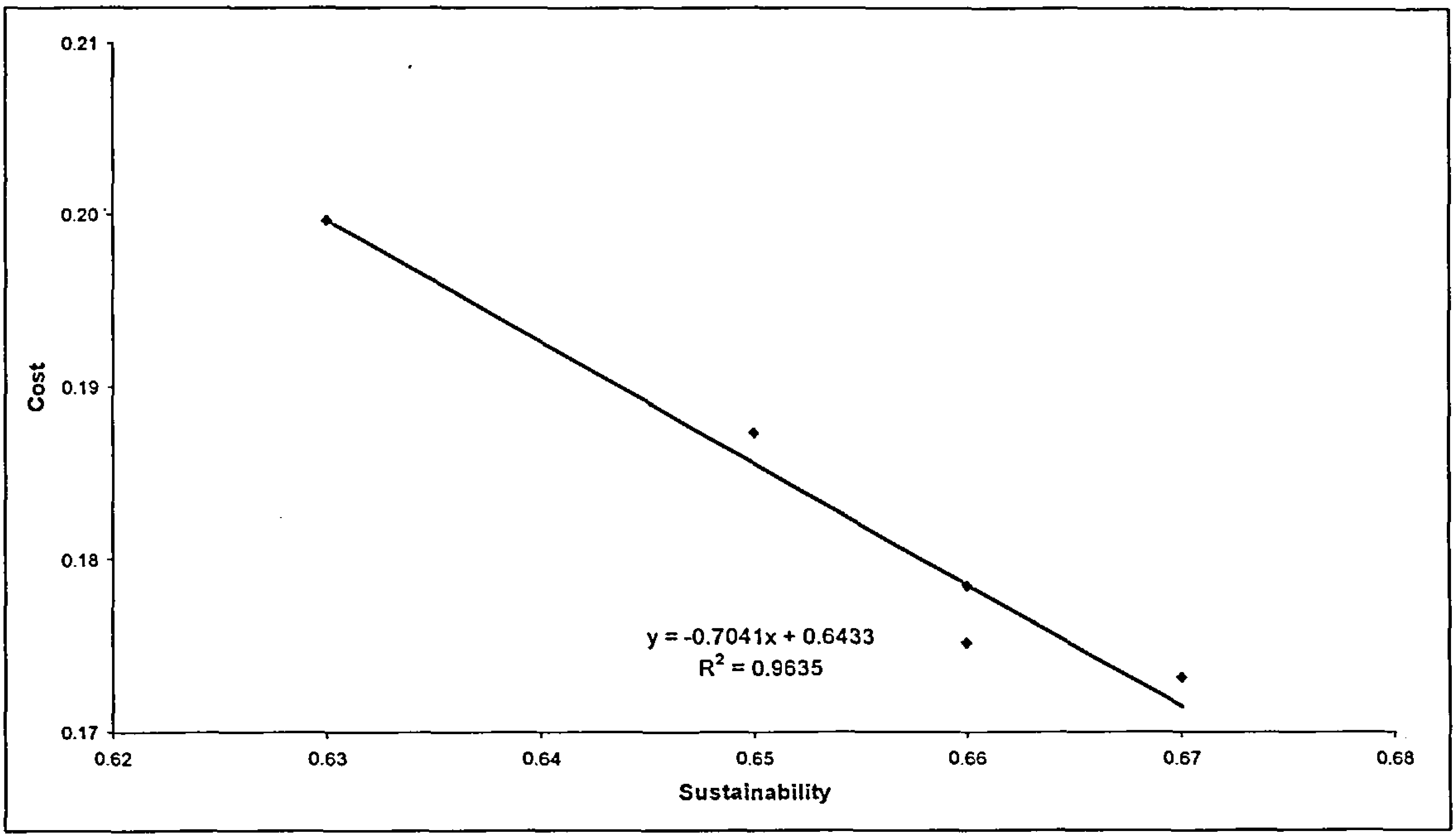


Figure 5.5: SUSMAQ DST NWB/CS- Cost vs. Sustainability



5.2 SUSMAQ – DST NWB/CS: Validity Inter-Model

The conceptual framework for assessing validity inter-model is discussed in this section: internal rate of return (IRR) in section 5.2.1 and cost benefit analysis (CBA) in section 5.2.2.

5.2.1 Internal Rate of Return of SUSMAQ Management Options & Strategies:

The sustainability analysis of SUSMAQ North West Bank Current Scenario MO includes the IRR as one of the economic sustainability indicators. IRR results for four management options (groundwater supply development, rainwater harvesting, demand reduction and wastewater reuse), as presented in SUSMAQ 52 (SUSMAQ, 2005c), are outlined in table 5.52[9].

SUSMAQ 52 (SUSMAQ, 2005c) defines IRR as being "the annualised costs and direct/indirect benefits over a 20-yr period", with computation details presented in SUSMAQ 56 (SUSMAQ, 2005g) and outlined in table 5.52. This data is used for computing the IRR excluding indirect benefits, as demonstrated in table 5.52.

[9] The "direct connection to Mekerot" MO is left out, as SUSMAQ 52 does not report an IRR value for this MO

Table 5.52: IRR of SUSMAQ MO (Source: SUSMAQ – DST Software)

	MO1 (GW Supply Development)	MO2 (Rainwater Harvesting)	MO3 (Direct Connection to Mekerot)	MO4 (Demand Management)	MO5 (Wastewater Reuse)
IRR (%)	11.6	-9.4		18.7	10.2
Capital Costs (US$1,000)	65,611.81	7,187.5		9.86	47,182.2
O&M Costs (US$1,000/yr)	3,432.06	359.38		0	864.98
Total Direct Benefits(1) (US$1,000/yr)	9,167	1.02		1.92	3,864
Total Indirect Benefits(2) (US$1,000/yr)	3,401	0		0	4,355
Total Benefits (US$1,000/yr)	12,568	1.02		1.92	8,219
IRR(Direct Benefits Only) (%)	6	-9.4		18.7	2.5
Additional Water (MCM)	12.5	0.4		1.2	0.3

(1) Direct benefits include domestic, industry and agriculture benefits
(2) Indirect benefits include domestic benefits (economic value of recharge, averted cost for water tankers, reduction in water related diseases, garden irrigation using wastewater, and time saved in collecting water), industry benefits (industry/commercial activity assisted, secondary activities encouraged, and averted costs of pollution of environment), and agriculture benefits (intensive irrigation of new crops, creation of jobs per farm, savings in fertilizers, and annual salary)

PS: Data presented in table 5.52 is based on SUSMAQ - DST software and are to be used as a draft estimate only - as mentioned in SUSMAQ 60 (SUSMAQ, 2005f), "the BI need to be recalculated using comprehensive and verified data"

Three conclusions can be drawn from table 5.52:

- MO ranking based on IRR – Direct Benefits Only is equivalent to MO ranking based on IRR; which results in the same ranking as that based on total sustainability: MO4>MO1>MO5>MO2.
- Indirect benefits can reach up to 50% of total benefits, e.g. MO5
- The most feasible strategy that can be proposed, based on IRR considerations, is an equally weighted combination of MO1, MO4 and MO5, for the reasons mentioned below:
    - o Based on IRR results, MO2, which has a negative IRR, is eliminated;
    - o Basing the decision-making on IRR values only generates two possible combinations: one including MO4 only (ST6), as it has the highest IRR

by far, and the other (ST7) combining the 3 MOs (MO1, MO4, and MO5) as MO1 and MO5 have a relatively equivalent IRR in comparison to MO4 (11.6 and 10.2) and, as such, should either be both included or both excluded.

- Taking into consideration the potential demand-supply gap reduction, the "feasible" combinations are reduced to one, that is ST7 (the equal weighted combination of MO1, MO4 and MO5), since the strategy that relies on MO4 solely will result in an additional 1.2 MCM/yr only, whereas MO1 would generate an additional 12.5 MCM/yr. This strategy would have an IRR of 13.5 and an IRR(Direct Benefits Only) of 9.07 and would generate an extra 14 MCM/yr, i.e. a gap of ~64.5 MCM. A third potential strategy (ST8), based on IRR and demand-supply gap considerations, would be an equally weighted combination of MO1 and MO4, as MO5 scores very low on both IRR (and especially IRR(Direct Benefits Only)) and demand-supply gap. It would have an IRR of 15.15 and an additional water of 13.7 MCM. Results are presented in table 5.53.

Table 5.53: IRR of SUSMAQ Strategies

	ST6 (MO4)	ST7 (MO1,MO4, MO5)	ST8 (MO1, MO4)
IRR (%)	18.7	13.5	15.15
IRR(Direct Benefits Only) (%)	18.7	9.07	12.35
Additional Water (MCM)	1.2	14	13.7
Demand-Supply Gap (MCM)	-77.34	-64.54	-64.84

How does this compare to SUSMAQ DST results? ST8 corresponds to DST-ST5 which ranks first on sustainability, and ST7 is pretty similar to DST-ST4 (full MO1 and MO4, 50% MO5), which ranks second on sustainability. This implies that the IRR method and the MCA method lead to the same conclusions.

5.2.2 *Cost Benefit Analysis of SUSMAQ Management Options & Strategies:*

5.2.2.1 *Cost Benefit Analysis of SUSMAQ Management Options:*

The data presented in table 5.52 is used for carrying out a CBA of SUSMAQ MO, based on 4 discount rates (3%, 5%, 7% and 10%) over a 15-yr period. Table 5.54 outlines the benefit/cost ratio of the various MO, including all benefits (direct and indirect), while table 5.55 presents the same information taking into account direct benefits only.

Table 5.54: CBA of SUSMAQ MO (Total Benefits)

	MO1 (GW Supply Development)	MO2 (Rainwater Harvesting)	MO3 (Connection Mekerot)	MO4 (Demand Reduction)	MO5 (Wastewater Reuse)
Discount rate 3%	1.6	$1.2*10^{-3}$		2.9	2.03
Discount rate 5%	1.44	$1.09*10^{-3}$		2.43	1.77
Discount rate 7%	1.3	$9.82*10^{-4}$		2.06	1.54
Discount rate 10%	1.13	$8.47*10^{-4}$		1.66	1.28

Table 5.55: CBA of SUSMAQ MO (Direct Benefits Only)

	MO1 (GW Supply Development)	MO2 (Rainwater Harvesting)	MO3 (Direct Connection to Mekerot)	MO4 (Demand Reduction)	MO5 (Wastewater Reuse)
Discount rate 3%	1.16	$1.2*10^{-3}$		2.90	0.96
Discount rate 5%	1.05	$1.09*10^{-3}$		2.43	0.83
Discount rate 7%	0.95	$9.82*10^{-4}$		2.06	0.73
Discount rate 10%	0.82	$8.47*10^{-4}$		1.66	0.60

Analysis of results presented in tables 5.54 and 5.55 demonstrate the following:

- MO ranking based on CBA (MO4>MO5>MO1>MO2) is slightly different from MO ranking based on CBA(Direct Benefits Only) (MO4>MO1>MO5>MO2); this shows the importance of accounting for indirect benefits in CBA.
- MO2 is obviously not feasible.
- MO5 is not feasible if CBA does not take into account indirect benefits.
- If indirect benefits are excluded, MO1 is feasible for low discount rates only (3% & 5%).

Table 5.54, which presents CBA results inclusive of indirect benefits, might appear as representative of SUSMAQ DST (or MCA) since it incorporates indirect benefits. However, the indirect benefits, as presented in table 5.52, might not be totally equivalent to the sustainability indicators/ benefits used in MCA. This is why, as discussed, MCA and CBA are combined (CBA(Direct Benefits Only) and MCA(Indirect Benefits Only) to limit redundancy) and results compared to CBA(Direct Benefits Only), CBA (i.e. CBA inclusive of indirect benefits), and MCA.

