

INTEGRATING WATER RESOURCES AND WATER SERVICES MANAGEMENT TOOLS

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

1. BACKGROUND

This project developed a Generic Integrated Conceptual Framework (GICF) to assess the numerous and complex trade-offs between and within water resources and water uses management options. The project was initially intended to integrate water resources and water services management tools. However, because water services is one of the water use sectors and is itself affected by and affects other water use sectors, it was realised that integration cannot be sustainable nor meaningful without the inclusion of the other water use sectors. This is in line with the concept of integrated water management which is seen as a way to contribute to sustainability as envisaged in Agenda 21 (Inforesources, 2003). Integrated Water Resource Management (IWRM) has been accepted as a vehicle to achieve integrated water management, and has been framed around the principles of equity, economic efficiency and environmental sustainability.

In a South African context, the National Water Act (NWA) commits to the ideal of IWRM (Pollard and Du Toit, 2005). However, IWRM cannot be seen as an end in itself, but rather a means to an end. In the case of South Africa, that end is defined in the policy and legislation as being the equitable, efficient and sustainable use of water and the beneficial use of water in the public interest. The realisation of this end requires management tools appropriate to the demands of the NWA, and which utilises state-of-the-art integrated systems capable of taking into consideration social, economic and environmental needs which have to be considered (Clark and Smithers, 2006).

The South African water sector has developed a range of tools for managing water and for resolving water related problems, and has also improved these tools significantly over time. However, in-light of IWRM, the usefulness of these tools depends on the logical structure of valuation procedures, and on the common system required for defining and discussing complex water problems. If these tools are properly integrated, they can enhance decision making and communication between those who have to make the decisions, and those who are affected by them.

The project began by reviewing the various, often unrelated tools that have been developed over the years for the evaluation of water management options from both the water resources and water uses perspectives. This review took off from the notion that water management tools need to embrace IWRM principles, and that there must exist a common platform for integration.

Based on this review the GICF has been developed that can be applied in a coherent manner to a wide range of water management issues. It allows the users to link their tools to the mandate and objectives, to the reporting requirements, to the information value chain, and to the required resources in assessing trade-offs. More importantly, the GICF allows for decision making and reporting in a single platform linking the water managers, users and other stakeholders to the national government objectives.

2. OBJECTIVES AND AIMS

In an endeavour to avert the impact of fragmentation in the South African water sector, the Water Research Commission (WRC) has initiated this project, with the aim of adding value

to the process of looking into requirements for a multidisciplinary approach to IWRM. The objectives of the project were:

1. To assess and review existing knowledge and literature on integration and the scope and benefits of further integration.
2. To develop a conceptual framework for the integration of water resources and water uses (initially services) management tools.
3. To investigate and identify new concepts, technology and data sources that can improve the processes involved on an integrated platform.
4. To develop a case study solution.

Therefore, the primary objective of this project was to review tools with an aim to develop a GICF which can incorporate relevant and appropriate water management tools. The framework should be able to link the water resources and water uses management tools by a common flexible and extensible database, for use in strategic, tactical and operational planning and management. In light of this objective, it was imperative to provide a broad definition of a tool, and a base management performance measure which would be common to all actors, and which could be used to measure the success of the water sector as a whole.

3. METHODOLOGY

3.1 Overview

The team saw it necessary to unpack the scope by defining a tool, and defining integration from both the enterprise integration and in the context of IWRM. This was aimed at building a common understanding of the meanings of the words “tool” and “integration”. Hence a tool was defined as something (either tangible or intangible) used to support operational and strategic actions in performing water management. Therefore, a tool can be a guideline, a procedure or protocol, a method or technique, a device, an apparatus and a software program dealing with all levels in relation to transition to IWRM (Barlebo, 2006). From the Enterprise point of view, integration is seen as the natural continuing evolution, amalgamation and assimilation of many advanced enterprise-wide management, computing science, and networking concepts. The Global Water Partnership (GWP) perceives integration as a new governance and management paradigm which if effective, could give long-term solutions to water problems (Mcdonnella, 2008).

Three levels of integration hierarchy were identified and adopted for use in the project. The three levels consist of frameworks as follows:

1. Level I Frameworks – these can be referred to as just “Frameworks” or “Integrated Tools”.
2. Level II Frameworks – these can be referred to as “Integrated Frameworks”.
3. Level III Frameworks – these can be referred to as “Generic Integrated Frameworks”.

In essence, the objective of “Level I Frameworks” is usually to provide a new tool, the objective of “Level II Frameworks” is to provide a mechanism by which existing tools can be linked or organised in a consistent manner, and the objective of “Level III Frameworks” is to reduce duplication of effort between the different domains/silos, and to facilitate tool use and development by providing optimal direction. In fact “Level III Frameworks” are like a loose “wrapper”, which ensures consistency both in the tools themselves and in their use, and delivers greater utility and value than the simple sum of the constituent parts (HarmonIT, 2002; Marston et al., 2002; Argent and Rizzoli, 2004).

3.2 Project Scope

The scope of the project covered the review of literature regarding integration, a review of a range of management tools as defined by GWP, the assessment of the requirements for integration, and the development of a GICF. A software product was envisaged for this project, however, it was recognised that full integration, and the development of a fully integrated software system, would require that all tools as well as institutional arrangements conform to the GICF requirements for integration. Such a change would require more effort, time and money, and therefore, only a prototype system was developed for the purposes of demonstrating how the GICF works.

3.3 Project Approach

The approach to undertake the study was split into five phases, and eight tasks. The phases were intended to guide the project in a measurable manner. Four of the five phases were structured so as to deliver a key deliverable in line with the objectives, and these deliverables were each tabled for discussion by the reference group. The eight tasks on the other hand related mainly to project management and sequencing of activities. The phases were structured as follows:

- Inception Phase – an Inception Report was the main deliverable
- Research Phase – a Literature Review Report was the main deliverable aimed at addressing the requirements of objective no. 1.
- Solution Formulation Phase – the GICF was the main deliverable aimed at addressing the requirements of objective no. 2.
- Tools Assessment Phase – a Tools Assessment Report with recommendations on available concepts, data sources, and technologies was the main deliverable. This addressed the requirements of objective no. 3.
- Application Phase – a Case Study Report and a Demonstration Workshop were the main deliverables aimed at addressing the requirements of objective no. 4.

The approach was structured so as to answer the following questions:

- Why integrate?
- What to integrate?
- How to integrate?

4. RESEARCH RESULTS

The project established that the South African water sector has made progress in the path of integration, starting with the development of legislature and policies premised on the ideal of IWRM. The project has also established that in the different domains or functional areas, the South African water sector has, on average, developed the components of the Level II Frameworks. The components of the Level II Frameworks were in most cases found to have reached maturity levels, making the whole water sector ready for the development of a Level III Framework.

In an effort to guide the transition to the level III of integration, the project has developed a GICF in line with the objectives by:

- Undertaking a literature review resulting in a literature report which has been incorporated in this report as chapter 2.
- Developing the GICF for integration, this is reported in detail in chapter 5.
- Reviewing the tools and Identifying trends in technology and data management in the water sector, and these has been detailed in chapter 3 and 4.

- Developing a case study solution, as detailed in chapter 6 and 7.

The GICF is a high level architecture process that frames major integration issues and is seen as a means to bring together the Level II frameworks for complete integration. The GICF has been framed as a two dimensional system as follows:

- Based on integrating water management frameworks – requiring the existence of structures to, assess water resources; set up communication and information systems; resolve conflicts in allocation of water; establish regulation, establish financing arrangements; establish self-regulation; research and development; undertake development works; ensure accountability; develop organisational capacity (GWP and INBO, 2009). See **Figure 39**.
- Based on integrating Information Technology (IT) and water business – requiring concurrent-interactive development built on a unified process; supported by information systems; embedded in management of the “system”; in line with business culture/knowledge; done by all; and consistently implemented. See **Figure 41**.

The project has identified ten Level II Frameworks of grouped related components as key in a move towards integration. These building blocks were grouped into three pillarly and seven foundational main-blocks. The foundational block consists of those Level II frameworks that are a prerequisite to the existence of the GICF, while the pillarly block consists of those that do not need to be all in existence at once, but a sufficient number of them must be in place in order to realise integration. The ten identified Level II Frameworks are as follows (**Figure 39**):

- Foundational – this consists of:
 - The coordination and conflict resolution integrated framework.
 - The monitoring and compliance integrated framework.
 - The data and information management integrated framework.
- Pillarly – this consists of :
 - The water resources assessment and development integrated framework.
 - The regulatory integrated framework.
 - The financing integrated framework.
 - The water allocation and use integrated framework.
 - The capacity building integrated framework.
 - The research and development integrated framework.
 - The domain/field specific integrated frameworks.

The Level III Framework or the GICF was itself framed around the need to make decisions in an integrated platform, to store and manage the water sector knowledge, to store and manage the water sector tools, store and manage the water sector data and information, and to allow for user interface. Therefore the GICF was designed to contain five modules (**Figure 41**) as follows:

1. Integrated Decision Support System (IDSS) Module – the IDSS brings together the three levels of the decision process, i.e. it contains the:
 - Strategic level DSS – this level of the IDSS is mainly concerned with high level policy/political decision making, and factors in all issues of policy and political nature to the water business
 - Tactical Level DSS – this level of the IDSS in mainly concerned with technical/scientific decision making, and factors in the science (including social sciences) surrounding the water business.
 - Operation Level DSS – this level of the IDSS is mainly concerned with

stakeholder involvement in decision making, and factors in the stakeholder preferences to the water business.

2. Integrated Database-Access (Data Mart) Module – data integration and standardisation is seen as core to integration, and the integrated data mart ensures that data requirements for planning purposes, and data produced by the tools are compatible, and that there is no duplication of efforts.
3. Knowledge Management System Module –This module ensures that as integration happens, the knowledge and purpose of the individual tools are also appropriately retained.
4. Tools Management Module – this module ensures that tools exist to support the business objectives, and consists of two sub-modules as follows:
 - Integrated Surrogate Tools Module – this module allows managers to perform analysis using data from different complex/specialist tools in a simplified environment.
 - Tools Inventory and Management Module – this module allows the users to put together all tools at their disposal with an ability to compare different tools, search for an appropriate tool for a particular assignment, classify and categorise tools, undertake gap analysis and assess maturity of tools.
5. User Interface Module – this module allows the user to interact with all the above mentioned modules, to choose the type of analysis to be performed and the tools to be used.

The application procedure to guide the use of the GICF consists of nine steps, grouped according to the GICF modules as shown in **Figure 42**. The nine steps are as follows:

- Step 1 – Identify the high-level mandate of an entity.
- Step 2 – Identify actors and their objectives.
- Step 3 – Identify the decision process and performance indicators.
- Step 4 – Identify required tools and assess their maturity, these tools are required to achieve the objectives as per the performance indicators.
- Step 5 – Identify the required data.
- Step 6 – Identify the data sources and point of contact on the value chain.
- Step 7 – Bring the actors with their objectives and data requirements to the unifying platform using the appropriate Level II Frameworks.
- Step 8 – Identify overlaps and gaps on objectives, tools and data.
- Step 9 – Streamline the processes accordingly.

The GICF was, for demonstration purposes, implemented into a prototype web-based software system called the WATERGRAL. The WATERGRAL demonstrated that the GICF provides a platform for defining, in a standardised simplified and logical manner, the interrelations between the different actors in the water sector as well as to provide a platform for trade-offs in the optimisation of the water balance equation. This is based on examining trade-offs among water quantity, water quality, efficiency, equity, and sustainability as well as to quantify the drivers, pressures, states, impacts and responses when analysing the design of water management programmes.

5. CONCLUSIONS

From the outcome of the project it is concluded that many of the water management tools in the South African water sector supports the principles of IWRM within their respective domains. However, it is also concluded that the tools, as a collective, do not embrace the principles of IWRM, and to enable a transition to IWRM, a unifying framework is required.

The project has also identified that many of the domain specific Level II Frameworks have reached their maturity level, and that efforts are being made to integrate with other Level II Frameworks on an ad-hoc basis, this could result in systems procured and developed to solve a specific problem, characterised by a limited focus and functionality, and containing data that cannot be easily shared with other systems.

The project has, therefore, developed a GICF, aimed at guiding the integration process in a holistic manner; and in order to illustrate its applicability, the GICF was implemented into a prototype software integrated system called the “WATERGRAL”. The web-based WATERGRAL prototype aimed to demonstrate how the GICF can help to assess the tools with respect to their collective ability to evaluate the state of a water resource system holistically (i.e. in terms of sources, usage, water cycles (pathways) and environmental state). The WATERGRAL prototype was used to demonstrate the GICF as a unifying platform for defining, in a standardised, simplified and logical manner, the interrelations between the different actors and tools in the water sector.

The project has shown that there are efforts towards integration, internationally. Although most of the efforts are not guided by a framework like the GICF developed in this project, they are, however, based on the same principles, and build towards a complete system as envisaged with the WATERGRAL. For example, the Australian government through the Bureau of Meteorology is building the Australian Water Resources Information System (AWRIS) which is to be a powerful information system capable of receiving, standardising, organising and interpreting water data from across Australia (initial investment of \$10 million and further \$50 million over 5 years) (NWC, 2011); Europe is developing a Water Information System for Europe (WISE) which is to manage information on projects, tools, documents or any other information relevant for the Water Framework Directive (WFD) implementation; the American Consortium of Universities for the Advancement of Hydrologic Science Inc (WISE, 2011); (CUAHSI) is developing a Hydrologic Information System (HIS) which should provide web services, tools, standards and procedures that enhance access to more and better data for hydrologic analysis (initial research investment was \$3 million, annual operating cost of \$3 million and capital investment of \$5 million) (CUAHSI, 2011). These developments and others presented in **chapter 4** have indicated the need for a long term perspective and a need for substantial investment in an effort to integrate water resources and water uses management.

It is hoped that the GICF, if implemented, will foster greater awareness of the issues affecting integration, and focus attempts and resources to address disintegration problems. The GICF represents a means to an end, rather than an end in itself, and what is ultimately required is for all the actors in the water sector to align with the GICF’s optimal direction leading to complete integration. It is therefore not expected that the GICF will be implemented all at once, but that it will be used to guide prioritisation on programmes that should be undertaken.

6. RECOMMENDATIONS

The GICF as implemented in the WATERGRAL is currently a concept, and the case study results have emphasised that integration requires both a short term and long term view, and that the water sector, particularly the DWA as a sector leader will have to act accordingly to:

- Undertake a benchmarking and cost benefit analysis exercise of implementing the GICF.
- Identify appropriate institutional model for implementing the GICF.
- Develop a long term plan and a funding model for implementing the GICF.

- Develop the three prerequisite foundational Level II frameworks i.e. the coordination, monitoring and compliance, and the data and information management integrated frameworks.
- Streamline the sector in line with the GICF.

The implementation of the GICF and the development of the WATERGRAL system is proposed to be in three phases as follows:

1. Phase 1: undertake the above recommendations focused on streamlining the sector wide objectives on a strategic level – top management (Minister to Deputy Director Generals and/or Chief Directors), mapping the relationships with other sectors and other government institutions.
2. Phase 2: focused on streamlining the functional areas on a tactical and operational level (middle and lower management in the water sector).
3. Phase 3: development and deployment of the WATERGRAL system.

Detailed recommendations are presented in **chapter 9**.

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LIST OF ABBREVIATIONS

ACRU	Agrohylogical Modelling System
AM	Adaptive Management
BENCHLEAK	Benchmarking of Leakage for Water Suppliers in South Africa
BI	Business Intelligence
CHART	(C)Hydro-Geochemical Analysis and Reporting Tool
CMA	Catchment Management Agencies
CMS	Catchment Management Strategy
CUAHSI	Consortium of Universities for the Advancement of Hydrologic Science
DEAT	Department of Environmental Management and Tourism
DHI	Danish Hydraulic Institute
DPSIR	Drivers Pressures States Impacts Response
DSS	Decision Support System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
ECONOLEAK	Economic Model of Leakage Management for Water Suppliers in South Africa
EIS	Economic Information System
FEA	Federal Enterprise Architecture
GICF	Generic Integrated Conceptual Framework
GIS	Geographic Information System
GWP	Global Water Partnership
HIS	Hydrological Information System
HRPMS	Human Resources Planning and Management System
HYCOS	Hydrological Cycle Observing Cycle
ICT	Information and Communication Technologies
IDSS	Integrated Decision Support System
IP	Internet Protocol
IT	Information Technology
IWRM	Integrated Water Resource Management
NGDB	National Groundwater Database
NGIS	National Groundwater Information System
NGO	Non-Governmental Organisation
NIS	National Information System
NWA	National Water Act
NWRS	National Water Resource Strategy
RWSSM	Regional Water Supply Service Model
SADC	Southern African Development Community
SAGDT	South African Groundwater Decision Tool
SFWS	Strategic Framework for Water Services
SPATISM	SPATial and Time Series Information Modelling
TOGAF	The Open Group Architectural Framework
UFW	Unaccounted For Water
WC/WDM	Water Conservation and Water Demand Management
WFD	Water Framework Directive
WfGDF	Water for Growth and Development
WMA	Water Management Area
WQMS	Water Quality Management System

WRC	Water Research Commission
WRIMS	Water Resource Information Management System
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model
WS	Water Service
WSAM	Water Situation Assessment Model
WSDP	Water Services Development Plan
WSNIS	Water Services National Information System
WSSD	World Summit on Sustainable Development
WUA	Water User Association

1 INTRODUCTION

1.1 Background

In a South African context, the National Water Policy (DWA, 1997b) sets out a framework for the management of water and provision of water services and forms the basis for the derivation of the two main laws: the NWA and the Water Services Act (Clark et al., 2009). The approach adopted by the water policy can be summarised in the slogan: “some, for all, forever”, and captures the constitutional obligation to provide access to “sufficient food and water to meet basic human needs” as a human right (“some, for all”) (Clark et al., 2009). Additionally, the water policy recognises the need to plan for sustainable management of water to ensure adequate water for present and future generations (“forever”). The “some, for all, forever” slogan is articulated in the two legislative instruments and then translated into implementation plans and strategies at national, provincial and local levels (Clark et al., 2009).

The NWA, albeit far reaching in the changes that it heralds for water resource management in South Africa, is a framework act, leaving much of the detail as to how it will be implemented to regulators and operators to define within a local context. However, the Act commits to the ideal of integrated water management, and therefore, takes its context from water management and catchment management boundaries (Clark et al., 2009). The Water Services Act on the other hand relates to the provision of water services, and, takes its context from the administrative boundaries of District and Local Municipalities. The Water Services Act details issues of water supply and sanitation and lays out some of the institutions associated with the water services provision such as water boards and water services providers (Clark et al., 2009).

The NWA has introduced new paradigms and significant challenges in the management of water in South Africa. These include the provision of reserves to meet human and ecological requirements as primary priorities, the devolution of the responsibility for the management of water from a national to a regional level, and the requirement that stakeholders participate in the management of water. Further, the NWA calls for the equitable, efficient and sustainable allocation of water resources. This requires management tools at temporal and spatial scales appropriate to the demands of the NWA, and which utilises state-of-the-art integrated systems capable of taking into consideration social, economic and environmental needs which have to be considered (Clark et al., 2009).

In essence, the water management paradigm has changed from a focus on meeting demands from surface water supplies to a more holistic approach which also considers other aspects such as water quality, demand side management, the environment as a water user, surface water-groundwater interactions, and social and economic impacts. In recent years there has been an international trend towards this new water management paradigm known as IWRM (Havnen et al., 2002; Schulze, 2002). In South Africa this new paradigm has been captured in Section 3 of the NWA.

According to the Water for Growth and Development Framework (WfGDF) (DWA, 2009b), a different mind-set is required to embrace the changes needed to ensure water availability and water quality management (i.e. there must be a move towards strengthening institutional capacity, mainstreaming of water, diversifying the water mix, promoting Water Conservation and Water Demand Management (WC/WDM), promoting and maintaining water quality, securing water for development, securing water for growth, and nurturing of

attitudinal and behavioural changes towards the value of water). The WfGDF also points to the relationship between water availability and the many forms of economic activities, that depend on available water supply of specific levels of quality; and, emphasises the need to ensure reliable information is available for decision making and trade-offs to better support cross-sectoral planning and development initiative (DWAF, 2009b). Despite the major advances in science to underpin water resources and river management that have taken place over the past two decades, a need remains to establish a unifying framework that will lead to new, appropriate tools for sustainable water management.

According to the National Strategic Planning Green Paper (NPC, 2009), the lack of a coherent long term plan has weakened the government's ability to provide clear and consistent policies, since growth and development require a long term perspective to frame shorter term trade-offs. In essence, a long term plan helps focus government and society to deal with the inevitable short term turbulences in a nation's progress (NPC, 2009). Therefore, there is a need for better long-term planning to inform shorter term plans, resource allocation, trade-offs and the sequencing of policies.

In light of the above, the developed GICF from this research is seen as the unifying framework which can incorporate relevant and appropriate water management tools that are used or required for use in water resources and water services, linked by a common flexible and extensible database-access for use at strategic planning and management. In developing the GICF it was imperative to provide a sufficiently generic definition and a classification method for the characterisation of all kinds of tools, with an aim of creating a common terminological platform and to provide for easily mapping key characteristics of a tool. Therefore, a tool was defined as something (either tangible or intangible) used to support operational and strategic actions in performing IWRM. A tool can therefore, be a guideline, a procedure or protocol, a method or technique, a device, an apparatus and a software program dealing with all levels in relation to transition to IWRM or a subset of levels and approaches (Barlebo, 2006). This definition accommodates both water resources and water services definition of a tool in a South African context.

1.2 Project Rationale

IWRM is a concept that has been used to refer to a system where all aspects of human interaction with water resources are considered as potentially inter-related. While these aspects are to be addressed together rather than separately, and while the definition of IWRM readily accommodates water services provision, narrower definitions that exclude water services are preferred by some stakeholders. Further, much of the work around IWRM, and the discussions around sustainable water services delivery, take place at a strategic level. This leaves behind Civil Society Organisations who are directly affected by the implementation (Dlamini and Cousins, 2009). The unity of the hydrological cycle warrants a holistic approach that appreciates the many aspects of the hydrological cycle, including all water uses and water resources management aspects.

In South Africa, water resources and water services are governed and managed under separate acts, namely the NWA and the water services Act, while water management and use, in the broader environmental and sectoral context, cuts through various government ministries and institutions. There are sound reasons for regulation of water resources and water services to be seen as distinctive competences, guided by separate policies and pieces of legislation. However, this has, unintendedly, led to the development of management tools, both in water resources and water services, which are competent in their own domains/silos

but do not embrace the concept of IWRM in a broader sense, and this could potentially result in the following points as stated in the Terms of Reference:

- Duplication of activities between water resources and water services which can result in suboptimal use of resources.
- Separation and disconnection of data and information systems between water resources and water services which can result in time-consuming decision-making processes.
- Excessive levels of tolerance for accommodating errors and low accuracy levels in combining the results from water resources and water services when making decisions.
- Lack of coherence and possible conflicting rationale in the issuing of recommendations relating to water resources and water services, possibly due to varied time and area scales of interest and differing limitations with regard to roles, responsibilities and resources.
- Poor accuracy in estimates of: available water; simulated or estimated water use; sector demands and/or losses, owing to the lack of a framework for facilitating interaction, and feedback among resource managers and services authorities/providers.
- Failure of the water sector, as a whole, to take sufficient advantage of improvements in technology (e.g. rapid communications technology, remote sensing, etc.) and the continuous expansion of existing knowledge, as a means of facilitating the coordinated enhancement of water management, planning and services.

1.3 Project Objectives

In an endeavour to avert the impact of fragmentation in the South African water sector, the WRC has initiated this project with the aim of adding value to the process of looking into requirements for a multidisciplinary approach to IWRM. The project focused on the integration of tools in general, including mobilisation of: social, economic, institutional, legal, environmental and technical expertise, in an effort to address water resources and water services in an integrated manner. A unique and key focus of the project was the integration of management tools that are currently being employed separately, in water services and water resources applications. In recognising that the resulting integration of data, information and technical approaches represents a means to an end, rather than an end in itself, the project was set to formulate of an optimal direction leading to complete integration.

The main objectives of the project were:

1. To assess and review existing knowledge and literature on existing water services and water resources monitoring, operation, management, planning and decision-making tools, and on the integration aspects, while focusing on those tools where the benefit of integration is evident and possible within South Africa's current practices or where integration has been attained in international situations. Also to review existing integration and the scope and benefits of further integration.
2. To develop a conceptual framework for the integration of water resources and water services management tools. The framework will present the best solution which takes into account the present state of needs, available resources, existing commitments and institutional frameworks.
3. Investigate and identify new concepts, technology and data sources that can improve the processes involved on an integrated water resources and water services platform; and make recommendations on how these can be effectively packaged into the

integrated water resources and services approaches.

4. Develop a case study solution that integrates water services and water resources tools for a specific complex water use area such as a large municipal area. This integration solution will deal with existing: infrastructure and resources; planning; water resource operation; water supply and treatment; water distribution; sanitation and return flows; and, pollution and waste water control. Preference will be given to tested and proven tools while allowing for new developments. The ability for remote users to access a single system at any one time is envisaged. The best ways of sharing real time data or at least making it available at the various remote points of contact is important.

Therefore, the primary objective of this project was to review the existing tools with an aim to develop a GICF which can incorporate relevant and appropriate water management tools that are used in water resources and water services management, linked by a common flexible and extensible database for use in strategic, tactical, and operational planning and management. In light of this objective it was imperative to provide a base performance measure common to all actors, and which can be used to measure the success of the sector as a whole.

1.4 Project Approach

IWRM is the approach which has become the main framework in which water is being managed, and which guides the South African water sector (Dlamini and Cousins, 2009). Although IWRM is still an evolving concept with not one universally agreed definition, there is a common ground in most definitions (i.e. it is commonly agreed that IWRM is about integrated and ‘joined-up’ management). It is about promoting integration across sectors, applications, groups in society and time, based upon an agreed set of principles. Therefore, IWRM is in response to the recognition that management approaches of the past have failed to deal adequately with the challenges posed by complex and rapidly changing systems (Pollard and Du Toit, 2008). Further, IWRM is seen as a progressive way of thinking in managing water rather than the end in itself, but rather a means to an end. In the case of South Africa, that end is defined in the policy and legislation as being the equitable, efficient and sustainable use of water, and the beneficial use of water in the public interest.

In a move towards IWRM implementation, the Department of Water Affairs (DWA) has adopted the GWP definition of IWRM. The DWA has used the GWP checklist as a basis against which to outline the implementation of IWRM in South Africa, both in terms of areas of success and areas where there remain significant challenges (DWAF, 2007). Hence, in this report the GWP definition of IWRM has been adopted and is as follows:

“IWRM is a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.”

According to GWP (2000), there are three key elements contributing to IWRM by seeking a balance between efficiency, equity and environmental sustainability, and these are:

- The Enabling Environment – which is the general framework of national policies, legislation and regulations and information for water resources management stakeholders
- The Institutional Roles – which are functions of the various administrative levels and stakeholders

- The Management Tools – these include operational instruments for effective regulation, monitoring and enforcement that enable the decision-makers to make informed choices between alternative actions. These choices need to be based on agreed policies, available resources, environmental impacts and the social and economic consequences.

Through the White Paper on a National Water Policy for South Africa, together with the enactment of the NWA and the Water Services Act, South Africa has managed to pave a way towards IWRM by creating an Enabling Environment. The White Paper takes as its basis the key elements of IWRM, including efficiency, equity and sustainability. The Water Services Act on the other hand provides a framework for the provision of water and sanitation services to which people are entitled. These two acts provide a comprehensive framework covering both water resource management, water use and, in particular, water services, and sets out rights for everyone to both basic water services, and to the benefits that can be derived from water resources (Moriarty et al., 2004).

In support of the Institutional Roles element of IWRM, the NWA outlines the different water management institutions as well as the specific functions of the different institutions. The Water Services Act sets out the roles and responsibilities of water services authorities and water services providers. Over the past decade, the South African water sector has been positioning itself to ensure that the institutions and roles are in-line with the IWRM requirements. These include: the restructuring of the DWA, the establishment of the catchment management agencies, water user associations, water services authorities, and many forums to enable the participation of stakeholders in water management. Further, South Africa together with neighbouring countries are well advanced in the establishment of basin organisations and agreements on water sharing (DWA, 2007).

The NWA makes it clear that tools (i.e. for conservation, pricing, conflict resolution, etc.) as required by IWRM, should be put in place. This supports the Management Tools element of IWRM. However, IWRM requires that the tools for each domain be integrated and that scientific experts, water managers and stakeholders collaborate in the holistic assessment and management of water. Thus, while integration is being pursued within the different domains/silos in the South African water sector (i.e. within Water Services, Water Resources Information Programmes, Integrated Water Resource Planning, Resources Directed Measures, catchment management agencies, the WRC, etc.), very little has been done to bring the tools of these disciplines together.

In general, availability of tools is a necessary condition for implementation of policies. However, IWRM goes further to say that integration between the tools is a necessary condition for successful implementation of water management policies aimed at managing water sustainably. Therefore, while the NWA is hailed across the world for getting the right mix between economic growth, social equity and environmental sustainability (Kasrils, 2004), the ultimate test is in its implementation, and consequently the sector's ability to develop and integrate the required tools.

The need to integrate water management tools has led to the recognition of the need for and development of frameworks to facilitate IWRM (Clark and Smithers, 2006). Frameworks can generally be divided into three levels in integration architecture, and they are as follows:

1. Level I Frameworks – this type of integration frameworks refers to a collection of tools that have been combined in order to represent a specific system/issue or a

domain (examples of Level I Frameworks are ACRU, SFWS, WRYM, WRSM2000, etc.). These can be referred to as just “Frameworks” or “Integrated Tools”.

2. Level II Frameworks – this type of integration frameworks refers to a collection of tools which have traditionally been used within their own separate systems, each consisting of similar tools to prepare input data, write input files and analyse model output, (examples of Level II Frameworks are WRIMS, WSDP, SPATSIM, WSNIS, HYDSTRA, WMS, WULATS, etc.) These can be referred to as “Integrated Frameworks”.
3. Level III Frameworks – this type of integration frameworks refers to open frameworks for linking integrated tools and/or frameworks focusing on generic linkages and functional modularity. These can be referred to as “Generic Integrated Frameworks”.

South Africa and many other countries have developed various Level I and Level II Frameworks. However, there are no generic integrated frameworks which have received wide acceptance and uptake, with open access to the framework components (Barlebo, 2006). This applies to South Africa, and this type of piece-by-piece development can make it difficult for the water sector to communicate coherent message to stakeholders, and therefore hinders proper practice of IWRM.

The scope of the project covered: the review of literature regarding integration, a review of a range of management tools as defined by GWP, the assessment of the requirements for integration, and the development of a GICF. A software product was envisaged for this project, however, it was recognised that full integration, and the development of a fully integrated software system, will require that all tools, as well as institutional arrangements, conform to requirements for such integration. Such a change will require more effort, time and money, and therefore, only a prototype system was developed for the purposes of demonstrating how the GICF works.

In undertaking the project it was important to establish why, how and what to integrate. This would guide the literature search and the formulation of the solution. Therefore, in summary the why, what and how were defined as follows:

- Why Integrate? – to achieve consistency and coherence both in space and time, and to achieve optimal use of resources resulting in sustainable water management.
- How to Integrate? – by bringing together the business, environment, institutional arrangements (Value chain) and the required support services. The water sector can be said to consist of four main components that need to be integrated between and within themselves.
- What to integrate? – the matured Activities/Perspectives of water supply and demand (between and within).

The approach to undertake the study was split into five phases, and eight tasks. The phases were intended to guide the project in a measurable manner. Four of the five phases were structured so as to deliver a key deliverable in line with the objectives, and these deliverables were each tabled for discussion by the reference group. The eight tasks on the other hand were relating mainly to project management and sequencing of activities.

The GICF provides a long-term high-level process that frames major integration issues and provides strategies and recommendations for addressing those issues.

1.5 Report Structure

The report is structured as follows:

Chapter 1 is the introduction and it provides an overview of the problem statement and approach to the solution.

Chapter 2 gives a summary of the literature reviewed covering issues around the need for integration, the South African situation, definition and categorisation of tools, concepts of integrated water management, concepts of water management as a business, enterprise architecture, integration maturity assessment and the required support services for integration.

Chapter 3 gives an assessment of the South African situation by assessing the available tools in terms of integration. The section also gives the inventory of tools.

Chapter 4 gives international experiences with regard to integration.

Chapter 5 introduced the approach to the development of the GICF for integration, and also details the developed GICF and the application process.

Chapter 6 gives the methodology used to implement the GICF into a software system called the WATERGRAL. The chapter gives the overview of the philosophy behind the WATERGRAL as well as the structure of the system.

Chapter 7 gives the approach and the results of the case study undertaken to demonstrate the WATERGRAL System.

Chapter 8 and 9 concludes the report and highlights some recommendations and suggestions for implementation and further research.

2 LITERATURE REVIEW

2.1 Overview

The water sector can be said to consist of four main components that need to be integrated between and within themselves. Hence, literature review was structured so as to unpack integration issues pertaining to bringing together the four components of the water sector which are as follows:

1. The water business – referring to the activities of ensuring a balance between availability and demand in a sustainable manner.
2. The water information value chain – referring to the flow of information in the water sector.
3. The operating environment – referring to the reporting requirements of the environment the water sector operates in.
4. Support services required – referring to the required support (i.e. human resource, financial, political or infrastructural) to carry out the water business.

