Chapter 17
Decision Support in the Context of IWRM: Lessons Learnt from Research Projects in Developing and Emerging Countries

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Abstract Decisions in integrated water resources management (IWRM) tend to be complex. Decision makers often face diverging and conflicting rights of use and interests in the utilisation and valuation of resources. The application of IWRM ranges from drinking water supply and groundwater management to wastewater treatment, irrigation, flood protection and navigation as well as the use of waters for tourism, without compromising the functionality of vital ecosystems. For the decision-making process, economic principles such as cost-effectiveness, cost-recovery and the costs-by-cause principle must be taken into account. Scientists or political advisers are often consulted in order to bring their expertise to the table. Good decision-making in IWRM requires the examination and comparison of alternative actions. Specific systems and methods are applied in order to support relevant decision makers and guarantee transparency for all participants in the decision process at all times. Decision Support in IWRM was conceived and implemented very differently across the funding priority launched by the German Federal Ministry of Education and Research (BMBF). Depending on the individual water management objectives, (geographical) information systems, knowledge platforms, decision tools or mathematical models were developed and implemented

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as Decision Support System. This paper classifies and discusses the contents, methods and functions of Decision Support Systems in the 13 research projects.

Keywords DSS · Water management · Knowledge management · GIS · Mathematical models

17.1 Decisions in IWRM

Integrated water resources management (IWRM) is oriented towards the sustainable use of the vital resource water. Important characteristics of an IWRM are the organisation of management in the relevant catchment areas (river basin management) and the integral, holistic consideration of management effects across different sectors, administrative boundaries and hierarchies. All management involves decision making. However, with extension of the management object and demands for an integrative approach to the problems, IWRM typically deals with highly complex decision situations with many actors involved in the decision making process, and many people affected by resulting decisions (Ganoulis 2005). Decision making in IWRM also takes place under high uncertainty and partial ignorance of e.g. potential management measures, the consequences of these measures, and the preference of those affected (Sigel et al. 2010).

Decision Support Systems (DSS) become relevant due to the complexity of decision situations and difficulties arising in making good decisions. These systems are computer-based tools that process decision-relevant information in order to provide interactive support to the decision-making process.

This paper presents results from the working group “Decision Support in IWRM” which was set up in the context of the IWRM funding priority of the BMBF. The objective was to identify obstacles occurring between the development and implementation of DSS and thus derive lessons learnt by summarizing and generalizing the experiences across the 13 projects on the development and application of different DSS. In these research projects diverse DSS were developed and implemented, depending on the objective of the projects in infrastructure and technology, water supply, water quality and sanitation, waste water treatment, groundwater management, irrigation or flood control.

17.1.1 Decision Processes

Generally, decisions on the sustainable development of water resources are not taken ad hoc but are the result of a long and careful planning and decision-making process. Consequently there is time to collect and order decision-relevant information, to develop and think through decision alternatives, to seek the advice of others, involve affected parties and to weigh positions, facts and evaluations in order to reach a balanced assessment and ultimately make an appropriate decision.

The basic model of decision making from Keeney and Raiffa (1976) is often used for structuring decision-making processes. It differentiates between the environment, which can be controlled by the decision-maker and the non-influenceable environment, in which external factors can affect the decision problem. Long-term effects due to climate change and regional socio-economic developments are examples of external factors on which decision-makers have little to no influence. However, these factors can have significant impacts on water resources in the water catchment area and consequently cause further side-constraints and uncertainties in the decision-making process. The following factors need to be taken into consideration. Uncertainties can, for example, be reflected in different development scenarios. In the controllable environment, which can be influenced by the decision-maker to a certain extent, the decision-making process comprises both planning and decision. Initially, decision alternatives such as a combination of water management measures would have to be elaborated and the possible consequences determined. In IWRM this task is generally very labour-intensive and includes both water management planning and efficient management of the water management system or river basin. The decision encompasses a comparative assessment of the alternatives as well as the actual selection of one alternative to be ultimately implemented. The decision-maker(s)'s preferences are crucial in the evaluation of subsequent consequences.

An advanced model of a decision process in IWRM was described by Dietrich and Funke (2009). They integrated progress supporting activities like monitoring and managing of process, information and learning into the five main responsibilities according to Mintzberg et al. (1976): problem identification, design, choice, authorisation and implementation (Fig. 17.1).

In practice, the simple idea of one person being solely responsible for decision-making needs to be modified. Typically, the decision-making process in IWRM involves at least one democratically legitimized competent authority acting within a hierarchy of administrative levels and consulting neighbouring administrative divisions (e.g. authorities responsible for agriculture or transport), and also involving stakeholders in the decision-making process. It is not always clear what the preferences of a public authority are and/or should be, unlike the more transparent consumer preferences. DSS can be used as an instrument to find out and make transparent preferences within an authority. The system can support communication within a group of decision makers as well as stakeholder participation. All kinds of DSS can be autonomously applied by a competent decision maker or can be run by professional consultants or scientists.