As indicated in the methodology (chapter 3), indirect benefits ought to be properly aggregated. SUSMAQ DST results are therefore screened as follows:

- The economic indicators are omitted as they are represented in the CBA(Direct Benefits Only) results;
- The environmental and socio-economic indicators are grouped, based on professional judgement, into the 4 categories of water benefits, as discussed by Young (2005):
    - Commodity benefits (B1): water connection (SE1), water quality (SE2), water usage (SE3)
    - Water for recreation, aesthetics, etc. (B2): aquifer water level (EN1), aquifer water quality (EN3), source yield and livelihoods (SE6)
    - Waste disposal benefits (B3): wastewater discharge (EN4), agricultural pesticide use (EN5), industrial effluent (EN6)
    - Disvalues: -

Table 5.56 presents the values associated with these three categories of benefits (B1, B2, and B3). Results can take one of two forms:

- Option 1: average of B1, B2, B3; where B1, B2 and B3 are the average of the respective indicators representing these benefits; i.e. the indirect benefits are scored over 1:

$$MCA(1) = \frac{(SE1+SE2+SE3)/3+(EN1+EN3+SE6)/3+(EN4+EN5+EN6)/3}{3}$$

- Option 2: sum of B1, B2, B3; i.e. the indirect benefits are scored over 3 to represent the three types of benefits:

$$MCA(2) = \frac{SE1+SE2+SE3}{3}+\frac{EN1+EN3+SE6}{3}+\frac{EN4+EN5+EN6}{3}$$

Table 5.56: MCA Results for SUSMAQ MO

	MO1 (GW Supply Development)	MO2 (Rainwater Harvesting)	MO3 (Direct Connection to Mekerot)	MO4 (Demand Reduction)	MO5 (Wastewater Reuse)
MCA (1)	0.76	0.64		0.73	0.74
MCA (2)	2.29	1.92		2.19	2.21

Adding CBA(Direct Benefits Only) to MCA (i.e. tables 5.55 & 5.56), using a weight of 70% and 30% respectively, as discussed in chapter 3, generates the results presented in tables 5.57 & 5.58:

Table 5.57: Combination of MCA-Indirect Benefits Only and CBA - Direct Benefits Only (option 1) - SUSMAQ MO

	MO1 (GW Supply Development)	MO2 (Rainwater Harvesting)	MO3 (Direct Connection to Mekerot)	MO4 (Demand Reduction)	MO5 (Wastewater Reuse)
Discount rate 3%	1.05	0.19		2.25	0.89
Discount rate 5%	0.97	0.19		1.92	0.80
Discount rate 7%	0.90	0.19		1.66	0.73
Discount rate 10%	0.81	0.19		1.38	0.64

Table 5.58: Combination of MCA-Indirect Benefits Only and CBA - Direct Benefits Only (option 2) – SUSMAQ MO

	MO1 (GW Supply Development)	MO2 (Rainwater Harvesting)	MO3 (Direct Connection to Mekerot)	MO4 (Demand Reduction)	MO5 (Wastewater Reuse)
Discount rate 3%	1.51	0.58		2.68	1.34
Discount rate 5%	1.43	0.58		2.36	1.25
Discount rate 7%	1.35	0.58		2.10	1.17
Discount rate 10%	1.26	0.58		1.82	1.09

Tables 5.57 and 5.58 point out the following:

- MO ranking based on the combination of MCA and CBA(Direct Benefits Only) is consistent with CBA(Direct Benefits Only) ranking: MO4>MO1>MO5>MO2, but not totally with CBA(Total Benefits).
- Table 5.57 (combination of MCA and CBA(Direct Benefits Only), where MCA is scored over 1 – option 1) presents results very similar to those outlined in table 5.55 (CBA(Direct Benefits Only)); i.e. MO2 and MO5 are not feasible; MO1 is feasible for very low values of discount rate.
- Table 5.58 (combination of MCA and CBA(Direct Benefits Only), where MCA is scored over 3 – option 2) presents results very similar to those

outlined in table 5.54 (CBA(total benefits)) in terms of feasibility with a slight difference in terms of ranking; which could imply that CBA that takes into account indirect benefits is similar to a combination of CBA(Direct Benefits Only) and MCA, provided indirect benefits (3/4 types) are not averaged.

5.2.2.2 Cost Benefit Analysis of SUSMAQ Strategies:

CBA analysis of SUSMAQ MO identifies almost the same 3 possible strategies generated based on IRR analysis. Results are presented in table 5.59:

Table 5.59: CBA of SUSMAQ Strategies

	ST6	ST7	ST8
CBA(Total Benefits)			
Discount rate 3%	2.90	2.18	2.25
Discount rate 5%	2.43	1.88	1.94
Discount rate 7%	2.06	1.64	1.68
Discount rate 10%	1.66	1.36	1.39
CBA(Direct Benefits Only)			
Discount rate 3%	2.90	1.67	2.03
Discount rate 5%	2.43	1.44	1.74
Discount rate 7%	2.06	1.25	1.51
Discount rate 10%	1.66	1.03	1.24
B1	0.73	0.74	0.75
B2	2.19	2.23	2.24
B3	2.90	1.67	2.03
CBA(Direct Benefits Only) & MCA(Indirect Benefits Only) (/1)			
Discount rate 3%	2.25	1.40	1.65
Discount rate 5%	1.92	1.23	1.44
Discount rate 7%	1.66	1.10	1.28
Discount rate 10%	1.38	0.94	1.09
CBA(Direct Benefits Only) & MCA(Indirect Benefits Only) (/3)			
Discount rate 3%	2.68	1.84	2.10
Discount rate 5%	2.36	1.68	1.89
Discount rate 7%	2.10	1.54	1.73
Discount rate 10%	1.82	1.39	1.54
Additional Water (MCM)	1.2	14	13.7
Demand-Supply Gap (MCM)	-77.34	-64.54	-64.84

Table 5.59 shows that although ST6 has the highest CBA in all scenarios, ST7 and ST8 can ensure a higher gap reduction, with still B/C ratios exceeding 1 irrespective of whether indirect benefits are accounted for or not, and no matter how they are accounted for in case they are, and with various discount rates ranging from 3% to 10% - with one exception where B/C is 0.94 (ST7, CBA(Direct Benefits Only) & MCA(Indirect Benefits Only), option 1). This is again very consistent with MCA results.

5.3 SUSMAQ - DST NWB/FS: Intra-Model Validity

Partial application of the conceptual framework to the North West Bank – Future Scenario (NWB/FS) to assess validity intra-model generates, for the assumptions listed in section 5.3.1, the results outlined in section 5.3.2:

5.3.1 Assumptions:

Assessment of validity intra-model for the NWB/FS relies, for steps 1 and 2 of the conceptual framework presented in chapter 3, on the results of the application to the NWB/CS (section 5.1):

- a high level of comprehensiveness of MO and BI as per the justifications listed in section 5.1.1 (step 1 of the framework)
- a medium to high level of confidence in the PVs assigned to the BI and a low degree of consensus on the W elicited for the BI, as per the justifications listed in section 5.1.2 (step 2 of the framework)

5.3.2 Results:

Based on the assumptions listed in section 5.3.1, the application starts with step 3 of the framework (sensitivity of MO ranking to BIPV and BIW) with the following results:

- indifference between MO3 (Direct Connection to Mekerot), MO4 (Demand Management) and MO5 (Wastewater Reuse) demonstrated by (1) the very low corresponding Euclidian distances for BIPV (table 5.60), (2) the very low corresponding robustness indexes for BIW (table 5.61), (3) the high corresponding sensitivity to BIW (table 5.62), (4) the very low corresponding Euclidian distances for BIW (table 5.63), and (5) the very low corresponding Euclidian distances for BIPV and BIW simultaneously (table 5.64;

- dominance of MO3, MO4 and MO5 over MO1 and MO2, as demonstrated by the corresponding values in tables 5.60 to 5.64.

Table 5.60: SUSMAQ DST NWB/FS – Euclidian Distance (BIPV)

MO Pair	Euclidian Distance	Value of MO at Reversal of Ranking	% Change in BIPV (Range)
MO1 (GW) = 0.64 & MO2 (RH) = 0.68	0.142	0.65	-100: 7.52
MO1 (GW) = 0.64 & MO3 (ME) = 0.71	*0.247*	*0.66*	*-24.5: 13.00*
MO1 (GW) = 0.64 & MO4 (DM) = 0.73	*0.304*	*0.67*	*-30.25: 16.07*
MO1 (GW) = 0.64 & MO5 (RE) = 0.72	*0.263*	*0.67*	*-24.42: 14.00*
MO2 (RH) = 0.68 & MO3 (ME) = 0.71	0.099	0.70	-9.22: 78.39
MO2 (RH) = 0.68 & MO4 (DM) = 0.73	0.152	0.70	-14.14: 120.18
MO2 (RH) = 0.68 & MO5 (RE) = 0.72	0.113	0.70	-5.63: 90.14
MO3 (ME) = 0.71 & MO4 (DM) = 0.73	0.049	0.72	-4.26: 4.26
MO3 (ME) = 0.71 & MO5 (RE) = 0.72	**0.012**	**0.72**	**-0.56: 1.06**
MO4 (DM) = 0.73 & MO5 (RE) = 0.72	**0.04**	**0.72**	**-3.79: 2.01**

Table 5.61: SUSMAQ DST NWB/FS – BIW - Robustness Index

	MO1 (Groundwater Supply GW)	MO2 (Rainwater Harvesting RW)	MO3 (Connection to Mekerot ME)	MO4 (Demand Management DM)	MO5 (Wastewater Reuse RE)
$r(a_1,...)$		-0.095	-0.209	*-0.25*	*-0.22*
$r(a_2,...)$			-0.14	*-0.423*	-0.13
$r(a_3,...)$				-0.086	**-0.03**
$r(a_4,...)$					**0.059**

Table 5.62: SUSMAQ DST NWB/FS – Sensitivity Analysis of BIW

MO Pair	Critical BIW	% Change in Weight
MO1 (GW) = 0.64 & MO2 (RH) = 0.68	EC4	70.32
MO1 (GW) = 0.64 & MO3 (ME) = 0.71	EN3	91.23
MO1 (GW) = 0.64 & MO4 (DM) = 0.73	-	-
MO1 (GW) = 0.64 & MO5 (RE) = 0.72	EN3	94.94
MO2 (RH) = 0.68 & MO3 (ME) = 0.71	SO3	-84.24
MO2 (RH) = 0.68 & MO4 (DM) = 0.73	-	-
MO2 (RH) = 0.68 & MO5 (RE) = 0.72	SO5	78.96
MO3 (ME) = 0.71 & MO4 (DM) = 0.73	EC4; SO3	55.35; 44.62
MO3 (ME) = 0.71 & MO5 (RE) = 0.72	**EC2;EC5;SO5;SO6;SO7**	**-20.62;-17.91;30.39;37.2;-29.48**
MO4 (DM) = 0.73 & MO5 (RE) = 0.72	**EC4; EC5; SO2; SO5**	**41.71; 31.09; -52.54; -27.88**

Table 5.63: SUSMAQ DST NWB/FS – Euclidian Distance (BIW)

MO Pair	Euclidian Distance	Value of MO at Reversal of Ranking	% Change in BIW (Range)
MO1 (GW) = 0.64 & MO2 (RH) = 0.68	0.017	0.67	-19.4: 18
MO1 (GW) = 0.64 & MO3 (ME) = 0.71	0.036	0.70	-49.5: 25.8
MO1 (GW) = 0.64 & MO4 (DM) = 0.73	*0.043*	*0.71*	*-49.7: 28.7*
MO1 (GW) = 0.64 & MO5 (RE) = 0.72	*0.055*	*0.66*	*-59.8: 43*
MO2 (RH) = 0.68 & MO3 (ME) = 0.71	0.028	0.71	-26.8: 20.7
MO2 (RH) = 0.68 & MO4 (DM) = 0.73	*0.043*	*0.72*	*-86.5: 31.1*
MO2 (RH) = 0.68 & MO5 (RE) = 0.72	0.024	0.70	-18: 20.2
MO3 (ME) = 0.71 & MO4 (DM) = 0.73	0.015	0.72	-16.1: 11.8
MO3 (ME) = 0.71 & MO5 (RE) = 0.72	**0.0047**	**0.71**	**-33: 6.3**
MO4 (DM) = 0.73 & MO5 (RE) = 0.72	**0.009**	**0.73**	**-7.7: 6.9**

Table 5.64: SUSMAQ DST NWB/FS – Euclidian Distance (BIPV & BIW)

MO Pair	Euclidian Distance	Value of MO at Reversal of Ranking	% Change in BIPV (Range)	% Change in BIW (Range)
MO1 (GW) = 0.64 & MO2 (RH) = 0.68	0.017	0.67	-1.87: 0.11	-19.14: 17.74
MO1 (GW) = 0.64 & MO3 (ME) = 0.71	*0.035*	*0.70*	*-0.55: 0.27*	*-48.64: 25.45*
MO1 (GW) = 0.64 & MO4 (DM) = 0.73	*0.042*	*0.71*	*-0.63: 0.34*	*-48.75: 28.15*
MO1 (GW) = 0.64 & MO5 (RE) = 0.72	*0.036*	*0.69*	*-0.53: 0.26*	*-49.8: 24.18*
MO2 (RH) = 0.68 & MO3 (ME) = 0.71	0.027	0.71	-0.61: 5.41	-24.89: 19.22
MO2 (RH) = 0.68 & MO4 (DM) = 0.73	*0.041*	*0.72*	*-0.97: 8.25*	*-79.87: 28.64*
MO2 (RH) = 0.68 & MO5 (RE) = 0.72	0.023	0.70	-0.49: 3.57	-17.52: 19.23
MO3 (ME) = 0.71 & MO4 (DM) = 0.73	0.015	0.72	-0.38: 0.38	-14.69: 10.73
MO3 (ME) = 0.71 & MO5 (RE) = 0.72	**0.004**	**0.72**	**-0.13: 0.15**	**-2.88: 5.44**
MO4 (DM) = 0.73 & MO5 (RE) = 0.72	**0.009**	**0.73**	**-0.19: 0.16**	**-7.32: 7.86**

Based on the above mentioned results, 4 strategies are developed that reflect the indifference and dominance between MOs (step 4 of the conceptual framework) (table 5.65). Strategies sustainability, demand-supply gap and cost are presented in table 5.66.