The literature review was undertaken on a broad scale covering issues around the need for integration, definition and categorisation of tools, integrated water management ideologies, water management as a business, enterprise architecture, integration maturity assessment, and support services as detailed in the following chapters.

2.2 The Imperative of Integration

The role and value of water to people's livelihoods are increasingly being recognised, particularly for women and the poor. The amount of water available to support these activities can be a key constraint to enabling diversification of livelihoods, improving income levels, and reducing poverty. One implication of promoting provision for productive activities is that water services needs then become higher than is often realised. Total household water requirements for poor people including water for productive uses are likely to be in the range 50-200 l/p/d, compared with the commonly accepted norms for a solely domestic water supply of around 25-50 l/p/d (LoGoWater, 2005).

Increased water utilisation as a result of water services projects may impact severely on the access of other water users to the same or linked resources. Further, the decline in the quality of surface and groundwater resources from, principally, industrial discharges and poor sanitation, is a major concern globally, especially where cities are growing rapidly. As well as being a finite resource, water services supplies and aquatic ecosystems are at increasing risk of pollution. This escalates the scarcity of good quality water and harms habitats. Clearly there is an urgent need to adopt integrated management in the water services, and equally, for water resources to acknowledge the water services sub-sector in planning and management of water resources (LoGoWater, 2005).

IWRM is considered to be able to cope with complex water management problems and integration. However, IWRM literature has very little water services content. Moreover, few water services managers or politicians have engaged with IWRM. The potential benefits of employing the IWRM concept at the municipality level are at best poorly understood. IWRM is typically seen as something to do with river basins and having limited relevance, as long as the municipalities continue competing successfully to secure additional sources of water (Rees, 2006). The content on water services in IWRM literature, as little as it is, has demonstrated potential value of the available water services tools when adopting an IWRM approach. For example, there are tools for: water services demand management, pollution

abatement, leakage control, dual supply, recycling, decentralisation, and public-private partnerships which can be useful in an IWRM approach. However, much of these tools are domain specific and do not explore the broader dimensions of IWRM in the water services context.

Just as the IWRM literature has tended to neglect the water services dimension, it has also been largely silent on the broad role of IWRM, making the gap between water resources and water services even larger. The water services literature does make reference to specific management tools which are potentially consistent with an IWRM approach; however, it does not consider the range of cross-sectoral actions and assessments, which would be involved in the implementation of an IWRM process. It neglects both the interrelationships between water resources and water services, and the role of the urban in the efficient and sustainable development of scarce natural and human capital resources (Rees, 2006). Furthermore, little attention has been focused on what specific problems could arise, when attempting to implement an IWRM approach in major urban centres. Agenda 21 recognises the vital role of local governments in addressing the many environmental problems encountered in developing world cities, including water-borne pollution, sanitation and vulnerability to water-related hazards (Rees, 2006).

Water Services sub-sector is impacted by, and has impacts on, other sub-sectors over a whole range of interfaces. The value of IWRM is most obvious at those points where water for domestic use directly interacts with other uses and the environment. Not all the impacts are negative, and an important benefit of IWRM is that it makes it possible to take advantage of synergistic developments, to make optimum use of water (LoGoWater, 2005). Hence, integration between water services and water resources can only be meaningful if other affected uses are taken into consideration. In this context, it is necessary to understand what rights other downstream users have to the resources, and what the implications of these rights are. Rights to water vary according to legal systems in different countries, and often overlap.

They may include:

- Administrative rights, where licences have been allocated (e.g. by a river basin authority)
- Riparian rights linked to rights to land adjacent to watercourses or above aquifers
- Rights linked to prior appropriations (first use)
- Other traditional/ customary rights based upon local laws or norms.

South Africa's water law dispensation changed dramatically with the promulgation of the NWA. The previous distinction between public and private water was abolished and the public trust doctrine was statutorily incorporated.

Traditionally, water services aspects are neglected in water resources management because the needs of the water services sector have been regarded as small; and, the impact of water services on water resources has been misguidedly regarded as negligible. With the delivery of enough clean water to safeguard health, and meet basic human needs becoming top priority in most national water policies, it becomes evident that water requirements for water services are not small. Also, with the improvement on sanitation, the impact of water services on water resources availability becomes clear. This is becoming evident in South Africa, due to a drive to ensure access for all, and to eradicate backlogs in water supply. As populations and demands on water resources continue to grow, professionals working in water services are faced with a range of critical questions (i.e. how to develop reliable sources of sufficient

water for the water services supplies? how to ensure adequate water quality, and protect sources from pollution? and, how to minimise the impacts of water abstraction and wastewater pollution on other water users?), (LoGoWater, 2005).

Finding answers to these questions, and putting in place processes that lead to sustainable solutions, is of increasing importance as more conflicts arise over access to water. Even where policy makes water services needs a priority; realities often mean that domestic consumers lose out when supplies become critically short. Ironically, it is at this times when health and social needs should dominate the equation, rather than the economic arguments of more influential industrialists and farmers (LoGoWater, 2005).

Therefore, given the above arguments, integrated water management and IWRM in particular, are important for the water services sub-sector and the following are the main points to bear in mind:

- Water services needs are not trivial
- Mechanisms to prioritise domestic water use often fail
- Not just domestic supplies, is also about meeting water needs for productive uses
- Water services impacts on and is impacted by other water users.

2.3 The South African Situation

2.3.1 Governance Structure

The South African government structure is organised into three tiers (i.e. national, provincial and local government). The water management institutions have been arranged into three tiers. The DWA – national government – is the custodian of the water resource and overall leader of the water sector. Catchment Management Agencies – are being established in all Water Management Areas and are to be responsible for water resource planning at the catchment level. Water Services Authorities (local government) have the constitutional responsibility for ensuring access, planning and regulating provision of water services within their area of jurisdiction.

The Minister of Water and Environmental Affairs has executive authority over the water boards, the WRC, the Trans-Caledon Tunnel Authority, the irrigation boards, water user associations and catchment management agencies . The DWA derives its mandate from various legislative and policy frameworks as follows: Water Research Act, 1971 (Act No. 34 of 1971), NWA, 1998 (Act No. 36 of 1998), Water Services Act, 1997 (Act No. 108 of 1997), National Forests Act, 1998 (Act No. 84 of 1998), National Veld and Forest Fire Act, 1998 (Act No. 101 of 1998) (DWAF, 2009).

Essentially, the South African water sector is governed by two acts, the NWA and the Water Services Act. The NWA provides the legal framework for the effective and sustainable management of water resources. The act was promulgated to redress the discriminatory past laws, which allocated water unfairly. The aim of the NWA is to ensure that water resources are protected, used, developed, conserved, managed and controlled as a whole. It promotes the integrated management of water resources with the participation of all stakeholders. The NWA recognises that South Africa is a water scarce country, and therefore, it requires that the water resource be managed in an integrated manner.

The Water Services Act on the other hand, provides the legal framework for water services (water supply and sanitation) delivery. Local government, as a water service authority, has been mandated to provide basic services including water supply and sanitation. Local government is not mandated to undertake IWRM, but as a major water user and bulk waste water service provider, municipalities should play a large role to ensure that the water resource is protected, used, conserved, managed and controlled, and to ensure a sustainable water resource. Local government is, thus, a key stakeholder in IWRM. However, the role of local government in IWRM is usually not apparent, yet municipalities are usually implementing some principles of IWRM in providing a sustainable water service.

Nevertheless, local government is constitutionally responsible for the implementation, and control of a range of activities that affect water resources. In particular, local government has key responsibilities related to water resources management including: ensuring provision of municipal services, rural development strategies, municipal spatial development, infrastructure planning, environmental planning and management, and pollution control and waste management. The South African Constitution and the Intergovernmental Relations Act require all organs of state and spheres of government to observe and adhere to the principles of, and conducts their activities within, the parameters of cooperative governance. The water sector has responded to this need by forming regional water sector collaborative forums. As local government continues to take on its constitutional mandates, the need for cooperation between water services and water resources managers is critical to the effective, efficient, and sustainable implementation of IWRM (Burke, 2006).

Various tools for achieving IWRM are available to the three tiers of government. However, some of these tools do not talk to each other, making it difficult to achieve the goals of IWRM (Burke, 2006), as the effectiveness of such tools is dependent on the level of collaboration between the different stakeholders (Burke, 2006). The following sub-sections give details of the water services, and water resources management and tools in South Africa.

2.3.2 Water Services Management and Tools in South Africa

Water services refer to water supply and sanitation services, and include: regional water schemes, local water schemes, on-site sanitation and the collection and treatment of wastewater. The responsibilities of water services have been divided between the national government, and the local government, acting through the DWA and the water services authorities respectively (DWA, 2002).

2.3.2.1 The role of the Department of Water Affairs

DWA is the national department responsible for both water resources management and water services provision; in the future, the DWA will play a central role in the following four areas with respect to water services (DWA, 2008b):

- Policy – DWA has overall responsibility for the management of water resources and for water sector policy (water resources and water services). DWA's specific functions in this regard include: sector leadership, promotion of good practice, development and revision of national policies, oversight of all legislation impacting on the water sector (including the setting of national norms and standards), co-ordination with other national departments on policy, legislation and other sector issues, national communications, and the development of national strategies to achieve water sector goals. DWA also has the responsibility to develop policy

regarding to international water services issues.

- Regulation – Regulation comprises two functions: monitoring sector performance (including conformity to national norms and standards) and making regulatory interventions (to improve performance and/or to ensure compliance).
- Support – Support to water services and related institutions to be undertaken in terms of the constitution and the principle of cooperative government. Financial support within the framework of the municipal infrastructure grant, the local government equitable share, and the capacity building grant. DWA to work with the Department of Cooperative Governance and Traditional Affairs (CoGTA), to establish appropriate conditions and to monitor compliance with these conditions. The nature of the support will depend on the specific needs and requirements of local government and water institutions.
- Information management – DWA to manage information being used for support, monitoring, regulation and planning.

In the interim, DWA is currently performing certain functions that are not part of its future core business, notably the operation and maintenance of water services works and the implementation of new water services infrastructure. These roles will cease once the transfer policy has been fully implemented. The development and implementation of these strategies must be understood in terms of the changing role of DWA since 1994. **Figure 1** gives an overview of the changing role of DWA with respect to water services from 1994 to 2014 (DWAF, 2008b). In 1994 DWA took on a direct role in the provision of water services. DWA also created new water boards in some areas. When local government legislative reform was completed, DWA began to transfer water services assets to water services authorities. Local institutional reform began in earnest, with the allocation of the water services function to water services authorities in terms of the Local Government Structures Act, and the transfer of DWA water services assets (DWAF, 2008b).

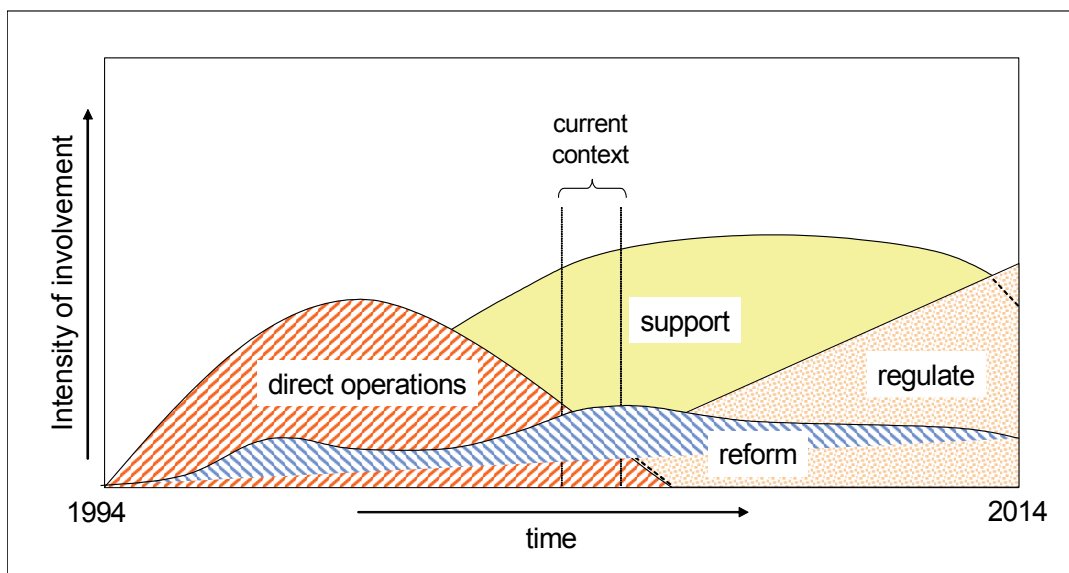


Figure 1: Changing role of DWA (DWAF, 2008b)

It is anticipated that the intensity of DWA's involvement as sector regulator will increase over time. In the medium to long term, the role of DWA in institutional reform and support is likely to diminish, and DWA's primary role will eventually be sector leader and regulator.

However, in the short to medium term, DWA is likely to intensify its involvement in three areas: regulation, institutional reform and sector support (DWAF, 2008b).

2.3.2.2 The Role of Water Services Authorities

Haigh and Fox (2008) argue that IWRM, in its widest context, is not a direct legislated mandate for local government, although it is implicit in many of the acts and policies. The principal role of local government is water supply and sanitation delivery, which has often overshadowed its role in IWRM. Implementation, therefore, relies on linkages to functions and priorities already mandated, in particular the development and annual reconsideration of the Integrated Development Plan, the Integrated Waste Management Plan and the Water Services Development Plan (WSDP). In this context, the authority functions of municipalities for IWRM include (Haigh and Fox, 2008):

- Control of development within the 100 year flood line and protection of wetlands and riparian areas.
- Management of storm water (Category A, B Municipalities).
- Disaster management as it relates to floods and droughts.
- Refuse removal (Category A, B Municipalities); refuse dumps and solid waste removal (Category A, C Municipalities) plus control of litter, particularly as it relates to protection of urban rivers.
- Pollution control through
 - industrial effluent disposal to sewer systems
 - appropriate disposal of hazardous materials and,
 - management of grey water.
- Ensuring provision of appropriate and effective sanitation (Category A, C Municipalities).
- Ensuring provision of safe drinking water through management of drinking water quality.
- Ensuring water conservation and demand management by water users to whom they supply water.
- Integration of local level development planning with water availability – in conjunction with DWA/catchment management agencies (Category A, B, C Municipalities).
- Manage municipal health – now defined as environmental health
- Control air pollution (Category A, B Municipalities)
- Manage municipal parks and recreation (Category A, B Municipalities)
- Manage beaches and amusement facilities, recreational water use (Category A, B Municipalities).

Further, Haigh and Fox (2008), state that the WSDP clearly sets out the business of water services delivery in ten business areas. If a municipality successfully fulfils these tasks, migrating toward IWRM will require shift in approach, through realigning operational areas and integrating management roles. Key areas in the WSDP for IWRM are: the water balance (requirements vs. availability), water conservation and demand management, and well-structured and implemented operation and management protocols. Realigning the operational areas of solid waste management with Stormwater management may be the biggest challenge, while incorporating water into planning might be a lesser adjustment. The Integrated Development Plan already requires integrated planning, so the bases for better integration is already there but the practice is still lacking. However, few municipalities,

especially that are category B, can successfully and wholly execute all their mandated water service responsibilities (Haigh and Fox, 2008).

As registered water users, municipalities have several other functions they are obliged to fulfil, a number of which fall in the ambit of successful IWRM. In terms of IWRM, the duty of a municipality, besides services provision, is principally to manage possible sources of water pollution so that the water resource is protected (i.e. undertake source directed control as it relates to licenses and to authorised water use). If local government was to follow a step by step approach to engaging in IWRM the first step would be to ensure that mandated tasks are performed as well as possible (Haigh and Fox, 2008).

There are two different aspects of the water management functions performed at local government level: the first are functions that must be performed by municipalities under their responsibilities as a water user governed by the Water Services Act (e.g. control of effluent discharge from Waste Water Treatment Works); the second are functions which municipalities should be performing as government authorities, among other things, through their own by-laws. There are, therefore, sections of the Water Act that by inference directly apply to local government (Haigh and Fox, 2008).

Compliance rather than regulation is at the heart of the local government mandates as determined by the NWA. However, the philosophy of the act implies sustainable management, conservation and protection of the resource while ensuring equal access to water. This should inform all decisions and actions that local government undertake as water services authorities and/or water services providers to the citizens in its jurisdiction. Compliance to source-directed controls is, therefore, a responsibility of a municipality (Haigh and Fox, 2008).

In Chapter 3 of the National Water Resource Strategy (NWRS) (DWAf, 2004a), source-directed controls are discussed in terms of their role as protective measures for water resources. Source-directed controls are now incorporated into conditions in water-use licences and general authorisations. The conditions that may be imposed on water use are described in section 29 of the NWA, and cover all aspects of every types of water use. They are closely associated with the resource quality objectives and are intended to ensure that the cumulative impact of water use, in respect of quantity and quality, does not exceed the limits appropriate to the class of the resource. Source-directed controls for all water use will continue to be implemented as licences are issued, and will contribute to the achievement of the objectives for the protection and use of a resource in terms of its class (Haigh and Fox, 2008).

The role of the local government, in contributing to and complying with source-directed controls, is to ensure that waste water discharges and solid waste management do not adversely impact the water resource, and that they comply with the conditions of their license as a water user. More emphasis on downstream water resource protection is an area desperately in need of municipal attention. Water resource protection within municipalities includes water conservation/water demand management (WC/WDM), and water quality and quantity management monitoring. There is not a single best model or recipe for either water resources authorities, or local governments for WC/WDM (Smits and Butterworth, 2005). However, municipalities have to ensure they:

- Reduce water wastage.
- Reduce unaccounted for water usage including loss from leakages, illegal

- connections, and poor billing & cost recovery.
- Delay costly water scheme upgrades.
- Reduce sewage treatment costs/ upgrades.

All four of the above points would be addressed in improved operation and maintenance protocols, and rehabilitation and improvement of infrastructure such as metres and monitoring systems. The overall effectiveness of IWRM at a small local government level relies on public participation. Unless the public comply and assist with patterns of behaviour facilitating resource management issues, the resource directed measures and source directed controls are likely to be relatively ineffective. As water users municipalities have responsibilities which fall within the ambit of IWRM. These include (Haigh and Fox, 2008):

- Effective operation and maintenance of Waste Water Treatment Works and ensuring that they comply with license conditions for discharge e.g. for Waste Water Treatment Works. Currently there are significant pollution problems arising from poor management of these facilities by municipalities. Improvement in this would considerably assist the quality of water resources, particularly in and immediately downstream of urban areas.
- Effective Operation & Maintenance and refurbishment of infrastructure such as pipes, reservoirs, pumps and meters to minimise real losses. Currently the water loss in municipal areas is unacceptably high, and management of this problem would assist considerably in managing water scarcity.
- Control of water weeds on municipal dams.
- Control of alien invasive plants on the commonage and municipal dams that impact on water use.

2.3.3 Water Resources Management and Tools in South Africa

The purpose of the NWA is to ensure that South Africa's water resources are protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons. The Act provides the national government – acting through the Minister of Water Affairs, who is the public trustee of the nation's water resources – with power to regulate the use, flow and control of all water in the Republic. The NWA also provides for the progressive decentralisation of water resource management to the appropriate level Catchment Management Agency (CMA) as well as providing for participation in water resource management in South Africa (Haigh and Fox, 2008). The responsibilities of water resource management have been divided between the national government (through DWA), the Catchment Management Agencies, and the Water User Associations.

2.3.3.1 The Role of the Department of Water Affairs

In accordance with the constitutional mandate for water reform, the NWA identifies the national government, acting through the Minister of Water Affairs and Forestry, as responsible for the achievement of the fundamental principles of equity and sustainability. DWA, as the public trustee of the country's water resources, has overall responsibility and authority within the guiding framework of the NWRS and within the broader framework of other environmental legislation, particularly the National Environmental Management Act and the Environmental Conservation Act of 1989, over their classification and protection, use, development, conservation, management and control, including equitable allocation and redistribution. The ultimate aim of water resource management is given as the sustainable use

of water for the benefit of all users, recognising the need to protect water quality to ensure such sustainability, and the need for integrated management of all aspects of water resources and, where appropriate, the delegation of management functions to a regional or catchment level (Haigh and Fox, 2008).

The NWA gives equal weight to groundwater and surface water and aims to ensure the protection of the water resource for sustainable use and ecosystem health. At the national level, the water resource pertains to rainfall and runoff, and aquatic ecosystems including rivers, dams, wetlands, estuaries and groundwater. At the municipal level, the water resource includes rivers, dams, groundwater and small pockets of wetlands. Under the NWA, the guiding principles of an IWRM strategy are that all water use must be sustainable, equitable and efficient, and water demands must be optimally reconciled with all available resources. “These guiding principles recognise the basic human needs of present and future generations, the need to protect water resources, the need to share some water resources with other countries, the need to promote social and economic development through the use of water and the need to establish suitable institutions in order to achieve the purpose of the Act” (NWA, Ch. 1) (Haigh and Fox, 2008).

According to Haigh and Fox (2008), a provision of the NWA, which may be one of the most challenging to effect, is that of “Monitoring, Assessment and Information” (chapter 14). The NWA recognises the critical importance of monitoring, recording, assessing and disseminating information on water resources. Part 1 of this chapter places a duty on the Minister, as soon as it is practicable to do so, to establish national monitoring systems. The purpose of the systems will be to facilitate the continued and co-ordinated monitoring of various aspects of water resources by collecting relevant information and data, through established procedures and mechanisms, from a variety of sources including organs of state, water management institutions and water users (Haigh and Fox, 2008).

As the various water resource management institutions are established and the responsibility and authority for water resource management is delegated or assigned to them, the DWA’s role will change. It will increasingly focus on national policy, a regulatory framework for water resource management, and ensuring that other institutions are effectively fulfilling their roles and responsibilities (Haigh and Fox, 2008).

2.3.3.2 The Role of Catchment Management Agencies

Catchment Management Agencies represent the second tier of the water resource management framework. Each CMA is responsible for the progressive development and broad implementation of a catchment management strategy, which must be consistent with the National Water Resource Strategy, within its water management area (DWAf, Undated). The progressive establishment of catchment management agencies, ultimately for all water management areas, is targeted for the purpose of delegating water resource management to the regional or catchment level and to involve local communities, within the framework of the NWRS (Haigh and Fox, 2008).

Under the NWA, in water management areas where no CMA is established or where an established CMA is not functional, all powers and duties of the CMA vest with the Minister of Water Affairs who is responsible for fulfilling the CMA’s functions. Specifically, the regional offices of DWA will manage water resources in their areas of jurisdiction until catchment management agencies are fully operational. Such functions include the

management, use, development, conservation, protection and control of water resources within the CMA's water management jurisdiction, which embraces the need to formulate a Catchment Management Strategy (CMS) and to promote coordination, participation and cooperative governance in realising their targeted principles and performance objectives. Until such time as a CMS can be drawn up by the future CMA, the Internal Strategic Perspective document provides the framework for integrated decision-making, and for DWA's management of the water resources in each Water Management Area (Haigh and Fox, 2008).

2.3.3.3 The Role of Water User Associations

The establishment and powers or functions of water institutions further provided for under the NWA are: Water User Associations. These are essentially cooperative associations of individual water users undertaking water related activities for their mutual benefit. Water management activities may be devolved to water user associations in which case they become the third tier of water management institutions (DWA, Undated). Chapter 13 of the NWA provides for the appointment, powers and duties of authorised persons to access properties and undertake inspections on water use, and further deals with access and rights over land in respect of servitudes, including waterworks on personal servitudes.

In essence, the purpose of a Water user Association (WUA) is to enable people within a community to pool their resources (money, human resources and expertise) to more effectively carry out water-related activities. Through a WUA, members can benefit from addressing their local needs and priorities. Water user associations operate at a restricted localised level and they can provide a mechanism through which the catchment management strategy can be implemented at local level. Water user associations also have an important role to play in terms of poverty eradication and providing food security (Haigh and Fox, 2008).

2.4 Definition and Categorisation of Tools

In integration endeavours it is important that a common ground is established in definition and meaning of terms. The following subsections are dedicated to defining a "tool" and explaining how tools can be categorised and classified. The form of integrated tools and the need for simplified tools (surrogate tools) in integration is also discussed.

2.4.1 Definition of a Tool

According to Barlebo (2006), a definition of a tool differs depending on the field of work one is involved in, and it is therefore important when moving towards integration, to find a common definition of a tool. In the past, water management was characterised by clearly defined problems that society wanted to be solved. These problems were dealt with in isolation, and the human dimension was taken into account as an "external" boundary condition. In general, and over years, a tool typically was understood as a stand-alone computer software describing mainly one topic e.g. groundwater flow (Barlebo, 2006).

In realisation of the need to account for all water components to ensure an efficient allocation and protection of water, IWRM was endorsed by a broad international scientific and policy community. This resulted in the human dimension and stakeholder involvement being identified as an integral part of water management. The natural science community reacted to the change by either considering knowledge from several disciplines in their software tools

design, or by making their original software tools to be part of an integrated modelling framework; this shifted a definition and an understanding of a tool (Barlebo, 2006).

More importantly, the change in management brought natural and social scientific worlds closer together, and closer to the water managers and stakeholders. Water managers have used the word tool in a broad sense for anything supporting an operational action (e.g. a guideline, a procedure or protocol, a method or technique, a device, or a software program), and, the natural science community is slowly adopting this definition thereby remembering or accepting that the term “tool” covers much more than computer software. Clearly the common acceptance of the meaning of the word tool is an important step in integration effort of management tools (Barlebo, 2006).

According to Barlebo (2006), there are three “levels” of tools:

- Level 1 – policy/guideline tools – which identify the activities at the sub level (meta tools).
- Level 2 – activity tools – which identify specific tools (processes).
- Level 3 – specific tools (methods).

Barlebo, therefore, defined a tool as something (either tangible or intangible) used to support operational and strategic actions in performing IWRM. Meaning that a tool can be a guideline, a procedure or protocol, a method or technique, a device, an apparatus and a software program dealing with all levels in relation to transition to IWRM or a subset of levels and approaches (Barlebo, 2006). This definition accommodates both water resources and water services definition of a tool in a South African context.

2.4.2 Categorisation and Classification of Tools

The definition of a tool as given above is broad, with the intention that it should be able to embrace the different uses of the term, in different scientific and professional sub-communities dealing with IWRM. To describe this broad group of tools Barlebo categorised them according to the following criteria (Barlebo, 2006):

- Problem life cycle
- Functionality
- Included topics
- Type of a tool
- Intended users/user friendliness
- Scientific verification of tool
- Extent of current use of tool.

The result of such classification is multidimensional with each of the above criteria as an axis. It should be emphasised that although the criteria view things from different perspectives there are overlaps. A tool may be characterised by choosing several categories and more groups within each category. The different criteria are described further in the following subsections (Barlebo, 2006).

2.4.2.1 Problem life cycle

A project or planning or management process typically goes through the following phases (Barlebo, 2006):

- Problem identification (i.e. definition and formulation of problems and tasks to be

- performed)
- Designing possible measures to solve the problem, comprising
 - Data collection and conceptualisation
 - Analysis, (e.g. by use of simulation models)
 - Decision making.
- Implementation of the selected measures
- Evaluation of the extent the implemented measures solves the problem.

In a Water Framework Directive (WFD) context the above four phases for instance correspond to (Barlebo, 2006):

- Identification – assess current status, analyse preliminary gaps, set up environmental objectives and establish monitoring programmes
- Designing – set up programme of measures and develop River Basin Management Plan
- Implementation – implement the programme of measures and the River Basin Management Plan
- Evaluation – run the monitoring programme and evaluate the effects of the implemented measures.

Typically, different tools are used in different project phases, hence the use of a tool will often support a part of the water management process. The interaction between the tool usage and the management process typically involves stakeholder participatory processes (Barlebo, 2006).

2.4.2.2 **Functionality**

A tool may have a different focus or functionality. Some tools are mainly used to handle data, while others focus on developing functional relationships (model codes) and use these to explore the consequences of certain actions. Other tools focus on communication to stakeholders and support various aspects of participatory processes and others deal with evaluation of outcomes of decisions (Barlebo, 2006). Thus, categories include:

- Organise, store and view data
- Model simulations
- Communication
- Participatory processes
- Monitoring and evaluation.

2.4.2.3 **Included topics**

A tool may deal with different topics or different disciplines of importance for IWRM. These topics may be classified in one or more of the following main groups according to the disciplines for which they provide support (Barlebo, 2006):

- Surface water
- Groundwater
- Ecology
- Economic aspects
- Governance
- Uncertainty aspects.

2.4.2.4 **Type of tool**

Many different classifications of tools exist. Two examples are (Barlebo, 2006):

- A site-specific tool is set up by using a model code (a software program) and some local data. Modelling tools may be sub-classified in many different ways. Within hydrological modelling three common groups of modelling tool types are: (a) empirical models (black box); (b) lumped conceptual models (grey box); (c) distributed physically-based models (white box).
- HarmoniCOP has identified about twenty IC-tools and categorised them according to four main criteria reflecting how the WFD public participation process is organised in practise: (a) communication direction (top-down, bottom-up, bi-directional); (b) public size (small working group, general public); (c) usage purpose (management of information and knowledge, elicitation of perspectives, interaction support and simulation); and (d) phases in the Public Participation process.

These classifications are limited as they address only a part of the entire field of topics. Therefore, to give a holistic picture, tools can be classified according to their nature in the following broad groups (Barlebo, 2006):

- Guideline
- Questionnaire/checklist
- Database and GIS
- Model code with simple relations
- Model code with complex processes
- Decision support system (DSS)
- Role playing game.

It may be noted that the category “Model code with simple relations” corresponds to the black box category of hydrological models, while the “Model code with complex processes” category contains the two other of the above categories of hydrological models (Barlebo, 2006). The groups are further explained as follows:

- Guideline – a guideline is a document providing practical guidance on what to do and how to do things. It often offers explanations of why something should be done and gives sources of further information. Guidelines may be embedded in a computer environment, but most often exist in the shape of reports.
- Questionnaire/checklist – questionnaires are ways of obtaining and selecting information in accordance with user priorities. Questionnaires are often used in social science and checklists are used in all disciplines. Questionnaires and checklists may be processed electronically or on paper.
- Database and GIS – databases and Geographical Information Systems (GIS) are general-purpose systems of hardware and software used for storage, retrieval, analysis and presentation of data. GIS particularly handles geographical (spatial) data, while many other databases handle time series data and other types of data.
- Model code with simple relations – such model codes may contain relationships that are static or dynamic (time varying). A model code with simple relations could typically be statistically based equations.
- Model code with complex processes – many hydrological model codes enabling dynamic simulations of flows and water quality in a river basin are based on rather complex process descriptions.
- Decision support system (DSS) – the decision support systems developed during

recent years function as participatory tools providing a platform for dialogue and common ground.

- Role playing game – role playing games are group gaming situations in which players take on their own or other people's roles or behavioural patterns in a real or imaginary context. It works in parallel to the real world but still involves people with their own experiences, viewpoints and objectives. They often aim at supporting social learning rather than actual decision making, and are sometimes used for decision making in terms of carrying out policy analysis of test management plans.

2.4.2.5 **Intended users/user friendliness**

The required user friendliness of a tool depends on the intended users. In general, a user that has considerable knowledge and experience on the subject and knows how the tool has been developed requires less support in terms of a user friendly Graphical User Interface (GUI), users guide and written documentation. The level of required user friendliness may be classified in the following five categories (Barlebo, 2006):

- Scientists – this group often has a solid background to understand the functioning of the tool and often wants the flexibility to use the tool to non-standard functions. The requirements for user-friendly interfaces and documentation are therefore less demanding for this group than for other users.
- Professionals – (e.g. consultants or water managers using a tool to generate results). This group typically has a solid background and considerable experience in using the tool and focuses on efficiency of use both for standard and non-standard functions. This group requires user friendliness that improves the efficiency of using the tool.
- Water managers – This group typically uses a tool to make decisions and does not have as much experience in using the tool, and generally masters only standard type of functions. User friendliness with focus on ease of use is therefore essential for this group.
- Stakeholders – This group typically does not have much experience in using the tool and often does not have a scientific background to fully understand how the tool works. This group uses the tool periodically and therefore a high level of user friendliness for inexperienced users is essential.
- General public – The general public often has no scientific background to understand the functioning of the tool and has limited patience in engaging with new tools. A high level of user friendliness for first time users is therefore a prerequisite for this group to use the tool.

2.4.2.6 **Scientific verification of tool**

Generally, the scientific basis of a tool may be documented. A tool should have been tested thoroughly and its ability proven for the types of applications intended in a particular case. The scientific documentation maybe, for example, in terms of verification of the accuracy of numerical algorithms, testing a software program for bugs or testing the adequacy/appropriateness of methodologies against independent data. Classes of level of documentation may be (Barlebo, 2006):

- Not verified
- Poorly verified
- Moderately verified
- Well verified.

2.4.2.7 **Extent of current use of tool**

Generally, even scientifically well-verified tools can never be considered universally valid. In principle, it is not possible to prove universal validity, and just one case of failure may falsify the theories behind a tool. Therefore, the credibility of a tool also depends on its proven experience record of practical use. A tool with thousands of daily users obviously has higher credibility than a tool with similar stated capabilities and scientific verification but only a few users. Classes of level of documented practical use may be (Barlebo, 2006):

- Not documented
- Only used in hypothetical cases
- Used in a few case studies
- Widely used professionally.