17.1.2 Decision Support Systems

The term Decision Support System dates back to the early 1980s, and resulted from new developments in systems analysis, operations research and computer technologies. User-friendly computer terminals made an online man-machine dialogue

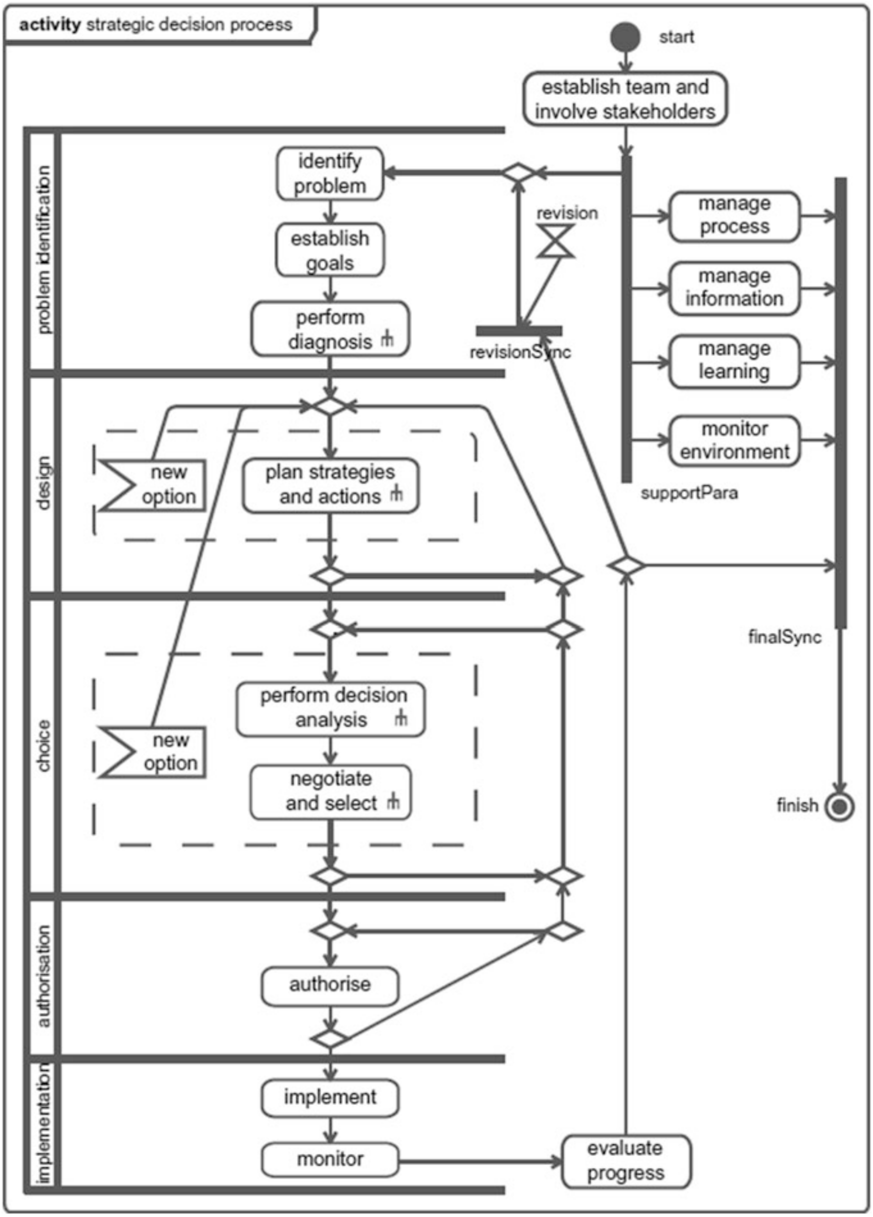


Fig. 17.1 Model of a decision process in IWRM (Dietrich and Funke 2009)

possible. One strong field of development has been water management due to its often highly complex nature. A number of water-related DSS were developed at the IIASA International Institute for Systems Analysis, Laxenburg, for example (e.g. Orlovski et al. 1986). Since that time the DSS market has emerged, not just in water management of course. With the triumphal procession of workstations and PCs beginning in the 1990s this process accelerated further; but not many of those DSS developments have been successfully implemented in practice. There are three major reasons: the DSS cannot cover the full complexity of problems, DSS are rarely tools for political decision makers, and the consideration of human factors and socio-economic criteria is practically limited.

There is a wide range of definitions and interpretations of the meaning of "Decision Support Systems". A rather general definition is given by Simonovic (1996): a DSS is a computer-based tool which enables decision makers to combine personal evaluation and computer-based results in a man-machine dialogue in order to gain substantial information for decision making. According to Haimes (1998) DSS are interactive, computer-based systems, which support decision makers in using data, mathematical methods, simulation and optimization models in an effective way in order to generate decision alternatives and to solve both structured and unstructured problems.

Our analysis has shown that in water management a wide range of methods appear under the term "DSS", from (geographical) information systems, mathematical models, decision tools to complex DSS. The systematization of the different DSS forms in IWRM is complicated due to the uniqueness and complexity of each application, the high variety of possible system solutions, the specifics of decision-making processes depending on the study region etc. A number of systematization and classification attempts can be found in the literature. A few examples are given below.