Table 5.65: SUSMAQ DST NWB/FS- Strategy Development

	ST9	ST10	ST11	ST12
MO1 (GW supply development)	1	0	0	0
MO2 (Rainwater harvesting)	1	1/3	0	0
MO3 (Direct connection to Mekerot)	1	1	6/7	0
MO4 (Demand management)	1	1	1	1
MO5 (Reuse)	1	1	1	1

Table 5.66: SUSMAQ DST NWB/FS – Strategies Sustainability, Demand-Supply Gap, & Cost

	ST9	ST10	ST11	ST12
Economic Sustainability	*0.66*	*0.65*	*0.64*	*0.66*
Environmental Sustainability	*0.74*	*0.89*	*0.90*	*0.89*
Socio-Economic Sustainability	*0.69*	*0.66*	*0.67*	*0.68*
Overall Sustainability	**0.70**	**0.72**	**0.72**	**0.73**
Demand-supply gap (MCM)	*46.378*	*-101.95*	*-104*	*-106.22*
Demand-supply gap (normalised)	-0.37	0.81	0.82	0.82
Least Demand-supply gap (normalised)	**1.37**	**0.19**	**0.18**	**0.16**
Cost (MUSD)	*156.83*	*18.95*	*17.09*	*15.02*
Cost (normalised)	1.66	0.2	0.18	0.16
Least Cost (normalised)	**-0.66**	**0.80**	**0.82**	**0.84**
Overall	**0.47**	**0.57**	**0.57**	**0.58**

Ranking results are schematized in figures 5.6 and 5.7; sustainability vs. demand-supply gap in figure 5.8; and sustainability vs. cost in figure 5.9:

Figure 5.6: SUSMAQ DST NWB/FS – Strategies Ranking (Normalised)

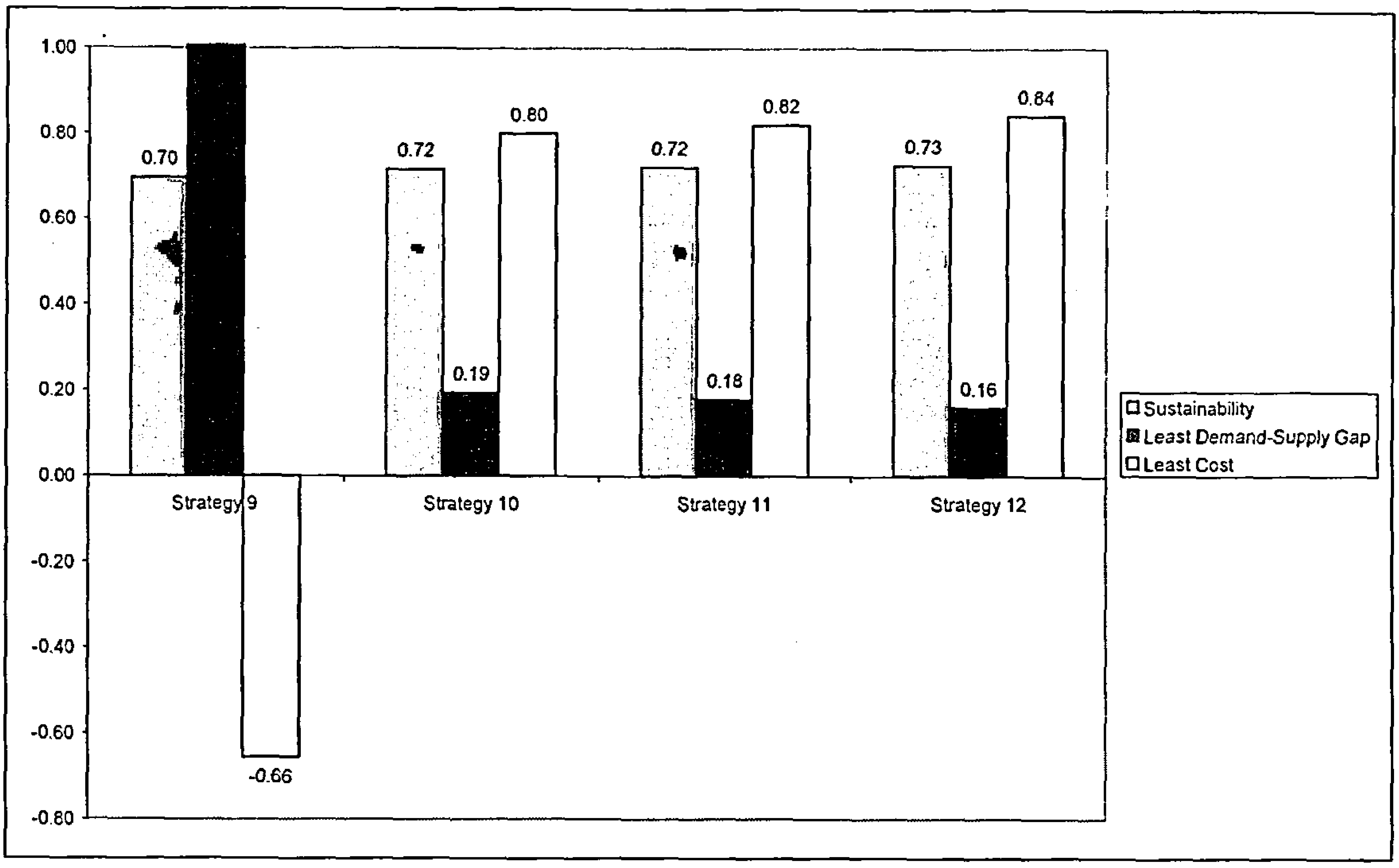
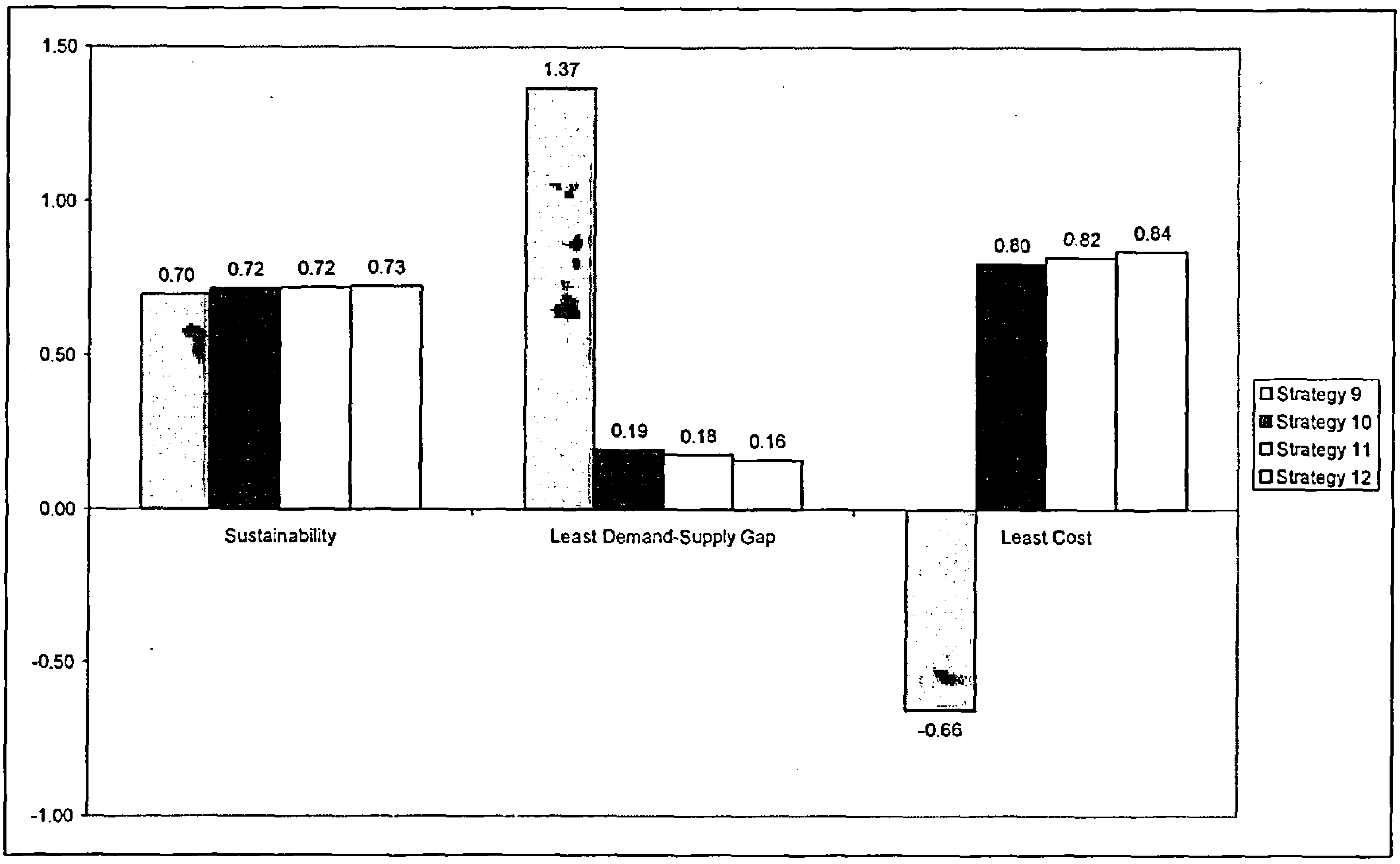


Figure 5.7: SUSMAQ DST NWB/FS – Strategies Ranking (Normalised Per Criterion)



It is clear, based on figure 5.7, that strategies 10, 11 and 12 are almost equivalent, scoring relatively high on sustainability and cost (least cost), and very low on demand-supply gap (least). Strategy 1 is the only one that closes the demand-supply gap with a positive balance, but at a very high cost and a lower sustainability.

Figure 5.8: SUSMAQ DST NWB/FS – Sustainability vs. Least Demand-Supply Gap (through Supply Enhancement)