2.4.3 **Integrated Water Management Tools**

According to Blind (2004), effective water and land management involves consideration of complex, interacting processes, and often, competing goals. In particular, trade-offs between economic, social and environmental outcomes must be considered to improve the sustainability of water resources. These types of complex interactions lend themselves to analysis by modelling approaches, with integrated tools required to describe the links between economic, social and environmental system outcomes under various management and climatic regimes (Blind, 2004).

In moving towards the collaborative planning process, diverse yet integrated tools are required (Blind, 2004). Blind notes that it is not feasible to develop a complex single system that is expected to support the entire process in water management, but a flexible framework; the number of domains to consider, the number of possible measures, and the different cultural situations, make such a system complex. In addition, the differences between basins (ecozones, population, culture, industry...), and the differences in data availability on all relevant aspects require so many different tools that a single system would not be workable, neither maintainable, as such a single system would need to contain simple and complex tools of each domain (Blind, 2004).

Therefore, the challenge is to link the right tools and data together at the right time (in the planning process). This means that at the various steps of the planning process the right tools need to be available, and it must be easy to combine these into integrated systems using an integrated framework. Adaptations (interaction of tools and systems) need to be facilitated. This results in the following ten needs for Information and communications technology (ICT) and tools' support (Blind, 2004):

1. To support linking the right tools to form integrated support systems in time, and to ease the adaptation of such systems, a standard interface is required. This standard should allow linking of models and tools without additional programming. Obviously the standard needs to be implemented, such that rapid development of integrated systems is facilitated. The standard should include the means to understand which data can be exchanged, either by providing a standard data-dictionary or self-descriptive methods (standard meta-data dictionary).
2. Tools must be adapted to the standard, such that a toolbox emerges which contains (multiple) tools for individual domains (hydrology, ecology, economy, business, institutional, etc.) in modelling. The toolbox should also include tools for multi-criteria analysis, cost effectiveness analysis, uncertainty analysis, scenario analysis,

- etc. Obviously, meta-data on, and easy access to models and of tools are required.
3. Having such a standard and toolbox the choice of the most appropriate set of tools is the next larger problem: what tool combinations are appropriate at different stages of the collaborative planning process? Guidance on tool selection and easy access to tools and systems pose major challenges. Currently an extensive overview on available tools and systems and the means to select the appropriate tools and systems is lacking. Tool selection criteria should not be limited to “content”: the quality of the software should also be seriously considered when integrating different tools and systems.
 4. Having a communication standard and being able to select the correct tools leads to the data needed to feed the tools. Databases, too, need to be able to work with the standard, since it will become increasingly important to use the same base-datasets (e.g. land use) in all tools without much effort. A common (high-level meta-) data tool is required. The link needs to be elaborated, both from the perspective of data and tools application. [Note: one should be aware that collecting the data for any type of reporting does not deliver a dataset that is sufficient for (advanced) modelling for example. Modelling will likely require much more detailed data. The problem becomes more complex in large, international river basins, with a large number of data-owning authorities. Since IWRM requires integration of many different domains, domain specific attention should be given to the data.]
 5. Following from above, multilingual support and support tools in transboundary regions will become increasingly important.
 6. Uncertainty assessment is another issue, which becomes more important in complex integrated systems. Information on uncertainty of observation data, and methodologies to assess the overall uncertainty of integrated systems need to be available. The need to include some information on uncertainty (qualitatively and quantitatively) makes the datasets more complicated. Following from this, meta-data and meta-data search tools become important to find information, to be able to query simultaneously in space and time. Data structures should be included in metadata descriptions, in order that the data can be easily accessed.
 7. With respect to data, earth observation technology could provide additional information relevant to the implementation of the IWRM. Knowledge and means to achieve this need further elaboration.
 8. Both tools and systems need to be accessible, both from the viewpoint of legal accessibility, as from the viewpoint of technical accessibility. Web based and distributed technologies may provide the means to further facilitate the IWRM implementation process.
 9. Setting-up and utilising an integrated tool/system is difficult. Methods and tools to transparently develop and use integrated systems are required. This is to make it easier on one hand, for the multidisciplinary team developing and using the system to collaborate and record their work, while on the other hand, it is to increase the trust in the results by, amongst others, the public.
 10. Concerning gaming (and related methodologies and tools) the usefulness has been demonstrated, but questions remain when to use which tools, how to use them effectively and what information needs to be incorporated. An important issue in this respect is the development of the end user interface and in particular the trade-offs between ease of use and scientific robustness, between the need to target a specific field of application and the preservation of adequate flexibility. Web-based tools may be further developed to support broad public participation.

The issues raised above are important for collaborative water management, but it is certainly not a complete list of issues (Blind, 2004).

2.4.4 Surrogate Tools

According to Meirlaen and Vanrolleghem (Undated), a problem encountered when creating an integrated system is the fact that the existing tools are quite complex and require sophisticated integration algorithms to solve them. This results in long calculation times, making these tools impractical to use, especially within optimisation problems where a number simulations need to be performed. Another problem in integrated systems is that the state-of-the art tools cannot be linked easily to one another due to differences in the respective state variables. The reason for this incompatibility is that these models have been developed independently during the. Hence these complex tools need to be augmented by faster surrogate tools (Meirlaen and Vanrolleghem, Undated).

Meirlaen and Vanrolleghem (Undated) defined a surrogate tool as a procedure where the parameters of such tools are derived either from measurements or from detailed physically-based tools results. The surrogate tools act as a simplified replica of detailed physically-based tools and they are less complex and computationally less expensive when compared to the physically-based tools, but still be able to produce reasonably accurate outputs for strategic planning purposes (Meirlaen and Vanrolleghem, Undated).

Qian et al. (2006) proposed a generic two-stage approach in developing a surrogate tool **Figure 2**. Stage 1 involves designing and generating computer experiments for detailed and approximate simulations. Key to the approach is Stage 2 – a novel two-step modelling strategy. It sets this method apart from existing surrogate tool building techniques. The basic idea is to use approximate solution results to provide a base surrogate tool and adjust the model by detailed solution results. Stage 3 consists of the application part of the procedure. When a final surrogate tool is available, various further investigations, such as optimisation, sensitivity analysis, and calibration can be performed (Qian et al., 2006).

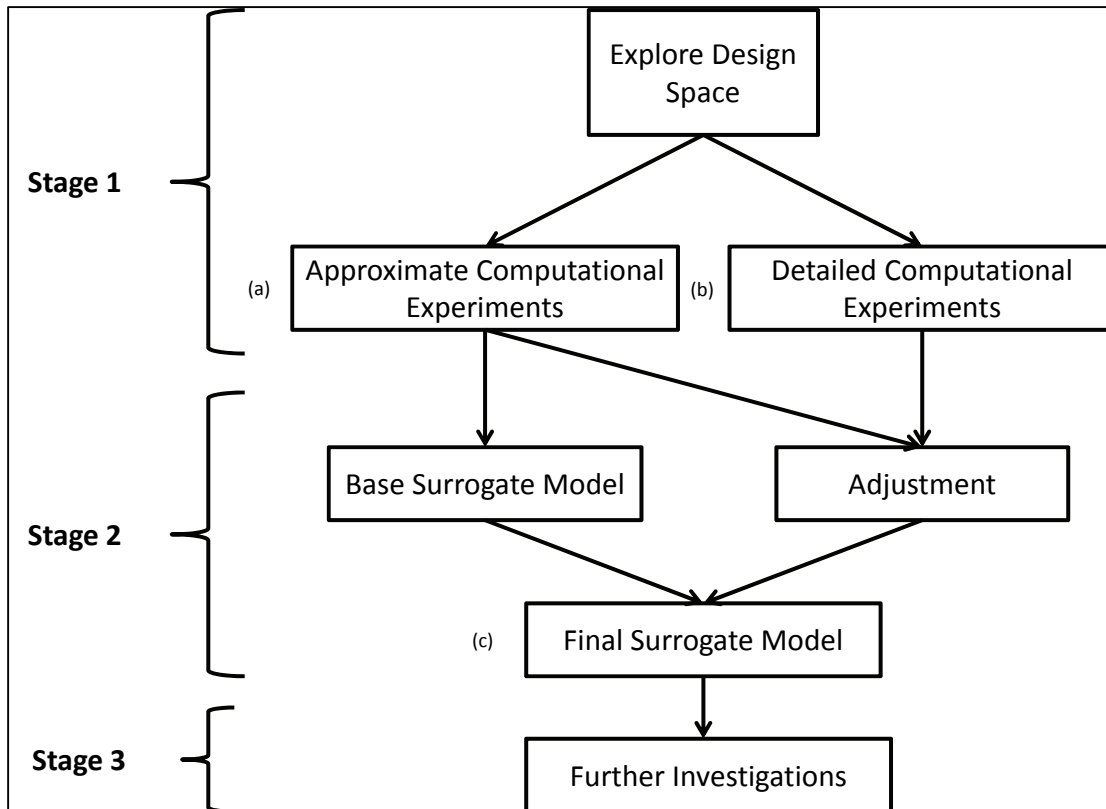


Figure 2: Approach for developing a surrogate model (Qian et al., 2006)

According to Vanclooser et al. (2002), the development of surrogate tools (Meta-Tools) from fully complex tools encompasses the following steps:

- Step 1: validate a fully spatially distributed reference tool for the considered water management process
- Step 2: perform a scenario analysis with the validated reference tool
- Step 3: define a parameter efficient tool (the meta-tool)
- Step 4: map the “complex reference tool” into the “parameter efficient lumped tool” (i.e. tool reduction).

Critical in the above mentioned procedure is the validity of the “complex reference tool”. Validation is the process of evaluating the tool to assure that the tool is an acceptable representation of the system. This evaluation comprises the comparison of resultant state variables with observations. For many processes considered in the complex reference tool, these data will not be available. In this case we need to rely on the default process descriptions and generic parameterisation without being able to verify these, which reduces compliance to any validation criterion (Vanclooser et al., 2002).

To circumvent this problem, an alternative to the above mentioned procedure could be to eliminate steps 1 and 2 (i.e. the validation and use of a complex reference tool) and directly identify tool parameters for a simple hydrological tool using the available data set (i.e. a data based hydrological modelling approach). This means that we try to model directly with a simple reference tool, a water management process using available data. If the data allows, effective parameters could be inferred for different periods or locations, allowing to map effectively, parameters in terms of catchment and scenario descriptors (i.e. by analysing sub-catchments separately or by analysing sub-periods separately) (Vanclooser et al., 2002).

2.5 Integrated Water Management

2.5.1 Overview

The imperative of integration stems from recognition of the interdependence of human and natural systems expressed in the research and policy agendas of sustainability. In the water sector such a need has been advocated for years, and the IWRM concept has been accepted as a means to realise integration (Lumbroso, 2003). However, IWRM has also received widespread critique on its underlying concepts but, particularly, on the way its implementation has progressed. Other concepts perceived to perform better than IWRM have also been proposed by others. Nevertheless, Sadoff and Muller (2009) argue that, despite the criticism, IWRM is the global good practice approach to water management: it recognises the holistic nature of the water cycle and the importance of managing trade-offs within it; it emphasises the importance of effective institutions; and it is inherently adaptive. The following sections are geared towards highlighting the principles of IWRM and the linkages to adaptive management and the water balance (trade-off) approach (Sadoff and Muller, 2009).

2.5.2 Integrated Water Resource Management Approach

IWRM is regarded as the “integrating handle” leading water management from sub-sectoral to cross-sectoral view. According to Moriarty et al. (2004), IWRM is about integrated and “joined-up” management and promoting integration across sectors, applications, groups in society and time, based upon an agreed set of principles. IWRM is a global movement driven by a perception of crisis, both current and future, underlain by a mixture of largely unavoidable development factors (population growth, increasing wealth and demand). IWRM seeks to tackle some of the root causes of the management crisis, namely the inefficiencies and conflicts that arise from un-coordinated development and use of water resources. Many of these problems and conflicts will be familiar to those working in the water services sector (i.e. groundwater management, conflict resolution, poverty reduction, pollution control, reducing health hazards, etc.) (Moriarty et al., 2004).

IWRM conceptual backbone is provided by a set of four core principles, agreed upon by the Dublin Ministerial Conference that preceded the first world summit on sustainable development in Rio de Janeiro in 1992. IWRM is therefore the water community’s contribution to the sustainable development dialogue that has been running since Rio (and before). Its principles of holism, decentralised control, and respect for the environment, are clearly recognisable as such. While the principles have been further refined and added to during subsequent conferences of the water community in the 1990s and 2000s, they remain the commonly accepted starting point for IWRM, and are set out in full as follows (Moriarty et al., 2004):

Principle No. 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment; Since water sustains both life and livelihoods, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or ground water aquifer.

Principle No. 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. The participatory

approach involves raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

Principle No. 3: Women play a central part in the provision, management and safeguarding of water. This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

Principle No. 4: Water has an economic value in all its competing uses and should be recognised as an economic good. Within this principle, it is vital to recognise the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognise the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

While the need to manage water in an integrated manner has long been recognised, IWRM is still an evolving concept, and there is no one universally agreed definition of IWRM. However, there is agreement on what IWRM should achieve and a great deal of common ground in most definitions. It is important to note that IWRM is not an end in itself, but rather a means to an end, and the following are some of the definitions in existence (Moriarty et al., 2004):

- IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.
- IWRM is a process of assignment of functions to water systems, the setting of norms, enforcement (policing) and management. It includes gathering information, analysis of physical and socioeconomic processes, weighing of interests and decision making related to availability, development and use of water resources
- IWRM involves the coordinated planning and management of land, water and other environmental resources for their equitable, efficient and sustainable use
- IWRM expresses the idea that water resources should be managed in a holistic way, coordinating and integrating all aspects and functions of water extraction, water control and water-related service delivery so as to bring sustainable and equitable benefit to all those dependent on the resource.

According to Moriarty et al. (2004), there are three key concepts which in one form or another are present in all definitions of IWRM (i.e. equity, efficiency and sustainability). Therefore, in summary, IWRM aims:

- To promote more equitable access to water resources and the benefits that are derived from water in order to tackle poverty
- To ensure that scarce water is used efficiently and for the greatest benefit of the greatest number of people
- To achieve more efficient utilisation of water, including for a sustainable environment.

A fourth key concept is that of process. IWRM is a process of moving from some existing state to some envisaged and preferred future state, by achieving commonly agreed principles or best practice in managing water through the involvement of all relevant stakeholders (Moriarty et al., 2004).

Moriarty et al. (2004) sum up IWRM as, at its heart, nothing more than the process of implementing the Dublin principles. It is about: people (professionals and users) talking to each other more; about joint planning activities across sectoral boundaries; about integrated planning at the basin, but also at the community level. Critically, IWRM is: about information and communication; about good planning based on a sound and broadly rooted understanding of people's wants and needs; and also, about their abilities and the constraints imposed by working with a finite resource (Moriarty et al., 2004).

The IWRM paradigm is widely accepted as conventional wisdom, and the principles have been widely accepted [see for example (Solanes and Gonzalez-Villarreal, 1999) who track the inclusion of the Dublin principles in national water legislation] with few but important exceptions, such as widespread debate on the "water as an economic good" principle. While widely recognised as "a good idea", practical implementation of IWRM, and mainstreaming the IWRM principles into worldwide water management practice still requires a massive international effort ranging from reforms of water management laws, institutions and regulatory systems, management tools to capacity building at a whole range of levels, and this effort has hardly begun (Moriarty et al., 2004).

Implementing IWRM can often seem daunting given the scale and complexity of the changes needed to fully implement it. However, this is where the importance of understanding IWRM as a process comes in. Any improvement in coordination or planning of water resource development represents a step in the process, and in many cases local level agreement and capacity-building on better sharing and use will have greater impact than new national laws or international level treaties (Moriarty et al., 2004).

Moriarty et al. (2004) go further to warn that IWRM must not (especially in the context of developing nations) be viewed as a body of complex legislation, or an expert control system in which, to be effective, all aspects of water resources supply and use are integrated into a complex centralised system under the control of one "super-agency". The process vision sees IWRM as a way of thinking (or a paradigm), where instead of attempting to control all aspects of water management through one system, the task is to help many different water managers to understand and take account of the wider implications of their actions and to collaborate more effectively (Moriarty et al., 2004).

A critically important element of IWRM is the integration of various sectoral views and interests in the development and implementation of the IWRM framework, as illustrated in **Figure 3**. Therefore, integration should take place within:

- The natural system, with its critical importance for resource availability and quality
- The human system, which fundamentally determines the resource use, waste production and pollution of the resource, and which must also set the development priorities and control associated infrastructure.

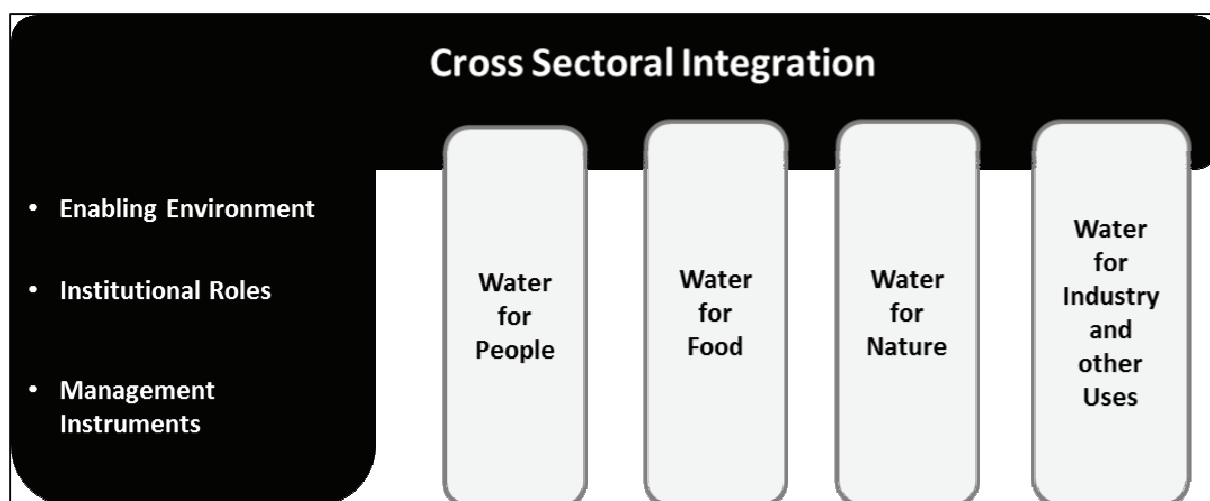


Figure 3: Cross sectoral integration (GWP, 2000)

Integration within the natural system concerns, for instance, the integration of land and water management, surface and groundwater, upstream and downstream water related interests recognising the full hydrologic cycle. Integration within the human system relates in particular to cross-sectoral integration of policies and strategies and integration of all relevant stakeholders in the decision-making processes. To secure the co-ordination of water management efforts across water related sectors, and throughout entire water basins, formal mechanisms and means of cooperation and information exchange need to be established. Such coordination mechanisms should be created at the highest political level and put in place in all relevant levels of water management (Moriarty et al., 2004).

There are three key elements contributing to IWRM in seeking balances between efficiency, equity and environmental sustainability, and these are the Enabling Environment, Institutional Environment and Management Tools which can be depicted as in **Figure 4**. Where:

- The enabling environment is the general framework of national policies, legislation and regulations and information for water resources management stakeholders
- The institutional roles and functions of the various administrative levels and stakeholders
- The management tools, including operational instruments for effective regulation, monitoring and enforcement that enable the decision-makers to make informed choices between alternative actions. These choices need to be based on agreed policies, available resources, environmental impacts and the social and economic consequences.

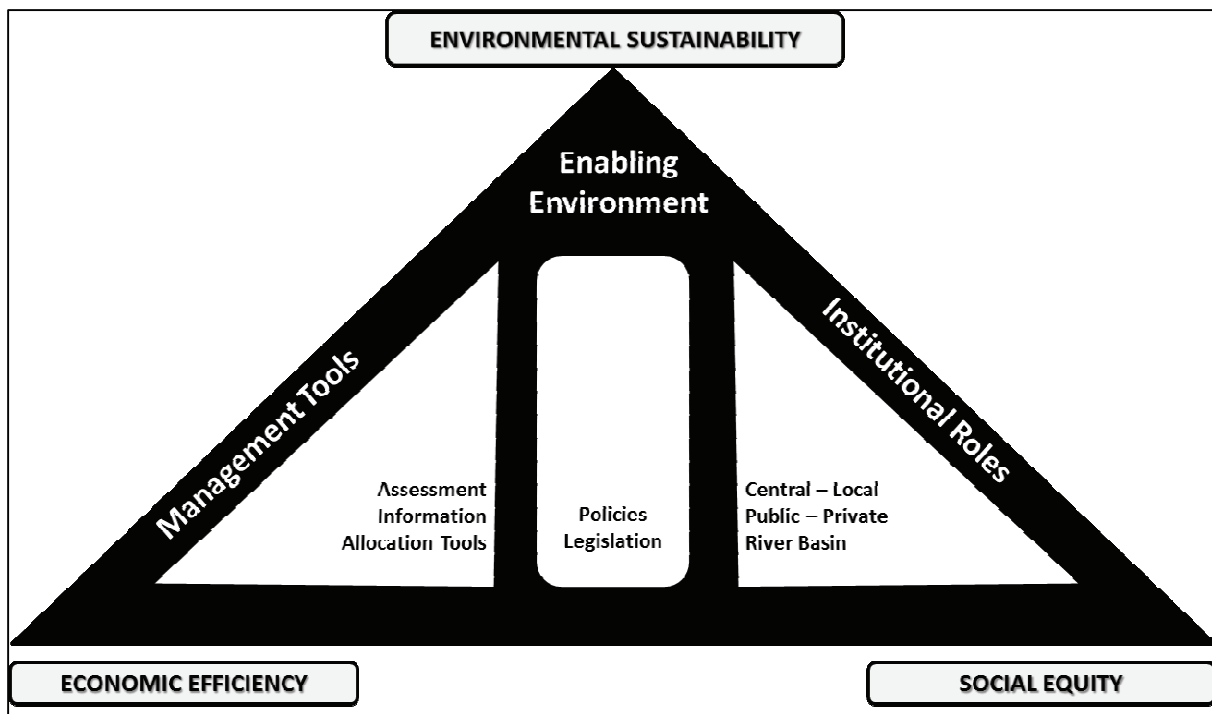


Figure 4: IWRM elements (GWP, 2000)

According to Moriarty et al. (2004), implementing an IWRM process is in fact a question of getting the three pillars right: moving towards an enabling environment of appropriate policies, strategies and legislation for sustainable water resources development and management; putting in place the institutional framework through which the policies, strategies and legislation can be implemented; and setting up the management tools required by these institutions to do their job (Moriarty et al., 2004).

A ToolBox on IWRM has been developed by GWP to elaborate on this framework and illustrates the concepts and useful approaches through specific tools (good practices) as well as relevant references and case studies of IWRM experience. These key elements consist of sub-elements that need to be considered when implement IWRM as follows (Moriarty et al., 2004):

A. Enabling environment

- A1. Policies – setting goals for water use, protection and conservation
- A2. Legislative framework – water policy translated into law
- A3. Financing and incentive structures – financial resources to meet water needs.

B. Institutional environment

- B1. Creating an organisational framework – forms and functions
- B2. Building institutional capacity – developing human resources

C. Management Tools

- C1. Water resources assessment – understanding resources and needs
- C2. Plans for IWRM – combining development options, resource use and human interaction
- C3. Efficiency in water use – managing demand and supply
- C4. Social change instruments – encouraging a water-oriented society
- C5. Conflict resolution – managing disputes, ensuring sharing of water
- C6. Regulatory instruments – allocation and water use limits
- C7. Economic instruments – using value and prices for efficiency and equity

C8. Information exchange – sharing knowledge for better water management.

According to Moriarty et al. (2004), the evolution to IWRM can be regarded as having five stages which occur along an uninterrupted pathway and overlap considerably as depicted in **Figure 5**.

While there are many different views of the IWRM concept, it will be crucial to come to a more holistic view and understanding of the IWRM concept in order to reach an effective translation of IWRM into operational reality, and to this end IWRM is seen as a progressive way of thinking in managing water, therefore IWRM cannot be seen as an end in itself, but rather a means to an end (Moriarty et al., 2004). In the case of South Africa, that end is defined in the policy and legislation as being the equitable, efficient and sustainable use of water and the beneficial use of water in the public interest.

Water Management: Phases of Development	Dates	Conferences
1. The Sectoral Approach ↓	1820 to 1950s	
2. The cooperative Approach ↓	1960s TO 1970s	
3. IWRM – Management oriented ↓	1980s	Mar del Plata (UN,1977)
4. IWRM Goal oriented ↓	1990s	
5. Capacity building for IWRM	2000+	New Delhi Meeting (1990) Dublin Meeting (1992) Rio de Janeiro (UNDP, 1992) Ministerial in Nordwijk (1994) Johannesburg (2003)

Figure 5: Evolution of IWRM (UN WVLN, Undated)

2.5.3 Adaptive Water Management Approach

Water management is facing major challenges due to increasing uncertainties caused by climate and global change and by fast changing socio-economic boundary conditions. To deal with these challenges, IWRM must be able to respond to changes in the natural and social environment and to anticipate the uncertainties associated with these changes. The current IWRM concept as defined in the section above does not elaborate on water management under uncertainty, nor does it include approaches and methods towards adaptive water management strategies. Hence, adaptive management is advocated as a timely extension of IWRM to cope with these challenges. Adaptive management aims at increasing the adaptive capacity of river basins based on a profound understanding of key factors that determine a basin's vulnerability (Pahl-Wostl et al., 2005).

According to Pahl-Wostl et al. (2005), the idea of adaptive management has been introduced

in resources management for quite some time. It is based on the insight that the ability to predict future key drivers, as well as system behaviour and responses, is inherently limited. Adaptive management can more generally be defined as a systematic process for continually improving management policies and practices by learning from the outcomes of implemented management strategies. The most effective form of adaptive management employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed. Pahl-Wostl et al. (2005) also propose that adaptive management has yet another target: to increase the adaptive capacity of the (water) system. It aims at integrated system design. The problem to be tackled is to increase the ability of the whole system to respond to change rather than reacting to undesirable impacts of change. Hence, it is a pro-active management style.

Integration across sectors and different levels of the system helps to avoid fragmented management and misunderstandings. When information about system responses to interventions is available, the management system will be able to adapt and respond more effectively to unforeseen changes. As pointed out by Holling (1978), the result of non-adaptive management is that the whole system, over time, can become less resilient and more vulnerable to disturbances and change (Holling, 1978). There is therefore, a need to improve our understanding of the transition of current water management regimes to adaptive water management. The leading edge of innovation points toward transition, but requires rigorous science/policy processes to bridge the many barriers that have fragmented our thinking and practices in water management. The transition to more adaptive management is part of the soft path advocated to build greater flexibility in water management regimes to address the rising uncertainty from global change.

The central tenet of our argumentation concerns the transition from currently prevailing regimes of water management into more adaptive regimes in the future. This transition, in general, calls for a highly integrated water resources management concept. **Figure 6** represents essential elements of this transition. It compares the prevailing management regime with an adaptive regime and key areas of policy oriented research required to understand the transition process. The integration of these key areas will be essential for success.

	PrevailingRegime	Transition to Adaptive management	Adaptive Regime
Governance	Centralised hierarchical, narrow stakeholder participation	Enhance governance with stakeholder processes integrated with policy and science →	Polycentric, horizontal, broad stakeholder participation
Sectoral Integration	Sectors separately analysed resulting in policy and chronic problems	Build adaptive capacity to reduce vulnerability → Integrate IWRM with spatial planning →	Cross-sectoral analysis identifies emergent problems and integrates policy implementation
Scale of Analysis and Operation	Transboundary problems emerge when river sub-basins are exclusive scale of analysis and management	Resolve resource use conflicts → Address poverty, health, gender issues →	Transboundary issues addresses by multiples scales of analysis and management
Information Management	Understanding fragmented by gaps and lacking of integration of information	Create and adapt transboundary institutions to driving forces and pressure →	Comprehensive understanding achieved by open, shared information sources that fill gaps and facilitate intergration
Infrastructure	Massive, centralised infrastructure, single sources of design, power, delivery	Test and incorporate novel monitoring system into decision making processes → Test and apply innovative methods and technologies for river basin buffering capacity →	Appropriate scale, decentralised, diverse sources of design power, delivery
Finances and Risks	Financial resources concentrated in structural protection (Stunk costs)	Investigate management of risks to identify innovative approaches in the financial sector →	Financial resources diversified using a broad set of private and public financial instruments

Figure 6: Transition an adaptive management regime (Pahl-Wostl et al., 2005)

To summarise, strategic policy in the water sector has developed from supply oriented through demand oriented to integrated approaches in the past. Although IWRM as an abstract model has been widely accepted as the appropriate framework to deal with complex water resources management issues, its principles have not been elaborating on management under uncertainty, nor did they specifically articulate adaptive capacity as a significant feature of water management strategies. Adaptive Management (AM), as a concept, has been designed to support managers in dealing with uncertainties. In relation to the water sector, AM is considered an approach that could improve the conceptual and methodological base and promote realisation of the goals of IWRM (Medema and Jeffrey, 2005). However, AM is not advocated as a type of ideology, but a complementary to IWRM.

2.5.4 The Water Balance Approach

Integrated hydrologic and economic optimisation models at the basin scale provide a framework for policy design, implementation, and evaluation in water-stressed basins. Despite the considerable potential that basin scale analysis offers, few basin-wide studies have examined trade-offs among efficiency, equity, and sustainability when analysing the design of water resource programs (Ward and Pulido-velázquez, 2008). Similarly, water balance has generally been used on the basis of quantity and quality, leaving out the efficiency, equity and sustainability. There is a need to ensure that a balance is achieved between the full social costs (i.e. private costs plus negative externalities) of a water-related activity and the benefits derived from that activity (Rees, 2006). This implies that the objective of a water balance is not to maximise, but a result of trade-offs.

The term “trade-offs” is central to this emerging agenda of integrated management, appearing prominently in many of the documents, speeches and presentations. This marks a significant

shift in the direction and content of water resource debates. Trade-offs has important resonance. It has both a technical and everyday common-sense meaning with positive connotations of making tough decisions in difficult circumstances through balance, reasonableness and compromise (Friend and Blake, 2009). The following subsections discuss the relationships between water and equity, efficiency and sustainability, in an attempt to define water balance in a broader context including these parameters.

2.5.4.1 **Water and Equity**

One of the aims of the NWA is to ensure greater equity in access to water, so that the benefits accruing from different water uses will be felt by a larger number of users. Equity is based on a principle of fairness that is accepted by all members of the community involved in sharing a common resource. The fairness reflects the values of the society and does not have to be based on equal share. Some people may get a larger share of water than others either due to prior rights, in compensation for more input in system construction or maintenance. It is much more difficult to define entitlement to water based on value systems than entitlement based on a principle of equal sharing because of the difficulty in accurately determining what a society considers fair (Murray-Rust et al., 2000).

According to Whiteley et al. (2008), equity is part of the tradition of common law and ideals arising from particular cases of water, deeply attached to its social and environmental setting. The principles of equity are complex and contingent on circumstances, varied and nuanced, and cannot be fully understood until put back into the life cycle of living things. Consequently, there is no simple principle or set of principles which can be implemented as rules and universally applied in all places and circumstances. Instead, equity is a complex and protean idea. Like the concept of democracy, equity is not some objective state of being, but rather an ideal, vision, or aspiration that continues to challenge citizens to strive towards achieving it in greater depth, scope, and authenticity. Justice is a broader concept than equity and embraces fairness, dignity, respect for mutual rights and obligations, and ensuring that institutional arrangements – for managing water, as for other necessities of life – nurture the full development of human capacity. Equity is a necessary condition for a just society. The search for equity requires deliberation, discourse, and inclusive argument (Whiteley et al., 2008).

Among the arguments bolstering equity in relation to water are its roots in antiquity and long-established practice. Classic philosophers concerned with establishing the conditions for a just society recognised that water is an important part of its health, defence, and beauty (Whiteley et al., 2008).

For some people in some cases, the values associated with water are intrinsic, not utilitarian. Therefore, equity requires that these values be treated even-handedly, even though equity does not allow one set of values in the abstract to trump all others. Water flows through natural and human communities in such close association that abstracting it from its setting and rationalising it by assigning a quantitative value is to do irremediable damage. In this reading of intrinsic value, humans, other living things, and water are inseparable. Ecosystem sustainability requires water for life for both human beings and animals in their natural habitat. The rights of future generations in relation to those of the present generation are clearly equity matters. Intergenerational equity may be served by providing citizens with long term scenarios and tools that project into the future trends such as climate change. Tools of likely future withdrawals from river basins measured against possible reductions in supply

may help refocus citizens towards longer term consequences of present day decisions (Whiteley et al., 2008).

Equity has emerged as one of the most pressing concerns with regard to matters of fairness and sustainability in water allocation. Lack of equity in current water resource management frameworks has contributed to significant conflicts and left many people disempowered and even denied their most basic human rights and freedoms (Lacey, 2008).

To completely assess the diversity of human experience and the impacts that need to be considered, there must be an inclusion of the social, political and institutional arrangements that also impact on our decisions about water. There is a need to recognise a broader range of values such as equity, justice and fairness as a way of responding to and balancing out the dominant focus on efficiency and markets. This is not to say that economic efficiency should have no place in discussions of water management; rather it is but one metric in the broader water management debate (Lacey, 2008).