According to Dietrich (2006), various specializations of DSS have been developed and have resulted in a multitude of acronyms due to different designs and applications of DSS, as shown in Table 17.1. Further information on the stated system types can also be found in Sauter (1997), Marakas (1999) and Malczewski (1999).

Combinations of the types are obviously also possible. The parentheses indicate that further DSS-subtypes are possible. According to Evers (2008) DSS can be classified into four different levels: a technical level, a management level, a decision-making level and an architectural level. Examples and further notes on each level are given below, in Table 17.2.

Table 17.1 Types of DSS (Dietrich 2006), extended by the authors

Acronym	Description	Notes
DSS	Decision Support System	Generic term for any DSS
GDSS	Group Decision Support System	Decisions in IWRM are not taken by a single person but by groups of decision makers with frequently controversial positions
SDSS	Spatial Decision Support System	IWRM per se are regional, spatially-related tasks; that is why GIS often play a strong role in DSS for IWRM
ADSS	Adaptive Decision Support System	DSS are frequently not only used once, but adapted to changing boundary conditions, socio-economic and environmental development
MDSS	Multi-criteria Decision Support System	DSS with multi-criteria optimization

Table 17.2 Characterization of DSS in different levels (after Evers 2008)

DSS level (Evers 2008)	Examples	Notes
Technical level	Data-driven, model-driven, optimization-driven DSS	The most advanced technical level combines all three
Management level	Planning/policy support systems and management oriented DSS (Geertman and Stillwell 2009)	Planning/policy support systems are long-term/strategic, have broad societal content and focus on simulation and exploration. Management-oriented DSS are short-term/immediate, have a specialized sectoral context and are optimization oriented
Decision-making level	Passive, active and cooperative DSS (Hättenschwiler 1999)	Active DSS result in the formulation of concrete proposed decisions. A cooperative DSS enables a step-by-step improvement of decision alternatives through both the decision-maker or decision-consultant and also through the system within an interactive process. Passive DSS aid the decision-making process but cannot give concrete solutions
Architectural level	(a) Hahn and Engelen (2000): User interface, data base, tool base, model base; (b) Power (2002): Communication-driven, knowledge-driven, data-driven, document-driven and model-driven DSS	The architectural level comprises fundamental components of a DSS; (a) this is a simplified but common structure of many DSS from the software technical point of view; (b) here the focus is different, the dominant system component or the application and desired functionalities are taken as the criterion

In this publication an approach for the systematization of DSS in IWRM is derived in consideration of fundamental system components and their application (according to Power 2002, see below; section “Classification of Decision Support Systems”).

In the past DSS was implemented on main-frame computers, later on workstations and PCs. These days DSS are increasingly accessible via the internet. This opens up the possibility of broader access to DSS for everyone from experts, to the public. The latter results in higher demands for user-friendliness, easiness of use and transparency in DSS-handling. In addition to classical DSS, as characterized above, formal Decision Support methods are also important. Included here for example, are structuring of the decision-making process that is adapted to both the problem and regional conditions, as well as monitoring of the decision-making process through specialist counselling and a wide range of participative measures during the decision-making process (Gregory and Keeney 2002; Klauer et al. 2012). Depending on the degree of computerization those methods and tools might also be called DSS.

The use of computer-based DSS has various advantages for decision-makers, such as improved efficiency, effectiveness, transparency, robustness, more reliable decisions or speed in decision support. DSS may lead to better (compromise) solutions where solution-finding happens with less effort. The chosen decision can be presented to third parties in a more extensive, illustrative and thus more convincing way. Decision Support therefore leads to more rational, robust and reproducible decisions. This means that, assuming the preferences and decision environment were the same, similar decision alternatives would be recommended every time.

Formal or computer-supported DSS address decision-making problems that the decision-maker finds too difficult, work-intensive or complicated. Decision-making in the context of IWRM always has something to do with evaluation, selection and preference behaviour. Human skills often exceed the abilities of the implemented DSS in this regard. Human beings are not dependent on computers whereas, computers do rely on human beings. Today many decisions depend on computers to a large extent (not necessarily on DSS). DSS can make the decision process faster, more efficient and more transparent, as mentioned above, but DSS should not attempt to automate decision making. Human ("decision makers") interaction with the DSS is crucial in order to consider preferences, expert knowledge etc. According to Mysiak et al. (2005) a successful DSS depends on the early involvement of future DSS users and a user-friendly intuitive interface.

17.2 Decision Support in the Funding Priority IWRM

A survey on Decision Support was carried out across the 13 IWRM research projects, and the results were analysed in order to illustrate the cross-cutting issue "Decision Support". Table 17.3 shows the surveyed projects and the partner countries involved. The questionnaire comprised the following range of topics:

- Characterisation of the problem and task
- General aspects of Decision Support
- Decision Support Systems
- Participation in Decision Support and
- Challenges to Decision Support in the implementation of project results

Decision Support was characterized based on this analysis. For the systematization it was determined which core functions are supported in practice within the decision process (Fig. 17.3), which in turn allowed the assignment of the particular method to the decision-making process.