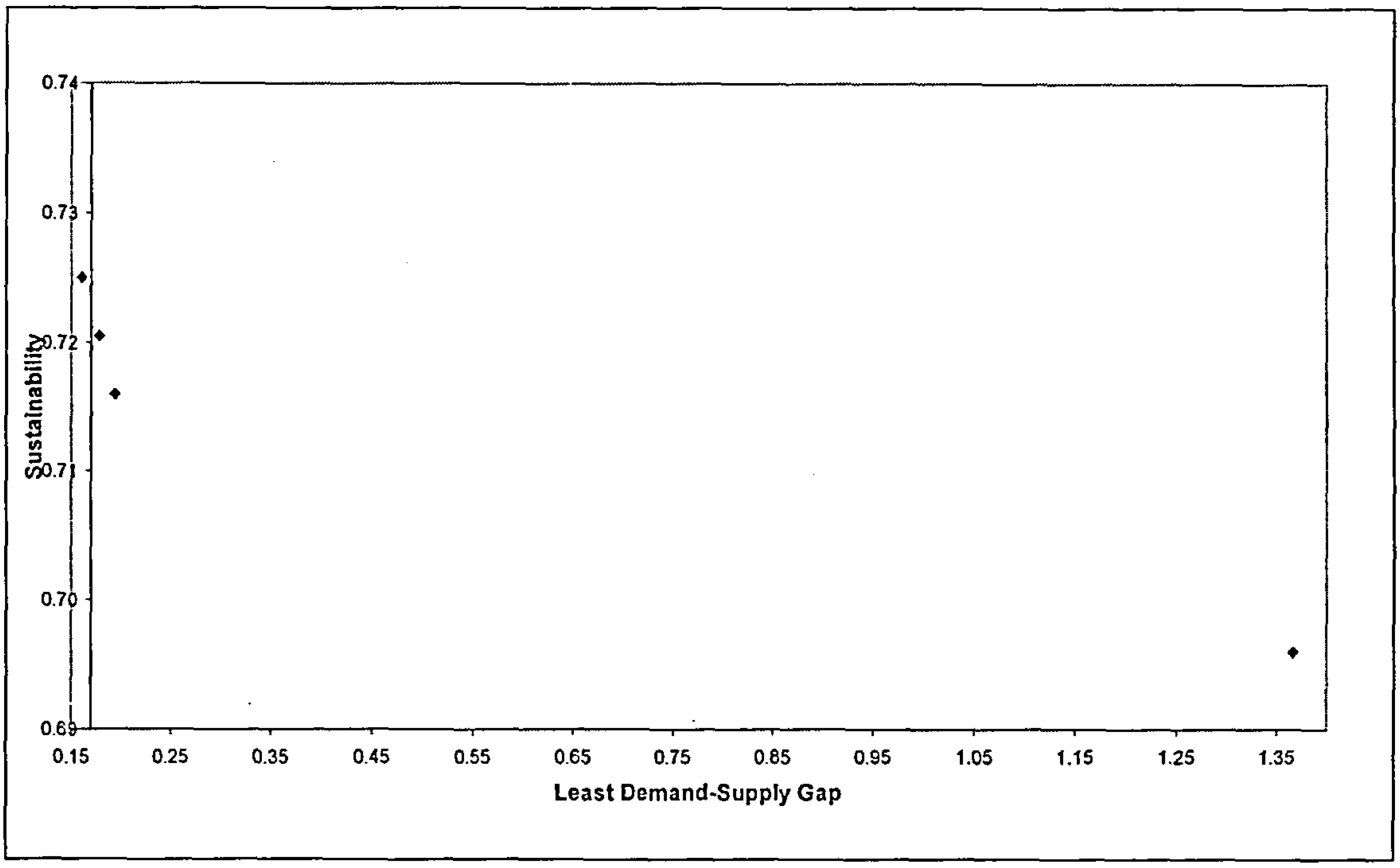
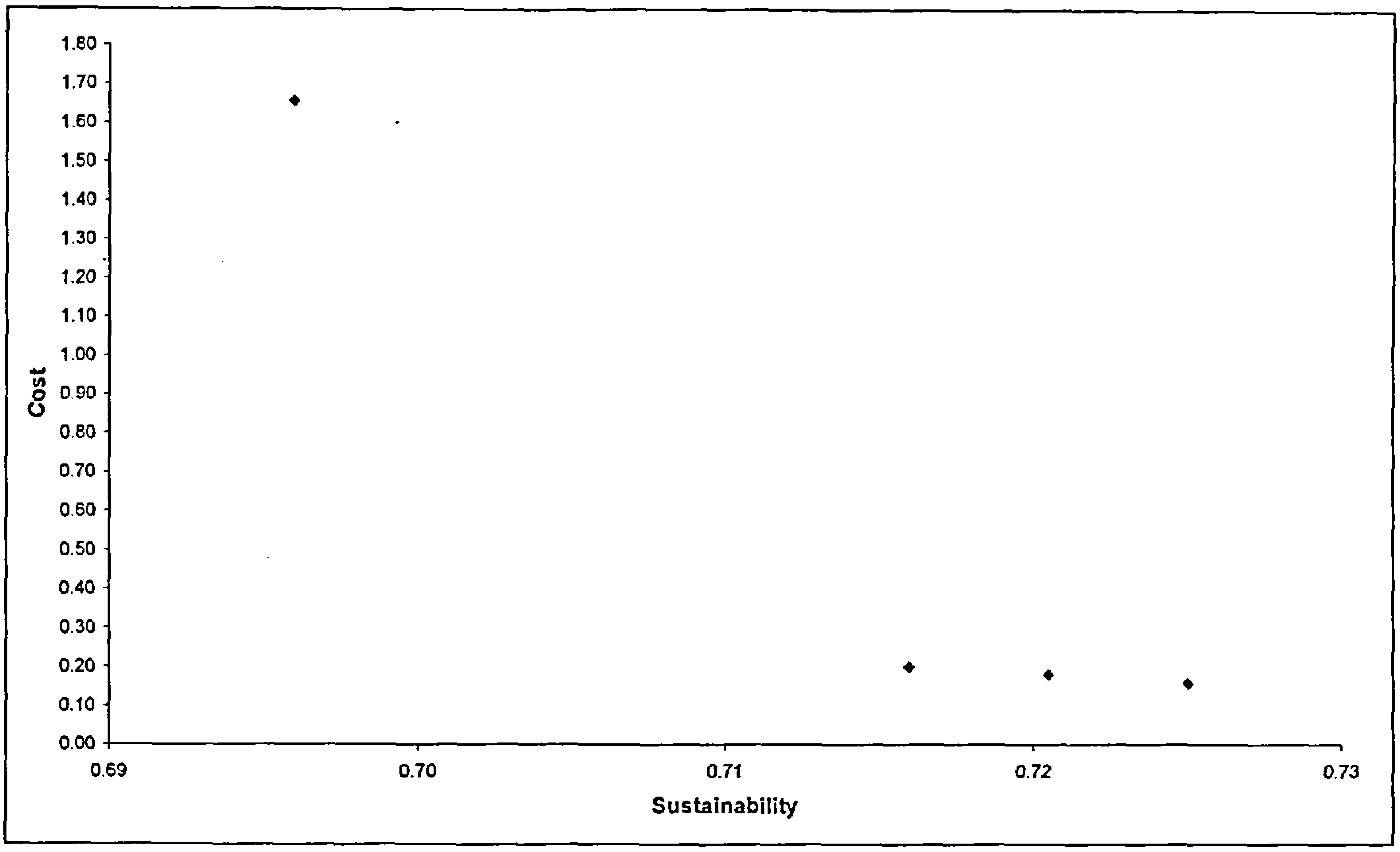


Figure 5.8 indicates that a higher score on the least demand-supply gap criterion is accompanied with a lower score on the sustainability criterion. More sustainable strategies are cheaper, as demonstrated by figure 5.9.

Figure 5.9: SUSMAQ DST NWB/FS – Cost vs. Sustainability



5.4 Summary of Strategies:

The application of the proposed validity assessment framework has generated a number of strategies, which are summarised and further reviewed in sections 5.4.1 (Current Scenario - Constrained Scenario) and 5.4.2 (Future Scenario - Less Constrained Scenario) below:

5.4.1 Strategies for a Constrained Scenario:

As presented in section 4.3.3 and Annex A, the current scenario is associated with a number of constraints ranging from political (control over water access, regional instabilities, etc.) to social (restrictions on movement of people, jobs, etc.) to financial (e.g. insufficient funds), to institutional (institutional instabilities), etc. These constraints restrict the choice of management options/ strategies, leading to equivalence of many of the MO/ strategies (e.g. table 5.51). These strategies for the current scenario are summarised and further reviewed below:

- ST1 is a strategy proposed for the current scenario based on SUSMAQ DSS, consisting of a full exploitation of all five management options (groundwater supply development, rainwater harvesting, direct connection to Mekerot, demand management & wastewater reuse). ST1 ensures the highest demand-supply gap reduction, reaching a gap of 62.84 MCM, with however the highest cost (13.975 million USD) and the least sustainability index (0.63).

- ST2 is a strategy proposed for the current scenario based on SUSMAQ DSS, excluding rainwater harvesting as an option and combining the remaining four MO, as follows: full groundwater supply development & full demand management, limited connection to Mekerot and wastewater reuse (2/3 of full capacity each). ST2 has the advantage of ranking second in terms of reducing the demand-supply gap; it is however associated with a relatively higher cost and lower sustainability index.

- ST3 is a strategy proposed for the current scenario based on SUSMAQ DSS, similar to ST2, but with even more limited exploitation of the direct connection to Mekerot option and wastewater reuse option (1/4 of full capacity each).
- ST4 is a strategy proposed for the current scenario based on SUSMAQ DSS, excluding both rainwater harvesting and direct connection to Mekerot, with full exploitation of the groundwater supply development option and the demand management option, and medium exploitation of the wastewater reuse option (1/2 of full capacity).

  ST3 and ST4 are almost similar in terms of the advantages they offer: very limited reliance on the direct connection to Mekerot and a relatively high sustainability index. The reduction of the demand-supply gap is however lower.

- ST5 is a strategy proposed for the current scenario based on SUSMAQ DSS, consisting of a full exploitation of the groundwater supply development option and the demand management option only. The main advantage associated with ST5 is the sustainability index (highest). Other advantages include a relatively lower cost and exclusion of the direct connection to Mekerot option. A major disadvantage however is the relatively lower demand-supply gap reduction.

- ST6 is a strategy proposed for the current scenario based on CBA and relying on the demand management option only. Despite the main advantage associated with this strategy (a relatively high benefit over cost ratio), it does not constitute a plausible solution given the extremely low demand-supply gap reduction it offers.

- ST7 is a strategy proposed for the current scenario based on CBA and consisting of a full exploitation of the groundwater supply development, demand management and wastewater reuse options. ST7 is very similar to ST4 (and ST3) in terms of the advantages and disadvantages associated with it.

- ST8 is a strategy proposed for the current scenario based on CBA and consisting of a full exploitation of the groundwater supply development and the demand management options only. ST8 is equivalent to ST5.

5.4.2 Strategies for a Less Constrained Scenario:

As discussed in section 4.3.3 and further detailed in Annex A, in the future scenario, all constraints associated with the current scenario are lifted. This allows a better testing of the proposed methodology, which is reflected in the final results - the overall values of the proposed strategies (table 5.66). These strategies for the future scenario are summarised and further reviewed below:

- ST9 is a strategy proposed for the future scenario based on SUSMAQ DSS and consisting of a full exploitation of the five management options (groundwater supply development, rainwater harvesting, direct connection to Mekerot, demand management and wastewater reuse). ST9 is the equivalent of ST1 for the future scenario. Its main advantage is that, unlike all other strategies, it offers a supply which exceeds the demand, at however a very high cost and with a lower sustainability index.

- ST10 is a strategy proposed for the future scenario based on SUSMAQ DSS, excluding groundwater supply development as an option and consisting of a full exploitation of the direct connection to Mekerot, demand management and wastewater reuse options and limited rainwater harvesting (1/3 of full capacity).

- ST11 is a strategy proposed for the future scenario based on SUSMAQ DSS, excluding both groundwater supply development and rainwater harvesting, and consisting of a full exploitation of the demand management and wastewater reuse options, with partial exploitation of the direct connection to Mekerot option (6/7 of full capacity).

  ST10 and ST11 are almost equivalent in terms of cost (very low compared to ST9), sustainability (average) and demand-supply gap reduction (low).

- ST12 is a strategy proposed for the future scenario based on SUSMAQ DSS, consisting of a full exploitation of the demand management and wastewater reuse options only. ST12 is very similar to ST10 & ST11 in terms of associated advantages/ disadvantages. An additional advantage though is the exclusion of the direct connection to Mekerot as an option.