The act of understanding and embedding the broader range of values in debates about water management provides a realistic and more comprehensive alternative to utilitarian focused frameworks. Equity considerations calls for the recognition of the complexity and diversity of realities and values surrounding water, including how the socio-political processes may even contribute to water scarcity and inequity. Preserving equity in the social governance systems also requires human involvement in those systems. Citizen participation in water management decisions and instituting basic entitlements or rights to water are just two mechanisms for addressing the social exclusion and scarcity that is created when people are denied access to such social and political processes (Lacey, 2008).

South Africa faces significant inequities in the allocation of water for productive purposes. Water allocation is one component of a wider government mandate to address the inequities of the past. Water allocation reform is being implemented by the DWA, through the Water Allocation Reform programme (Anderson et al., 2008). Anderson et al. (2008) proposed an approach for determining indicators that can be used to monitor targets for Water Allocation Reform and for prioritising areas for specific Water Allocation Reform interventions. The inclusion of equity when designing water programs is particularly important in South Africa, which is still facing significant inequalities in access to and use of water.

2.5.4.2 Water and Sustainability

According to Milman and Short (2008), sustainability has become a guiding principle and goal for human and economic development over the past two decades. Though there is no consensus on the precise definition of sustainability, it is widely agreed that any conception of sustainability must account for the interconnections of environmental, economic, and social factors; consider both the local and global resource base; and be attentive to the long-term needs of future generations. Efforts to define, quantify, and measure progress towards sustainability have led to the development of a variety of indicators that monitor these aspects of sustainability at multiple scales. Indicators of sustainability have the potential to help organisations and governmental institutions track progress towards or away from sustainability, and to set policies that will aid progress, thereby transforming the abstract concept of sustainability into an actionable objective (Milman and Short, 2008; McKenzie et al., 2002)

The concept of sustainable development is based on the observation that economy, environment and well-being can no longer be separated. The definition of sustainable development is often quoted from the World Commission on Environment and Development as “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs”. The fundamental principle behind this definition is to accept that all human individuals have equal rights, whether living today or in future. This sketches a concept, rather than giving a rigid rule, that can be applied right away (Balkema et al., 2002).

Therefore, sustainability can and will be interpreted differently by different people, evoking the critique that the term sustainability could mean almost anything. However, the room left for interpretation proves to be valuable as ideas about sustainability are destined to be discussed over time and place, since different generations will have to deal with different problems and different cultures, and local circumstances will give different perspectives on these problems. According to Balkema et al. (2002), the multi-dimensional character of sustainability is view fundamental, and they defined three dimensions, namely economic, environmental, and social-cultural as follows (Balkema et al., 2002):

Economic sustainability – this implies paying for itself, with costs not exceeding benefits. Mainly focussing on increasing human well-being, through optimal allocation and distribution of scarce resources, to meet and satisfy human needs. This approach should, in principle, include all resources: also those associated with social and environmental values (e.g. in environmental economics). However, in practice most analyses include only the financial costs and benefits.

Environmental sustainability – meaning the long-term viability of the natural environment should be maintained to support long-term development by supplying resources and taking up emissions. This should result in protection and efficient utilisation of environmental resources. Environmental sustainability refers to the ability of the functions of the environment to sustain the human ways of life. The latter mainly depends upon the ethical basis: to what extent should policies be anthropocentric and to what extent does nature have endogenous qualities. Although public opinion goes further, public policies mainly remain limited to so-called use-values, which can be incorporated in economic analysis relatively easily.

Social-cultural sustainability – the objective of which is to secure people’s social-cultural and spiritual needs in an equitable way, with stability in human morality, relationships, and institutions. This dimension builds upon human relations, the need for people to interact, to develop themselves, and to organise their society. Sustainable development is seen as an interaction between three systems: biological, economical, and social, with the goal to optimise across these systems by taking into account the trade-offs. The difficulty to express and weigh these trade-offs suggests that the optimisation is a political process rather than a scientific one. This is in line with the vision of the Scientific Council for Governmental Policies. The basic philosophy of this council is that when implementing the concept of sustainability, one cannot ignore the uncertainties and the mutual dependencies between the environment and the society. The forthcoming risks for the environment and for the economy will have to be balanced.

In general, the purpose of IWRM is to achieve ecological sustainability. In other words, current water use should be managed in a way that does not prevent future generations from obtaining the same quality of life from the same resource. This is accomplished by achieving

an appropriate balance between using the water for livelihoods and conserving the resource to sustain its functions and characteristics (Placht, 2008).

Anderson et al. (2008) developed a sustainability indicator for the South Africa situation. The indicator developed reflects whether there is enough unallocated water available to meet the requirements of the ecological reserve. The purpose of this indicator is to give an indication of the level of compliance with the reserve, given the current allocation of water in a catchment. A comparatively high indicator is interpreted as having enough water available to meet the requirements of the reserve once it is implemented (Anderson et al., 2008).

2.5.4.3 **Water and Efficiency**

Efficiency in water use is a core tenet of IWRM. Because of the increasing scarcity of financial resources, the finite and vulnerable nature of water as a resource, and the increasing demands upon it, must be used with maximum possible efficiency. The World Summit on Sustainable Development (WSSD) highlights two main aspects of efficiency in water use, technical efficiency and allocation efficiency. Improved efficiency necessitates user efficiency, supply efficiency, and recycling. This is achieved, in part, by economic efficiency, which includes using tools such as water pricing and tariffs, the introduction of appropriate incentives and subsidies, and realistic cost-benefit analyses. However, efficiency in the IWRM context must also consider the social and environmental value of water. (GWP, 2002; Smits and Butterworth, 2005).

Improving water efficiency allows countries to reduce water scarcity and maximise the benefits provided by existing water infrastructure. It also frees up water for other uses and reduces environmental degradation. Efforts to improve water efficiency can therefore contribute directly to the development goals of many countries, especially those that are chronically short of water or the capital to invest in water development. In 2002, the need to improve water efficiency was recognised and given new impetus by the (WSSD). Article 26 of the WSSD Plan of Implementation, which sets an action target for the preparation of “IWRM and water efficiency plans” by 2005, makes reference to water efficiency in two different ways (GWP, 2002; Smits and Butterworth, 2005):

- Art. 26 (a): “... introduce measures to improve the efficiency of water infrastructure to reduce losses and increase recycling of water”
- Art. 26 (c): “Improve the efficient use of water resources and promote their allocation among competing uses in a way that gives priority to the satisfaction of basic human needs and balances the requirements of preserving or restoring ecosystems and their functions, in particular in fragile environments, with human domestic, industrial and agriculture needs, including safeguarding drinking water quality”.

Improving efficiency has multiple aspects. It entails finding ways to maximise the value of water use and allocation decisions within and between sectors for sustainable social and economic development. It involves getting the most not only out of scarce water resources but also out of other natural, human and financial resources. It relates not only to the efficiency with which water is used, but the efficiency with which it is managed, (i.e. the efficiency of the processes that go into providing water when, where and in the appropriate quantity and quality needed for a particular use). All this emphasises the need for a multi-faceted approach that considers wider social issues and values as well as physical and technical concerns. Such an approach should be based on four key inter-related concepts: (a) technical efficiency, (a) productive efficiency, (c) product choice efficiency and (d) allocative

efficiency. All four are useful in different contexts and are best viewed as different parts of an integrated whole (GWP, 2002; Smits and Butterworth, 2005):

1. Technical efficiency – is the production of as much physical output as possible given a particular level of physical inputs. Engineers were probably the first to use this concept, and for them it implies producing a product using the smallest amounts of inputs possible, such as materials and energy. The concept of technical efficiency is relevant both to water as an output, when producing usable water supplies (through reservoir construction, water transfers, etc.), and to the use of water as an input, in agriculture, industry and households. When dealing with the use of water as an input, “technical efficiency” is referred to as water-use efficiency.

Achieving this requires measures such as recycling and reusing water, improving user practices, and ensuring that water infrastructure functions efficiently. Given the high proportion of water used by the agricultural sector in many countries, the gains from improving water-use efficiency are likely to be greatest in that sector. Though analysis and decision-making to address water-use efficiency can occur at different levels, they usually occur at a rather local level – when considering the efficiency of a particular irrigation system, for example. However, interventions to improve technical efficiency should also be considered in the context of the water basin as a whole, in order to take into account the water recycling and reuse that occur within hydrological systems (GWP, 2002).

2. Productive efficiency – is an economic concept which deals with the need to maximise the value of an output in relation to a specific level of inputs. If a given level of output is produced using least cost methods of production, then the enterprise demonstrates productive efficiency. So, productive efficiency is similar to technical efficiency, except that technical efficiency is concerned with physical production in relation to inputs and outputs, while productive efficiency measures inputs and outputs in terms of their value. Despite the fact that technical and productive efficiency are similar concepts, their policy and planning implications can be very different. For example, using a technical efficiency framework to examine an urban system with 40% Unaccounted-For Water (UFW,) might suggest more effective strategies for reducing UFW such that the maximum number of households could be served given the input of a particular volume of raw water at the system intake. An (economic) productive efficiency framework, however, would lead us to reduce UFW only to the extent that the benefits of doing so (through increased revenue, public health improvements, etc.) exceeded the costs of achieving that reduction (GWP, 2002).

Productive efficiency, like technical efficiency, is relevant both to the production of usable water supplies and to the use of water as an input. Efficiency in the production of usable water is important, given the opportunity costs involved in foregone investments elsewhere in the economy. For example, this might mean making use of natural aquifers rather than building surface storage to store and supply water of appropriate quality when and where it is needed. When water is an input, improving productive efficiency could mean increasing output or producing a higher value output while using the same or a lesser amount of water, for example, “more crop per drop”. Again, analyses and decision-making concerned with productive efficiency in water use are typically carried out at the local level. But, again, a broader view is needed in order to determine whether or not production is actually efficient. This is

because when water is used for specific purposes such as irrigation or municipal water supply, only part of it is actually consumed. The rest remains in the hydrological system and is, in most cases, available for reuse or recycling. Importantly, as this water is recycled through the hydrological system, its efficiency of use increases (GWP, 2002).

Thus, while all parts of a system may display low levels of water use efficiency individually, the system as a whole might be operating at a high level of efficiency. Importantly, efforts to minimise the amount of water used to produce certain goods or services must take into account issues of environmental sustainability and social equity. But doing this is not always easy, because using water-saving options in one location can adversely affect users in other areas. For example, if a change in a production process leads to less water being available for groundwater recharge, groundwater users may find their water supply declining. The whole issue can be made more difficult by the fact that people do not always agree upon what the output is, even within a given system. Outputs related to hygiene, sanitation and recreation, for example, are difficult to define and make efficiency hard to assess. So, like inputs, water-related outputs must be considered in social and environmental terms as well as in economical terms.

3. Product-choice efficiency – means ensuring that goods and services reflect consumers' preferences and their ability or willingness to pay. In market situations, product-choice efficiency tends to assert itself automatically. However, this almost never happens in the water sector. Instead, users generally get the quality of service and the type of water infrastructure that water-sector professionals decide are appropriate. This leads to distortions, such as the provision of a high-quality service to a small number of users. Ways of overcoming this include widening the range of service and technology options available to users and ensuring that users participate in any decision making related to such options (GWP, 2002).
4. Allocative efficiency – is an economic concept that relates to the distribution of factors of production (i.e. the resources used to produce particular goods and services) and to the distribution of the goods and services produced within an economy. From a water perspective, the concept covers the allocation of the resources needed for the production of water products and services (including services to the environment). It also relates to the allocation of the available water resources among competing uses such as agriculture, domestic and industrial water supply, and ecosystem use. In both cases the allocation is efficient when the net benefits gained from the use of water (and other resources) in these various ways are maximised. More generally, allocative efficiency is the efficiency with which a country allocates water and related resources to achieve its sustainable development goals. Typically, decision-making and actions related to allocative efficiency occur at the regional or national level (GWP, 2002).

Allocative efficiency can be achieved through a range of measures that ensure that water is allocated to the highest value uses, as well as through rigorous cost-benefit assessments. Importantly, when determining what the highest value uses actually are, social and environmental as well as economic concerns must be taken into account. Likewise, costs and benefits need to be assessed in social, environmental, and economic terms. Improving allocative efficiency therefore means examining how water can best be allocated, and used to achieve in a balanced way, a multitude of

society's goals. For example, if reducing poverty is an important goal, decision makers need to ask which water policy and allocation measures would contribute most to achieving that target. In sum, therefore, technical, productive, product-choice and allocative efficiency, though distinct concepts (see Box), are significantly inter-related. All require that social and environmental, as well as the economic value of water be recognised. Each concept also has a role to play in ensuring that water is produced, used and allocated in ways that strike the best balance — in terms of the goals of economic efficiency, environmental sustainability, and social equity (GWP, 2002).

Anderson et al. (2008) developed an efficiency indicator for the South Africa situation. The efficiency indicator monitors how many jobs and the GDP are created within a specific WMA. However, the indicator does not consider the benefits of small-scale water use as a contributor to poverty alleviation and micro-enterprise activities. This is mainly due to the data only reflecting large-scale commercial use.

2.5.4.4 **The Balancing Act**

According to Pollard and Du Toit (2008), the cornerstones of the NWA that set the strategic direction for IWRM in South Africa are efficiency, equity and sustainability. The strategic path to achieving efficiency, equity and sustainability lies not in one sub-strategy alone but in the expression of these as cross-cutting and interrelated themes. This is consistent with managing complex systems where outcomes reflect the consequences of multiple factors, and moreover, because they are not entirely independent of each other or predictable, there is a need to adapt while learning. Both of these principles rely on the whole – the collective effort of all the different sub-strategies – rather than simply on a single strategy. For example, it is easy but naïve to assume that equity will be achieved through compulsory licensing or water allocation reform alone. Similarly, sustainability cannot be achieved simply through the development of a reserve determination or the determination of a class, but must be addressed through the synergies of various sub-strategies (Pollard and Du Toit, 2008).

What is therefore required is the vision, to address both principles through the creation of a desired long-term view for the water resources that captures the idea of sustainable development, efficiency and equity. Hence the assessment of the current and future situation must take into consideration the Drivers Pressures States Impacts Response (DPSIR) indicators of the catchment in question in light of sustainability, efficiency and equity, by asking – “is this an optimal representative situation?” – then plan accordingly. The assessment clearly calls for a holistic approach, while striking a balance between the goals of equity, sustainability and efficiency. The basis for equity is, in essence, provided by the situation assessment and visioning. The former requires an assessment based on criteria pertaining to equity; the latter requires a vision that talks to equity, redress and transformation. Additionally, the ideal of securing water for basic human needs is provided for by the Basic Human Needs Reserve that is part of resource directed measures. While the principle of equity aims to adjust the imbalances and inequities of decades of skewed water access, it is unlikely to adequately emphasise the need to provide water for the most vulnerable groups in society (Pollard and Du Toit, 2008).

2.5.5 Integration and Frameworks Approach

HarmonIT in their research (HarmonIT, 2002) have observed a move towards frameworks where legacy tools (i.e. hydrological, hydrodynamic, ecological models, etc.) may be linked under a common framework, while the legacy models still run as if on their own, but their results are analysed and processed and visualised using tools that are part of a framework. Legacy tools can be brought into a common environment, which should facilitate their use. Depending on the pre- and post-processing and the visualisation tools, the tools may need reprogramming or at least being “wrapped” so that they fit into the framework. Tools linked under a common framework may also have access to common data. However, the domain tools remain functionally separate in this type of environment. Linking tools in a common framework has obvious advantages for the user, in that all processing tools are available and accessible and the results can be processed and visualised in a systematic and consistent way (HarmonIT, 2002).

Data commonly used by different tools (e.g. cross-sections) can be managed more easily and more consistently, and any changes made to the database are implemented equally in different tools (HarmonIT, 2002).

Integrated tools are a collection of tools that have been combined in order to represent a specific system or set of physical domains; that frameworks are generally open collections of “tools/integrated tools” that leave some choice with the end user as to which “tools/integrated tools” to be used; and that “generic frameworks” are open frameworks for linking integrated tools and/or frameworks focusing on generic linkages and functional modularity. The objective of integrated tools is usually to provide a new tool, whereas the objective of a framework is to provide a mechanism (or tool) by which existing tools can be linked or organised in a consistent manner (HarmonIT, 2002).

To date there are no generic frameworks which have received wide acceptance and uptake, with open access to the framework components. Several initiatives have delivered or are developing tools frameworks but, in general, most of these frameworks exist because that is what the end-users need in order to solve a particular problem. However, these ad hoc frameworks tend to be built from component tools that do not necessarily combine well especially when confronted with the need to transform to a more adaptive regime (Barlebo, 2006).

According to Barlebo (2006), to deal with the new complexities, IWRM must be able to respond to changes in the natural and social environment and to anticipate uncertainties associated with these changes. The use and application of an integrated framework will depend upon the practical needs of targeted end users. The range of tools in any framework will be various, ranging from survey procedures through guidance documents to software as already mentioned in a definition of a tool. Tools can range from complex deterministic models and decision-support systems, to role-playing games and simple textual guidance documents.

As expressed by Barlebo (2006), the Key elements of an integrated framework (see **Figure 7**) include:

- Integration of guidance, tools and systems across different sectors or fields of expertise
- Levels of assessment based on spatial scale and the level of decision making.

- An understanding and application of policy and management cycles over different times-scales. In particular, the continual process of monitoring and improving of water management
- Clear recognition and understanding of key issues such as risks and uncertainty
- Stakeholder engagement at all levels and stages of water management
- Tools to support all aspects of IWRM including guidance, decision support systems and tools.

Assuming that a range of appropriate tools are available for the main elements shown above, then at the highest and simplest level, such an integrated framework needs to fulfil the following requirements:

- Combine or present the various tools as a sensible and useful single resource.
- Provide some form of decision support or expert system that provides the manager with guidance and advice on how to best use the tools.
- Include guidance and structures for the effective management of data/information (in terms of both, how the information should be stored and its movement between the different tools).

An integrated framework need not be a rigid or highly formal structure. In fact a framework should be like a loose wrapper which ensures consistency both in the tools themselves and in their use, and delivers greater utility and value than the simple sum of the constituent parts. Such a loose wrapping (perhaps package is a better word) is also fundamental to the use in an IWRM framework, where flexible development and adaptation of tools, paradigms and approaches is the key driver. A useable framework is likely to be one that allows the component tools and methods to fit together well (Barlebo, 2006).

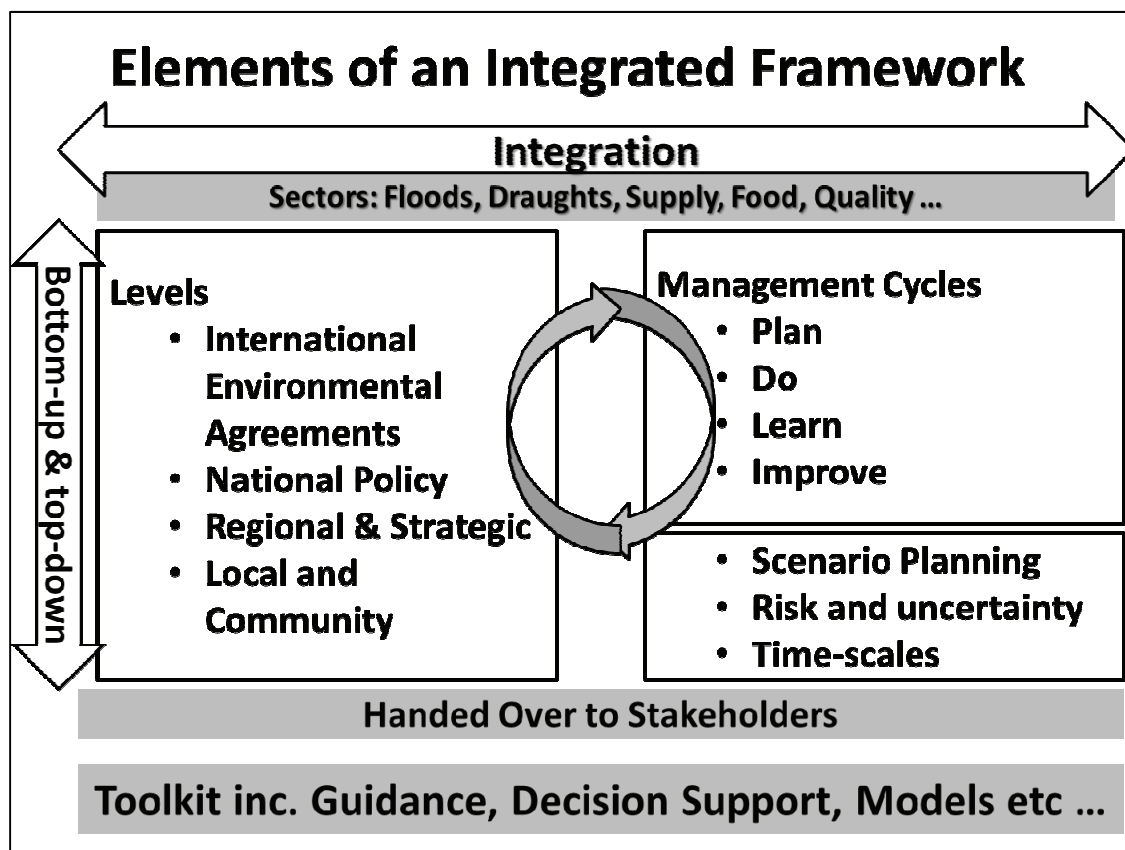


Figure 7: Elements of integrated framework (Barlebo, 2006)

It is clear from the above discussion that there are many issues that need to be addressed, covering technical, business/institutional and social functions, when establishing an effective generic framework for IWRM. These include (Barlebo, 2006):

- Technical functions – hydropower, water supply and quality
- Business/institutional functions – legal, social, organisational structures
- Multi-disciplines within the above activities
- Feedback loops and process links between all of the above
- Vast quantities of information that need to be classified, structured, and managed effectively
- Developing best practice from existing and envisaged working practices.

Given such complexity, there is clearly a need for an organisational structure or framework, which can be developed and adapted according to the needs/characteristics of individual areas or systems, instead of trying to impose a single model framework that is inappropriate for all cases. Some of the issues that need to be addressed include (Barlebo, 2006):

- Selection of required/appropriate topic/activity areas
- Data/information management
- DSS and expert systems
- Linkage of existing tools/systems.

In a South African context, the NWA calls for the equitable, efficient and sustainable allocation of water resources. This will require decision support at temporal and spatial scales appropriate to the demands of the NWA and which utilises state-of-the-art hydrological, social, economic and environmental needs. In South Africa a number of tools and frameworks have been developed mainly to deal with particular issues either in water resources or water services: (i.e. Water Services Reference Framework, Water Resource Information Management System (WRIMS), Hydrological Decision Support Framework, Framework for National Sanitation Strategy, to mention a few). This type of piece by piece development has made it difficult for DWA to communicate coherent message to other spheres of government and therefore hindered proper practice of IWRM (Burke, 2006).

Internationally there has been a move to develop frameworks and it is clear that whatever tools are developed to assist in the understanding and management of water, some framework will be needed to bring them into a coherent, consistent and useful whole. At present most strategic tools are aimed at water resource planners and operational tools are aimed at water managers. The integrated approach occurs at these levels through the use of a variety of tools and methods. Such integration though is often locally based and heavily dependent upon addressing a particular problem and a set of needs, now and in the future (Burke, 2006).

2.5.6 Integration and Systems Approach

2.5.6.1 Systems Approach

Although IWRM is generally accepted as a necessary step to improve water management and planning, it does not provide a clear definition of what should be integrated. The various water-related issues that IWRM might encompass are well documented in the literature, but they are generally addressed separately. Therefore, water management lacks a holistic, systems-based description, with a special emphasis on the interrelations between issues. To facilitate this holistic understanding and to communicate it, there is a need for a mental map (Falkenmark, 2004; Schenk et al., 2008).

In essence, the fundamental difficulty regarding the implementation of IWRM is the identification of what to integrate. The probably most quoted definition of IWRM provided by the GWP, states (Schenk et al., 2008) is: “IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (GWP, 2000). In practice, this definition leaves room for a large number of varying interpretations of what to integrate (Biswas, 2004), including various blends of components and concepts such as surface water and groundwater, water supply and demand, various uses, different administrative levels, policies, equity, education, health, and so forth (Biswas, 2004).

Therefore, the integration of these components and concepts requires understanding the way they interact as a system (Schenk et al., 2008). Mitchell (2005) proposed two basic interpretations for this system’s approach: (1) comprehensive, implying an exhaustive inventory of the variables and relationships, and (2) integrative, focusing on the identification of key variables and relationships. Mitchell (2005) mentions that while the former generally shows the drawback of being very time-consuming, the second one might present the risk of overlooking important elements. In parallel, systems’ approaches might show features of hard or soft methods, or blends of both. The former strive towards quantification and objectivity, whereas the latter includes qualitative analysis and tends to capture stakeholders’ knowledge through participatory processes (Schenk et al., 2008).

Furthermore, a recent series of promising studies and applications promoted – although they recognise the difficulties – the inclusion of complex, soft aspects (linked with some of the social, environmental, or economic fields) within water or other natural resources management. The major advantages put forward by these methods are the social learning brought by the process and the gain of a deep understanding of the complex problems tackled. However, one of the drawbacks is the time requirement for the participatory process, especially when water issues are complex, as the latter might involve numerous components, influences, conflicts, and feedback interactions (Schenk et al., 2008).

However, although these water-related issues are well documented, they are generally described separately. Therefore, it is difficult to extract the relationships among elements to apprehend the system holistically. To sum up, the path in IWRM going towards a comprehensive system’s approach including soft elements can really lead to rich and interesting insights and robust outputs, but it requires investigation time, for eliciting the components and interactions to be integrated. To facilitate this elicitation process, and therefore reduce the time it necessitates, Schenk et al. (2007) proposed a generic conceptual model for the water management system. The model synthesises as exhaustively as possible the generic components and interactions involved in water-related issues within a graphical view. It also comes along with an exhaustive review of the water issues, of their related components, and, with special emphasis, of their interrelations (Schenk et al., 2007).

The model developed by Schenk et al (2008) is an effort to provide a holistic reference view on the water management system in its broader sense, including elements that don’t strictly belong to the field of water, such as energy or housing policies. The model lists as exhaustively as possible any kind of components involved in this broader view upon water management. Components are classified into two main groups: physical (infrastructures, environment, natural and anthropogenic resources) and cultural objects (policies, laws). It

describes the interactions between these components, and finally, it provides a graphical view with a possible way of organising components and interactions (Schenk et al., 2008).

A graphical view of the model is shown in **Figure 69** in the **Appendix**. Rectangles are components and black arrows represent functional interactions; diamond-terminated links represent composition relations (of type “belongs to”). For instance, in this figure, the component “Water” (1) belongs to the general “Resource” component. It has a functional interaction with “Energy” (4), as the latter may require water for its production (directly, for hydropower production by hydropower plants (5), or for cooling). Conversely, water requires energy for its production (treatment processes, pumping, etc.). Water is also required by the ecosystem (2) and may be virtually contained in food and goods (3) (the concept of virtual water covers the water embedded in items, either directly, such as in beer, or indirectly, for production purposes, such as washing or cooling) (Schenk et al., 2008).

The model developed by Schenk et al (2008) is seen as an aide-memoire and a generic reference, providing background knowledge helping to elicit actual system definitions, in possible combination with other participatory systems approaches. While the focus of this project is to integrate water resources and water services management tools, it is realised that such an integration can only be realised if all aspects of water and their interrelations are taken into consideration (Schenk et al., 2008). Hence, the Schenk model has been adopted for this project and is used to help explain the interactions between water resources and water use in particular water services.

2.5.6.2 Systematic Approach with Water-Balance Principles

The decision-making processes associated with the utilisation of water resources are very complex, and require thorough consideration and analysis (Assimacopoulos, Undated). Sectoral approaches to water resources development and management have been and still are dominant, but there is need for a shift towards a holistic approach to avoid fragmented and uncoordinated policies. Additional challenges arise in the field of water policy from the multi-dimensional interactions between the various aspects of human activities, their impact on natural systems and the corresponding influence of natural responses upon the human domain (Assimacopoulos, Undated).

In general, the systematic evaluation of water management interventions should be performed for a long time horizon, simulating long-run accumulative effects and anticipating potential future changes and uncertainties. Indicators selected should assist decision-makers in identifying the appropriate policy and management instruments in relation to regional economic growth and environmental sustainability. Complex integrated modelling can meet those objectives when based on comprehensive information systems (Assimacopoulos, Undated). Multidisciplinary information is needed for the analysis of strategies and evaluation of their effects, taking into account economic, hydrologic and environmental interrelationships. A variety of models and systems have been developed for water allocation and quality estimations, such as Mike Basin by Danish Hydraulic Institute (DHI), or WEAP system by the Stockholm Environment and Tellus Institutes. Systematic formulation and evaluation of alternative policies and strategies integrating the economic principles of the WFD is however missing (Assimacopoulos, Undated).

The WaterStrategyMan project has developed a prototype DSS for assisting decision making under a GIS environment for strategic planning in the context of the economic and

environmental sustainability objectives, with special emphasis on the water stress problems encountered in arid and semi-arid regions. The approach is demonstrated through an application in a typical Greek island (Assimacopoulos, Undated).

The DSS uses the concept of a water management scheme, defined as a set of scenarios for variables that cannot be directly influenced by the decision maker (i.e. rainfall patterns constituting a water availability scenario and population growth formulating a demand scenario) and the application of one or more water management interventions (Assimacopoulos, Undated).

A water management scheme is defined in terms of a database containing information on the water infrastructure at a certain region and reference year, at which the implementation of scenarios and strategies begins. A base case is always present, serving as input for the creation of new water management schemes. User interaction with the DSS falls under three functional groups, accessed via a hierarchical navigation tree: (a) base case editing, allowing for the editing and introduction of new data for the reference year; (b) creation of water management schemes, providing the capabilities for defining scenarios on water availability and demand, definition of strategies and visualisation of results, and for conducting a parametric economic analysis, and; (c) evaluation, which permits the comparison of different water management schemes according to a predefined set of indicators, see **Figure 8** (Assimacopoulos, Undated).

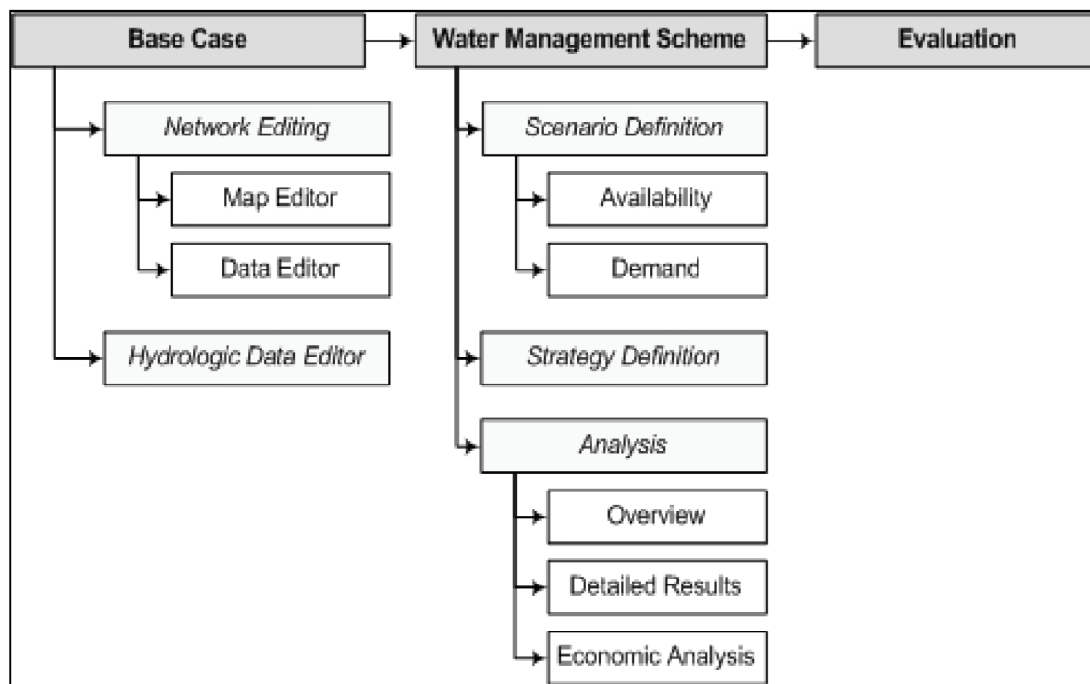


Figure 8: The DSS operational framework (Assimacopoulos, Undated)

The demand scenarios module produces forecasted time-series of water demand for all water uses, generated by specifying appropriate growth rates to the key variables (drivers) that govern demand pressures, such as population for domestic use, cultivable area and livestock for agricultural practices, production growth for industries and minimum required energy production from hydropower plants. Application of water management instruments can be performed either through proper customisation of abstract actions, or through modification of

the properties of network objects and the introduction of new ones (Assimacopoulos, Undated).

As an example, supply regulation through quotas can be performed through application of the respective action, where the user defines the maximum volume of demand that can be met under a specified time period, and the geographic area of application. The analysis branch provides the visualisation of results from the simulation of each water management scheme, through three functions. The overview displays yearly aggregated results on water demand and shortage for the main sectors, freshwater abstractions, and costs (direct and environmental) as well as benefits from water use (WaterStrategyMan, 2004).

The detailed results section provides the results of the allocation in terms of appropriately customised indicators aggregated either for the entire region or presented for each type of network object. An example of the interface of the DSS is presented in **Figure 9**. Finally, the economic analysis branch permits the selection of appropriate models and parameters for the estimation of direct, environmental and resource costs and the definition of benefits from water uses, avoiding repetition of the entire simulation procedure (Assimacopoulos, Undated).