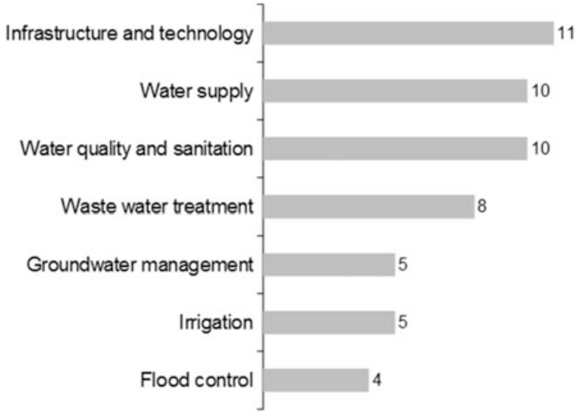
The majority of the IWRM projects (n = 10) carries out the IWRM investigations in river basins, whereby pilot studies are carried out in representative subareas. Only the AKIZ project is limited on the local level due to planning issues.

Table 17.3 Projects from within the BMBF funding priority on IWRM

Project	Partner countries
Water-related information system for the sustainable development of the Mekong Delta (WISDOM)	Vietnam
Sustainable water resources management in the coastal area of Shandong Province (SHANDONG)	China
Sustainable water and agricultural land use in the Guanting watershed under limited water resources (GUANTING)	China
Economic and ecological land and water use in Khorezm in Uzbekistan. A pilot project in development research	Usbekistan
Integrated water resources management in Gunung Kidul, Java (GUNUNG)	Indonesia
Integrated water resources management in central northern Namibia—Cuvelai-Etosha Basin (CUVEWATERS)	Namibia
Integrated water resources management in Central Asia—model region Mongolia (MOMO)	Mongolia
Integrated water resources management in Vietnam (IWRM VIETNAM)	Vietnam
Integrated waste water concept for industrial zones exemplified by the Tra Noc industrial zone (AKIZ)	Vietnam
IWRM pilot project "Middle Olifants" in south Africa with technology transfer through a franchise concept	South Africa
IWRM in the Lower Jordan Valley—sustainable management of the available water resources with innovative technologies (SMART)	Palestine, Israel, Jordan
Development and implementation of a scientific based management system for non-point source pollution control in the Miyun basin near Beijing	China
Integrated water resources management in Isfahan	Iran

The joint projects support decisions for different areas of IWRM depending on the particular water resources management problems addressed. Figure 17.2 shows the different focuses of the projects. The majority of Decision Support is related to the expansion of water infrastructure and the implementation of new technological solutions for increasing water supply. A number of these projects link the planning tasks with questions of management, or the operation of water management systems; for example, the intermediate storage or allocation of water. The expansion of wastewater treatment is often a fundamental aspect in the improvement of water quality and sanitation. Water supply during water scarcity and dealing with conflicts of interest on water use are preferential tasks (e.g. SMART). Decision Support also concentrates on land-use, for example with measures for groundwater management (e.g. implementation of artificial recharge facilities, SHANDONG), irrigation and flood control. An essential aspect of water supply management is the minimization of leaks in water pipe systems (e.g. GUNUNG and MOMO). Approximately half of the projects also integrate climate change scenarios in the DSS in order to take possible future changes in precipitation, water availability and the effects of extreme weather events into account.

Fig. 17.2 The numbers of research projects addressing IWRM topics. *Source* Decision Support survey within the IWRM funding priority (n = 13)



17.2.1 Core Functions and Requirements of Decision Support Systems

Hättenschwiler and Gachet (2000) defined core functions of Decision Support as shown in Fig. 17.3. In this publication a (computer-based) decision tool, knowledge platform, mathematical model or (geographical) information system is defined as DSS as soon as it supports at least one of the listed core functions directly or indirectly. The IWRM projects have been analysed with regards to how far they correspond to these functions.

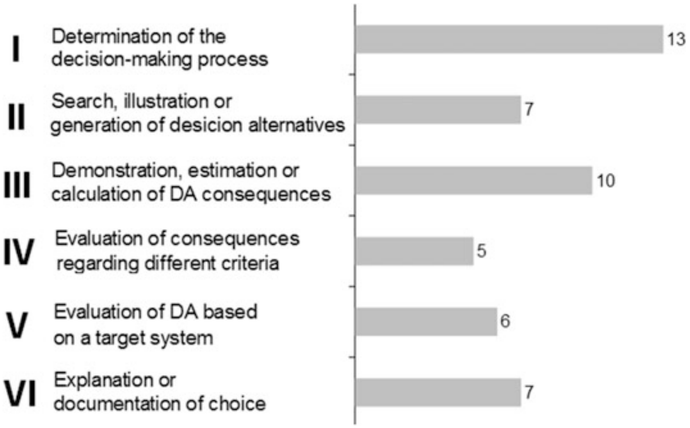


Fig. 17.3 Core functions of Decision Support and the number of IWRM projects (n = 13) realizing these functions (modified after Hättenschwiler and Gachet 2000)

The experiences from the IWRM projects on the functions of DSS can be summarized as follows:

I. Determination of the decision-making process

The decision situation can be determined by an information system for example, which collects decision-relevant data, assumptions, restrictions, tasks, targets or guidelines (from decision-makers). Decision-relevant data can be illustrated with information systems, analysed and presented in a structured form. All of the IWRM projects therefore rely on information systems, mostly some kind of geographical information system (GIS). The WISDOM and IWRM VIETNAM projects are two examples for broad decision support based on GIS.