6 GENERAL APPLICABILITY OF THE CONCEPTUAL FRAMEWORK

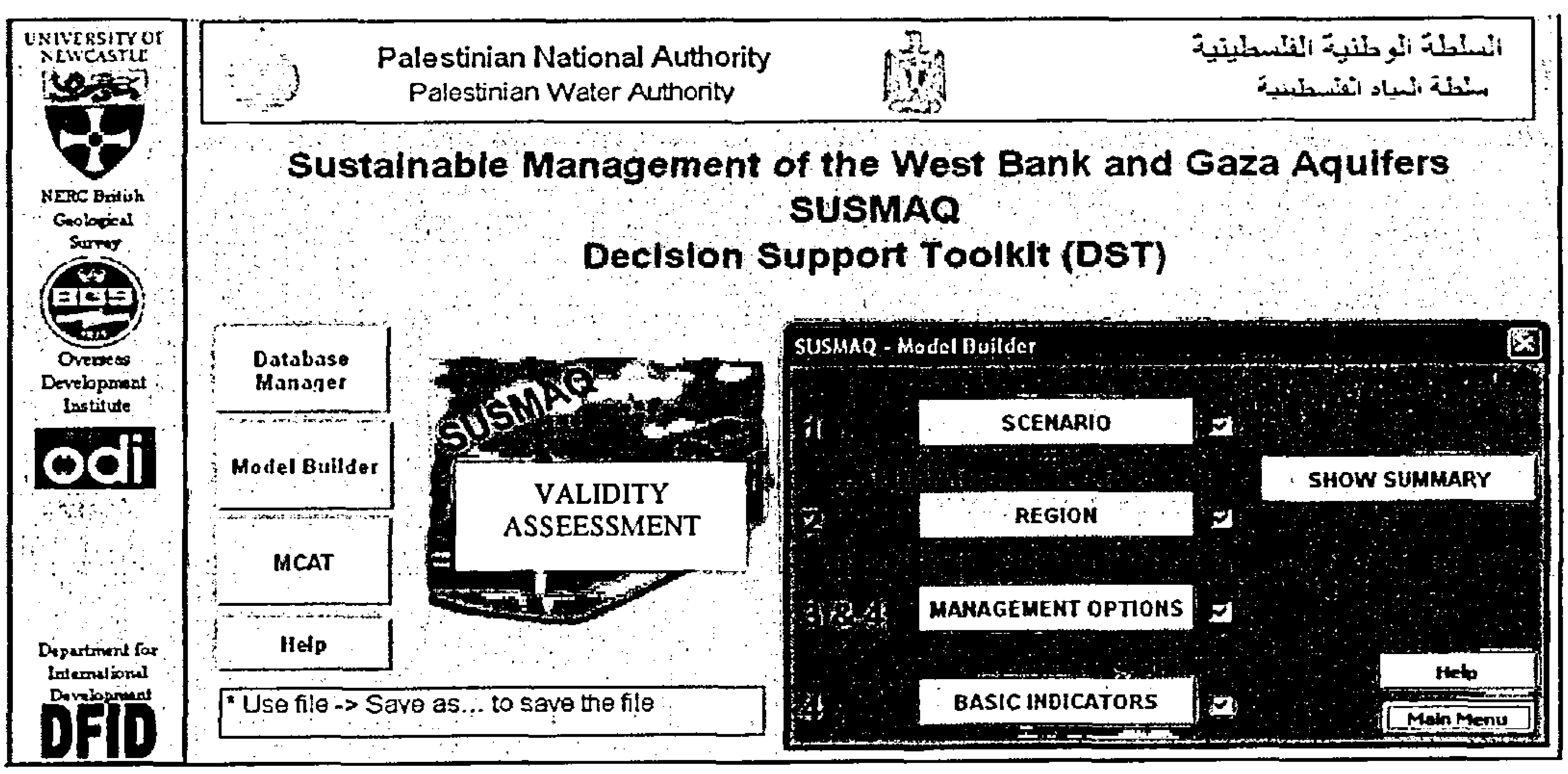
The proposed conceptual framework to assess validity of decision support systems, as described in chapter 3 and applied to the SUSMAQ project in chapters 4 and 5, is further schematised in this chapter to highlight its generic nature. This is reflected by a set of guidelines to develop a user-interface that helps using the framework, understanding its results & applying it to other projects of various natures (section 6.1). Elements of a corresponding user manual are outlined in section 6.2.

6.1 Towards a User-Interface:

Extracting a user-interface from the conceptual framework described in chapter 3 should abide by the following terms of reference:

- o The user-interface should complement the SUSMAQ DST software; as such it should be in harmony with the SUSMAQ DST software configuration.
- o The user-interface should be user-friendly; to that end, tests will be carried out with SUSMAQ stakeholders and the user-interface refined accordingly.
- o The user-interface will be accessed through a link on the SUSMAQ DST software, as per the figure 6.1 below:

Figure 6.1: Revised SUSMAQ DST Software

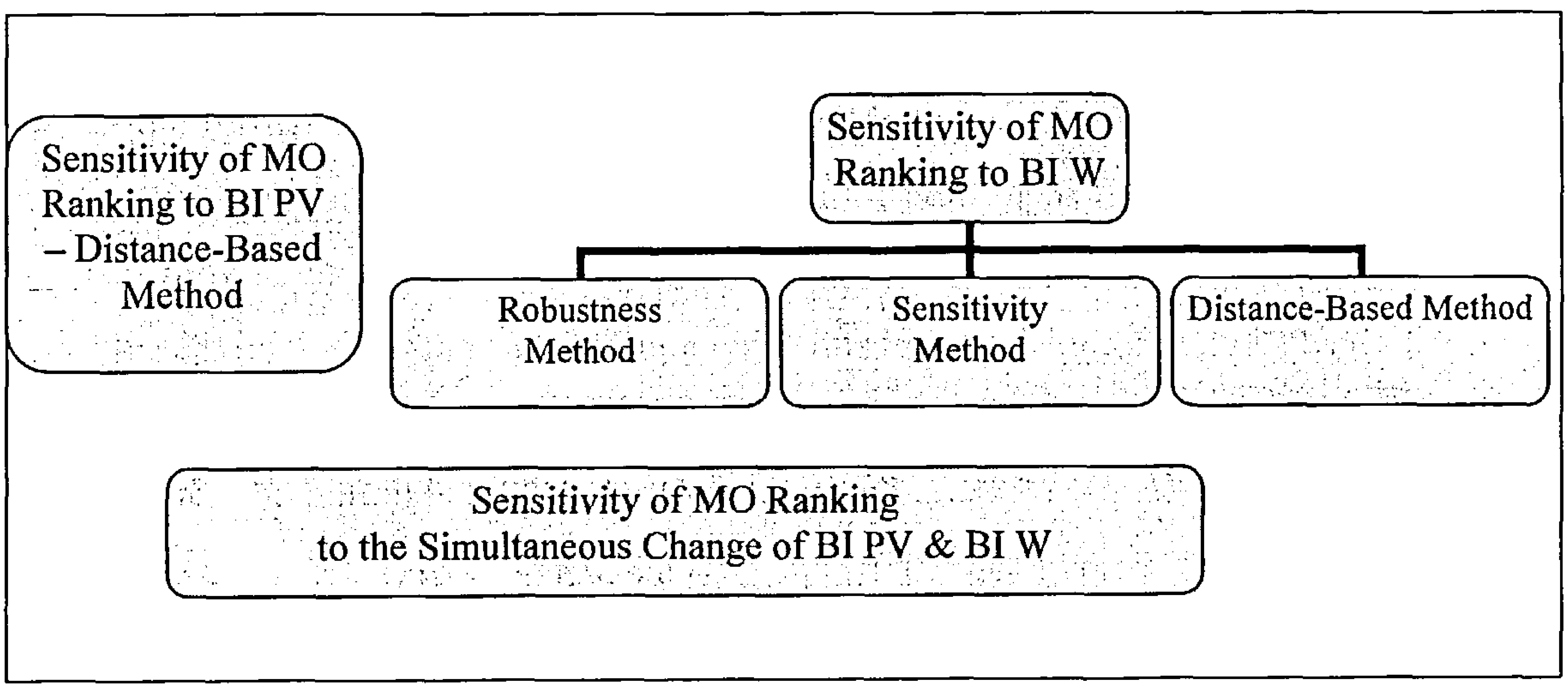


- A click on the validity assessment icon will open a window that briefly explains the conceptual framework and outlines the two approaches: intra-model validity and inter-model validity, with a note drawing the user's attention to preferably test both approaches.

- Clicking the intra-model validity icon will open a window that briefly reviews the approach as presented in pages 3-1 to 3-12, outlining the steps presented in figure 3.1 and summarised below:

  - Level of comprehensiveness of MO & level of comprehensiveness of BI: for each, the user will choose between high and low based on expert judgement – if the "low" button is selected, a message will appear advising the user to carry out further literature review &/or stakeholder consultation.
  - Level of confidence in BI PV & degree of consensus on BI W: for each, the user will choose between high and low based on his personal assessment of the PV calculation and W assignment results. A third button titled "Uncertainty Analysis" will also be made available with the following message popping up when the button is hit "Under Construction".
  - Level of sensitivity of MO ranking to BI PV & level of sensitivity of MO ranking to BI W, as per figure 6.2:

Figure 6.2: Revised SUSMAQ DST Software – Sensitivity Analysis Window



⇒ Hitting the "Sensitivity of MO Ranking to BI PV – Distance-Based Method" will generate a table of three columns inspired from tables 5.6 & 5.17, i.e. a first column outlining the various pairs of MO, a second column presenting the corresponding Euclidian distance (programmed as per the calculation details listed in pages 3-3 & 3-5) and a third column interpreting the significance of the value of the Euclidian distance (low sensitivity, medium sensitivity & high sensitivity).

⇒ Hitting the "Distance-Based Method" will generate a table of three columns inspired from tables 5.26 & 5.31, similar to the one presented above (and programmed based on the calculation details listed in pages 3-8 & 3-9).

⇒ Hitting the "Robustness Method" will generate a table of three columns inspired from tables 5.18 & 5.31, similar to the one outlined above, with the value of the robustness index (programmed based on the calculation details listed in page 3-6) instead of the Euclidian distance.

⇒ Hitting the "Sensitivity Method" button will generate a table of three columns inspired from table 5.31, similar to the one outlined above, with the value of the minimum quantity that the weight needs to be changed by (programmed based on the calculation details listed in page 3-7) instead of the Euclidian distance.

⇒ Hitting the "Sensitivity of MO Ranking to BI W" will generate a table similar to table 5.31 (i.e. a comparison of the three methods).

⇒ Hitting the "Sensitivity of MO Ranking to the Simultaneous Change of BI PV & BI W" will generate a table of three columns inspired from tables 5.34 & 5.45, i.e. a first column outlining the various pairs of MO, a second column presenting the corresponding Euclidian distance and a third column interpreting the significance of the value of the Euclidian distance (low sensitivity, medium sensitivity & high sensitivity).

- Strategy Development: the user will be invited to develop strategies by combining MO, i.e. by choosing a percentage which can vary from 0 to 100 for every MO, where the user's attention is drawn to the importance of taking into account sensitivity assessment results in choosing the percentages. Once the percentages selected, a table will appear, similar to table 5.51, i.e. outlining for every strategy its sustainability index, the demand-supply gap reduction index and the cost index, with a figure similar to figures 5.1 and 5.2.

o Clicking the inter-model validity approach will open a window summarising the approach as presented in pages 3-12 and 3-13, and inviting the user to select a discount rate and then hit the CBA button. A table presenting the CBA of each MO, similar to table 5.54, will then appear - this will require a direct link to the WBWMAT for calculation details. Another table or graph comparing ranking of MO based on the two methods, MCA & CBA, will also appear – this would be extracted from the comments following table 5.54.

o The user-interface shall contain any other element that the developer thinks will improve the understanding of the validity assessment exercise and facilitate its use. As an example, coding colours such as the ones presented at the bottom of figure 3.1 can be used to guide the user as to when it is appropriate to make a recommendation.

o The interface developer should hold a proven record of experience in designing user-interfaces. He will work in close collaboration with SUSMAQ team, for an estimated three man-month duration.

6.2 Towards a User Manual:

The user manual, or guide to the user-interface described in section 6.1, should contain the following information:

- A disclaimer which mentions that although all reasonable efforts have been made to develop a comprehensive methodology/interface, the authors assume no legal responsibility for the results that can be generated from the use of the interface. The disclaimer should refer to the limitations associated with the methodology, and which can be extracted from section 3.3 (Chapter 3).

- General instructions on how to access the user-interface, run it, save information, exit, etc.

- One section for each step of the framework, which will present the objective of the step, outline pre-requisites, detail data required and explain outputs. Further details are presented below:
  - Level of comprehensiveness of MO & BI:
    The manual should remind the user of the importance of considering all plausible options and of capturing all indicators. Guidelines can be extracted from relevant sections in the literature review and conceptual framework chapters.

  - Level of confidence in BI PV & degree of consensus in BIW:
    The manual should summarise the information presented in tables 5.1, 5.2, 5.3 & 5.4 to guide the user on how to assess the level of confidence in BIPV and the degree of consensus in BIW. The manual should also draw the user's attention to the definition and techniques of uncertainty analysis that could be applied, specifying that this option is still under construction. This is further tackled in section 7.2 (chapter 7).

  - Sensitivity of MO ranking to BIPV & W:
    The manual should include a brief definition of each sensitivity method as well as a short description of how to interpret sensitivity results. This can be extracted from section 3.1 (chapter 3).

- Development & evaluation of strategies:

  The manual should guide the user on how to develop strategies, based on the introductory section of step 4 of the methodology (page 3-10). It should also be made clear to the user that three additional key data are needed to perform the evaluation section of this step. These are (1) demand data, (2) supply that can be generated from each MO, and (3) cost of each MO. The manual should also clearly describe when the DSS can be considered validated, i.e. when it is appropriate to make a recommendation for decision-making. This can be extracted from step 5 of the methodology (pages 3-11 & 3-12).

- Inter-model validity:

  The manual should include a definition of CBA and CBA calculation method. It should also provide some guidance on the potential discount rates that could be tested, drawing the user's attention that the use of lower discount rates can better capture environmental effects, which are of the long-term type.

It is expected that the development of the user-interface and its associated user manual will facilitate the use of the proposed validity assessment framework in the context of the SUSMAQ project for a continuous assessment of results based on existing and future data. This would make replication of the framework to other projects of similar or different natures in various regions more plausible. This is the subject of one of the recommendations listed in chapter 7.

7 DISCUSSION AND CONCLUSIONS

The outcome of this thesis is a framework methodology for assessing the validity of decision support systems, and more particularly Multi-Criteria Analysis (MCA) and Cost-Benefit Analysis (CBA) methods, as a basis for decision-making. The framework methodology has been tested on a water resources management application- the "Sustainable Management of the West Bank and Gaza Aquifers"/ North West Bank/Current Scenario and Future Scenario (SUSMAQ) – and validity results used for proposing water strategies.