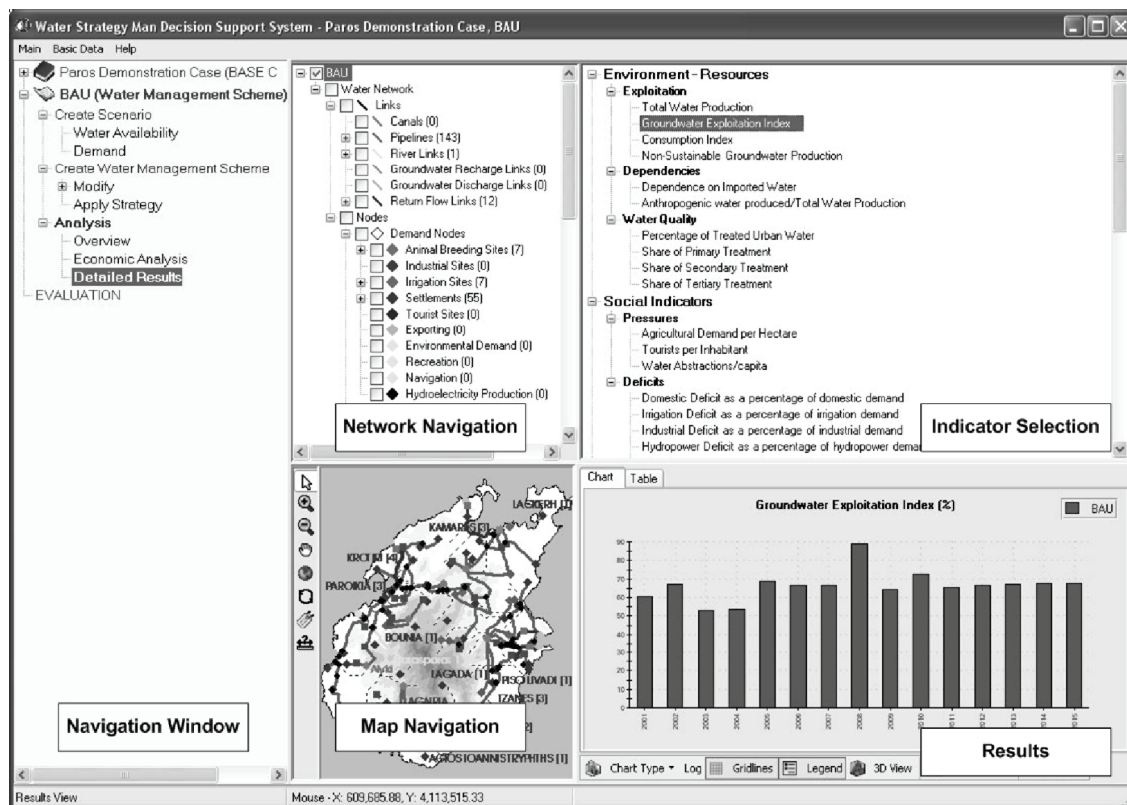


Figure 9: The detailed results interface (Assimacopoulos, Undated)

The Decision Support System (DSS) has been implemented in Visual Basic .NET using the Arc Objects COM technology by ESRI, which is also the platform for the GIS Database. The tool was designed according to the four step schema presented in **Figure 10** that involves: a) the database, b) the object model linked to mathematical models for water allocation, quality and economic estimations, c) a logical coordination unit, responsible for the communication with external models, and d) the user interface which allows for the definition of parameters related to the simulation and the presentation of results through customisable charts, tables

and maps. Water management strategies or single interventions can be simulated under different scenarios, compared, and the decision maker or the analyst can formulate responses to mitigate water stress impacts with respect to their objectives (Assimacopoulos, Undated).

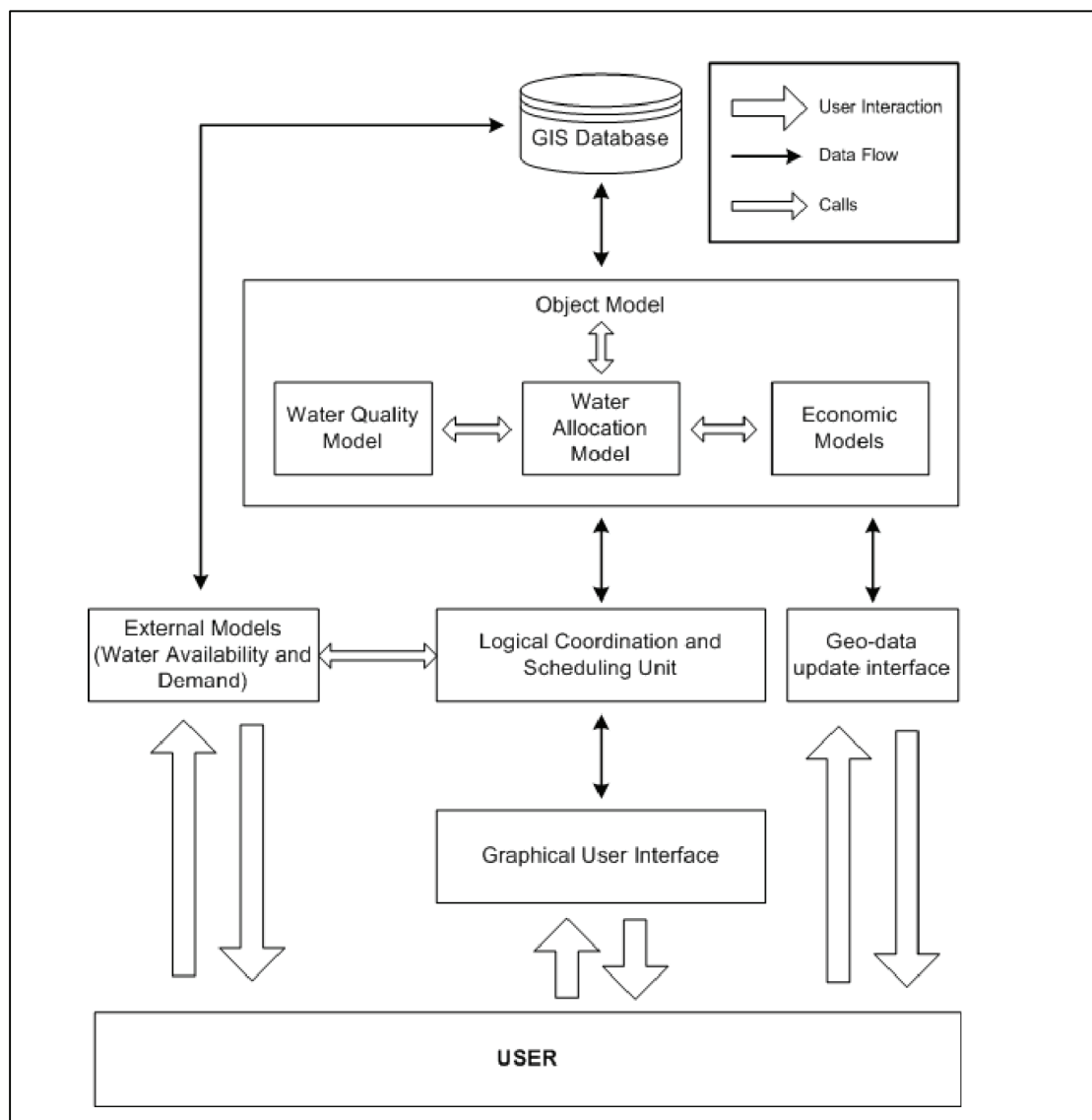


Figure 10: The DSS architecture (Assimacopoulos, Undated)

All specific regional data are stored in an ESRI GIS database (geodatabase). Special attention has been given to the portability of the DSS. The developed object model with the inter-linked mathematical models can easily be transported to other GIS environments since most GIS functions are implemented outside the modelling procedures and algorithms (Assimacopoulos, Undated).

The GIS database, as well as the object model of the DSS, is formulated around the concept of an ESRI geometric network. A geometric network is described as a set of junctions (points) and edges (polylines) that are topologically connected to each other. In the object model junction elements are conceptualised as water nodes while the connections between them are the water links. Water nodes are classified into three categories: (a) supply nodes, representing alternative water supply sources, characterised by the monthly available supply,

(b) demand nodes, modelling water uses and flow requirements, and (c) transshipment nodes referring to treatment plants and generic network junctions (Assimacopoulos, Undated).

Water link objects are classified in four categories according to the connectivity rules of the network and the particular modelling requirements of the DSS: (a) supply links (pipelines and canals) conveying water from supply sources to demand nodes, (b) groundwater interaction links (recharge and discharge), representing the natural interaction between surface and groundwater bodies, (c) return flow links, conveying return flows from consumptive demand uses to receptor bodies (surface or groundwater) or wastewater treatment plants, (d) and river links, representing the natural course of a river water body. An overview of the object model for water nodes is presented in **Figure 11** (Assimacopoulos, Undated).

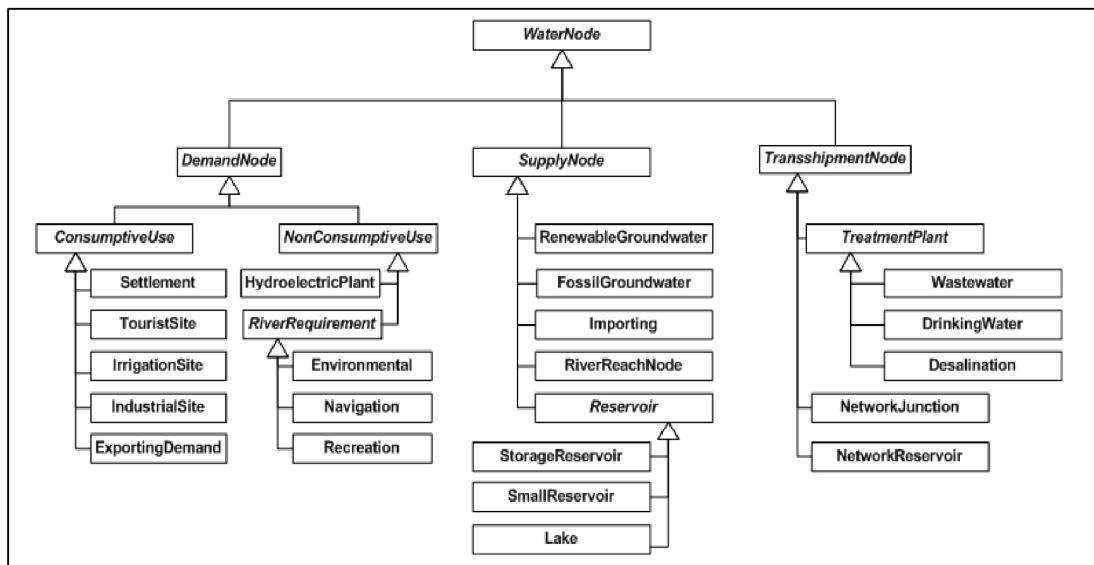


Figure 11: Overview of the object model for water nodes (Assimacopoulos, Undated)

Economic optimisation models, aiming to maximise the social water surplus require the monetary valuation of environmental impacts, societal objectives, developmental priorities and property rights, which in most cases are subject to many constraints, and limits the applicability of a tool. The DSS water allocation model minimises water shortage under limited water supplies. In situations of water shortage, distributing the water available from the various supply sources to the connected uses creates conflicts (Assimacopoulos, Undated).

The allocation model can solve this problem using two user-defined priority rules. By competing demand sites are treated according to specified priorities. Those can express social preference or constraints, economic preference (prioritisation to activities with highest economic values), or a system of water rights. In case that a particular use can be supplied by more than one resource, supply priorities are used to rank the choices for obtaining water. Supply priorities in this case express: (a) cost preference, (b) quality preference of uses (e.g. domestic or industrial use) for supply sources with high water quality, (c) need for the protection of resources, and (d) the formation of strategic reserves (Assimacopoulos, Undated).

The primary aim of the economic analysis is the estimation, according to the results of the allocation algorithm, of financial, environmental and resource costs. A full water services cost recovery strategy can be used as an indication of pricing structures that could meet the

desired cost recovery levels. Estimation of financial costs associated with the provision of water supply is straightforward and depends on the depreciation of capital construction costs and specific energy, operation and maintenance costs associated with each part of the infrastructure (Assimacopoulos, Undated).

Two types of environmental costs have been incorporated, one for the abstraction and consumptive use of freshwater resources (surface and groundwater) and one for the disposal of polluting effluents from demand activities. Resource costs are associated with the scarcity rent of freshwater resources, defined as a surplus, the difference between the opportunity cost of water and the per unit costs of turning that natural resource into products (agricultural crops for farmers, water services for the residence of an urban centre, industrial production, etc.) (Assimacopoulos, Undated).

A characteristic of the DSS is that it predefines a number of abstract water management instruments (actions) and incorporates them as methods into the system. Those methods modify accordingly the properties of the network objects or introduce new ones, related to water infrastructure development. An “abstract” action becomes “application specific” by the user-definition of its magnitude, time horizon and geographic domain. An initial set of actions that can be taken into consideration is presented in **Table 1**. Actions incorporated are mainly focused on instruments to deal with the frequent water shortages occurring in arid regions. The main aim is to either enhance supply, promoting the protection of vulnerable resources through structural interventions, or to regulate demand through the promotion of conservation measures, technological adjustments for promoting efficiency of water use, and pricing incentive (Assimacopoulos, Undated).

Table 1: Policy options and related actions (Assimacopoulos, Undated)

Policy Options	Actions
Supply Enhancement	○ Unconventional/untapped resources ○ Surface Waters and precipitation (direct abstraction, dams, reservoirs) ○ Groundwater ○ Desalination ○ Importing ○ Water Reuse
Demand Management	○ Quotas, Regulated supply ○ Irrigation method improvements ○ Conservation measures in the home ○ Recycling in industry and domestic use ○ Improved infrastructure to reduce losses (networks, storage facilities) ○ Raw material substitution and process changes in industry
Social-Developmental Policy	○ Change in agricultural practices ○ Change of regional development policy
Institutional Policies	○ Economic Policies (Water pricing, Cost recovery, Incentives)

Evaluation of alternative schemes takes into account the entire simulation horizon. As a first step, time series of indicators are computed, describing the behaviour of the water system in terms of environmental, efficiency, and economic objectives **Table 2**.

Table 2: Indicators in the DSS evaluation procedure (Assimacopoulos, Undated)

Category	Indicator
Environment Resources	Dependence on Inter-basin water transfer
	Desalination and reuse percentage
	Groundwater exploitation index
	Non-sustainable water production index
	Share of treated urban water
Category	Indicator
Efficiency	Coverage of Animal breeding, Domestic, Environmental, Hydropower, Industrial and Irrigation demands
Economics	Direct Costs
	Benefits
	Environmental Cost
	Rate of cost recovery

The comparison is performed through a multi-criteria analysis based on the computation of statistical criteria for reliability, resilience and vulnerability. The statistical criteria express the behaviour of the monthly or yearly time series of each indicator with respect to the predefined range of satisfactory values that the indicator can assume. Reliability is identified as the probability that any particular indicator value will be within the range of values considered satisfactory. Resilience describes the speed of recovery from an unsatisfactory condition. Vulnerability statistical criteria measure the extent and the duration of unsatisfactory values. Performance for each indicator is computed as the product of the above criteria, and the relative sustainability index of each water management scheme is the weighted sum of the performance of the selected indicators, and can be used to rank alternative strategies or instruments according to the objectives of the undertaken analysis (Assimacopoulos, Undated).

2.5.6.3 **Knowledge Management**

In the modern knowledge-based economies, the decision makers use digital enterprise data and tools in a networked, global, and distributed environment. Decision making in such an environment requires a new framework to store and use knowledge capital of the organisation (Malhotra, 2008). The decision makers need a knowledge-based decision support environment that not only manages data and tools, but also manages tool-use knowledge. Tool-use knowledge plays an important role in effectively managing and reusing tools and tool components. The use of meta-tools (tools that store knowledge about other tools) is seen as a major tool for creating, organising, and managing tool-use knowledge. Tool-use knowledge is the most important aspect of effective tool management. Therefore, knowledge-based systems should model organisational knowledge to conveniently manage and store existing tools and their use knowledge, and facilitate creation of new Tools using existing tools and tool components. Thus, organisations will be able to achieve their objectives of knowledge sharing, management, and reuse (Price, 2001).

Plato defined knowledge succinctly as “justified true belief”; knowledge management for an organisation requires a longer definition (Price, 2001):

- The strategic and systematic acquisition, application and dissemination of existing and created knowledge.

- Identified by taking into account the needs of practitioners involved in a particular knowledge generating activity.
- To ensure the organisation's productivity, adaptation and competence in the face of increasingly discontinuous change in society.
- Centred on organisational processes providing a collaborative working environment and means of sharing both explicit and tacit knowledge assets.
- About bringing together appropriate ICT within the context of suitable methodologies with the creative and innovative capacities of human beings.
- To set up an environment to foster individual and organisational learning.

The definition for knowledge management referred to above introduces the need for organisational processes that provide a means of sharing knowledge and working collaboratively together (Price, 2001). From this statement emerges a model that consists of communities of practice, (and possibly complemented by the concepts of communities of interest and intention). This is a group of people who have a common interest in knowledge relevant to a particular domain of activity. The group is essentially voluntary; that is, people join it because they want to rather than because they are required to (Price, 2001).

It also means that the group is self-regulatory: there is a real sense of commitment by the participants for its success. Such groups are formed by those involved in research or practice within a typical urban water management organisation. A number of different facilities are provided on a particular platform to enable a community to function in an efficient and effective manner, and also to form strong links when needed with other communities of practice or external individuals. Each community of practice is constructed on a common generic framework but may include different types of facilities, even some that may be tailored specifically for the particular community (Price, 2001).

A community of practice platform may include some key facilities (Price, 2001):

- Document management (archiving, retrieval, version control, etc.)
- Text analysis (summarisation, technical term and knowledge concept extraction, translation, etc.)
- Group management of grey literature (for which there are a number of interesting models in the research community)
- Chat groups (initiated and managed by any individual)
- Video conferencing (especially with broadband links)
- Notes (in place of emails)
- News (for broadcasting)
- Map and search (for expertise, knowledge, products, customers, etc.)
- Work flow manager (for projects)
- Access to archives (libraries, GIS, MIS, databases, knowledge bases, case studies, educational materials, etc.)
- Access to tools (modelling systems, monitoring systems, etc.)
- Learning systems (including “lessons learned” protocols)
- Shared agendas
- E-commerce
- E-publishing
- Help desk.

Necessarily this discussion on knowledge management is applicable to organisations in many sectors, let alone the water sector. However, it is argued here that it is especially appropriate for the water sector on several grounds (Price, 2001):

- It brings together in virtual communities of practice, engineers and other stakeholders concerned with different phases of the water cycle and different parts of the planning cycle; for example, these could include those concerned with urban water, river basins, or coastal waters
- It provides structured means of sharing knowledge and working collaboratively together within these communities
- It opens up new ways of sharing access to computational modelling software, GIS, databases, monitoring and visualisation systems, etc.
- It can provide new tools and an environment for innovation and on-the-job or lifelong learning.

One word of caution should be made about the implementation of a community of practice: it must be driven “bottom-up”. There can be a “top-down” incentive for ensuring that a community of practice is developed, but the details of how it is done should be left to those participating (Price, 2001).

Water management, like many other areas of engineering, is facing a number of far reaching changes through the introduction of new forms of ICT. Hydroinformatics is the study of how ICT can influence our understanding and management of water-based systems through an appreciation of the flow of associated information. Because information is a human concept and provides the building blocks of knowledge, it is inevitable that hydroinformatics should also be concerned with the acquisition of existing knowledge and the generation of new knowledge. Again this is a human activity which is augmented by the tools available from ICT. Therefore, hydroinformatics must be involved with knowledge management (Price, 2001).

As hydroinformatics evolves it should become immersed in knowledge management in all its aspects. It must be stressed, however, that this is not so that it will lose its identity to the much larger sphere of knowledge management, but that it may retain its focus on utilising all (ethical) means at its disposal in pursuing the understanding and management of the world's waters. Discoveries and facilities from the area of knowledge management have the potential to improve our activities. Water-based organisations should therefore ensure that both hydroinformatics and knowledge management are on their agendas for the future (Price, 2001).

What knowledge management does is provide a rationale for better management of knowledge, regarded increasingly as a collection of objects rather than something to be “known” by the knower. This shift in cultural thinking has brought with it a whole series of implications of how we acquire, archive, analyse, generate, apply, share, assimilate and dispose of knowledge. In other words, there is a knowledge cycle (or knowledge value chain) associated with knowledge management. ICT forms a crucial role in helping us work with such a cycle and to apply it to our particular sector (Price, 2001).

Hydroinformatics considers water systems from an information point of view. Yet we frequently make reference to the importance of knowledge. Much of this knowledge is associated with the accumulated experience of experts. For example, we refer to software modelling systems as encapsulated knowledge systems; that is, they embody knowledge about the real world in terms of solving equations describing physical processes within well-

defined geometrical domains. This is in contrast to data-driven modelling systems where the encapsulated knowledge is only concerned with the connection of different data sets, such as through (artificial) neural networks or fuzzy logic generators, and not with the physics of the processes. (This is not to say that a good physical understanding is needed for a successful application of data-driven modelling.) The knowledge we are talking about here is second-hand; that is, it has been made explicit, having originally been implicit or tacit, in the sense of residing in somebody's mind or experience (Price, 2001).

From Nonaka and Takeuchi's (1995) theory one can say that, besides being encapsulated in tools such as modelling systems and decision support systems, knowledge is also encapsulated in (multi-media) documents (Price, 2001). Indeed, documents containing text, drawings, etc. are a standard way of transferring knowledge. Many published (and therefore quality assured) documents are stored in libraries, and we use the insights of information science to manage the information they contain. There are also many more documents containing knowledge and information, such as reports, manuals, papers, memos, even emails that never become archived within a library system. This grey literature (with minimal quality assurance) forms a very important part of the communication process between individuals and groups. Any document is evidence of the knowledge encoding process during which tacit knowledge has been made explicit. Similarly, when documents are brought together or tools are developed the process is called the synthesising process (Price, 2001).

2.6 Water Management as a Business

2.6.1 Business Model

In an effort to achieve integration, it is necessary to understand the underlying processes of the entities involved, i.e. understanding how the business model is structured. Also it is necessary to realise that government institutions are different to private institutions and yet they are also challenged to innovate their traditional structures into new electronic structures responding on new technical and societal challenges similar to the private sector (e-commerce) (Wassenaar, 2000).

E-commerce business models often focus on maximising profit and differentiating from competitors, whereas the primary interests of governments are in gaining more efficiency, enhancing the existing, and/or, developing new public services. Public networks are quite different from organisational hierarchies, as they require autonomous organisations to work with each other in a collaborative, non-bureaucratic structure. In this regard, the business models and the coordination challenges associated with public networks can be very different from that of managing individual organisations (Wassenaar, 2000).

In a public network, actors with varying resources and capabilities often need to engage in a reciprocal relationship to benefit from each other's unique resources and capabilities. The focus is one of managing the interdependencies among activities. Essentially, each type of interdependency relates the actors' own and others' resource contributions to the performance of service provisioning. This necessitates the development and understanding of the government business model. The following sub-sections discuss the business model concept in general, the transferring of the concept to government institutions, and present the proposed government model (Wassenaar, 2000).

2.6.1.1 **Business model concept in literature**

Business models are often mentioned, but not a well-defined concept in literature. There is a variety in interpretation of this concept. However, literature stresses that the core of any business model is a value activity, performed by actors aiming at producing and exchanging material and immaterial resources (value) (Wassenaar, 2000). Porter (1996) stresses the strong relation between strategy and what he calls an activity or business map of a company. The map shows the strategic themes and their strongly related value activities. In developing activity maps, companies need to make trade-offs between activities (Porter, 1996).

Wand et al. (1999) state that a business model reflects the core business of an organisation from the perspective of its main function – products and services that it provide to its customers. It captures at a high strategic level, how organisations behave, independent of the actual organisational structure and implementation of business processes. For this reason, they believe a business model is usually stable, even under major changes, to the structure and operations of the business. It will only change if the basic nature of the products and services changes. In their perspective a business should be used to drive the evolution of information systems and guide the re-use of existing components (Wanda et al., 1999). Finally, Timmers (1998) defines a business model as an architecture for a product, service and information flows, including various actors and their roles. To conclude, a business model is an overall architecture reflecting the core business of an organisation (network) expressed by strategic themes (rooted in strategic positioning) and their underlying value activities in the field of marketing and sales, operations, sourcing, and organisational and human competence management (Wassenaar, 2000).

2.6.1.2 **Transferring the concept of business model(ling) to the public sector**

The definition of the core business of the public sector depends on a huge variety of political views on the basic task of the public sector. Wassenaar (2000) defines the core public business as shaping the society. This basic task is classically structured after the legislative, executive and legal power. In the legislative sector, the strategic themes (rooted in the governmental strategic positioning) are discussed and defined on a strategic level in, for example, a political programme, a financial plan and a service action plan for the next three to five years. This overall programme has to be realised in the executive sector by value activities or processes. In analogy to private business models there are two distinct management fields: the primary activities and the support or administrative resource activities. The field of service delivery management embraces the primary activities, and the field of administrative resource management consists of the support activities. In fact, the activities of these two fields can be compared with primary value activities; marketing and sales, and operations, and the support activities; sourcing and organisational and human resource delivery (Wassenaar, 2000).

In essence, the governmental basic model embraces three governmental management fields of legislative governance, administrative (resource) management and service delivery management. Each field is structured after a strategic-constitutional, tactical-intermediation and operational-retail level, **Figure 12**. The field of legislative governance embraces the constitutional institutions like the government, parliament and their relations to the citizens. In this field the fast growing interactive ICT capabilities are enabling systems like electronic democracy, electronic election and discussions. They are enabling a new system of direct

democracy compared to the traditional ways, based on the indirect representative systems (Wassenaar, 2000).

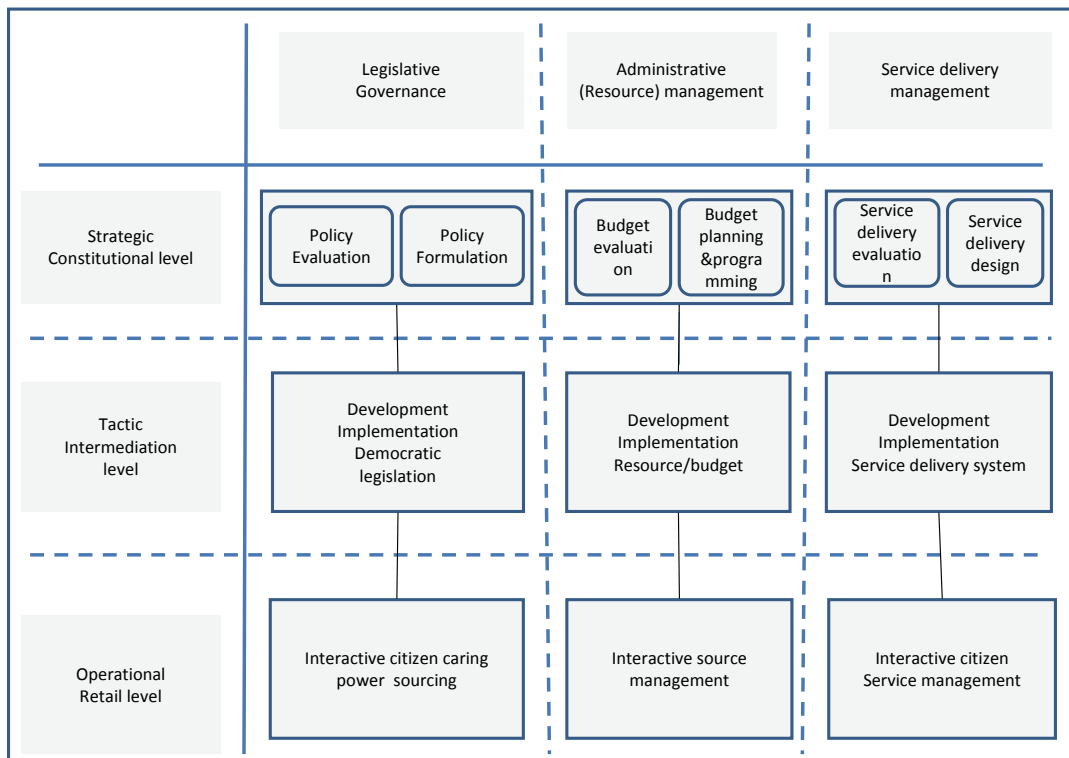


Figure 12: Government business model (Wassenaar, 2000)

Basically, the development of e-government systems requires rethinking of the existing (representative) democratic forms. The field of administrative management is involved in the public resource allocation especially in planning, programming and budgeting the resources for the public sector. In this field the fast growing ICT interactive capabilities are a trigger from re-engineering of administrative management in the public sector. New managerial control concepts based on downsizing and empowerment are enabling flatter administrative structures eliminating many existing hierarchical governmental layers (Wassenaar, 2000). Development of e-government systems demands rethinking of the existing vertical and hierarchical oriented administrative structures. Finally, in the field of service delivery management, new interactive ICT capabilities like front/back office systems and service component-based development are streamlining the governmental service delivery chain by eliminating many bureaucratic rituals in the interaction between governmental agencies and their citizens. The integration of information systems is enabling user a friendly, one stop shopping concept of public services. E-government systems in this field are asking a complete reengineering of the existing governmental service delivery chain and their systems (Wassenaar, 2000).

2.6.2 The Decision Process

According to Rapids (Undated), government leaders and officials are responsible for a full spectrum of decisions, some routine and others that are complex and often controversial. They face a wide spectrum of strategic pressures to balance between long-term economic and social development, while filling near-term community and citizen needs. Seamless, personalised government services are demanded along with supporting information privacy

and enhanced security features. Operational pressures to maintain public assets and infrastructure efficiently must coexist with the loss of skilled human resources and heightened demands for convenient and quick services. Information lies at the nexus of these decisions. More specifically, having the right information at the right time to make the right decision is essential. According to Rapids (Undated) the Balanced Decision Process model provides an outline that can be used for these complex decisions, see **Figure 13**. This model requires rigorous application of process discipline that separates decision-making for complex issues into three distinct elements (Rapids, Undated):

1. Process discussion – where agreement is reached on the process and information that will be necessary to assure high quality and timely discussion of policy issues.
2. Policy discussion – where information is reviewed, analysed and discussed with the goal of clarifying questions and information prior to a final decision action. The policy discussion includes establishing and refining policy goals and a thorough discussion of the advantages and disadvantages of the options and policy implications.
3. Decision discussion – where, with all the information available, final agreement is reached on the policy after a thorough and vigorous debate based on policy information and data gathered as part of the process.

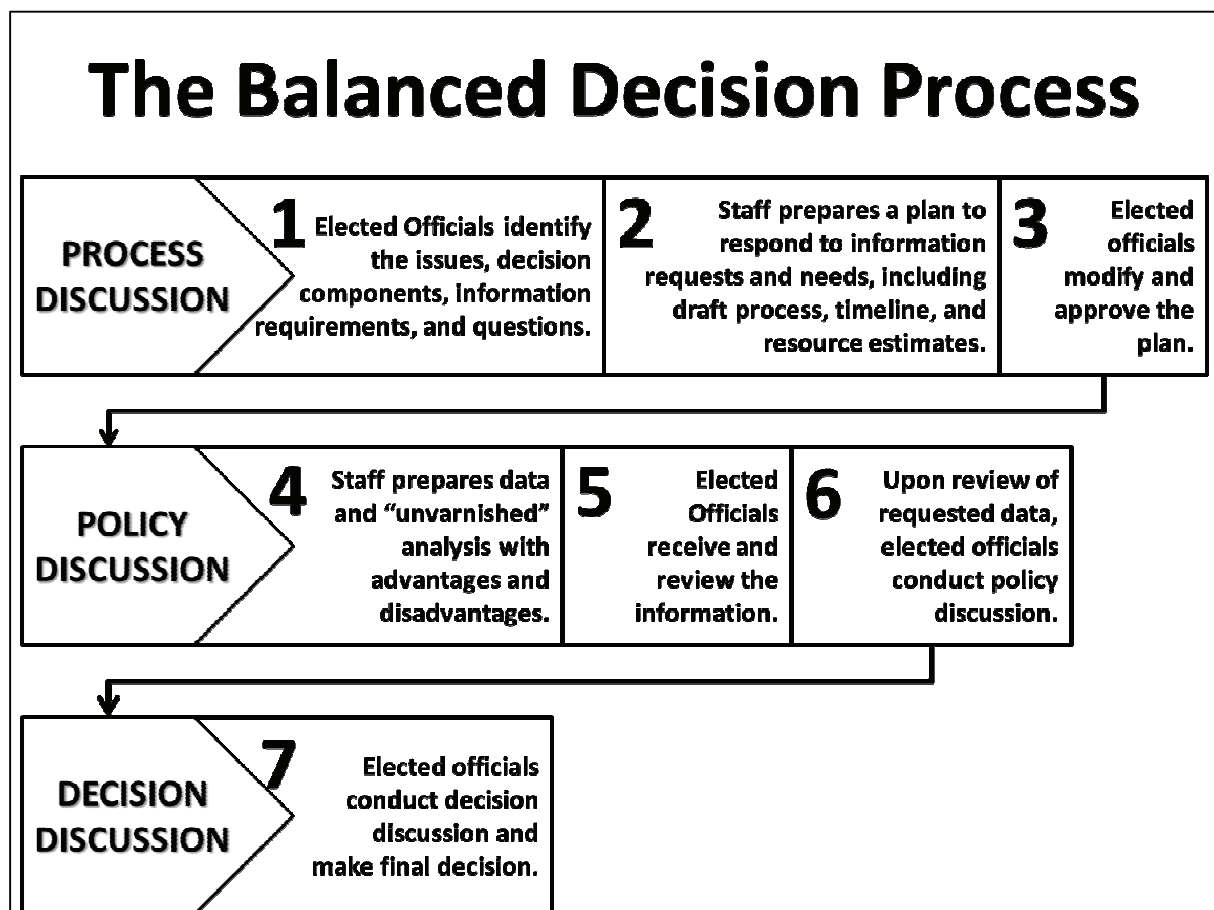


Figure 13: Balance decision process (Rapids, Undated)

Clearly, creating value in decision-making processes requires more than attaching a piece of software to a system. Department silos must not inhibit information flow. Efforts must be made to verify that accurate information exists – the first time it is captured. Plans must exist to proactively seek out people who can use the information. Investments are needed in analytical tools and education for employees. Having the right information at the right time to

make the right decisions means a new culture – it means viewing information as a part of an information value chain. **Figure 14** describes this value chain. It shows that effective decision making begins by identifying needs and capturing, updating and storing information effectively. Strategies can then be developed to verify that information is passed to the right people at the right time. Access at the right time will enable an analysis, action and learning that will help promote the right decision (Gresham and Andrulis, 2002).