II. Search, illustration or generation of decision alternatives

Decision alternatives (DA) frequently evolve from combinations of specific measures. The evaluation of consequences from the possible implementation of single decision alternatives includes the selection of special socio-economic and ecological decision criteria that best express essential IWRM development targets. Approximately half of the projects offer computer-based decision support for the selection, search or generation of specific (water management) measures (core function II). These include, for example, the planning of facilities for controlled groundwater recharge (SMART-project), waste water treatment (GUNUNG-project) or rainwater harvesting (CUVEWATERS-project). This also applies to the planning of measures for land-use and irrigation agriculture (Uzbekistan). A wide variety of measures from water saving to land-use planning is analysed e.g. in the GUANTING-project (Wechsung et al. 2014). From a methodological point of view the multi-level approach used for scenario selection (Fig. 17.4), which is implemented e.g. in the SHANDONG-project (Kaden and Geiger 2013), is interesting: The advantage of this stepwise system is that in the beginning of the planning process, when only coarse data are available for the multitude of aspects, potential

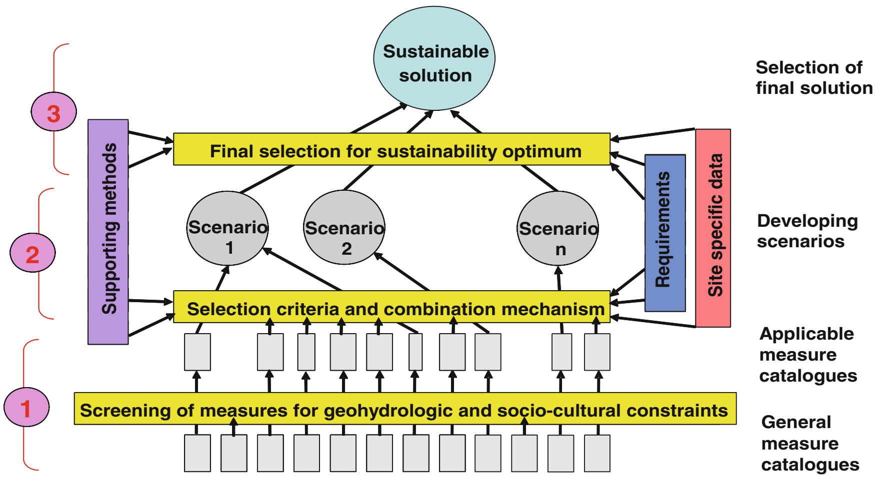


Fig. 17.4 IWRM—system for achieving sustainable water management (Geiger 2011, simplified)

actions can be screened roughly for their success and linked to potential solutions. DSS Stage 1 is designed to be gradually improved whenever more detailed information becomes available. It forms the basis for DSS Stage 2. There, preselected alternatives need to be studied in more detail. In the last stage the final solution is developed and analysed.

III. Demonstration, estimation or calculation of DA consequences

A majority of 10 projects demonstrated, estimated or calculated consequences of decision alternatives but only three of those did so by using computer-based systems which can be used to support the development of IWRM strategies as combined (water management) measures. Highlighted here are the DSS used in the previously-mentioned SHANDONG-project, the GUANTING-project and the MOMO-project toolbox.

IV. Evaluation of the consequences regarding different criteria

Five of the 13 projects used computer-based Decision Support in order to evaluate the consequences of different criteria.

V. Evaluation of DA based on a target system

Roughly half of the IWRM projects have implemented mathematical models in order to investigate the consequences of the possible implementation of decision alternatives, and for the evaluation of alternatives based on a target system (see below, section "Classification of Decision Support Systems")

VI. Explanation or documentation of choice

Explanation or documentation of the decision process or suggested decisions has been a core function of Decision Support in about half of the IWRM projects.

17.2.2 Classification of Decision Support Systems

To facilitate decision-making, Decision Support has been implemented by all research projects of the IWRM funding priority. Depending on the specific management activities, decision processes and decision-makers in IWRM, different types of Decision Support were implemented. In order to systematize these different types, a distinction is made between complex, integrative DSS on the one hand, and systems named after their main component on the other; either as a knowledge platform, (geographical) information system, decision tool or mathematical model. These components were either applied separately and independently (as stand-alone tools) in the IWRM projects, or combined with other components.