Discussion and recommendations are therefore centred on three axes:

- the framework itself: the methodology for assessing validity
- application results: from management options to strategies
- end results analysis: strategies' implications

7.1 Methodology for Assessing DSS Validity

The proposed methodology for assessing DSS validity[10], as detailed in chapter 3, addresses many of the DSS validity concerns expressed in literature and summarised in chapter 2. While some of these concerns are directly addressed by the proposed framework, others (mainly the overall usefulness) are not, as explained below.

DSS usefulness, as a major element in validity assessment[11], was not directly addressed by the methodology outlined in chapter 3, for the reasons mentioned below – bearing in mind that usefulness often depends on how much the end user understands the analytical algorithm behind the method, as mentioned in chapter 2-:

[10] Validity, as defined in chapter 2, is the "process of checking the extent to which the DSS developed to allow experimentation on a surrogate world is appropriate to the task in hand"

[11] based on improvements made to the effectiveness and quality of decision-making, time required to reach a decision, incorporation of knowledge from various sectors and disciplines, developing a product that is industry rather than research oriented, end users' involvement as well as user friendliness

- *Effectiveness and quality of decision-making*: the proposed framework did not include a stakeholder consultation process to assess clients' satisfaction with the delivered product, e.g. how much stakeholders think the DSS has helped improving the effectiveness and quality of their decision-making. The main reason is that not much time has elapsed since the SUSMAQ DST delivery date (December 2005/ January 2006). During the construction of the DST and its appended validity assessment framework (the output of this thesis), all available resources have been used to maximise chances of later clients' satisfaction: (1) end users have been involved in the various steps of DSS development; and (2) a thorough uncertainty/sensitivity analysis has been included in the validity assessment framework. The final product is therefore expected to improve the effectiveness and quality of the water decision-making process in the West Bank, and more importantly enhance transparency. Further research on how to assess the usefulness of the proposed approach is listed among the recommendations in section 7.2.

- *Time required to reach a decision:* as mentioned above, data is not yet available to assess whether the DST has helped accelerating the decision-making process.

- *Incorporation of knowledge from various sectors and disciplines*: the process of DST development grouped various experts from various disciplines (engineers, social scientists, economists, etc.). The various outputs or complementary documents to the DST tool (SUSMAQ reports) clearly indicate the incorporation of knowledge from various sectors and disciplines.

- *Delivering a product that is Industry rather than research oriented:* one of the key features of the SUSMAQ DSS is that it has been developed in the context of a public/private (academic) partnership, which allowed interactions between decision-makers and public servants on one hand, and researchers and academicians on the other hand. This maximises the chances of a practical use of the end product.

- *End users' involvement:* close communication between the DST developers and its end users (the technicians who will use the DST upon its delivery) prevailed throughout the various phases of DST development.

- *User friendliness:* stakeholders' feedback on the ease of use of the DST has not been solicited for time constraints mentioned above. The DST interface however (visual basics) hides to the end users the various science and engineering complexities, thus allowing them to at least believe the DST is easy to use. As per the guidelines outlined in chapter 6, it is proposed that the validity interface abides by the same specifications; this is highlighted as a recommendation in section 7.2. This has a direct consequence on the DST perceived usefulness and willingness to use it, as discussed in chapter 2.

As for the technical aspects of DSS validity – i.e. comprehensiveness, uncertainty analysis, sensitivity analysis, and comparison to other decision-making methods-, the proposed framework directly addressed them, as outlined below:

- *Comprehensiveness:* the proposed validity assessment framework starts with an assessment of whether the management options (MO) and basic indicators (BI) are exhaustive. This is a crucial step, one of the 4 elements of success of long-term policy analysis (LPTA) as detailed in chapter 2: that is the importance of considering "large scenarios/ alternatives"

- *Uncertainty:* uncertainty analysis is addressed in the second step of the proposed methodology: uncertainty with respect to (1) the degree of consensus on the weights elicited for the various BI, and (2) the level of confidence in the performance values assigned for the various BI. This analysis addresses, in an indirect way, uncertainty associated with all data and models (assumptions, subjective judgment, etc.). While the proposed method for analysing uncertainty is relatively simple compared to existing uncertainty analysis methods presented in chapter 2, it is nevertheless considered adequate, especially when coupled with sensitivity analysis, in the context of a broader integrated framework. Further research on incorporating more advanced uncertainty analysis techniques is recommended in section 7.2.

- *Sensitivity:* sensitivity analysis (SA) directly follows uncertainty analysis in the proposed framework. Sensitivity of MO ranking to changes in BI weights and/or BI performance values, or even to the simultaneous change of BI weights and performance values, is explored. For some parameters, various SA methods are explored and results cross-checked. SA having a key role to play in increasing confidence in the DSS by understanding how it responds to changes in inputs, it is allocated a more in-depth review in the proposed framework. It is considered the second element of success in LTPA: "seek robust, not optimal, solutions".

- *Comparison to other methods:* the second part of the validity framework, inter-model validity, compares DST results to the cost benefit analysis (CBA) approach. This constitutes an opportunity to address typical CBA issues such as: importance of indirect benefits with respect to direct benefits, influence of the discount rate on CBA results as well as complementarity or even equivalence between CBA and multi-criteria analysis (MCA) - complementarity because CBA needs MCA to address the "incommensurables" and "intangibles", as explained in chapter 2, and MCA needs CBA for monetary quantification; equivalence as for some, CBA evolved to MCA by encompassing the social and environmental dimension in the costs and benefits, and assigning weights to the various costs and benefits.

Last but not least, the proposed methodology for assessing DSS validity takes the validity assessment a step forward towards strategy building, further discussed in sections 7.2 and 7.3. This enhances the usefulness of both the DSS and the validity assessment framework. It also helps improving the adaptivity and interactivity of the DSS, the two remaining elements of the 4 elements of success of LTPA.

This thesis has therefore proposed an integrated framework methodology for assessing the validity of DSS, one that addresses almost all DSS challenges as outlined in the literature (chapter 2) and summarised above. Applied to a water resources management case in the West Bank in the context of this research, this framework methodology can be applied to other water resources management case studies or any other management project, thus enhancing the overall performance of DSS. This is particularly important given the increasing demand for such decision-aid tools despite their weaknesses; which makes any research for alleviating these barriers critical.

When coupled with the incremental benefits of sharp validity assessment tools, the overall benefits of building DSS are better reflected, especially when compared to the associated costs: SUSMAQ DSS, including the present validity analysis framework, can assist Palestinian decision-makers in developing more sustainable water strategies, without the need for any additional information to the information normally required by decision-makers for such a task. The time and cost associated for putting the DSS together are negligible compared to the expected associated benefits, such as a faster generation of sustainable management options and strategies and a more scientifically integrated tool to defend these options and strategies.

7.2 Validity Results: From Management Options to Strategies

Is the DSS developed in the context of the SUSMAQ project valid based on the application of the proposed methodology to SUSMAQ (chapter 4) and associated results (chapter 5)?

Giving a clear cut answer to the above mentioned question is rather impossible given that:

- such a question presumes that a right answer exists, which is not the case: on one hand, the "best" solution is very much influenced by subjective and individual preferences, and on the other hand, the lack of full knowledge, even if accounted for in the validity assessment framework, will always remain a factor, thus making absolute statements such as "best alternative" rather not recommended; and
- as pointed out in section 7.1, it is still early to make a judgement given that SUSMAQ DSS was delivered in January 2006 only. It is therefore not possible at this stage to validate DSS statistics results available in the literature and listed in chapter 2 (that 80-90% of DSS do not meet their performance goals, while 10% meet success criteria).

It is however possible to draw up the following conclusions, some of them concurring with many of the findings available in the literature.

⇒ Sensitivity analysis (SA) is indeed a practical alternative to uncertainty analysis: SUSMAQ Management Options (MO) SA results and subsequent strategies formulation and evaluation with pseudo-equivalence of ranking results supersede the need for any complex uncertainty analysis at the basic indicators weights (W) and performance values (PV) level.

⇒ Ranking of MO is more sensitive to basic indicators (BI) PV than to W.

⇒ Simultaneous changes in PV and W generate results very consistent with separate changes to PV and W.

⇒ MO ranking results should only serve as a guidance for better strategy building by generating several MO combinations based on sensitivity results.

⇒ DSS is indeed meant as a "supplement rather than a substitute for intuition": a careful look at SUSMAQ management options sustainability values coupled with professional judgement, before undertaking any sensitivity analysis and maybe even before calculating the sustainability values, would have generated almost the same MO combinations/ strategies. This could be considered a further method of validation of the DSS in question.

This emphasises the conclusions reached by many experts on the importance of decision-making tools, such as DSS or CBA, being to (1) introduce better scientific thinking, (2) benefit from the process of model building, rather than focus on completing the model only, and (3) increase willingness to use such decision-making tools. Therefore DSS benefits should not be reduced to enhancing the quality of decision-making only, but also making it possible to quantify assumptions and enabling new plans to be generated quickly if old plans diverge from reality.

⇒ Adequately reflecting the demand-supply gap constraint in the sustainability indicators is not straightforward: the demand-supply gap having more than one dimension (one social, one environmental and one economic), its representation in the sustainability indicators follows a piecemeal pattern; thus not adequately reflecting this major challenge.

⇒ Indirect benefits should be accounted for in cost benefit analysis (CBA) as (1) in some cases in the context of the SUSMAQ project, indirect benefits reach ~ 50% of the total benefits; (2) ranking of SUSMAQ MO with and without indirect benefits proved different; and (3) some MO in the SUSMAQ project are not cost justified if indirect benefits are not accounted for.

⇒ The choice of discount rate has a direct consequence on MO assessment: for some cases in the SUSMAQ project, and more specifically when indirect benefits have not been integrated, the MO turned out to be feasible at low discount rates only (3% and 5%).

⇒ CBA that accounts for indirect benefits is, to a certain extent, equivalent to multi-criteria analysis provided indirect benefits are properly integrated.

⇒ There is no one single most preferred strategy, especially for the NWB/Current Scenario: all generated strategies are almost equivalent. They all rank very low on the demand-supply gap criterion; their total values, whether based on one criterion only (i.e. sustainability), or three (i.e. sustainability, demand-supply gap and cost), vary across an extremely small range (one criterion: range from 0.63 to 0.67; three criteria: 0.54 to 0.56). Decision-making can therefore be made based on other criteria of the politico-institutional nature.

⇒ In the NWB/CS, all strategies rank highest in terms of cost (least), followed by sustainability, and finally demand-supply gap (least). The difference in ranges between the three criteria is worthwhile mentioning: least cost (0.8 – 0.83); sustainability (0.63-0.67); and least demand-supply gap (0.17-0.20). This raises questions on whether any strategy can be identified that scores high on both the demand-supply gap criterion and the sustainability criterion .

⇒ Strategies that rank highest on sustainability rank also highest on cost (least); they, however, rank lowest on demand-supply gap (least).

The conclusions drawn above concur with most of the literature findings on decision support systems and validity related issues as well as cost benefit analysis and related challenges. While an attempt has been made to refine the decision support tool developed in the context of the SUSMAQ project (DST), by undertaking a validity assessment exercise and related strategy formulation, it is recommended to undertake the following activities for further refinement of the product:

- Incorporate more advanced uncertainty analysis techniques in step 2 of the proposed methodology - intra-model validity, i.e. studying the uncertainty associated with the performance values and weights associated with the BI. This includes asssessing both (1) variability, which occurs because of the natural fluctuation of a parameter over time, or space or within a group - this is applicable to the three categories of basic indicators (economic, environmental and social) as well as the weights; and (2) incertitude, caused by measurement error, systematic bias, missing data, incomplete description of a mechanism or process and other limitations of scientific knowledge. This would allow a better application of the proposed framework, particularly for the cases where MO ranking is sensitive to BI PV and/or W. It would also provide the opportunity of studying the level of uncertainty in the MO sustainability value, and therefore the level of uncertainty in the ranking of MO. A comparison between sensitivity analysis and uncertainty analysis could be also looked at, thus refining the proposed methodology. The uncertainty analysis methods that could be explored range from Monte Carlo simulation to information gap theory to fuzzy representation, as discussed in chapter 2.