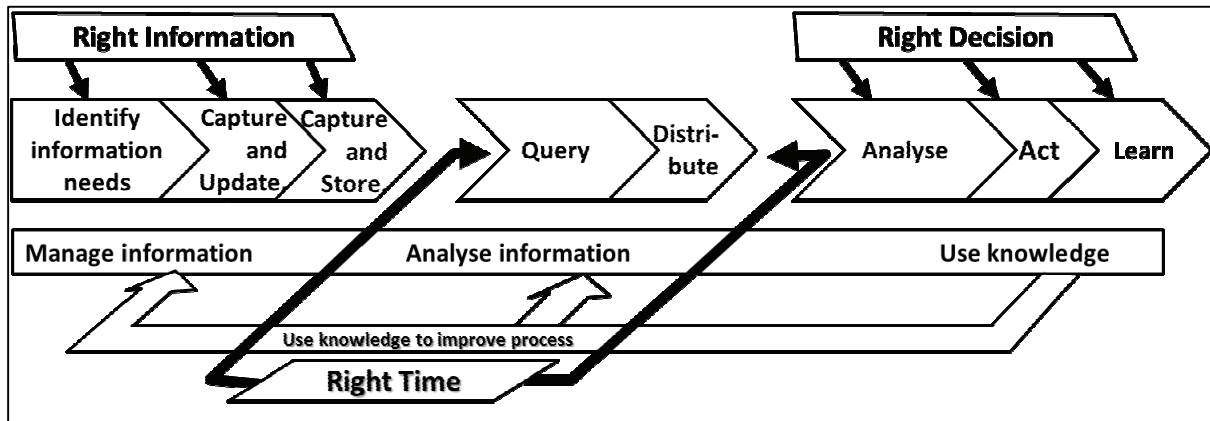


Figure 14: Information value chain (Gresham and Andrulis, 2002)

Gresham and Andrulis (2002) stress that sound decision making requires that governments analyse information proactively and act effectively, based upon detailed assessments and spend time learning from the results. Skilled resources need the tools and time to analyse information. Acting on the analysis requires integrated policies and procedures to mitigate risks; clear roles and responsibilities to support efficient services; and a decentralised decision-making structure to promote a customer focus. Finally, an organisational commitment to evaluate existing processes, use leading practices and establish performance objectives is necessary to create a learning culture (Gresham and Andrulis, 2002).

The effectiveness of these strategies depends on people. Right decision strategies seek to leverage the investments that governments have made in technology and process improvements by creating an organisational culture that can efficiently and effectively reach the right decision. The efficiencies gained in right information and right time – from automating manual processes, implementing systems to effectively share and store information, and reducing data collection costs – will provide employees with more time to analyse and learn from information. Right decision strategies provide concrete, purposeful analysis as the basis for decisions, by enabling skilled individuals to use tools to pool the right information together in an efficient, timely fashion. If government regularly integrates lessons learned into the process, improved decision making can result (Gresham and Andrulis, 2002).

2.6.3 Value and Supply Chains

Before getting into the concepts of value and supply chains, it is important to first define what is meant by information. This will help in differentiating between data and information, as well as between the respective systems. Goldratt (1990) defines data as every string of characters that describes something, anything, about reality. He further defines information as that portion of the data which impacts human actions, or which if missing or not available will impact human actions. His definition brings to the realisation that the distinction between data and information does not lie in the content of a given string of characters, but lies in its

relationship to the required decision. Hence, if it is not known in advance what exactly will be needed, then every piece of data might at some time be considered information (Goldratt, 1990).

Generally, in any organisation it is desired to have a system that can supply information to all managers, for all types of decisions. This brings to the realisation that in designing information systems, the first logical step should be to start asking what type of possible questions every function in an organisation might face in the future, and from there start defining which pieces of data/information will be required (Goldratt, 1990). Goldratt further emphasises that information can therefore be visualised as an answer to the question asked, which implies that information is not an input to the decision process, it is rather the output of the decision process, and this means that the decision process must be embedded in an information system (Goldratt, 1990).

Therefore, any logical discussion of the composition and structure of an information system must be done within the framework of the decision process. This brings about a burden to the managers to be able to articulate what they want in advance. The core of any business model is a value activity, and there is a strong relation between strategy and an activity or business map of a company which shows the strategic themes and their strongly related value activities (Goldratt, 1990). Further, business activities are themselves depended on information and hence it is imperative to understand the information value and supply chains as well as to ensure that they are synchronised.

According to BetterManagement (2010), supply chain can be defined as a network of autonomous or semi-autonomous business entities collectively responsible for procurement, manufacturing, and distribution activities associated with one or more families of related products. They define value chain as a high-level model of how businesses receive raw materials as input, add value to the raw materials through various processes, and sell finished products to customers (BetterManagement, 2010).

With this in mind it is important to define information supply chain. According to Carey (2006), like a physical supply chain, an information supply chain comprises of the organisations that connect to produce a desired end-product or service for a user. The information supply chain is: "the full set of elements – technology-based, process-specific and organisational in nature – that are necessary to; 1) collect information from discrete processes, 2) transform this information from data into knowledge, and 3) distribute this information efficiently and in a timely manner to the appropriate data consumers." But where other supply chains may be roughly linear, the information supply chain is more reminiscent of a web, which requires infrastructure to accommodate the many users with their varying requirements. It is imperative to grow the supply chain in terms of what can go through it, however, it is more important to make sure that we don't inhibit the speed of interaction that goes through it (Carey, 2006).

The Information Value Chain on the other hand is, according to BetterManagement (2010), a framework for determining how to leverage information resources across an organisation and its many third party and market connections. Feller et al. (2006) likens value to beauty which is in the eye of the beholder, and suggests that value should be defined from a customer's perspective, which necessitates knowing the customer and their value. According to Information Value Chain (2009), the information value chain consists of primary and support activities where primary activities involve the direct handling of information resources in

ways that increase their values: information acquisition, information processing and information distribution. Support activities ensure that the primary activities can take place continuously and in the most efficient way possible. The latter is an addition to Porter's definition of support activities. While the support activities (i.e. human resources and IT infrastructure, see **Figure 15**) mainly focus on ensuring continuous execution, the other support activities (i.e. knowledge management and information governance) focus on the additional aspect of ensuring execution in the most efficient way (Information Value Chain, 2009).

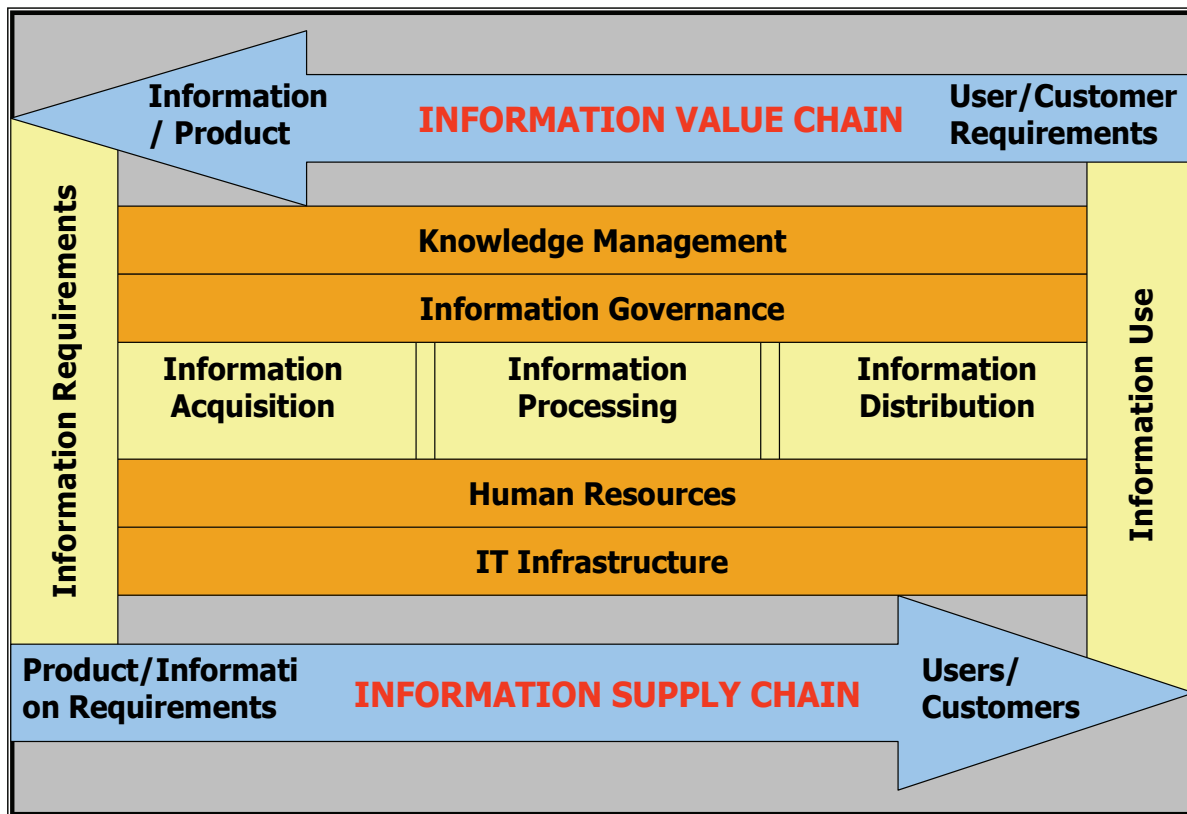


Figure 15: Information supply/value chain collaboration (Information Value Chain, 2009)

While value chains have traditionally been regarded as flowing from the process of adding value to the users, Feller et al. (2006) argue that value should flow from the customer, in other words since value is in the eyes of the users, then value should be derived from customer needs. From **Figure 15**, we depict the value chain indicating that the customer requirements determines how value should be added along the value chain, and this in turn emphasise the need to understand the user's requirements, consequently the decision process (Information Value Chain, 2009).

According to Feller et al. (2006), a supply chain and a value chain are, in common parlance, complementary views of an extended enterprise with integrated business processes enabling the flow of products and services in one direction, and of value as represented by demand and cash flow in the other. Both chains overlay the same network of companies. Both are made up of companies that interact to provide goods and services. Generally, supply chains refer to downstream flow of goods and supplies from the source to the customer. Value flows the other way (Feller et al., 2006).

The customer is the source of value, and value flows from the customer, in the form of demand, to the supplier. That flow of demand, sometimes referred to as a demand chain, is manifested in the flow of orders and cash that parallel the flow of value, and flows in the opposite direction to the flow of supply. Thus, the primary difference between a supply chain and a value chain is a fundamental shift in focus from the supply base to the customer. Supply chains focus upstream on integrating supplier and producer processes, improving efficiency and reducing waste, while value chains focus downstream, on creating value in the eyes of the customer. This distinction is often lost in the language used in the business and research literature (Feller et al., 2006).

Value is highly conditioned by the larger social and economic environment through which complex and numerous interactions affect the human perception of value-based transactions. Therefore, for supply chains to generate maximum value in this dynamic environment, they must synchronise the flow of supply with the flow of value from customers in the form of rapidly shifting tastes, preferences, and demand. This requires a shift from a mind-set of thinking of supply chains and value chains as different entities, but, rather, should integrate the two (Feller et al., 2006).

Third generation supply chains require that the material flow and product delivery be synchronised and lean, and that the information, knowledge, and financial flows be fully integrated and instantaneous. The SCM 3.0 software for example requires that product design be fully integrated with production capability, delivery processes, and information about customer demand. This can be achieved by taking a holistic view of the end to- end business process throughout the product life cycle and across geographical borders. To continue to debate the importance of supply chain management versus the value chain concept would be folly. Instead, the next level of business performance will be achieved by companies that learn to integrate fully the concurrent flows of value and supply (Feller et al., 2006).

2.6.4 The Performance Measurements

The standard performance measurement clichés sayings are commonplace, they go like: “what gets measured gets done”, “if you don’t measure results, you can’t tell success from failure and thus you can’t claim or reward success or avoid unintentionally rewarding failure”; “if you can’t recognise success, you can’t learn from it; if you can’t recognise failure, you can’t correct it”; “if you can’t measure it, you can neither manage it nor improve it”; but, what eludes many people is the easy path to identifying truly strategic measurements without falling back on things that are easier to measure, such as input, project or operational process measurements (Wikipedia, 2011).

The focus on strategic objectives, which should articulate exactly what the organisation is trying to accomplish, is the key to identifying truly strategic measurements. Strategic performance measures monitor the implementation and effectiveness of an organisation's strategies, determines the gap between actual and targeted performance and determines organisation effectiveness and operational efficiency. In essence, good Performance Measures (Wikipedia, 2011):

- Provide a way to see if the strategy is successful.
- Focus employees' attention on what matters most for success.
- Allow measurement of accomplishments, not just of the work that is performed.
- Provide a common language for communication.
- Are explicitly defined in terms of owner, unit of measure, collection frequency, data

- quality, expected value (targets), and thresholds.
- Are valid, to ensure measurement of the right things.
- Are verifiable, to ensure data collection accuracy.

In general, private companies exist to make money for their shareholders, owners and employees. They may have other purposes, but profitability is the primary goal, and an indicator of success. Profitability is correlated to return on investment and productivity, or revenues minus total cost of ownership. These figures are tracked carefully and they are all measured in the same currency units, so at any time it is easy for managers to determine the net worth of the company (Arveson, 1998).

On the other hand, public and not-for-profit organisations exist to support a particular mission. In the case of the government, there are some “inherently governmental functions” that are defined or implied by statute, and they may not be carried out by the private sector. Although they may be protected and even subsidised, in this era of deregulating and downsizing of government, many agencies have an increasing concern about their competition. Public organisations often do have opportunities and competitive threats, just as private companies do (except for police, armed forces and a few other organisations that are still protected from competition by law). So most government agencies must create a credible impression that they are the best at what they do, and that they do it efficiently. For, if that is not the perception, then their sponsors or customers may go elsewhere for their services, leaving the organisation to wither and die (Arveson, 1998).

It is therefore desirable for government agencies, like private companies, to measure their performance using metrics and measurements. Systems such as the one developed by Arveson (1998), attempt to define metrics that will provide leading indicators of the health of any organisation, public or private. But because public organisations do not have financial results as the primary indicator of success, some other metrics must be put into this place.

These metrics should be mission effectiveness and efficiency so as to accomplish their mission in the best way, within minimum time and cost. Success is indicated by the extent of their effectiveness and efficiency in the eyes of their customers and sponsors (Arveson, 1998). For example, in the case of a public electrical utility, effectiveness would be the fraction of time that the electric grid is powered. In the case of police, effectiveness would be measured by the crime rate. In the case of the water, it would be the reliability of water availability and distributions. These are cases where the mission is clear, and its effectiveness is relatively easy to define and measure.

While measuring of performance is desirable, it should be noted that abstract measures are worthless. To use a performance measure – to extract information from it – a manager needs a specific, comparative gauge, plus an understanding of the relevant context (Behn, 2003). According to Behn (2003) there are eight purposes for measuring performance, and to use performance measures to achieve any of these eight purposes, the public manager needs some kind of standard with which the measure can be compared:

1. To use a measure to evaluate performance, public managers need some kind of desired result with which to compare the data, and thus judge performance.
2. To use a measure of performance to control behaviour, public managers need first to establish the desired behavioural or input standard from which to gauge individual or collective deviance.

3. To use efficiency measures to budget, public managers need an idea of what is a good, acceptable, or poor level of efficiency.
4. To use performance measures to motivate people, public managers need some sense of what are reasonable and significant targets.
5. To use performance measures to promote an agency's competence, public managers need to understand what the public cares about.
6. To use performance measures to celebrate, public managers need to discern the kinds of achievements that employees and collaborators think are worth celebrating.
7. To use performance measures to learn, public managers need to be able to detect unexpected (and significant) developments and anticipate a wide variety of common organisational, human, and societal behaviours.
8. To use performance measures to improve, public managers need an understanding (or prediction) of how their actions affect the inside-the-black-box behaviour of the people who contribute to their desired outputs and outcomes.

All of the eight purposes require (explicitly or implicitly) a baseline with which the measure can be compared; and, of course, the appropriate baseline depends on the context (Behn, 2003).

The standard against which to compare current performance can come from a variety of sources – each with its own advantages and liabilities. The agency may use its historical record as a baseline, looking to see how much it has improved. It may use comparative information from similar organisations. Of course, comparative data also may come from dissimilar organisations; citizens may compare – implicitly or quite explicitly – the ease of navigating a government website with the ease of navigating those created by private businesses. Or, the standard may be an explicit performance target established by the legislature, by political executives, or by career managers. Generally, managers need some kind of tailor made standard to be met by those whose behaviour they seek to control. Whether public managers want to evaluate, control, budget, motivate, promote, celebrate, learn, or improve, they need both a measure and a standard of performance (Behn, 2003).

However, in the political world the complexity is who will choose the purpose, the measure, and the performance standard? The leadership team of a public agency has both the opportunity and the responsibility. However, others – elected executives and legislators, political appointees and budget officers, journalists and stakeholders, and of course individual citizens – have the same opportunity, and often the same responsibility. Consequently, the agency's managers may discover that a set of performance measures has been imposed on them. In some ways, however, public managers have more flexibility in selecting the performance measures that will be used by outsiders than do private-sector managers. After all, investment analysts long ago settled on a specific collection of performance measures – from return on equity to growth in market share – that they use when examining a business. For public agencies, however, no such broadly applicable and widely acceptable performance measures exist. Thus, every time those outsiders – whether they are budget officers or stakeholders – wish to examine a particular agency's management, they have to create some performance measures (Behn, 2003).

At times, a legislator or a budget officer will know exactly how he or she thinks the performance of a particular public agency should be measured. Other times, no outsider will be able to devise a performance measure that makes much sense. In other occasions several outsiders – an elected executive, a newspaper editor, and a stakeholder organisation – will

each develop a performance measure (or several such measures) for the agency; and when this happens, these measures may well conflict. Mostly, these outsiders use their performance measures to evaluate, control, budget, or punish. Some might say, “there is a need for this performance measure to hold the agency accountable.” By this, they really mean that there is a need for this performance measure to evaluate the agency and if (as suspected) the agency doesn’t measure up, it would be punished by cutting its budget (or saying nasty things that will be reported by journalists)”. Outsiders are less likely to use performance measures to motivate, promote, or celebrate – though they could try to use them to force improvements. Thus, the managers of a public agency may not have complete freedom to choose their own performance measures (Behn, 2003).

The public managers, therefore, may have to pay attention to measures chosen by others. Even when they must respond to measures imposed by outsiders, however, the leaders of a public agency have not lost their obligation to create a collection of performance measures that they will use to manage the agency. The leadership team still need to report the measures that outsiders are, legitimately requesting. They may be able to use some of these measures for one or more of their own eight purposes. However, when others have chosen their own measures of the agency’s performance, its leaders still need to seriously examine the eight managerial purposes for which performance measures may prove useful and carefully select the best measures available for each purpose (Behn, 2003).

As Behn (2003) further argues that “what gets measured gets done” is, perhaps, the most famous aphorism of performance measurement, implying that if you measure it, people will do it. Unfortunately, what people measure is often not precisely what they want done; and, people – responding to the explicit or implicit incentives of the measurement – does what people are measuring and not what they actually want done. This is, as Steven Kerr wisely observes, “the folly of rewarding A while hoping for B”. Thus, although performance measures shape behaviour, they may shape behaviour in both desirable and undesirable ways (Behn, 2003).

For a business, the traditional performance measure has been the infamous bottom line – although any business has not just one bottom line, but many of them: a variety of financial ratios (return on equity, return on sales) that collectively suggest how well the firm is doing – or, at least, how well it has done. But many have criticised financial measures because of their well-documented inadequacies, their backward-looking focus, and their inability to reflect contemporary value creating actions. Thus, balanced scorecard becomes favourable to give businesses a broader set of measures that capture more than the firm’s most recent financial numbers. They want performance measures that answer four questions from four different perspectives (Behn, 2003):

1. How do customers see us? (customer perspective).
2. What must we excel at? (internal business perspective).
3. Can we continue to improve and create value? (innovation and learning perspective).
4. How do we look to shareholders? (financial perspective).

No single measure of performance answers all four questions. Similarly, there is no one magic performance measure that public managers can use for all of their eight purposes. The search for the one best measurement is just as futile as the search for the one best way. Indeed, this is precisely the argument behind Kaplan and Norton’s balanced scorecard: Private-sector managers, they argue, “should not have to choose between financial and operational measures”; instead, business executives need “a balanced presentation of both

financial and operational measures”. The same applies to public managers, who are faced with a more diverse set of stakeholders (not just customers and shareholders), a more contradictory set of demands for activities in which they ought to excel, and a more complex set of obstacles that must be overcome to improve and create value. Consequently, they need an even more heterogeneous family of measures than the four that Kaplan and Norton propose for business. The leaders of a public agency should not go looking for their one magic performance measure. Instead, they should begin by deciding on the managerial purposes to which performance measurement may contribute. Only then can they select a collection of performance measures with the characteristics necessary to help them (directly and indirectly) achieve these purposes (Behn, 2003).

As Goldratt (1990) stated, measurements are direct results of the chosen goal. There is no way that one can select a set of measurements before the goal is defined. For example, to use money based measurements to judge the performance of an army or a church is quite ridiculous. However, the measurements which are referred to as the fundamental quantities are the measurements that enable judging the impact of a local decision on the company’s goal (Goldratt, 1990).

2.6.5 Concept of Dashboards

Popular phrases like “you cannot manage what you cannot measure”, “what gets watched gets done”, are just some of the adages that help in understanding dashboards. Increasingly, organisations are using models, and research and business intelligence to understand their performance. The outputs can be complex and hard to interpret. Nor are they easily manipulated to enable leaders to develop “what if” scenarios to explore how changes to inputs in different business areas may impact their costs or profits.

According to Eckerson (2006), dashboards are the most visual elements of a performance management system that merges the functionality of business intelligence technology and performance management. Besides displaying metrics visually, these full-fledged information systems let users drill into detailed data to identify the root causes of problems and intervene while there's still time. Dashboards represent next-generation business intelligence because they are easy to use for a majority of business users who find traditional reporting and analysis tools too complex. In addition, dashboards and scorecards are critical elements in supporting business performance management processes, which enables executives to effectively communicate, monitor, and adjust business strategy and plans. Dashboards resonate with business users because they conform to the way users work, rather than forcing them to conform to the way analysis and reporting tools work. These applications let users monitor the status of Key Performance indicators at a glance and alert users via pager, e-mail, or wireless devices when performance deviates from predefined targets (Eckerson, 2006).

In essence dashboards represent the convergence of two distinct disciplines in desperate need of each other: performance management and business intelligence. Like long-lost siblings, these two disciplines have struggled on their own to deliver real business value and gain a permanent foothold within organisations. But together they offer an unbeatable combination whose whole is greater than the sum of the parts (Eckerson, 2006).

Performance management is defined as the process of measuring progress towards achieving key goals and objectives in order to optimise individual, group, or organisational performance. Performance management encompasses strategy-setting, goal-setting, planning,

budgeting, forecasting, and modelling techniques. Business Intelligence (BI), on the other hand, consists of the tools, technologies, and processes involved in turning data into information and information into knowledge to optimise decision making. BI encompasses data warehousing, data integration, reporting, analysis, and data mining technologies (Eckerson, 2006).

Together, these two disciplines provide a powerful new way to communicate strategy to all employees and monitor and analyse business activity designed to optimise performance. The result is a dashboard new type of performance management system that uses BI technologies to apply performance management techniques on an enterprise scale (Eckerson, 2006).

According to Eckerson (2006), there are three major benefits offered by the dashboards when properly deployed, the benefits are as follow:

1. Communicate strategy – dashboards provide executives with a powerful means to communicate key strategies and objectives continuously by tailoring metrics to each employee based on his or her role and level in the organisation. As an agent of organisational change, dashboards enable executives to get the entire organisation marching in a coordinated fashion towards the same destination.
2. Monitor and adjust the execution of strategy – once goals are established, dashboards let executives and managers monitor the execution of the strategy and plans on an hourly, daily, weekly, or monthly basis depending on requirements. These performance management systems enable executives and managers to work proactively and identify and address critical problems undermining progress before it's too late to fix them.
3. Deliver insights and information to all – dashboards deliver critical information at a glance using graphical symbols, colours, and charts. The applications graphically highlight exception conditions and alerts and let users drill down into more detailed data to find the root cause of a problem. These tools conform to the way users work and don't force users to conform to the way BI tools work. This is a major reason dashboards are so useful.

There are many different types of dashboards and each can look and function slightly differently, and often go by different names depending on the organisations implementing them. However, there is a general definition of dashboards as follows:

- Dashboards are multilayered performance management systems, built on a business intelligence and data integration infrastructure, that enable organisations to measure, monitor, and manage business activity using both financial and nonfinancial measures (Eckerson, 2006).

Dashboards provide more than just a screen populated with fancy performance graphics: they are full-fledged business information systems designed to help organisations achieve strategic objectives. They help measure the past, monitor the present, and forecast the future, allowing an organisation to adjust its strategy and tactics in real time to optimise performance (Eckerson, 2006).

Despite the variation among dashboards and scorecards, each shares three basic characteristics – the "three threes" according to Eckerson (2006) – (and if they don't, they are impostors that won't deliver lasting business value):

1. Three applications – each dashboard contains three applications woven together seamlessly: (1) a monitoring application, (2) an analysis and reporting application, and (3) a management application. Each application provides a specific set of

functionalities delivered through various means. Technically speaking, the applications are not necessarily distinct programs (although sometimes they are), but sets of related functionalities built on an information infrastructure designed to fulfil user requirements to monitor, analyse, and manage performance.

2. Three layers – perhaps the most distinctive feature of a dashboard is that it consists of three views or layers of information: (1) graphical, abstracted data to monitor key performance metrics, (2) summarised dimensional data to analyse the root cause of problems, and (3) detailed operational data that identifies what actions to take to resolve a problem. Like peeling the layers of an onion, a performance management system lets users peel back layers of information to get to the root cause of a problem. Each successive layer provides additional details, views, and perspectives that enable users to understand a problem and identify the steps they must take to address it.
3. Three types – the last thing to know about dashboards and scorecards is that there are three major types: operational, tactical, and strategic. Each type applies the three applications and layers described previously, in slightly different ways:
 - Operational dashboards track core operational processes and often display more real-time data. Operational dashboards emphasise monitoring more than analysis or management
 - Tactical dashboards track departmental processes and projects and emphasise analysis more than monitoring or management. They are often implemented using portals and run against data marts or warehouses where data is loaded periodically
 - Strategic dashboards monitor the execution of corporate strategic objectives at each level of the organisation and emphasise management more than monitoring or analysis. Strategic dashboards are often implemented using the balanced scorecard methodology and referred to loosely as "scorecards".

An organisation can and should have multiple versions of each type of dashboard described earlier, each focused on different business problems or functional areas. Ideally, these dashboards are all built on a single data infrastructure and application platform to deliver consistent performance information throughout the enterprise.

In reality, few companies stay ahead of the wave of dashboard implementations. To avoid creating silos of information, organisations should coordinate these efforts using an enterprise program office, a BI competency centre, and/or a governance program. Otherwise, they'll be forced to consolidate these diverse, non-integrated dashboards, which is challenging and costly (Eckerson, 2006).

There are many ways to architect dashboards. Since they are full-fledged information systems that require extracting and merging data from multiple systems to meet business needs, the technical architecture must map to the business to deliver the required functionality (Eckerson, 2006).

A performance management system (by implication a dashboard) needs to align with an organisation's business architecture, which consists of: stakeholders (investors, board, executives, workers), strategy (mission, goals, objectives, vision, values), and tactics and resources (people, technology, capital, projects). Business architecture is based on business semantics and metrics. Semantics are the terms, definitions, rules, and metadata that comprise an organisation's vocabulary and govern how it communicates about performance. Metrics,

on the other hand, translate an organisation's strategy into measures that enable the organisation to track its performance against goals (Eckerson, 2006).

In the case of dashboards, the type of metrics used are usually referred to as the Key Performance Indicators, and this can be defined as metric that embeds performance targets so organisations can chart progress towards goals. The targets reflect desired end states (e.g. amount of revenue by end of year) as well as interim targets for reaching those end-state goals (i.e. monthly revenue targets that factor towards the overall goal). Most Key Performance Indicators have minimum and maximum targets or thresholds that define an acceptable range of performance for interim and end-state goals. When performance exceeds a threshold, the performance dashboard highlights the change in status using conditional formatting (e.g. stoplights change colour) or by sending alerts (Eckerson, 2006).

One overlooked aspect of creating metrics is defining the organisational levels to which they apply. Ideally, metrics cascade down from the top of the organisation to the bottom, while data rolls up from the bottom to the top. A single metric deployed universally enables organisations to easily aggregate detailed data, provide a comprehensive view of organisational performance, and create drill paths from summary to detailed data. This provides the transparency and visibility that visionary executives desire and regulators now require (Eckerson, 2006).

2.7 Enterprise Architecture

2.7.1 Overview

An enterprise architecture is the explicit description and documentation of the current and desired relationships among business and management processes and information technology. It describes the "current architecture" and "target architecture" to include the rules and standards to optimize and maintain the environment which the agency wishes to create and maintain by managing its IT portfolio. The enterprise architecture should also provide a strategy that can enable the agency to support its current state and also act as the roadmap for transition to its target environment. These transition processes will include an agency's capital planning and investment control processes (CMII Research Institute, 2010).

Enterprise architectures are essential for evolving information systems and developing new systems. This is accomplished in logical or business terms (e.g., mission, business functions, information flows, and systems environments) and technical terms (e.g., software, hardware, communications), and includes a Sequencing Plan for transitioning from the baseline environment to the target environment. If defined, maintained, and implemented effectively, these institutional blueprints assist in optimizing the interdependencies and interrelationships among an organization's business operations and the underlying IT that support operations (FCIOOC, 2001).

Many enterprise-architectural methodologies have come and gone in the last 20 years. At this point, perhaps 90% of the field use one of these four methodologies (Sessions, 2007):

- The Zachman Framework for Enterprise Architectures — Although self-described as a framework, is actually more accurately defined as a taxonomy
- The Open Group Architectural Framework (TOGAF) — Although called a framework, is actually more accurately defined as a process

- The Federal Enterprise Architecture — Can be viewed as either an implemented enterprise architecture or a proscriptive methodology for creating an enterprise architecture
- The Gartner Methodology — Can be best described as an enterprise architectural practice

2.7.2 History of Enterprise Architecture

The field of enterprise architecture essentially started in 1987, with the publication in the IBM Systems Journal of an article titled "A Framework for Information Systems Architecture," by J.A. Zachman. In that paper, Zachman laid out both the challenge and the vision of enterprise architectures that would guide the field for the next 20 years. The challenge was to manage the complexity of increasingly distributed systems (Sessions, 2007).

Zachman's vision was that business value and agility could best be realized by a holistic approach to systems architecture that explicitly looked at every important issue from every important perspective (Sessions, 2007). A summary of enterprise architecture evolution timeline is as follows (CMII Research Institute, 2010):

- 1987 – A Framework for Information Systems Architecture by Zachman.
- 1994 – Technical Architecture Framework for Information Management (TAFIM) by the Department of Defence.
- 1996 – The Clinger-Cohen bill passed by Congress.
- 1998 – TAFIM was retired but revived by the Open Group and is now The Open Group Architecture Framework (TOGAF).
- 1999 – A CIO Council with CIOs from each government agency released the Federal Enterprise Architecture Framework (FEAF).
- 2002 – The Office of Management and Budget (OMB) took over and re-named FEAF as the Federal Enterprise Architecture (FEA).
- 2005 – Gartner purchased the Meta Group and became the dominant enterprise architecture provider in the private (commercial enterprise) sector.

The following sections look more closely at today's main methodologies and draw a comparison amongst them.