17.2.2.1 Knowledge Platform

In the IWRM projects knowledge platforms are mostly web-based and strengthen participation in the decision process, communication between stakeholders and public relations. The implementation of such systems therefore increases the probability of successful implementation of the developed IWRM strategies

(Pinheiro and Böhl 2007). The aim is to determine and structure decision-making relevant information, similar to the (geographical) information systems. These systems can also be integrated with (web-based) decision tools and contribute to the explanation of the selected decision. Therefore, decision support can be extended to all core functions apart from core function III (estimation or calculation of the consequences of decision alternatives). This is due to the fact that coupling with mathematical models has proven difficult.

17.2.2.2 Geographical Information Systems

In IWRM data-based information systems usually command a geographical platform for the illustration and analysis of spatial information and can be integrated in DSS. Georeferencing the data used is of decisive importance for GIS and this is what differentiates GIS from Knowledge Platforms. Commercial software, for example ArcGIS (ESRI Inc.), Oracle or open source software (e.g. GRASS GIS, SAGA GIS, Quantum GIS) can be used for development. These systems can also be seen as DSS, as long as they can be specifically applied to Decision Support or they fulfil at least one core function. Frequently, these systems concentrate on the determination and structuring of decision-making relevant information and thus support core function I (see Fig. 17.3) (Renaud and Künzer 2012). GIS are commonly coupled with specific decision tools or mathematical models. Decision Support can thus be extended to core function II, III and V; an example being the determination and comparison of alternative locations for the implementation of controlled groundwater recharge using GIS-based spatial analysis (Rahman et al. 2012). Different system components can be incorporated into a DSS. For example, the web-based information system used in the WISDOM project comprises system components such as data, logic and presentation tier in order to deal with environmental monitoring, water management, demographics, economy, information technology, and infrastructural systems (Gebhardt et al. 2010).

17.2.2.3 Stand-Alone Tools

Stand-alone tools are decision tools which can be applied for Decision Support independent of a main system. Further, those tools can be integrated in a “Tool Base” of integrated DSS as shown in Fig. 17.4. They are often based on Operations Research methods, particularly multi-criteria analysis, and can be used for the determination, evaluation and selection of decision alternatives and for explanation of the decision choice (core functions II, IV, V and VI). Multi-criteria analysis methods enable the comparative assessment of decision alternatives in different socio-economic and ecological situations, and with opposing preferences, as well determining compromise solutions. These processes are therefore of utmost importance for integrated water management. These include the analytical-hierarchy-process (AHP) according to Saaty (2008), the Fuzzy-process (Liu 2008), ELECTRE, PROMETHEE (cf. Klauer et al. 2006), Goal Programming, Compromise Programming and others. Hajkowicz and Collins (2007) and Zarghami and Szidarovszky (2011) address the possible applications of the different processes and discuss the selection, quantification and weighting of decision-making criteria in this context.

17.2.2.4 Mathematical Models

Mathematical models are mainly used in DSS for determining the consequences of decision alternatives. These include simulation models, which can be used to illustrate components of the water cycle but also water management models such as WBalMo (Kaden and Kaltofen 2004). The simulation model MONERIS, for example, makes the simulation of discharges, retention and loads in river systems possible (Venohr et al. 2008). Statistical processes and climate models also belong to this group. They can be used to determine the influence of development scenarios, particularly socio-economics and climate change, on relevant factors for water management or to foresight actions (Werner and Gerstengarbe 1997). Various water allocation and user-behaviour scenarios can be simulated and analysed in the Middle Olifant project using the "Water Evaluation and Planning" system (WEAP) (Lévite et al. 2003).

Finally, all mathematical models that enable the assessment of socio-economic or ecological criteria for decision alternatives (core function IV) belong to this group. Other examples are tools used for cost-benefit analysis or for the determination of economic indicators (Hellegers et al. 2010).

17.2.2.5 Complex DSS

The DSS is often seen as a complex system composed of several components and supported by a number of core functions. Figure 17.5 shows the basic components of a complex, integrative decision support system. A complex DDS integrates a database system with mathematical models and specific decision tools. A graphic user interface supports interaction with the system user. Professionals or decision-making consultants can thus communicate directly with decision makers on this basis. MULINO-DSS (Giupponi et al. 2004) and Elbe DSS (Kok et al. 2009) are examples of complex, integrative DSS in the context of IWRM.

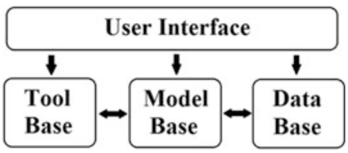


Fig. 17.5 Basic components of a complex, integrative DSS in IWRM (Hahn and Engelen 2000)