- Assess with practicing decision-makers the usefulness of the proposed approach, particularly that DSS usefulness represents a major validity concern. This would enhance the chances of reaching an "industry-based" product, as opposed to a "research-based" product. The various developments in the sociotechnology theory should help initialising this research[12]. Interactions between the various stakeholders may lead to new features that can be added to the proposed framework, thus enhancing its quality. Future research would in particular cover the following aspects: (1) whom to involve in the assessment exercise (the Palestinian Water Authority staff, SUMSAQ team at large, civil society, etc.); (2) how to carry out the assessment (questionnaires, interviews, trials, electronic networks, collaboration and negotiation platforms, etc.); (3) where, which is very much related to the whom and the how; (4) when (single or repetitive, single audits or continuous monitoring, etc.); (5) what criteria (improvement in the quality of decision-making, acceleration of the decision-making process, increase in the numbers of users, etc.) ; and (6) who is to coordinate the assessment (a knowledge provider, a social scientist, a "judgement engine", ...).

- Build in the validity assessment framework – in its two components, intra-model validity and inter-model validity- in the DST tool, for a continuous assessment of results based on new data, and for replication to other regions of the West Bank and other scenarios, as per the set of guidelines presented in chapter 6.

Both these activities will not only improve or attempt to improve the integrated water resources management process in the West Bank, but also enrich the literature related to DSS and its application to water resources management.

[12] Specific details – as extracted from the work of Abbott and Jonoski (section 2.1.4) - include: sessions of collaborative learning for the various stakeholders that precede key sessions dedicated to the identification of management options, basic indicators and weights. Such sessions would provide an opportunity for communication in a knowledgeable and well-informed way between various types of stakeholders (farmers, citizens, scientists, government officials, etc.), thus educating them all on the process of transforming advice into actions by the forming of right judgments. This should lead to a higher level of consensus on the weights elicited for BI and therefore more robust ranking of MO and strategies.

Some of the above findings go beyond decision support systems to tackle a key serious global environmental challenge, that is water scarcity in selected regions, particularly the Middle East, and related solutions, as discussed in section 7.3.

7.3 Strategies' Implications

Although the aim of this research is methodological, and by no means a prescription of water options for the West Bank, it is nevertheless important to discuss strategy formulation and related results, as detailed in chapter 5 and summarised in section 7.2, and which point out two findings in relation to the North West Bank – Current Scenario:

- Sustainability is inversely proportional to demand-supply gap (least) by 1.5: for every additional unit gained on the demand-supply gap (least), through supply enhancement, a unit and a half is lost on sustainability.
- More sustainable management options (MO) are cheaper: for every additional unit gained on sustainability, the cost is reduced by 0.7 of a unit. This concurs with literature findings.

These trends are also valid for the NWB/Future Scenario. Unfortunately, lack of data does not allow further elaboration on the first conclusion: neither to fully validate the findings, nor to carry out similar analysis about sustainability in relation to demand-supply gap (least) but through demand management rather than supply enhancement. Additional studies are therefore recommended to illustrate sustainability as a function of supply enhancement and demand reduction.

Demand data for the North West Bank/ current scenario, as presented in chapter 5, show a municipal demand of about 60.75 MCM/yr (i.e. 166L/cap/day for a population of about 1 million), an industrial demand of 4.95 MCM/yr and an agricultural demand of 80.64 MCM (i.e. 600 CM/dunum/yr for an agricultural area of about 134,400 dunums – that is 600 L/sq.m./yr for an agricultural area of 134.4 sq.km.). The available supply is limited to 68 MCM. Closing the gap between water supply (68 MCM) and water demand (~146 MCM) without reverting to supply enhancement would mean reducing demand by 78 MCM, which implies one of the following policy options:

- Drop out all agricultural activities; this would result in a positive water balance of 2 MCM/year. This is not feasible for many reasons: economic (agriculture accounts for 30% of the GDP (Aliewi et al., 2005)), social (cultural traditions and job opportunities under the prevailing circumstances) and last but not least political, as zero agriculture would mean total dependency on food for a country in war.

- Invest heavily in demand reduction by measures targeting citizens and farmers: (1) controlling leakage; installing high-efficiency, low water uses appliances and fixtures in homes and businesses; limiting water uses; increasing water prices where feasible; and reducing demand per capita through conservation education; (2) improving irrigation efficiency; reducing the total area of irrigated crops; changing crop planting patterns to more water efficient crops; and removing water consuming plants from unproductive lands. This option cannot solely remedy the problem; it should be accompanied by a strategy to enhance supply, one that looks at more sustainable management options, most of which, if not all, have been considered in the context of the SUSMAQ project, but with not enough data for some of them. Such a policy therefore requires further investigation and studies on both supply enhancement and demand reduction, and associated sustainability and demand-supply gap reduction values, before any recommendation can be made.

- One policy option that has not been investigated yet in Palestine is water banking. Despite the limitations it is subject to, water banking has been seriously recommended in many countries, some of them located in the region, such as Cyprus. Water banking allows the coexistence of all sectors (agriculture, industry, tourism, etc.). At the same time, it can be implemented with virtually no capital costs, and most importantly, it only needs to be activated in years of scarcity, which, unfortunately, is the rule, rather than the exception in Palestine and the region. But should water be more abundant in some years, by natural or man-made means, the water bank would not need to be activated and there would be no side implications.

For the NWB/Future scenario however, one of the strategies ensures a full satisfaction of demand, with a positive balance on the supply-demand equation. This stratgey consists of a full combination of groudnwater supply development, rainwater harvesting, direct connection to Mekerot, demand mangement and wastewater reuse. The associated cost is however much higher and the sustainability lower.

7.4 Conclusion

This research has resulted in an integrated framework methodology for assessing the validity of decision support systems (DSS) in application to water resources management. More particularly, Multi-Criteria Analysis and Cost Benefit Analysis methods have been compared, as a basis for decision-making. By studying the validity, both intra and inter model, the proposed framework addresses most of the experts' concerns about DSS, primarily validity concerns, thus enhancing the performance of DSS. This framework can be easily replicated for other water management case studies and/or other management projects. This is particularly important given the increasing demand for DSS and the ability of the proposed framework to improve the reliability of DSS as strategy recommenders, by introducing an integrated tool to assess their validity. The benefits of such a validity framework tool and application are further accentuated by the negligible costs associated with them.

The conclusions brought by the application of the proposed framework to the Sustainable Management of the West Bank and Gaza Aquifers (SUSMAQ) and more particularly the North West Bank under the current scenario (fully) and the future scenario (partially) are consistent with literature findings: importance of sensitivity analysis as a practical alternative to uncertainty analysis, sensitivity of alternatives ranking to criteria performance values more than to criteria weights, importance of accounting for indirect benefits in cost benefit analysis and for the choice of discount rate, complementarity if not equivalence of Multi-Criteria Analysis and Cost Benefit Analysis.

The validity assessment results were used to generate strategies for the management of water resources in the SUSMAQ/North West Bank, as an illustrative example only. No conclusion could be reached as to the most preferred strategy, especially for the NWB/Current Scenario, since all strategies have led to almost equivalent results: sustainability values more or less equal with an average score, but a demand-supply gap value of almost 100% of the supply value for all strategies. The analysis shows that for every unit gained on the demand-supply gap, by enhancing supply, a unit and a half is lost on sustainability. The same trend appears in the NWB/Future Scenario, for which however, unlike the Current Scenario, there exists one strategy where demand is fully met, with even a surplus of water in the supply-demand balance, but at a very high cost in comparison to other strategies. This highlights the need to further investigate measures for demand management in areas with scarce water, such as the North West Bank, along with checking or re-checking more sustainable management options for enhancing supply, and also start investigating other water policy options such as water banking.

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Annex A. SUSMAQ Hydropolitical/Socio-Economic Scenarios

	Current	Consolidating	Future
Macro socio-economic environment	Substantially subsistence agriculture and internal market economic environment	Still significant reliance on agriculture but initiation of more internal regional trading	Changing economic development pattern from agriculture to industry
	Development aid focused on budget support and humanitarian projects	Industrial development starts, particularly agro-industries initially	Agro, service, skilled and tourism industries and international trading developing
	Major closures throughout the West-Bank and Gaza	Major internal closures lifted but controls still in place and limited external border movement	Internal and external border controls lifted
Constraints/ Assumed conditions	Political control over water (Access)	Agreement reached on equitable share of water resources	*As for consolidating state plus the following:*
	No control over borders – Movements of goods	Transfer of water within internal regions permitted but possibly not yet between regions	Importation/transfer of external water sources permitted
	Closures: restrictions on movement of people jobs etc (SE)	Relatively free movement of people and goods internally and within the region	Free movement of people and goods internally and externally
	Insufficient funds (Financial)	Development funding increasing but insufficient	Development funding moves to semi-commercial basis and is sufficient
	Regional political instabilities	Regional political stability achieved	
	Institutional instabilities	Institutional development/stability	
	Limited water resources (Availability)	Limitations in movement/water sources etc related to the separation wall lifted	
	Separation wall		
Objectives	Water for basic human needs (health, life,……)	Improved water quality and quantity to basic WHO standards	Water quality and quantity progressing to regional standards as economy permits
	Water for sustainable livelihoods based on agriculture	Agriculture can develop to serve the growing needs of the population within economic practicality	Water utilisation is developed in an optimal socio-economic manner taking account of domestic, agricultural, industrial and environmental needs
	Water for limited commercial agriculture	Provision of sufficient water for fledgling industries	Water policy, regulation and service delivery is developed and applied in an efficient and integrated manner alongside sustainable resource development
	Protect the aquifer from over abstraction and pollution	Sustainable development of water resources	

Source: SUMSAQ, 2005f

Annex B. Water availability (ceiling values) for SUSMAQ Management Options (MCM/annum)

MO ref.	Brief Description	Total (MCM)	Gaza	W. B. Total	West Bank		
					North	Central	South
Baseline							
1	GW supply	243.0	145.0	98.0	49.0	43.0	6.0
2	Rain water	8.0	2.0	6.0	2.3	1.2	2.5
3	Tanker supply	9.8	0.8	9.0	4.0	1.0	4.0
4	Mekerot	43.6	3.6	40.0	10.3	17.0	12.7
5	Desalination	0.8	0.8	0.0	0.0	0.0	0.0
6	Demand management	1.5	0.0	1.5	0.5	0.5	0.5
7	Protection/conservation	1.0	0.5	0.5	0.0	0.5	0.0
8	Re-use	1.0	0.5	0.5	0.20	0.10	0.20
9	Sectoral Reallocation	5.0	2.0	3.0	3.0	0.0	0.0
10	Changes to agricultural policy	25.0	5.0	20.0	6.0	8.0	6.0
11	Water Transfer	22.0	0.0	22.0	0.0	0.0	22.0
12	Administrative and institutional structures	N/A	N/A	N/A	N/A	N/A	N/A
Baseline supply		**296.4**	**151.9**	**144.5**	**61.8**	**61.3**	**21.4**
Demand reduction		**26.5**	**5.0**	**21.5**	**6.5**	**8.5**	**6.5**
Cumulative value		**322.9**	**156.9**	**166.0**	**68.3**	**69.8**	**27.9**
Re-allocation		**5.0**	**2.0**	**3.0**	**3.0**	**0.0**	**0.0**

Current Scenario							
CUR01.1	GW supply	268.0	145.0	123.0	61.5	54.0	7.5
CUR02.1	Rain water	9.0	2.0	7.0	2.7	1.4	2.9
CUR03.1	Tanker supply	10.8	0.8	10.0	4.4	1.1	4.4
CUR04.1	Mekerot	48.6	3.6	45.0	11.6	19.1	14.3
CUR05.1	Desalination	0.8	0.8	0.0	0.0	0.0	0.0
CUR06.1	Demand management	3.5	0.0	3.5	1.2	1.2	1.2
CUR07.1	Protection/conservation	1.5	0.5	1.0	0.0	1.0	0.0
CUR08.1	Re-use	2.0	0.5	1.5	0.5	0.50	0.50
CUR09.1	Sectoral Reallocation	5.0	2.0	3.0	3.0	0.0	0.0
CUR10.1	Changes to agricultural policy	25.0	5.0	20.0	6.0	8.0	6.0
CUR11.1	Water Transfer	22.0	0.0	22.0	0.0	0.0	22.0
CUR12.1	Administrative and institutional structures	N/A	N/A	N/A	N/A	N/A	N/A
Cumulative supply		**328.4**	**151.9**	**176.5**	**76.3**	**75.0**	**25.2**
Demand reduction		**28.5**	**5.0**	**23.5**	**1.2**	**1.2**	**1.2**
Cumulative value		**356.9**	**156.9**	**200.0**	**77.4**	**76.2**	**26.4**
Re-allocation		**5.0**	**2.0**	**3.0**	**3.0**	**0.0**	**0.0**