2.7.3 The Zachman Framework for Enterprise Architectures

The Zachman Framework for Enterprise Architecture is a two dimensional classification scheme for descriptive representations of an Enterprise. It was derived through observation of descriptive representations (design artefacts) of various physical objects like airplanes, buildings, ships, computers, etc. in which it was empirically observed that the design artefacts (the descriptive representations, the product descriptions, the engineering documentation) of complex products can be classified by the audience for which the artefact was constructed (the Perspective) as well as classified by the content or subject focus of the artefact (the Abstraction) (Zachman, 2003) . The Zachman Framework is diagrammed in **Figure 16**.

	Data (What)	Function (How)	Network (Where)	People (Who)	Time (When)	Motivation (Why)
Objectives / Scope	List of things important to the enterprise	List of processes the enterprise performs	List of locations where the enterprise operates	List of organizational units	List of business events / cycles	List of business goals / strategies
Model of the Business	Entity relationship diagram (including m:m, n-ary, attributed relationships)	Business process model (physical data flow diagram)	Logistics network (nodes and links)	Organization chart, with roles; skill sets; security issues.	Business master schedule	Business plan
Model of the Information System	Data model (converged entities, fully normalized)	Essential Data flow diagram; application architecture	Distributed system architecture	Human interface architecture (roles, data, access)	Dependency diagram, entity life history (process structure)	Business rule model
Technology Model	Data architecture (tables and columns); map to legacy data	System design: structure chart, pseudo-code	System architecture (hardware, software types)	User interface (how the system will behave); security design	"Control flow" diagram (control structure)	Business rule design
Detailed Representation	Data design (denormalised), physical storage design	Detailed Program Design	Network architecture	Screens, security architecture (who can see what?)	Timing definitions	Rule specification in program logic
Function System	Converted data	Executable programs	Communication s facilities	Trained people	Business events	Enforced rules

Figure 16: The Zachman Framework

The rows represent the points of view of different six players in the systems development process, while columns represent different aspects of the process, and the players are as follows (Hay, 1997):

1. Scope (Ballpark view) – Definition of the enterprise's direction and business purpose. This is an industry view, concerned with the things that define the nature and purpose of the business. This is necessary to establish the context for any system development effort.
2. Model of the business (Owner's view) – This defines “in business terms”, the nature of the business, including its structure, functions, organization, and so forth.
3. Model of the information system (Architect's view) – This defines the business described in step 2, but in more rigorous information terms. Where row two described business functions, for example, as perceived by the people performing them, row three describes them specifically as transformations of data. Where row two described all the things of interest to the enterprise, row three describes those things about which the organization wishes to collect and maintain information, and begins to describe that information.
4. Technology model (Designer's view) – This describes how technology may be used to address the information processing needs identified in the previous rows. Here

relational databases are chosen over network ones (or vice versa), kinds of languages are selected and program structures are defined, user interfaces are described, and so forth.

5. Detailed representations (Builder's view) – This is a view of the program listings, database specifications, networks, and so forth that constitute a particular system. These are all expressed in terms of particular languages.
6. Functioning system – Finally, a system is implemented and made part of an organization.

The columns in the Zachman framework represent different areas of interest for each perspective. The columns describe the six dimensions of the systems development effort, and these are as follows (Hay, 1997):

1. Data – Each of the rows in this column address understanding of and dealing with any enterprise's data. This begins in row one with a list of the things that concern any company in this industry, affecting its direction and purpose. As you pass down through the rows, you move to progressively more rigorous descriptions of the data (row two is the business person's view, and row three is a disciplined translation of this), until you get to row four, where a specific design approach (and a specific database management system) is specified. Row five is the detailed representation of the data on the computer (tablespaces and the like), and row six is the working database.
2. Function – The rows in the function column describe the process of translating the mission of the enterprise into successively more detailed definitions of its operations. Where row one is a list of the kinds of activities the enterprise conducts, row two describes these activities in a contiguous model. Row three portrays them in terms of data transforming processes, described exclusively in terms of the conversion of input data into output data. The technology model in row four then converts these data conversion processes into the definition of program modules and how they interact with each other. Pseudo-code is produced here. Row five then converts these into source and object code. Row six is where the code is linked and converted to executable programs.
3. Network – This column is concerned with the geographical distribution of the enterprise's activities. At the strategic level (row one), this is simply a listing of the places where the enterprise does business. At row two, this becomes a more detailed communications chart, describing how the various locations interact with each other. Row three produces the architecture for data distribution, itemizing what information is created where and where it is to be used. In row four, this distribution is translated into the kinds of computer facilities that are required in each location, and in row five, these facilities requirements are translated into specification of particular computers, protocols, communications facilities, and the like. Row six describes the implemented communications facilities.
4. People – The fourth column describes who is involved in the business and in the introduction of new technology. The row one model of people is a simple list of the organizational units and each unit's mission. In row two, this list is fleshed out into a full organization chart, linked to the function column. Here also, requirements for security are described in general terms. In row three, the potential interaction between people and technology begins to be specified, specifically in terms of who needs what information to do his job. In row four, the actual interface between each person and the technology is designed, including issues of interface graphics, navigation paths, security rules and presentation style. In row five, this design is converted into the

outward appearance of each program, as well as the definitions of access permissions in terms of specific tables and/or columns each user can have access to. In row six, you have trained people, using the new system.

5. Time – The fifth column describes the effects of time on the enterprise. It is difficult to describe or address this column in isolation from the others, especially column two. At the strategic (row one) level, this is a description of the business cycle and overall business events. In the detailed model of the business (row two), the time column defines when functions are to happen and under what circumstances. Row three defines the business events which cause specific data transformations and entity state changes to take place. In the technology model (row four), the events become program triggers and messages, and the information processing responses are designed in detail. In row five, these designs become specific programs. In row six business events are correctly responded to by the system.
6. Motivation – This concerns the translation of business goals and strategies into specific ends and means, and can be expanded to include the entire set of constraints that apply to an enterprise's efforts. In row one, the enterprise identifies its goals and strategies in general, common language terms. In row two, these are translated into the specific rules and constraints that apply to an enterprise's operation. In row three, business rules may be expressed in terms of information that is and is not permitted to exist. This includes constraints on the creation of rows in a database as well as on the updating of specific values. In row four, these business rules will be converted to program design elements, and in row five they will become specific programs. In row six, business rules are enforced.

The major contribution of the Framework is its explicit recognition that there is more at work than functions and data.

2.7.4 The Open Group Architecture Framework

The Open Group Architecture Framework (TOGAF) is an attempt to create a generic architecture framework for development and management of software intensive systems within an enterprise. The framework is adaptable for use in any type of organisation (Pulkkinen, 2004).

TOGAF takes as a starting point, that several architecture frameworks exist that describe each a set of deliverables (outcomes / work products / outputs). Yet these frameworks or models do not advise in how to proceed in producing an architecture using the outputs (Pulkkinen, 2004). As shown in the **Figure 17**, TOGAF divides the enterprise architecture into four categories, as follows (Sessions, 2007):

1. Business architecture – Describes the processes the business uses to meet its goals
2. Application architecture – Describes how specific applications are designed and how they interact with each other
3. Data architecture – Describes how the enterprise datastores are organized and accessed
4. Technical architecture – Describes the hardware and software infrastructure that supports applications and their interactions

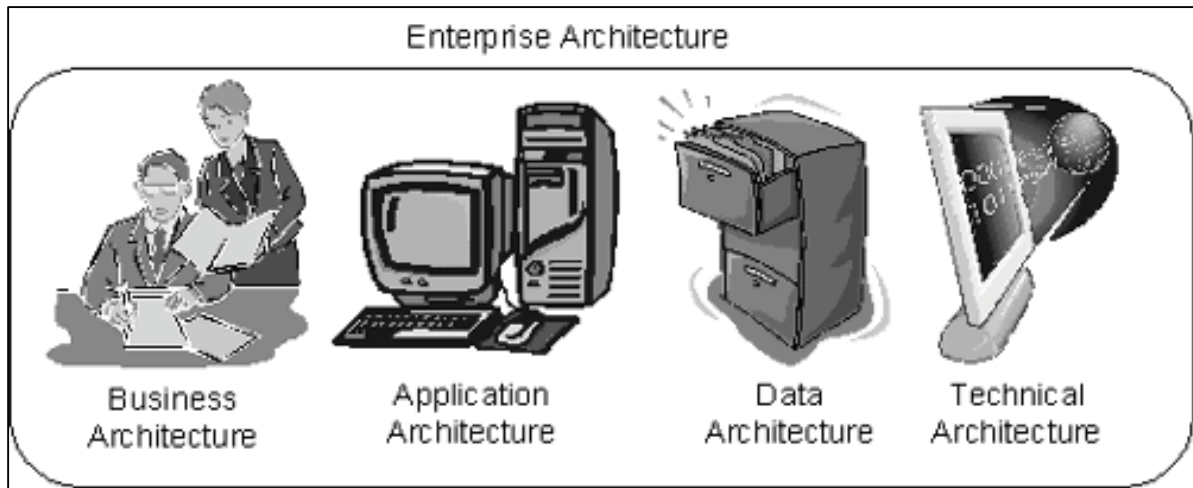


Figure 17: TOGAF's enterprise architecture (Sessions, 2007)

The three main components of TOGAF are as follows (Pulkkinen, 2004):

1. Architecture Development Method (ADM) – this consists of cyclic architecture development phases, with the phases concentrating on either the development of a viewpoint, an architecture, or tasks related with architecture management. The phases can be expanded to development cycles. Fully defined is the Technology Architecture development cycle. ADM can be used as a reference methodology, but is not as such ready to be used in IT companies that are providing architecture consultation and development services.
2. Foundation Architecture – this is a concept that refers to various architecture frameworks and reference architectures, and provides a map for dealing with architecture issues in the organisation. The Foundation Architecture consists four components providing comprehensive sets of details about the generic reference architectures, and this are:
 - A Technical Reference Model (TRM)
 - A Standards Information Base (SIB)
 - Integrated Information Infrastructure Reference Model (III-RM)
 - Building Blocks Information Base (BBIB, organization specific)
3. Resource Base – The resource base contains good practices for development and management of user organisation enterprise architectures.

TOGAF sets therefore the main emphasis on the process expressed in ADM, and provides a set of deliverables (outputs) as an example. However, the use of any other set with the process model is encouraged. Viewed as an architectural process, TOGAF complements Zachman Framework. Zachman tells how to categorize artefacts, TOGAF gives a process for creating them (Pulkkinen, 2004).

2.7.5 The Federal Enterprise Architecture

The Enterprise Architecture (FEA) is the attempt by the federal government of the United States to unite its myriad agencies and functions under a single common and ubiquitous enterprise architecture. FEA emerged in response to a piece of legislation, the Clinger-Cohen Act of 1994 (officially the Information Technology Management Reform Act), which instructed federal agencies to develop a master plan for integrating new technologies,

managing IT acquisitions, and measuring and reporting on performance. FEA is still in its infancy, as most of the major pieces have been available only since 2006 (Sessions, 2007).

The FEA is a strategic information asset base that defines the business, information necessary to operate the business, technologies necessary to support the business operations, and transitional processes for implementing new technologies in response to the changing needs of the business. FEA has both a comprehensive taxonomy, like Zachman, and an architectural process, like TOGAF. FEA can be viewed as either a methodology for creating an enterprise architecture or the result of applying that process to a particular enterprise (namely, the U.S. Government) (Sessions, 2007).

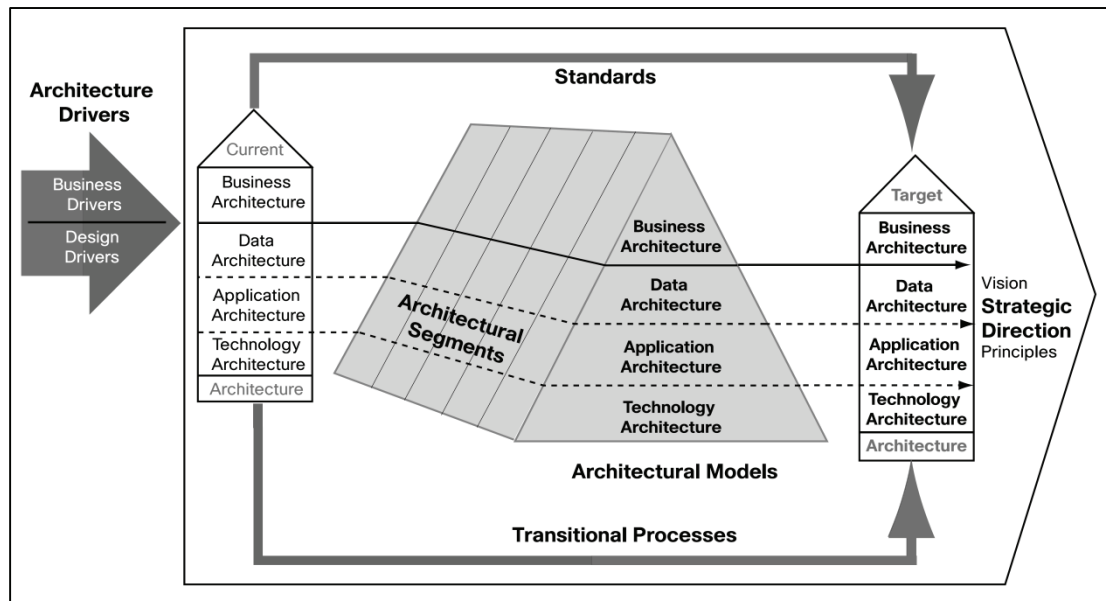


Figure 18: The FEA overview diagram (CISCO, 2009)

The FEA consists of five FEA reference models aimed at giving standard terms and definitions for the domains of enterprise architecture and, thereby, facilitate collaboration and sharing across the federal government. The five reference models are as follows (Sessions, 2007):

1. The Business Reference Model (RBM) – this gives a business view of the various functions of the federal government. For example, the BRM defines a standard business capability called water resource management that is a sub-function of natural resources that is considered a line-of-business of the broader services for citizens business area.
2. The Components Reference Model – this gives a more IT view of systems that can support business functionality. For example, the Customer Relationship Management defines a customer-analytics system that I described earlier in the hypothetical interchange between the IRS and the GPO.
3. The Technical Reference Model (TRM) – defines the various technologies and standards that can be used in building IT systems. For example, the TRM defines HTTP as a protocol that is a subset of a service transport that is a subset of service access and delivery.
4. The Data Reference Model (DRM) – defines standard ways of describing data. For example, the DRM defines an entity as something that contains attributes and participates in relationships.

5. The Performance Reference Model (PRM) – defines standard ways of describing the value delivered by enterprise architectures. For example, the PRM describes quality as a technology measurement area that is defined as "the extent to which technology satisfies functionality or capability requirements."

The five FEA reference models are all about establishing common languages. The goal is to facilitate communication, cooperation, and collaboration across political boundaries to facilitate cross-agency analysis and the identification of duplicative investments, gaps, and opportunities for collaboration within and across agencies. **Figure 19**, for example, shows a segment map of the federal government and it can be seen that there are many segments (the vertical columns) that are used in multiple agencies, and any or all of these are good candidates for sharing (Sessions, 2007).

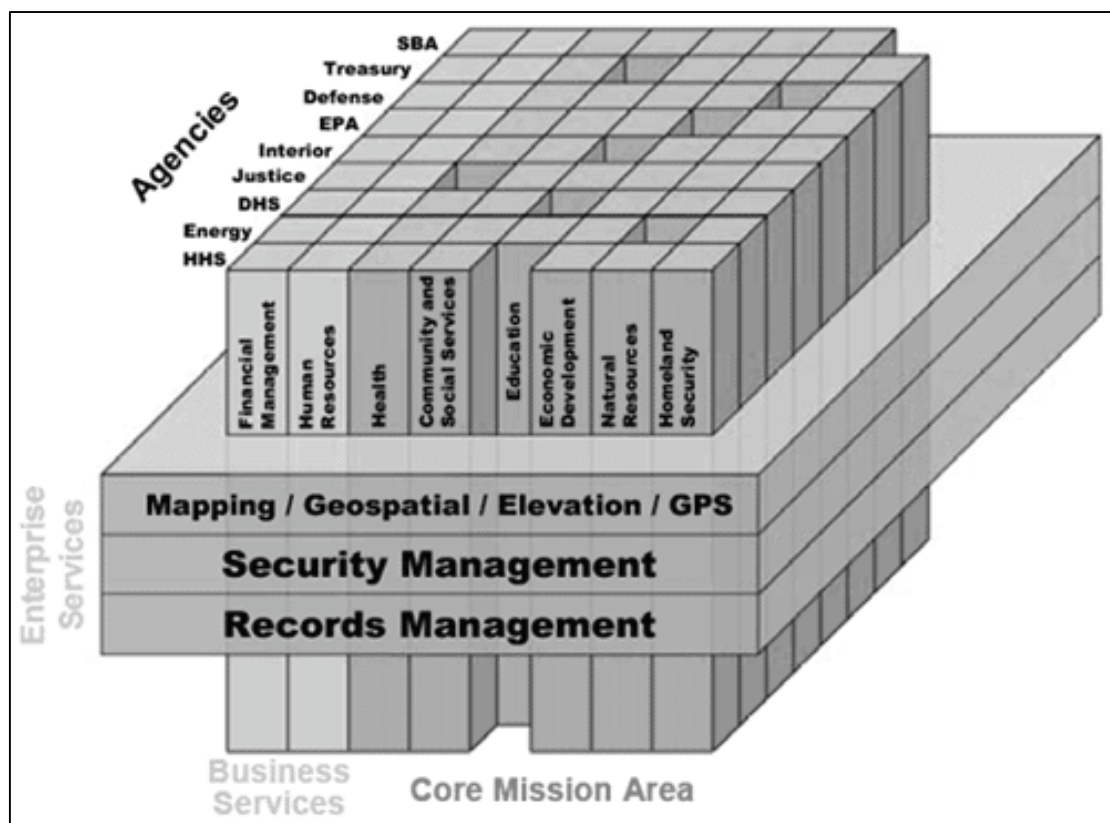


Figure 19: Segment map of the federal government (Sessions, 2007)

The FEA Process is primarily focused on creating a segment architecture for a subset of the overall enterprise (in FEA's case, the enterprise is the federal government and the subset is a governmental agency). The overall segment-architecture development process is (at a very high level) as follows (Sessions, 2007):

- Step 1: Architectural Analysis – Define a simple and concise vision for the segment, and relate it back to the organizational plan.
- Step 2: Architectural Definition – Define the desired architectural state of the segment, document the performance goals, consider design alternatives, and develop an enterprise architecture for the segment, including business, data, services, and technology architectures.
- Step 3: Investment and Funding Strategy – Consider how the project will be funded.

- Step 4: Program Management Plan and Execute Projects – Create a plan for managing and executing the project, including milestones and performance measures that will assess project success.

2.7.6 The Gartner Enterprise Architecture

There is very little documentation about the Gartner methodology in the public domain although the methodology is widely used. However, to support their users, Gartner has a subscription services giving user access to Gartner's view of enterprise architecture which provides a solid base for new research into the discipline and gives their clients insight into the best practices for building a well-defined, well-aligned enterprise architecture in a mature, productive enterprise architecture program. See **Figure 20** for the Gartner Framework.

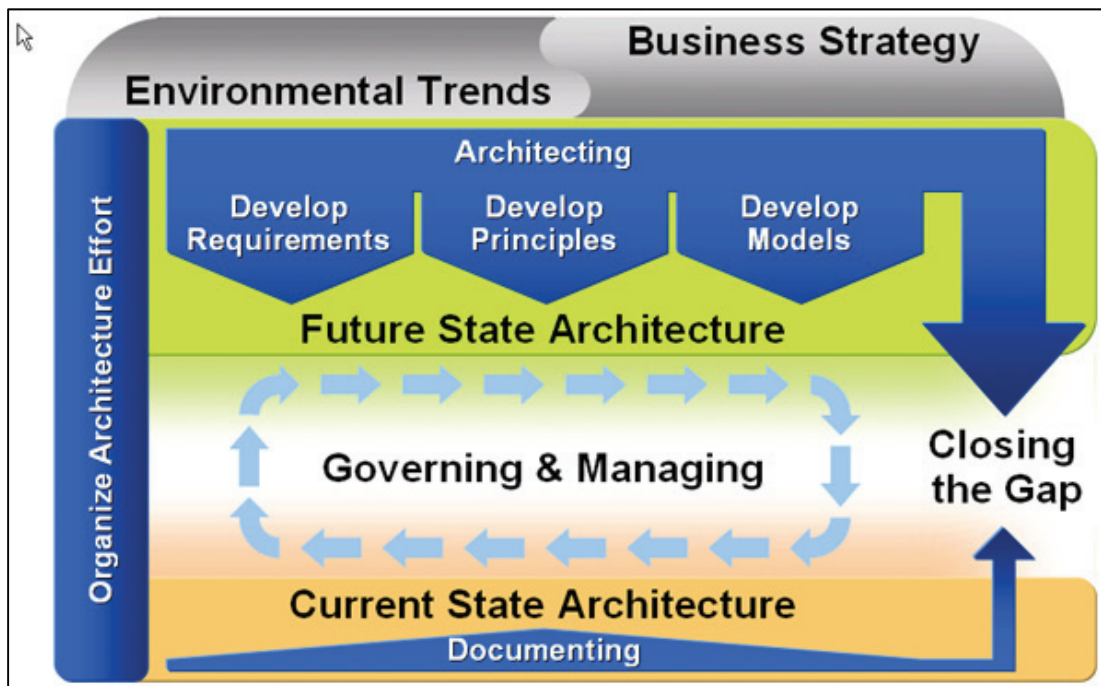


Figure 20: Gartner Framework (WIKIDOT, 2011)

The Gartner methodology is a little different to the three previously presented it that It is not a taxonomy (like Zachman), a process (like TOGAF), or a complete methodology (like FEA). Instead, it can be defined as a practice. It is the enterprise-architecture practice of one of the best known IT research and consulting organizations in the world (Sessions 2007).

Basically, Gartner believes that enterprise architecture is about bringing together three constituents: business owners, information specialists, the technology implementers. If one can bring these three groups together and unify them behind a common vision that drives business value, then one has succeeded; if not, it is a failure (Sessions 2007).

Gartner also believes that the enterprise architectures must start with where an organization is going, not with where it is. Gartner recommends that an organization begin by telling the story of where its strategic direction is heading and what the business drivers are to which it is responding. Gartner requires this story in plain language, without worrying about prescribed documentation standards, acronyms, or techno-babble. The only goal is making sure that everybody understands and shares a single vision (Sessions 2007).

As soon as an organization has this single shared vision of the future, it can consider the implications of this vision on the business, technical, information, and solutions architectures of the enterprise. The shared vision of the future will dictate changes in all of these architectures, assign priorities to those changes, and keep those changes grounded in business value (Sessions 2007).

Enterprise architecture, in the Gartner view, is about strategy, not about engineering. It is focused on the destination. The two things that are most important to Gartner are where an organization is going and how it will get there. Any architectural activity that is extraneous to these questions is irrelevant (Sessions 2007).

2.7.7 Comparison of Enterprise Architecture Methodologies

In general, there is no one enterprise architecture methodology that can be suitable for all organisations and purposes. Therefore, it is up to the organisation to choose one or a combination of the methodologies depending on the organisation needs. To aid the choice, Sessions (2007) has undertaken a comparison of the following top four enterprise architecture methodologies: Zachman Framework, The TOGAF, the FEA and the Gartner methodology.

Sessions (2007) summarizes the similarities and differences in the four methodologies compared on the basis of twelve criteria using the following ratings scale:

1. does a very poor job
2. does an inadequate job
3. does an acceptable job
4. does a very good job.

The twelve criteria are as follows (Sessions 2007):

1. Criteria 1: Taxonomy completeness – how well the various architectural artefacts are classified.
2. Criteria 2: Process completeness – how well the methodology guides you through the process.
3. Criteria 3: Reference model guidance – how useful the methodology is in helping you build a relevant set of reference models.
4. Criteria 4: Practice guidance – how much the methodology helps you develop a culture in which enterprise architecture is valued and used.
5. Criteria 5: Maturity model – how much guidance the methodology gives you in assessing the maturity of your organization using enterprise architecture.
6. Criteria 6: Business focus – whether the methodology will focus on using technology to drive business value via reduced expenses and/or increased income.
7. Criteria 7: Governance guidance – how helpful the methodology will be in creating an effective governance model for enterprise architecture.
8. Criteria 8: Partitioning guidance – how well the methodology will guide you into effective autonomous partitions of the enterprise.
9. Criteria 9: Prescriptive catalogue – how well the methodology helps you set up a catalogue of architectural assets that can be reused.
10. Criteria 10: Vendor neutrality – ability to avoid getting locked in with one consulting organization by adopting this methodology.
11. Criteria 11: Information availability – the amount and quality of inexpensive information about this methodology.
12. Criteria 12: Time to value – time before you will be using this methodology to deliver business value.

The results of the assessment are shown in **Figure 21**. One of the important points of **Figure 21** is that none of the enterprise architecture methodologies is really complete. Each has its strengths and weaknesses. This presents the difficulty on how to choose a suitable methodology for an organisation. Sessions (2007) recommended the following approach:

- Going through the rows (criteria) in **Figure 21**, eliminating any that are not important to an organization.
- Adding any additional rows (criteria) that are important, and rate each of the methodologies in that area.
- Changing any of the ratings.

At the end of this exercise, one should have a good idea about the strengths and weaknesses of each methodology with respect to an organisation's needs. There will be fewer instances where a clear winner emerges from the methodologies. In situations where there is no clear winner, it is recommended that a blended approach be used, in which an enterprise architectural methodology is creating consisting of bits and pieces of each of the methodologies that provide the highest value in the specific areas of concern.

	Ratings			
Criteria	Zachman	TOGAF	FEA	Gartner
Taxonomy completeness	4	2	2	1
Process completeness	1	4	2	3
Reference-model guidance	1	3	4	1
Practice guidance	1	2	2	4
Maturity model	1	1	3	2
Business focus	1	2	1	4
Governance guidance	1	2	3	3
Partitioning guidance	1	2	4	3
Prescriptive catalog	1	2	4	2
Vendor neutrality	2	4	3	1
Information availability	2	4	2	1
Time to value	1	3	1	4

Figure 21: Criteria and ratings for each methodology (Sessions 2007)

2.8 Integration Maturity Assessment Process

The maturity assessment process facilitates the assessment of an organization's current and desired future states of integration and flexibility. Applying maturity assessments leads an organisation towards a more agile, flexible organization; it results in a roadmap showing how to get from the current to the desired situation. However, in order to increase maturity in a number of critical processes, steps must be taken to ensure that proper documentation, training and measurement is established for every process (Newcomb, 2009). There are a number of maturity assessment models relating to IT, enterprise architecture, business

strategy, however there are fewer models that relate to integration. The following sections discussed one of the integration maturity models.

2.8.1 The Integration Maturity Model

Nelson (2005) developed the Integration Maturity Model as shown in **Figure 22**. The Model explains how integration takes place within context of organizational maturity. This means that the organization must “mature” through stages of the integration model and that needs at one stage must be fulfilled before an organization can move to a more advanced stage of integration.

Strong  Integration None	Effective Partnerships	Effective cross-functional integration; seamless interaction; sophisticated systems; effective use of IT to achieve goals in another area; strong and transparent communication structures
	Data and Needs Resolution	Developing more proactive and collaboration mechanisms; efforts focused on developing a shared understanding on data and support needs; access to data and resolving data quality.
	Communication Development	Working toward better interdepartmental understanding and developing quality communication; begin getting more interdepartmental input in planning and decision-making processes; basic participation and collaboration occur
	Basis Understanding	Trust, basic understanding, and appreciation are all issues to be resolved; interaction begins to focus on communication of basic information such as priorities and rationales for decision making; the medium and frequency of communication are very important
	“Dis-Integration”	Integration does not exist; open hostility or nearly complete lack of understanding or trust might be present; there is little to no effective interaction related to the work relationship

Figure 22: Integration Maturity Model (Nelson, 2005)

According to Nelson (2005), the first stages of the integration maturity model require the IT unit and other functional units to address basic needs for an effective working relationship, such as improving communication, trust, appreciation, and understanding. The later stages focus on the work-related dimensions of integration unique to the collaboration of the two functional areas. Thus, without basic understanding, communication, and trust between IT

and other functional units, an organization will be less able to make effective use of technology to support the other functional units (Nelson, 2005).

2.8.2 Stages of Integration Maturity

The lowest level or earliest level of integration maturity is what might be best termed “disintegration” or the complete absence of an effective working relationship between IT and another functional area. Disintegration may exist because the two functional areas never had a reason or incentive to interact, or it could be rooted in deeper problems related to internal politics or battles. At this stage there is little understanding regarding how each department operates, makes its decisions, sets its priorities, or even performs its work. This lack of understanding and communication may lead to mistrust and other unproductive conditions (Nelson, 2005).

At the second stage of the integration maturity model, issues of trust and appreciation are most prevalent. Individuals in the units typically focus on communicating basic information between units. Organization D is an example of an organization typical of this stage, where integration is poor, but the organization has begun to address the problem. Organizations at the earlier stages of the integration maturity model are likely to have unsophisticated systems and perhaps little more than standardized “green bar” reports where the format and data are mostly pre-determined, inflexible, and available on a regular schedule (as compared to “as needed”) (Nelson, 2005).

At the third stage, the quality of communication becomes a greater concern. Organization C is a characteristic of an organization at this stage. The emphasis here is on communicating effectively. At this stage, developing quality communication between IT and the functional unit is more important than the data infrastructure or system sophistication. Cross-functional work groups are more likely to act and perform like committees than teams as participation and collaboration mechanisms initiated and residual early-stage issues are further addressed. Some early stage organization may have a sophisticated functional information system, such as decision-support system of some type, but the functional users report that the system does not meet their needs and therefore may not be used (Nelson, 2005).

At the fourth stage, the two departments focus on resolving data issues and building a shared understanding of data support needs. Organization B is a characteristic of this stage of integration. Data accuracy is an important issue, as is further improving joint participation in decision making and system development. Unlike the earlier stages, where communication was a significant problem or focus, at this stage there is a greater sense that “we do a pretty good job communicating” cross-functional work groups begin to function more like teams than committees. Similarly, individuals in one functional unit appear to have a better understanding and respect for the work of individuals in other functional area. Integrated data sets, data warehousing, and initial data mining tools emerge that are driven by the other function’s needs for information. These refinements in the system and data infrastructure will lead to functional information systems that are often more sophisticated and more effective (Nelson, 2005).

At the final stage of the integration maturity model, the focus is clearly on making effective use of available data. Organization A is a representative of this stage, where the functional information systems are used more often and more sophisticated than at earlier stages. The systems are likely based on data-warehousing infrastructure with advanced decision support

tools and flexible, real-time inquiry and reporting capability. System changes and enhancements required to meet changing business needs often occur very quickly, and functional users report high degree of satisfaction with the systems data. While individuals in organizations at other stages might be quick to point out problems in their interaction between departments, at this stage the interface is more seamless. Less energy is spent on managing the interface and more is spent on cooperation for effective achievement of goals (Nelson, 2005).

2.8.3 Using the Integration Maturity Model

Placement in the integration maturity model can be determined through several mechanisms i.e. manager experiences, staff focus groups, specialists' evaluations. In order to valuate observational experiences or other data collected in the assessments process, managers should look for patterns in line with the different stages of integration. For example, poorly integrated functional areas are likely to find that integrative mechanisms, such as effective group participation patterns and high quality communication are lacking and employees will place a high importance on improving these. In contrast well-integrated functional areas would place importance on the communication and integrative mechanisms based on the experience (not just the assumption) that they are working well (Nelson, 2005).

Once an organization identifies its stage of maturity within the integration maturity model, the core issues for that stage can be addressed. For example, an organization at one of the early stages should focus on building trust and understanding. To do this, they must share the reasoning behind decisions that are made, institute cross functional training, and communicate plans and priorities. They must also take special care to reduce the risk of miscommunication, which can be common at this stage. At lower stages of integration maturity, face-to-face communication, while time consuming, is frequently more effective than telephone conversation or e-mail. As trust and communication quality improve, additional focus can be placed on participation decision making and planning. When these basic integrative mechanisms are in place, the focus can shift to improving the data infrastructure and end-to-end process through joint effort. This path to improving integration would yield integrated data, application and process infrastructures that are more effective and useful in achieving the business objectives at the department level (Nelson, 2005).

2.9 Support Services for Integration

2.9.1 Technology

2.9.1.1 Overview

During the past decades, research and technological development have contributed to the societies' advancement in awareness, knowledge and policy insight of the role water plays in the environmental and socio-economic welfare, and the need to proactively defend the sustainability of our aquatic ecosystems (European Union Research, 2006). However, also over the last two decades, water management has changed from a focus on distinct sectors, to a more integrated perspective in which a holistic approach has to be adopted to construct and to select the most suitable alternatives for water management. In this paradigm shift water management has proved to be a complex process involving many actors, with different knowledge and at different levels. The success of management initiatives in such a context has become dependent on the capability to facilitate the cooperation between the actors

(depicted using integrated tools/systems) and the integration between different sources of knowledge (Integrated information/data) as well as the technology (Barlebo, 2006).

This deeper understanding, combined with scientific underpinning of the diverse impacts of global change processes, have resulted in a wider recognition of the urgent need for new concepts and tools to support a paradigm shift in the way water resources are planned, managed and used in all aspects of everyday life. Policy, regulatory systems, institutions and governance, knowledge management systems and promotion of technological ingenuity, social acceptability and affordability are some of the main elements to be taken into account when trying to devise solutions to this complicated equation of a sustainable paradigm shift in water resources management (European Union Research, 2006).