17.2.2.6 Variety of Decision Support in IWRM Projects

The distribution of different types of DSS in IWRM projects is shown in Fig. 17.6. A complex, integrative DSS has only been developed for the IWRM project China (SHANDONG). The system enabled the generation, assessment and selection of alternative IWRM strategies as a combination of measures. Other projects focus on the application and development of computer-based systems, classified according to their main component as geographical information systems, knowledge platforms and decision tools or as models. In addition to decision tools used for the assessment of decision alternatives, GIS-based tools are also used, e.g. for water allocation. Apart from GIS, mathematical models and model systems have been often implemented. Models using a GIS interface are also used, for example to illustrate hydro (geo)logical processes and not spatial systems, e.g. to generate and analyse development scenarios. For example the Khorezm project combines hydro(geo)logical field-level modelling and GIS approaches in order to improve groundwater recharge estimation (Awan et al. 2013). The majority of decision tools which are components of an integrated DSS are stand-alone tools and can also be used independently. Some of these tools analyse the current situation and support the decision process until a defined target has been reached e.g. thresholds for water quality standards (Stärz 2012) in the IWRM VIETNAM-project. DSS are often web-based in order to improve access to the system, increase participation and the distribution of tools. Several projects (n = 5) apply formal Decision Support in order to structure the decision-making process. Only three projects (SMART, Khorezm Uzbekistan and GUANTING) applied standards for the implementation of decision processes. For instance, the GUANTING project implemented the so-called Integrative Methodological Approach. It is characterized by the following steps: (a) scenarios: compilation of a catalogue of so-called developmental scenarios, which combine frames of development, including a set of global change scenarios on climate, demographic, economic, and societal developments, and possible policy actions at the regional scale (land use, policy etc.), (b) indicators and criteria: identification of context-relevant indicators and corresponding criteria for the evaluation of different developmental scenarios, (c) impact analysis: analysis of the scenario impacts with respect to the selected indicators and criteria, using all available data, models as well

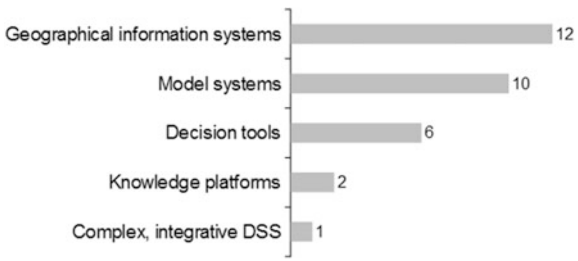


Fig. 17.6 Number of projects using different types of DSS in IWRM (n = 13)

as expert and literature knowledge, and (d) evaluation: multi criteria analysis and equity analysis to assess the results, and especially the policy strategies, in face of current policy objectives and actor preferences (see Wechsung et al. 2014).

Most of the developed DSS are designed by the IWRM projects in that way to be transferable to problems in different regions.

17.2.3 Obstacles of Implementation of DSS

During the implementation of DSS within the projects, a number of drawbacks occurred (Fig. 17.7). Across all projects long-term, bilateral cooperation is considered to be essential for project success. Furthermore, intensive training is regarded crucial by most projects for the sustainable implementation of Decision Support. This is necessary in order to prepare specialists and advisers for decisions on site and the efficient use of the developed systems, and in order to implement the decision process transparently. Staff turnover amongst the project partners, acceptance as well as language barriers also constitute further obstacles in the use of DSS.

17.3 Discussion

Decision Support has been implemented very differently within the IWRM projects. According to the results of the survey, Decision Support must be individually planned for each river basin depending on the legal background, water management objectives, spatial and temporal framework conditions, and social, ecological and economic aspects. Successful Decision Support is achieved through concerted and interdisciplinary cooperation between relevant stakeholders on all levels. Intensive exchange on the expert and decision-making level is particularly important in order to formulate highly acceptable corporate compromise solutions for challenges

Fig. 17.7 Problems arising during IWRM projects with regards to the implementation of Decision Support (n = 13)

arising from mostly opposing interests (Fig. 17.7). This implies participation and communication between all stakeholders in all phases of the decision-making process (see also Kok et al. 2009). In this context, Volk et al. (2010) propose an improved methodological stakeholder involvement through an iterative development process that enables social learning of the different groups that are involved in the decision-making process.

Kok et al. (2009) postulated: "Most DSS developments in environmental issues [...] are science-driven rather than user-driven, which means that the design is based on models and data addressing specific scientific problems, instead of real-world issues from a potential users' perspective." It may hold true in many cases that the DSS in IWRM described in this paper neglected the user perspective to a certain extent, but we disagree with the statement that those DSS are solely driven by scientific problems. Obviously there are many "scientific DSS" described in the literature that have not found their way from case study application to practical implementation (e.g. Gallego-Ayala 2013). But there is indeed a second commercial DSS world, which is in turn not extensively documented in scientific publications, but can be traced in the internet (e.g. www.bgr.bund.de or www.dhigroup.com).

However, it is beyond doubt that Decision Support Systems are helpful tools in IWRM. In this context, crucial questions are: do the DSS meet the requirements of real-world decision problems, are those available in-time for decision making and are the DSS successfully implemented? The success of DSS in practice depends above all from: the client, the developer, the software, the maintenance and the operation of the DSS. In this section the influence of these factors will be discussed in more detail. The major intention of this paper was to describe and evaluate the development of DSS for IWRM within the research projects of the named BMBF funding priority. Here, this topic will be moved beyond that scope and real-world water-related DSS will be discussed in general.