MO ref.	Brief Description	Total (MCM)	Gaza	W. B. Total	West Bank		
					North	Central	South
Consolidating Scenario							
CON01.1	GW supply	385.00	150.00	235.00	109.00	112.00	14.00
CON02.1	Rain water	15.00	4.00	11.00	4.22	2.20	4.58
CON03.1	Tanker supply	8.00	2.00	6.00	2.67	0.67	2.67
CON04.1	Mekerot	60.00	10.00	50.00	12.9	21.3	15.9
CON05.1	Desalination	25.00	25.00	0.00	0.00	0.00	0.00
CON06.1	Demand management	15.00	5.00	10.00	3.00	3.00	4.00
CON07.1	Protection/conservation	7.00	5.00	2.00	1.00	0.50	0.50
CON08.1	Re-use	35.30	23.20	12.10	6.10	3.00	3.00
CON09.1	Sectoral Reallocation	25.00	20.00	5.00	3.00	1.00	1.00
CON10.1	Changes to agricultural policy	50.00	10.00	40.00	12.00	16.00	12.00
CON11.1	Water Transfer	54.00	20.00	34.00	4.00	8.00	22.00
CON12.1	Administrative and institutional structures	N/A	N/A	N/A	N/A	N/A	N/A
CON13.1	Surface water	10.00	2.50	7.50	3.50	4.00	0.00
Additional supply		**530.30**	**214.70**	**315.60**	**135.69**	**142.45**	**37.46**
Demand reduction		**65.00**	**15.00**	**50.00**	**15.00**	**19.00**	**16.00**
Net additional		**595.30**	**229.70**	**365.60**	**150.69**	**161.45**	**53.46**
Re-allocation		**25.00**	**20.00**	**5.00**	**3.00**	**1.00**	**1.00**

Future Scenario							
FUT01.1	GW supply	552.0	150.0	402.0	194.0	173.0	35.0
FUT02.1	Rain water	27.0	8.0	19.0	7.3	3.8	7.9
FUT03.1	Tanker supply	4.0	1.0	3.0	1.3	0.3	1.3
FUT04.1	Mekerot	10.0	10.0	0.0	0.0	0.0	0.0
FUT05.1	Desalination	105.0	55.0	50.0	0.0	0.0	50.0
FUT06.1	Demand management.	40.0	15.0	25.0	8.0	8.0	9.0
FUT07.1	Protection/conservation	28.0	20.0	8.0	3.0	2.0	3.0
FUT08.1	Re-use	97.4	62.8	34.6	13.0	14.0	7.6
FUT09.1	Sectoral Reallocation	50.0	40.0	10.0	3.0	4.0	3.0
FUT10.1	Changes to agricultural policy.	80.0	20.0	60.0	18.0	24.0	18.0
FUT11.1	Water transfer	86.0	40.0	46.0	12.0	12.0	22.0
FUT12.1	Administrative and institutional structures	N/A	N/A	N/A	N/A	N/A	N/A
FUT13.1	Surface water.	133.0	5.0	128.0	80.0	48.0	0.0
FUT14.1	Importation	20.0	10.0	10.0	3.0	4.0	3.0
Additional supply		**944.4**	**300.8**	**643.6**	**297.3**	**242.8**	**103.5**
Demand reduction		**120.0**	**35.0**	**85.0**	**26.0**	**32.0**	**27.0**
Net additional		**1064.4**	**335.8**	**728.6**	**323.3**	**274.8**	**130.5**
Re-allocation		**50.0**	**40.0**	**10.0**	**3.0**	**4.0**	**3.0**

NB: figures to be used as rough estimates only (SUSMAQ, 2005f)

Annex C. Basic Indicators that Do Not Directly Measure the Impact of Management Options

MO / BI	1 GW supply	2 Rain water	4 Mekerot	5 Desalination	6 Demand management	7 Protection/cons	8 Re-use	13 Surface water	14 Importation of water
EC01 – Internal rate of return									
EC02 – Agricultural water production cost									
EC03 – Public network production cost							x		
EC04 – Production cost per beneficiary							x		
EC05 – Industrial/ agricultural water prodcutivity									
EN01 – Change in aquifer water level				x		x			
EN02 – Reliability of supply from aquifer						x			
EN03 – Yield of major aquifer springs						x			
EN04 – Aquifer water quality									
EN05 – Wastewater discharge									
EN06 – Agricultural pesticide use									
EN07 – Industrial effluent									
SE01 – Household Connections		x				x			
SE02 – Water Quality									
SE03 – Water Usage									
SE04 – Agricultural job creation									
SE05 – Industrial job creation									
SE06 – Source yield & livelihoods		x	x						x
SE07 – Domestic water expenditure									

Source: SUSMAQ, 2005f

Annex D. Data Needed for the Calculation of the Basic Indicators

Economic Indicators:

BI	Name	Data needed
EC 01	Internal Rate of Return	Total Capital Costs US$1000
		Total O&M Costs US$1000/yr
		Additional agriculture saved/waste/fresh water (volume)
		Additional domestic saved/waste water (volume)
		Additional industrial saved/waste/fresh water (volume)
		Total volume
		IRR
EC 02	Agricultural water production cost	Total Capital Costs US$1000
		Total O&M Costs US$1000/yr
		Additional agriculture saved/waste/fresh water (volume)
EC 03	Public network production cost	Total Capital Costs US$1000
		Total O&M Costs US$1000/yr
		Additional domestic saved/waste water (volume)
		Additional domestic water (volume) existing costumers
		Additional domestic water (volume) new Costumers
EC 04	Public network production cost per beneficiary	Total Capital Costs US$1000
		Total O&M Costs US$1000/yr
		Additional domestic saved/waste water (volume)
		Additional people served
		Existing people served
EC 05	Industrial/Agricultural water productivity	Additional agriculture saved/waste/fresh water (volume)
		Additional industrial saved/waste/fresh water (volume)

Source: SUSMAQ, 2005c

Environmental Indicators:

BI	Name	Details
EN01	Aquifer water level	1. From the steady state models, estimate the best and the worst water levels for each zone/aquifer. 2. Define the rainfall scenario for the management period 3. Translate the management option into abstraction time series for each zone/aquifer. 4. Run the models for rainfall/abstraction scenario. 5. Calculate the water level basic indicator for year (t) as follows: $(EN01)^t_{i,j} = (Best\ waterlevel)_{i,j,k} - (water\ level)^t_{i,j}$ $where \quad i: zone$ $j: aquifer$ $t: year$ 6. If the aquifer is composed of two connected layers (e.g. WAB), then take the largest water level indicator for year (t) to represent the value of indicator for the aquifer. 7. Calculate the average value of water level indicators, this value representing the overall water level indicator.
EN02	Reliability of supply from aquifer	The calculation method for this indicator is related to the calculation method used to calculate the first indicator (EN01). The method is as follows: 1. From water level indicator (EN01) database, count the number of years for which EN01 is higher than the maximum drawdown for each zone/aquifer. 2. The value of this indicator is calculated by dividing the number of failed years by the number of years of the management period.
EN03	Yield of major aquifer springs	The calculation method for this indicator is based on the historical discharge for all springs in all the zones. The method is as follows: 1. From the spring discharges database, calculate the sum of historical discharges of all springs within each zone/aquifer before any well drilled. 2. Multiply the historical amount of discharges by 50% to calculate the minimum limit of spring discharges. 3. From the model runs (as specified in EN01) for each MO, calculate the sum of all spring discharges for each year within the zone/aquifer. 4. Account the number of years that the total discharges are below the minimum discharge limits. 5. Apply the above equation to calculate value of the Basic Indicator.

<table>
<tr><th>BI</th><th>Name</th><th>Details</th></tr>
<tr><td>EN04</td><td>Aquifer water quality</td><td>A set of observation boreholes was identified for use in the calculation of the EN04 indicator based on availability of observation well data, and the output from the regional groundwater pollution model. The pollution model is run as a set of simulations for each scenario representing the uncertainty in the model parameter values and pollution sources (SUSMAQ Report#47). The EN04 indicator is calculated as

$$EN04 = \frac{1}{n}\sum_{i=1}^{n}\overline{C}_{mi}$$

where $\overline{C}_{mi}$ is the mean concentration from a set of uncertainty simulations for borehole number i at the end of the simulation period (2025), and n is the number of observation boreholes.</td></tr>
<tr><td>EN05</td><td>Wastewater discharge</td><td>For the scenario studies, the total additional wastewater from each package is estimated in the SUSMAQ Package Database, and can be aggregated for each MO. The pollution load may also be reduced by construction or rehabilitation of wastewater treatment plants (WWTPs). The indicator is evaluated as:

$$EN05 = \sum (P96 * C_{ru} - P98 * C * E)$$

where
P96 is attribute number 96 in the SUSMAQ Package Database: "Additional total waste supplied (Mcm/y)"
P98 is attribute number 98 in the SUSMAQ Package Database: "Additional waste water treated by project Mcm/yr"
C_{ru} is BOD concentration in reuse water (mg/l)
C is influent concentration (BOD) in WWTP (mg/l)
E is WWTP efficiency (between 0 and 1)</td></tr>
<tr><td>EN06</td><td>Agricultural pesticide use</td><td>Using data from the package database, the EN06 indicator describing th total pollution load on aquifers from agricultural pesticides is written as:

$$EN06 = \sum 1000\,(A_{irr}\,P_{irr} + A_{int}\,P_{int})$$

Where
<table>
<tr><th>Variable</th><th>Units</th><th>Description</th></tr>
<tr><td>A_{irr}</td><td>dunum</td><td>Area of irrigated agriculture (attribute P89)</td></tr>
<tr><td>A_{int}</td><td>dunum</td><td>Area of intensive agriculture (attribute P81)</td></tr>
<tr><td>P_{irr}</td><td>Kg/dunum</td><td>Annual average pesticide use per unit area for irrigated agriculture</td></tr>
<tr><td>P_{int}</td><td>Kg/dunum</td><td>Annual average pesticide use per unit area for intensive agriculture</td></tr>
</table></td></tr>
<tr><td>EN07</td><td>Industrial effluent</td><td>The EN07 indicator describing the total pollution load on aquifers fr industrial effluent is written as:
$EN07 = \sum 10^6 (P78 * C_{iww} * f_{iww}) - V_{it} * C_{iww} * E_{it}$; where
<table>
<tr><th>Variable</th><th>Units</th><th>Description</th></tr>
<tr><td>P78</td><td>m^3/annum</td><td>Additional industrial saved/waste/fresh water (volume)</td></tr>
<tr><td>C_{iww}</td><td>mg/l</td><td>Concentration of heavy metals in industrial effluent</td></tr>
<tr><td>f_{iww}</td><td>-</td><td>Fraction of supplied industrial water discharged as wastewater</td></tr>
<tr><td>V_{it}</td><td>MCM/annum</td><td>Total volume of industrial wastewater treated on-site</td></tr>
<tr><td>E_{it}</td><td>-</td><td>Efficiency of industrial wastewater treatment (fraction of heavy metals removed from treated industrial wastewater)</td></tr>
</table></td></tr>
</table>

Source: SUSMAQ, 2005d

Socio-Economic Indicators:

BI	Name	Details
SE01	Water connections	1) The proportion of households in the region with no existing network connection. (1 (high), 5 (low)) 2) Immediate or indirect relationship to network connection. (1 (low), 5 (high)) 3) Proportion of urban households. (1 (low), 5 (high))
SE02	Water quality	1) The proportion of households in the region using non-network water. (1 (high), 5 (low)) 2) Immediate or indirect relationship to improving water quality. (1 (low), 5 (high)) 3) Existing water quality issues. (1 (high), 5 (low))
SE03	Water usage	1) Existing regional usage above/below 150 lpcd. (1 (high), 5 (low)) 2) Immediate or indirect relationship to providing 150 lpcd. (1 (low), 5 (high)) 3) Availability of (non-network) small supply alternatives (not tanks/cisterns). (1 (high), 5 (low))
SE04	Agricultural jobs per volume supplied	1) Regional significance of the agricultural sector. (1 (low), 5 (high)) 2) Immediate or indirect relationship to agricultural water provision. (1 (low), 5 (high)) 3) Labour involvement in the agricultural sector. (1 (low), 5 (high))
SE05	Jobs in industry per volume supplied	1) Regional significance of the industrial sector. (1 (low), 5 (high)) 2) Immediate or indirect relationship to industrial sector water provision. (1 (low), 5 (high)) 3) Labour involvement in the industrial sector. (1 (low), 5 (high))
SE06	Small source yield	1) Availability of small sources (not tanks/cisterns) at regional level. (1 (low), 5 (high)) 2) Immediate or indirect relationship to source yield improvement. (1 (low)), 5 (high)) 3) Significance of small sources to local livelihoods. (1 (low), 5 (high))
SE07	Expenditure on water as a percentage of total household expenditure	1) Regional cost of water. (1 (low), 5 (high)) 2) Immediate or indirect impact on water expenditure. (1 (low), 5 (high)) 3) Levels of expenditure on water. (1 (low), 5 (high))

Source: SUSMAQ, 2005e