The client/the user

Both, client and user (if different from client) can be single institutions or groups of institutions. For complex DSS in large study areas the identification of clients and users is difficult. Mostly the different members of the groups have different functions, responsibilities and objectives. This makes the development and implementation of complex DSS rather difficult. In case of third party funded Research and Development projects there is not a real client (who pays). There is (or should be) a user (-group). For any type of DSS in IWRM it is important that there are continues problems to be solved and according to that long-lasting interest of the client/the user applying the DSS. The problems encountered during the design of a DSS as well as its (institutional) implementation by the users have led to scepticism regarding the usefulness of these tools (de Kok et al. 2009). Although some time has gone by since then, this scepticism still exists.

The problems addressed in the DSS

DSS are implemented for certain study areas. The range is from small catchments up to international river basins. According to Global Water Partnership (2012) "IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." If possible a DSS should indeed address the three "pillars" of sustainability, economy, society and environment. However, more decisive than such abstract claims should be that the DSS meets the objectives of the client/user and that it reflects the conditions and the structure of the decision making problem. In order to guarantee a proper representation of the decision problem by the DSS the participation of the client/the user from the region under study is crucial. Otherwise the DSS may be of scientific but low practical value.

The developer

The developers are typically teams from Research and Development institutes or commercial IT companies. Only in rare cases the clients/users themselves work as developers. In case of DSS developed in funded Research and Development projects, the developer is in most cases a group from different institutions with a leading institution. The more development partners are involved the more difficult the development process is. Also the integration of clients/users in the development process gets more difficult. Additionally, the partners frequently come from different scientific disciplines with different languages which might be fruitful and even necessary in order to tackle the problems at hand but creates additionally communication problems.

The software

In Sect. 17.2.2 different types of decision support have been described, from knowledge based systems to complex DSS. Consequently different software is used, from single software (models) and toolboxes up to complex software systems. In many cases the components rely on certain basic software (as DBMS, GIS and different programming languages). This may result in design problems of interfaces between modules. The advantage of toolboxes is that components of the DSS can be used separately for specific tasks and users.

The data

The data of the DSS should be as far as possible complete and up-to-date to the problems to be solved. As already discussed in previous sections the data scarcity is the main challenge for the development of a successful DSS. For a continuous DSS application, the data need to be up-dated in the DSS on a regular basis (see below maintenance).

The maintenance

The maintenance of a DSS has two aspects: maintenance of the software and of data. It needs to be clarified who is responsible for that and who bears the costs. Maintenance of basic software relates to the maintenance of the software tools, in case the tools depend on basic software (as e.g. GIS software). With new releases of basic software usually the tools that are based on it have to be (re-)adopted. Maintenance is especially complicated if the development was financed by research funds because of the high fluctuation of the developers at research institutes and the discontinuity of the funds.

The operation
In general the user or a third party assigned by the user should operate the DSS. Again the question arises: who pays? With the complexity of the DSS and consequently the diversity of users in a user group this becomes even more difficult. A basic presumption for successful operation is the training of operators by the developers of DSS.

17.4 Conclusions

The success of DSS depends on many factors. Hättenschwiler and Gachet (2000) summarize the basic requirements for computer-based DSS, by emphasizing user-friendliness, performance, integration and data interfaces which enable future system expansions. In IWRM, only those systems which have a clear client/user, real-word and continuous problem contents, durable software concepts and stable data basis, guaranteed long-term operation and maintenance will be successfully implemented and sustainably used. In this respect, the development of complex, completely integrative DSS is not always strictly necessary, and often not even possible due to complexity, the unavailability of resources and time constraints. There is a tendency that more complex decision problems favour more complex DSS. With increasing complexity of the DSS software in turn design problems, problems of data availability and above all long-term system maintenance increase. In most cases developer and operator of the DSS will be different—it is not the task of the research community to operate DSS for practice beyond the research projects. Next to central DSS, the application of stand-alone tools can indeed make sense in decision-making and is common practice. Advantages of this are the targeted implementation of individual systems for specific IWRM problems, reduced training expense, easier transferability and applicability to similar problems in different regions, reduced development expenses and accelerated deployment.

Independent of the kind of DSS, participation was deemed crucial in all phases of the decision processes supported in the IWRM projects. To assist this, web-based systems improve the acceptance of stakeholders directly involved in the decision-making process. Easy access to decision-relevant information and systems improves participation and increases understanding of the methodical approach. This is particularly true for geographical information systems, knowledge platforms and decision tools. Similar to this, Volk et al. (2010) mentioned that data availability needs to be improved to allow more efficient development and use of DSS. Moreover the authors suggest an improvement of scaling issues, model integration, calibration, validation and uncertainty analysis.

For all BMBF joint projects, long term cooperation is deemed essential. A decrease in staff turnover, improved training measures and the prevention of language barriers could be the key to a higher acceptance, and thus lead to successful long term cooperation. As problems with acceptance often occur in the initial phases, long-term projects should make sure to establish confidence between network partners. Regarding the avoidance of language barriers, the extensive documentation of DSS published as a handbook in local languages and the usage of those by individuals on the ground could be taken into consideration. An advantage that comes along with this is the decrease of time between effective workflows due to staff turnover. To achieve long lasting collaboration, Kok et al. (2009) suggest that project budgets should allow for maintenance of the DSS and keep users involved in its further development.

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