New conceptual pillars have emerged embracing sustainability, risk assessment and risk management, in an effort to harness uncertainty and better simulate real life conditions and – global and local – ecosystem processes. Therefore, it has also become evident that the enormous investment in knowledge needed for transformation and harmonised change, adaptive to local water conditions, has to be pursued through wider multi-stakeholder collaborations beyond national and continental borders. Thus, the flow of information between the actors, the analysis of the ways in which networks of actors and institutions communicate internally and externally is vital, (Barlebo, 2006). This has rendered traditional management systems unsuccessful: in providing integrated solutions, timely identification and warning of emerging environmental problems; in delivering effective feedback on the adequacy of policies and programs; and, in providing policy-makers with a sound basis for action. But, above all, traditional monitoring systems are less successful in delivering information to the public, stakeholders, research personnel, and managers so as to raise awareness, educate and provide the basis for informed decisions and choices. Therefore, there is a need to integrate technological advancements, diverse water knowledge and diverse tools/systems into today's water management approaches (Barlebo, 2006).

It is a fact that technology/integrated-tools/information-systems cannot solve the problems of a basin by themselves; rather it is people that can do that (BDMF, 2000) cited in (Barlebo, 2006). Thus, the technology/integrated-models/information-systems should be used to facilitate the communication and positions represented by those who participate in the decision-making process in the basin. Therefore, while the systems maintaining their scientific foundation and keep up with technological advancement; they must also meet the following basic characteristics (Barlebo, 2006):

- Multisectorintegrality.
- Representativity of the problem.
- Flexibility.
- Accessibility.

Considering these characteristics in the application of technology and development of tools or information systems for IWRM, they would lead to greater compatibility with this new planning paradigm shift, which need to be visualised as a dynamic process that should evolve through time.

2.9.1.2 Technological advancement towards sustainability

In evaluating the range of available management tools, the role of and scope for technological advances should still be carefully considered as a factor that may help achieve sustainable

water resources management. There is scope for substantial progress both in technology refinement within the water sector itself and in those other productive sectors which critically affect the supply of and demand for water services. Although traditional technologies like rainwater harvesting can also play a key role, technological innovation and adaptation are key components of many efforts within the water sector (GWP, 2000).

At the conceptual level, tools and forecasting systems are being improved, particularly as a result of advances in computer technology, to allow better predictions of temporal and spatial variations in the quantity and quality of available water resources. This may help to reduce uncertainties and risks in the use and management of the resources. Water saving technologies, improved and cost-effective methods for the treatment and reuse of wastewater, aquifer recharge technologies, human waste disposal systems that require no or extremely small quantities of water, and cheap but effective water purification systems for villages are other examples of promising innovations which can promote the sustainability of future water resources (GWP, 2000).

In addition to the above-mentioned promising prospects, a word of caution is warranted on the issue of technology. Many projects in the water sector have failed due to the uncritical application in developing countries of technologies that have worked in industrialised nations but in totally different physical, social and economic settings. It has to be realised that technological choices must take account of specific conditions prevailing at the location of use. This means that the most advanced and modern technology is not necessarily the optimal choice in certain cases. If the system cannot be sustained because of lack of spare parts, skilled manpower or economic resources for operation, it is not the most appropriate solution (GWP, 2000).

Moreover, high-cost technologies can prevent community and household involvement in water management.

2.9.1.3 Technology Life Cycle

According to Khalil (2000), the performance of technology has a recognisable pattern over time that, if properly understood can be of great use in strategic planning. As a matter of fact, neglecting this pattern as a key factor in the planning process may prove very costly to the effectiveness of the way the water sector performs. Managing technology requires deep understanding of the life cycle of the technology, product, process and system (Khalil, 2000).

In essence the technology's improvement performance follows the so called S-curve (i.e. when a technology performance parameter (y-axis) is plotted against time (x-axis), the result resembles an s-shaped diagram called the S-curve). In general, technology progresses through a three-stage technology life cycle, **Figure 23**: (1) the new invention period, also known as the embryonic stage; (2) the technology improvement period, also known as the growth stage; and (3) the mature-technology stage period. The technology becomes vulnerable to substitution or obsolescence when new or better performing technology emerges (Khalil, 2000).

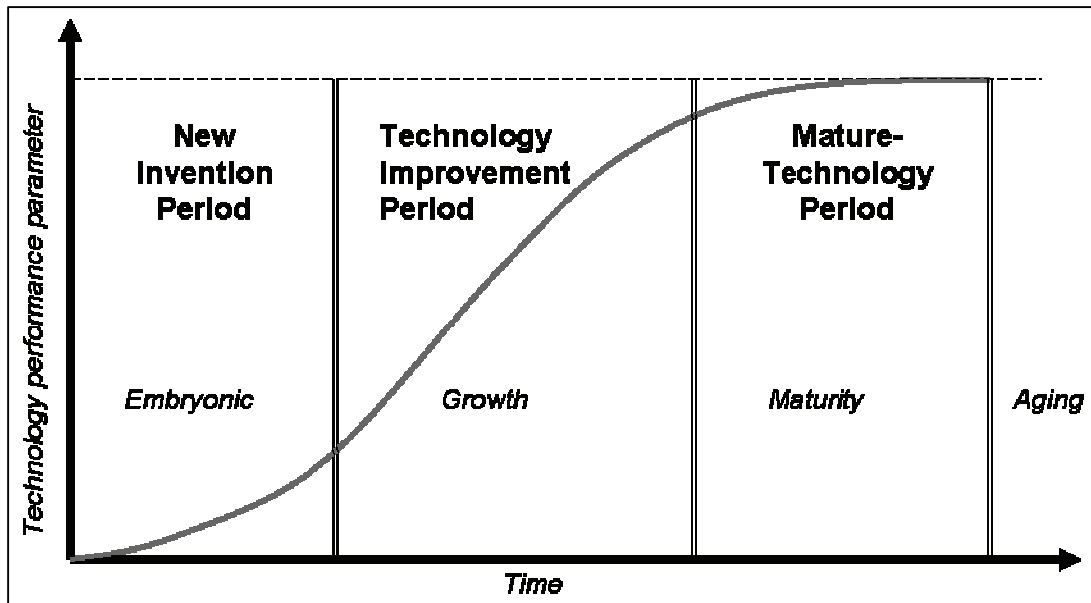


Figure 23: The S-curve of technological progress (Khalil, 2000)

The new invention period is characterised by a period of slow initial growth. This is the time when experimentation and initial bugs are worked out of the system. The technology improvement is characterised by rapid and sustained growth. The mature technology period starts when the upper limit of technology is approached and progress in performance slows down. This is when the technology reaches its natural limits as dictated by factors such as physical limits (Khalil, 2000).

Technology, like all systems, has a hierarchy. A system can consist of a number of sub-systems, and each sub-system may have a number of components. Therefore, technology need not consist of a single component or derive from a single innovation. Technology can consist of multiple technologies and derive from different generations of innovation i.e. the personal computer is a technology and has a technology life cycle; it, however consists of several sub-technologies, for example the microprocessor which can be defined as a technology with a technology life cycle all in its own. It is important for a company to understand their technology hierarchy, as the company has to invest to update its technologies in order to extend the life cycle of the technology (Khalil, 2000).

In today's economy a company's competitiveness is directly linked to its technology. Competitiveness is a comparative concept of the ability and performance of a firm, sub-sector or country to sell and supply goods and/or services in a given market. Therefore to be competitive, several factors must exist: ability, the desire to win, commitment or perseverance, and the availability of certain resources. Management of technology plays a major role in creating and maintaining competitiveness (Khalil, 2000).

2.9.1.4 Technology Planning

Events of the past two decades have shown that business competitiveness is no longer a matter of choice but is a matter of survival. Achieving organisational goals and competing successfully require the development of sound strategies. Strategy involves envisioning and planning for the future. It is the means by which long-term objectives will be achieved. In essence a strategy entails defining goals, deciding the way to reach these goals, setting action

plans to execute specific tasks, and following up on accomplishments to ensure that objectives have been met (Khalil, 2000).

There is a tendency in people to think of strategy as developing a long-range plan, assuming that they will continue to do what they are already doing. There is a fallacy in this assumption, since the underlying environment and technological scene are continually changing. A more appropriate way of thinking about strategy is to think what should be done regardless of what has been done without saddling the plan with existing practices. Therefore, formulating a strategy should be seen as a continuous challenge, requiring the evaluation of old practices and the search for new ones. Thus, a strategy must first affirm the core of the business – what the business knows – and then develop what the business can do (Khalil, 2000).

When an organisation develops a strategy and its associated plans of action, it creates the vehicle that moves it towards the fulfilment of its mission and the attainment of its vision. The purpose of the business strategy is to gain a sustainable economic advantage, while the purpose of technology strategy is to gain sustainable technological advantage that provides a competitive edge. The two strategies must be closely intertwined and highly integrated. The first step towards integrating business and technology strategies is to get the business and technical sides of the organisation to agree on a common set of priorities (Khalil, 2000).

Technology planning is a central component of corporate business planning and is essential for successful strategy implementation and evaluation. The first step in technological planning is forecasting. Forecasting provides visions of the future that can be used to guide actions of the present in anticipation of future states. The traditional forecasting methods – which depends, to a great extent, on projecting past performance into the future – has an inherent weakness in that the future may not behave like the past, as the future state depends on the characteristics and physical limits of the technology, the social and environmental factors. The problem of predicting the future is more difficult with technology as it experiences rapid change. Management must be able to predict discontinuities, which occur when one technology is replaced by another. Therefore, in order to develop a good forecast, a technology forecaster must have a good understanding of technology life cycles and the factors that influence technological development and the rate of innovation. This involves scanning the horizon for emerging critical technologies and requires plotting technology maps that help planner navigate the landscape, i.e. identifying future technologies and sifting through the maze of promising existing technologies (Khalil, 2000).

Another important factor in technology management is technology auditing. A technology audit is an analysis performed to identify the strengths and weaknesses of the technological assets of the organisation. Its aim is to assess the organisation's position in technology in relation to its vision and the state-of-the-art. The technology audit is hence a continuous process of assessment. After an audit, an organisation can develop a statement of objectives that form the core of its strategy. It should then select an optimal strategy for the acquisition and exploitation of technology (Khalil, 2000).

2.9.1.5 Integrated water information systems

Data exchange is a major constraint that impedes the implementation of IWRM in many countries. Data about any given water resource will usually be fragmented between multiple owners, if indeed it exists in the right spatial and temporal granularity at all. In most cases,

there is no coordination between various authorities with respect to data collection and management. Data collection and monitoring programmes are often carried out by various authorities without coordination and integration which leads to inefficient utilisation of available technical and financial resources. For instance, water quality monitoring networks may be established by agencies responsible for water, environment and health without exchanging or sharing the monitoring results (Unknown Author, undated). There is a need to harmonise the water-use terminologies used such as water duties, water requirement, water consumptions, etc., which could be misinterpreted by water experts from the same institution.

Moreover, the frequency of data collection is variable and some data is not regularly updated as there are no standard procedures developed for data collection and analysis. There is a need to establish a mechanism for data exchange and dissemination among various stakeholders. Moreover, no legal framework that regulates data collection, analysis, and dissemination processes exists in many countries. It is essential to develop a centralised, accredited and shared database that includes all data and information related to IWRM through advanced information systems and powerful communication tools and networks. There is also a need to develop protocols, agreements, decrees, etc., and to establish effective mechanisms for data exchange and data sharing among all concerned institutions at all levels: and to provide the legal support to the right-to-know, and means of dissemination of simplified information to all water users and the public at large, about critical water resources issues (Unknown author, Undated).

Sustainable and adaptive IWRM is dependent on the availability and accessibility of information for system analysis and modelling, social learning, and sustainable decision making. According to Letcher et al. (2006) these different aspects are related to a comprehensive basin assessment that requires an efficient data and information management comprising the following considerations:

1. A holistic systems approach must be applied that differentiate between generic components and their regional variation
2. A methodical concept should be implemented that accounts for the systems core components within its natural environment and human dimension
3. The system assessment should account for basins heterogeneity in terms of spatial distribution and determining underlying generic rules
4. The process need to interface multidisciplinary assessment techniques and analysis methods in relation to scale issues in an interdisciplinary manner.
5. IWRM should be seen as a decision making process that is based on comprehensive, spatially distributed information, and adopting a holistic systems approach.

2.9.1.6 Interoperability

2.9.1.6.1 *Overview*

Interoperability refers to the ability of diverse systems and organisations to work together (inter-operate) taking into account social, political, and organisational factors that impact system to system performance (Wikipedia, 2010).

2.9.1.6.2 *Interoperability in government*

Speaking from an e-government perspective, interoperability refers to the collaboration ability of cross-border services for citizens, businesses and public administrations. Exchanging data can be a challenge due to language barriers, different specifications of

formats and varieties of categorisations. Many more hindrances can be identified (Wikipedia, 2010).

If data is interpreted differently, collaboration is limited, takes longer and is not efficient. For instance, if a citizen of Country A wants to purchase land in Country B, the person will be asked to submit the proper address data. Address data in both countries include: full name details, street name and number as well as a post code. The order of the address details might vary. In the same language it is not an obstacle to order the provided address data; but across language barriers it becomes more and more difficult. If the language requires other characters it is almost impossible, if no translation tools are available (Wikipedia, 2010). Hence e-government applications need to exchange data in a semantically interoperable manner. This saves time and money and reduces sources of errors. Fields of practical use are found in every policy area, be it justice, trade or participation, etc. Clear concepts of interpretation patterns are required (Wikipedia, 2010).

Many organisations are dedicated to interoperability. All have in common that they want to push the development of the World Wide Web towards the semantic web. Some concentrate on e-government, e-business or data exchange in general. In Europe, for instance, the European Commission issue the European Interoperability Framework. They also initiated the Semantic Interoperability Centre Europe. A European Land Information Service was established in 2006, as a consortium of European National Land Registers. The aim of the service is to establish a single portal through which customers are provided with access to information about individual properties, about land and property registration services, and about the associated legal environment. In the United States of America, the government's CORE.gov service provides a collaboration environment for component development, sharing, registration, and reuse (Wikipedia, 2010).

2.9.1.6.3 Achieving Software Interoperability

Software Interoperability is achieved through five interrelated ways (Wikipedia, 2010):

1. Product testing – products produced to a common standard, or to a sub-profile thereof, depend on clarity of the standards, but there may be discrepancies in their implementations that system or unit testing may not uncover. This requires that systems formally be tested in a production scenario – as they will be finally implemented – to ensure they actually will intercommunicate as advertised (i.e. they are interoperable). Interoperable product testing is different from conformance-based product testing as conformance to a standard does not necessarily engender interoperability with another product which is also tested for conformance.
2. Product engineering – implements the common standard, or a sub-profile thereof, as defined by the industry/community partnerships with the specific intention of achieving interoperability with other software implementations also following the same standard or sub-profile thereof.
3. Industry/community partnership – industry/community partnerships, either domestic or international, sponsor standard workgroups with the purpose to define a common standard that may be used to allow software systems to intercommunicate for a defined purpose. At times an industry/community will sub-profile an existing standard produced by another organisation to reduce options and thus making interoperability more achievable for implementation.
4. Common technology and Internet Protocol – the use of a common technology or Internet Protocol may speed up and reduce complexity of interoperability by reducing variability between components from different sets of separately developed software

products and thus allowing them to intercommunicate more readily. This technique has some of the same technical results as using a common vendor product to produce interoperability. The common technology can come through third party libraries or open source developments.

5. Standard implementation – software interoperability requires a common agreement that is normally arrived at via industrial, national or international standard.

Each of these has an important role in reducing variability in intercommunication software and enhancing a common understanding of the end goal to be achieved (Wikipedia, 2010).

2.9.1.6.4 *OpenMI*

Integrated catchment management asks for integrated analysis that can be supported by integrated tools/systems (Gijsbers and Gregersen, 2004). These integrated tools/systems can only be developed and maintained if they are based on a collection of interlinked tools. OpenMI has been developed as part of the HarmonIT research project co-funded by the European Commission to provide a widely accepted unified method to link modelling tools, both legacy code and new ones. Model applications consist of many parts, the most common being the user interface, input files, the engine and output files. OpenMI only addresses the engine part of a model application, where a model can be regarded as an entity that can provide data and/or accept data. Using this data exchange paradigm as a leading principle for model linkage, OpenMI is based on direct access of the model at run time, thus not using files for data exchange. In order to make this possible, the engine needs to be turned into an engine component and the engine component needs to implement an interface through which the data inside the component is accessible. OpenMI defines a standard interface that engine components must implement to become OpenMI compliant engine components. When an engine component implements this interface it becomes a linkable component (Gijsbers and Gregersen, 2004).

The linkable component interface enables online (memory based) data exchange between components on a time (e.g. a time stamp or a time span). By combining this linkable component interface with a state management interface, advanced model combinations can be developed with simple controllers for iteration or optimisation purposes. Most important however is the fact that OpenMI is not based on framework, it is based on communicating linkable components only. In summary, OpenMI primarily focuses on providing a complete protocol to explicitly define, describe and transfer (numerical) data between components on a time basis, including associated component access (Gijsbers and Gregersen, 2004).

The OpenMI has a standard that addresses the following items required for model linkage:

- Data definition – the base data model of OpenMI addresses the numerical values itself, and its semantics in terms of quantity (what), element set (where), time (when), and data operations (how).
- Meta data defining potentially exchangeable data – quantities, elements sets and data operations are combined in exchange item definitions to describe the data that can potentially be provided and accepted by a linkable component.
- Definition of actually exchanged data – a link describes the data to be exchanged, in terms of a quantity on an element set using certain data operations.
- Data transfer – linkable components can exchange data by a pull mechanism, meaning that a (target) component that requires input asks a source component for a (set of) value(s) for a given quantity on a set of elements (i.e. locations) for a given time. If required, the source component calculates these values and returns them. This pull

mechanism has been encapsulated in one single method, the `GetValues()` method. Dependent on the status of the source component, this call may require associated computation and even more requests for data. An important feature is the obligation that components always deal with requests in order of receipt.

- Generic component access – all functionality comes available to other components through one base interface, the linkable component interface. This interface needs to be implemented by any component to become OpenMI compliant. Two optional interfaces have been defined to extend its functionality with discrete time information and state management. To locate and access the binary software unit implementing the interface, the OMIfile has been defined. The OMI file is an XML file of a predefined XSD format which contains information about the class to instantiate, information about the assembly hosting the class, and the arguments needed for initialisation.
- Event mechanism – in addition to the above mentioned functionalities to link components, a lightweight event mechanism has been introduced. Via this mechanism a wide range of messages can be passed to enable call stack tracing, progress monitoring and to flag status changes which might trigger other components (e.g. visualisation tools) to request for data via a `Get Values()` call.

By convention, a linkable component has to throw an exception if an internally irrecoverable error occurs. This exception should be based on the exception class as provided by the development environment. Therefore to become an OpenMI linkable component, a tool has to (Gijsbers and Gregersen, 2004):

- Be able to expose information (what, where) to the outside world on the concerned variables which it can provide, or which it is able to accept.
- Submit to runtime control by an outside entity.
- Be structured in a way that initialisation is separate from computation, where boundary conditions are collected in the computation phase and not during initialisation.
- Be able to provide the values of the concerned variables for the requested points in time and space.
- Be able to respond to a request, even when the component itself is time independent; if such response requires data from another component, the component should be able to pass on the time as well in its own request.
- Flag in the value set In case some values in the value set are missing.
- Throw in an exception in the exceptional case that an entire value set is unavailable and be aware that such exception will stop the entire computation process and thus should be prevented whenever possible.

Although the concept of integrated tools is gaining momentum, HarmonIT has identified the main constraints within existing software and approaches which limit their ability to provide a truly integrated but open modelling interface (HarmonIT, 2002). The following are the weaknesses identified by HarmonIT (2002) and discussed in their report in more detail:

- Scale
- Dimensionality
- Parameter meaning
- Process control
- Legacy model compatibility
- Closed systems

- Platform/language constraints.

2.9.2 Infrastructure

To achieve water security, investments will be needed within the infrastructure to store and transport water, treat and reuse waste water, as well as in robust institutions, and the information and capacity to predict, plan for and cope with climate variability. Such investments will help societies to adapt to long-term climate change and manage current climate variability and shocks – thus offering water security to the world’s poorest people and countries (Sadoff and Muller, 2009).

Inadequacies in water supply and sanitation infrastructure pose separate, but linked problems. The immediate problems result in a string of further consequences, which adversely affect the quality of life of the poor.

2.9.3 Human Capital and Capacity Building

2.9.3.1 Overview

South Africa is a country with unique circumstances affecting water availability and supply. These circumstances include limited and uneven distribution of water resources, the concentration of economic activities (and water demand) in certain areas, and the legacy of a political system that resulted in non-equitable access to water resources. This combination of circumstances places difficult demands on those responsible for the optimal utilisation and protection of the country’s water resources as required by the NWA. Adequately trained and educated people at different levels of training are needed to address these problems in order to ensure sustainable and equitable use of South Africa’s water resources (Schutte, 2004).

Management of water resources penetrates the entire society touching the different administrative entities, stakeholder groups, social classes, urban and rural populations, generations and gender. Capacity building; i.e. education, training and awareness raising; are key elements in forging a strategy to prepare humankind for the challenges of the twenty-first century (Bogardi and Hartvelt, 2005).

The concept of capacity building was recognized as a priority item at Mar del Plata, even though during this United Nations Water Conference in 1977, the term capacity building did not exist. The emphasis at Mar del Plata was on human resources development in terms of education, training, and research and institutional strengthening, all of which are now considered as integral components of the capacity building process. The United Nations Development Programme (UNDP) Symposium on capacity building for the water sector, convened in Delft in 1991, defined capacity building as having three elements: (a) an enabling environment with appropriate policy and legal frameworks; (b) institutional development, including community participation; and, (c) human resources development and strengthening of managerial systems (Tortajad, 2001)

Building human and institutional capacity is the foundation of sustainable water resources management and service delivery. The importance of capacity building was further recognized during the Second World Water Forum and Ministerial Conference, The Hague, 17-22 March 2000 (Bogardi and Hartvelt, 2005).

The term “capacity building” has different meanings and interpretations depending on who uses it and the context in which it is used (Silayo, 2010). According to Abrams (2001), Capacity building is a process whereby a community equips itself to undertake the necessary functions of governance and service provision in a sustainable fashion. The process of capacity building must be aimed at both increasing access to resources and to changing the power relationships between the parties involved. The "community" may be a local government, a village level committee or even a central government department. Capacity building is not only constrained to officials and technicians but must also include the general awareness of the local population regarding their services and development in general (Abrams, 2001).

2.9.3.2 Pillars of sustainable capacity building in water management

Sustainable and responsible use of water begins in the hearts and minds of individuals, who make up neighbourhoods, communities, cities, states and nations. The cumulative impact of their attitudes and actions ultimately determines whether or not sustainability is achieved. Four stakeholders play a major role in sustainable capacity building in the water sector. These are as follows on **Figure 24** (UN-WVLC, undated):

1. The public sector – Within a specific community, the water supply and sanitation agency often has the direct responsibility to ensure that a sustainable urban water cycle is in place. This includes quantity and quality protection as well as provision of efficient and effective services to users. Officials can also play a facilitating role in non-technical areas such as public awareness building and education (UN-WVLC, undated).
2. Academia – Academic institutions make an essential contribution to the capacity building component in the areas of applied research, education and training, and develop community awareness on water issues. Academics are trusted by the community and provide a measure of credibility to the capacity building efforts and to the goal of sustainability (UN-WVLC, undated).
3. Community-based organizations – NGOs and other less formal, community-based organizations can directly reflect the aspirations and concerns of the people and are often created out of a need to solve a problem or have a voice on an issue that directly affects them. These organizations are important because they can serve as bi-directional channels providing information to the people and input into the decision-making process. Generally, the more information provided to, and input received from the community, the greater the commitment of citizens and the more successful the program (UN-WVLC, undated).
4. The private sector – The private sector has a large vested interest in sustainability. Permanent water management systems and practices create stable markets and support informed clients for sales of products and services. Effective systems and practices reduce risk, improve the return to investors and generate locally-available commodities needed to sustain the urban water cycle. Given the vitally important role of the private sector, it is important that they have a voice in the development of the systems for which they will provide essential products and services (UN-WVLC, undated).

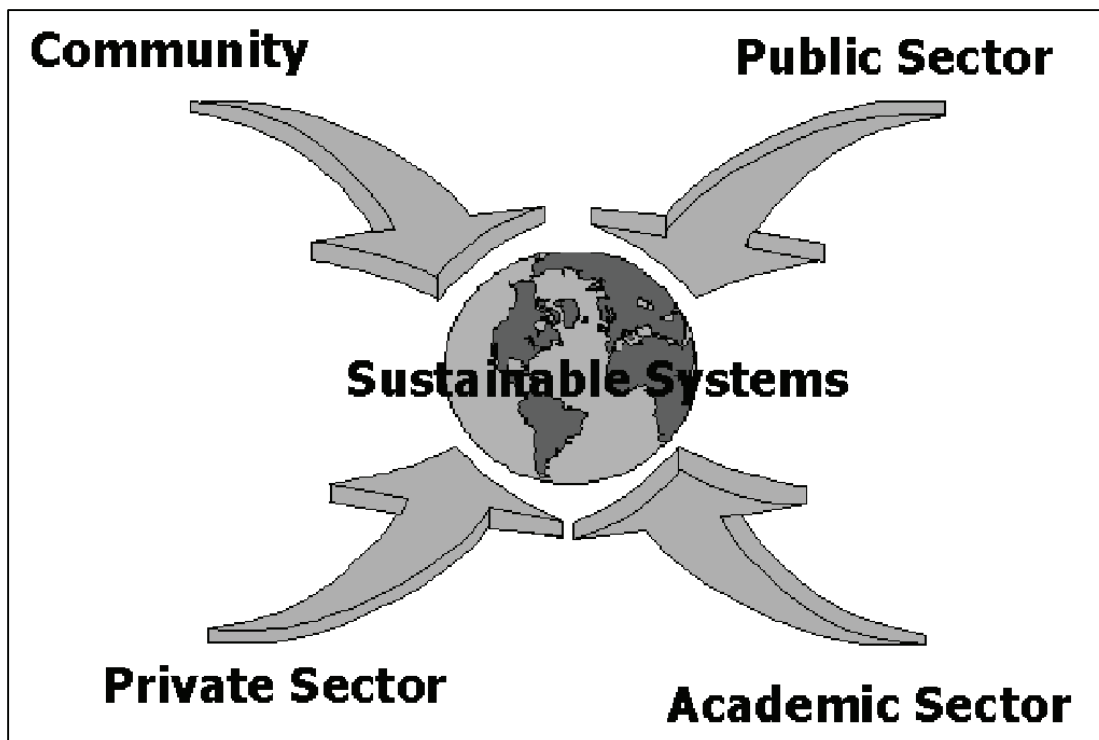


Figure 24: Four pillars for sustainable water use (UN-WVLC, undated)

Although the older view of capacity building (short workshops, courses, etc.) can still be useful in restricted cases, the newer view is that development of the capacities and the education/training component must be done locally so that it is sustainable. The newer view of capacity development includes much more than just transfer of technical skills; it also includes improving the capacities in various sectors such as academia, the private sector, the public sector and the community (UN-WVLC, undated).

Three groups of stakeholders should be targeted, namely, Education and Training Providers, Users and External Support Agencies. In order to match the demand for education with the supply of educators and trainers, the target groups need to interact with each other through networking and other forms of communication. It is recognized that if education and training is to be fully effective it needs to be linked with institutional reform and enabling policy/legal frameworks, which together constitute the building blocks of capacity building (Bogardi and Hartvelt, 2005).

2.9.3.3 Challenges that affect Capacity building

There are a number of challenges that affect capacity building as indicated in **Figure 25**. Just to mention few, Human capital flight from South Africa is one of the country's major development constraints. The loss of trained and highly skilled individuals to the industrialised countries has intensified the capacity constraints facing the public and the private sector and thus the deficit skilled manpower, which South Africa need for poverty reduction and sustainable development (UN-WVLC, undated).

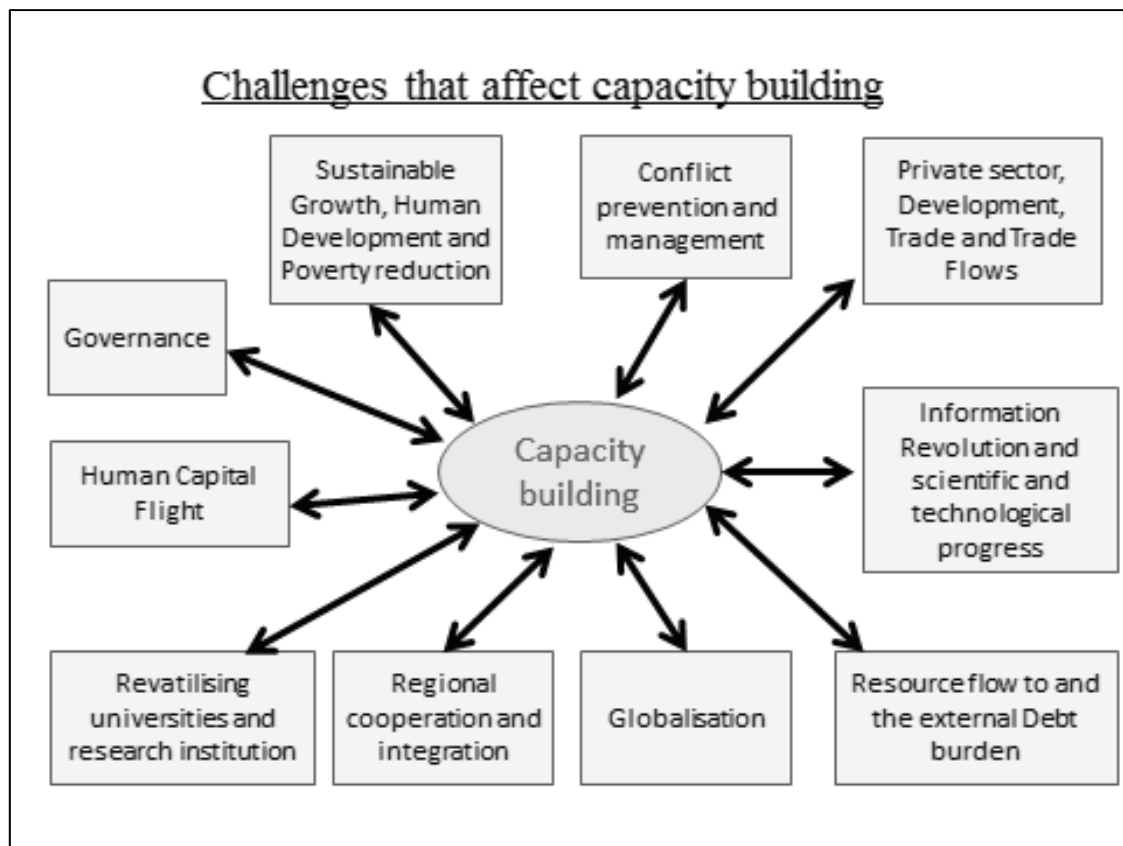


Figure 25: Challenges that affect capacity building (UN-WVLC, undated)

In addition, one of the obvious problems in some countries is weak human resource base of capable counterparts that can take over the technical responsibilities at the end of projects. Technology transfer, on-the-job training, involvement of schools and universities, and study tours are commonly used to train staff. However, training follow-up remains minimal in many countries. In addition, the lack of relevant positions available for those trained is also a dilemma (IRC, 2007).

Many failures in water resources management are, in fact, the results of the weakness of many governmental agencies and institutions capacity building as well as the lack of trained staff. Governments, in general, tend to organize and administer water sector activities consequently capacity building separately; irrigation might be under one department, domestic water supply and sanitation overseen by another; hydropower activities managed by a third; transport supervised by a fourth, water quality controlled by a fifth, environmental policy under a sixth; and so forth. These fragmented bureaucracies make uncoordinated capacity building decision, according to individual agency mandates that are independent of each other. This project-by-project, department-by-department and region-by-region approach is no longer adequate for addressing water issues and provoked several problems confronting governments in managing their water resources (Chioccioli et al., Undated).

Institution building seems to be a key for better capacity building. However, this discussion remained very general. Nations, cities, tribes, even villages, have their own needs and traditions. Improvements in institutional capacity have to be tailored for each society. National and regional plans should be the starting point. Education and training are key elements, in addition to material resources. At individual level, it can also be a way out from poverty (IRC, 2007).

Capacity building takes a long time and requires a long-term commitment from all involved. Success of capacity building efforts should not be measured in terms of disbursements or outputs with little to sustainability. Long-term change takes into account not only short-term but also intermediate- and long-term results (Milèn, 2001).

2.9.3.4 **Education and training requirements**

Water-related education concerns all the knowledge of the hydrological cycle. This concerns the entire profile of terrestrial freshwater resources assessment, monitoring, and management. The education, therefore, should include the formative years at pre-school, primary and secondary educational levels, vocational training, university and professional education at undergraduate and postgraduate levels, lifelong continuing education and training, as well as the informal and innovative ways of knowledge and information transfer as indicated in **Figure 26**. In addition it should reflect the different target groups such as policy makers, managers within and outside the water sector, professionals, technicians and service personnel. Capacity building activities need to be directed to all stakeholders and include traditionally underserved groups as water is everybody's business (Bogardi and Hartvelt, 2005).

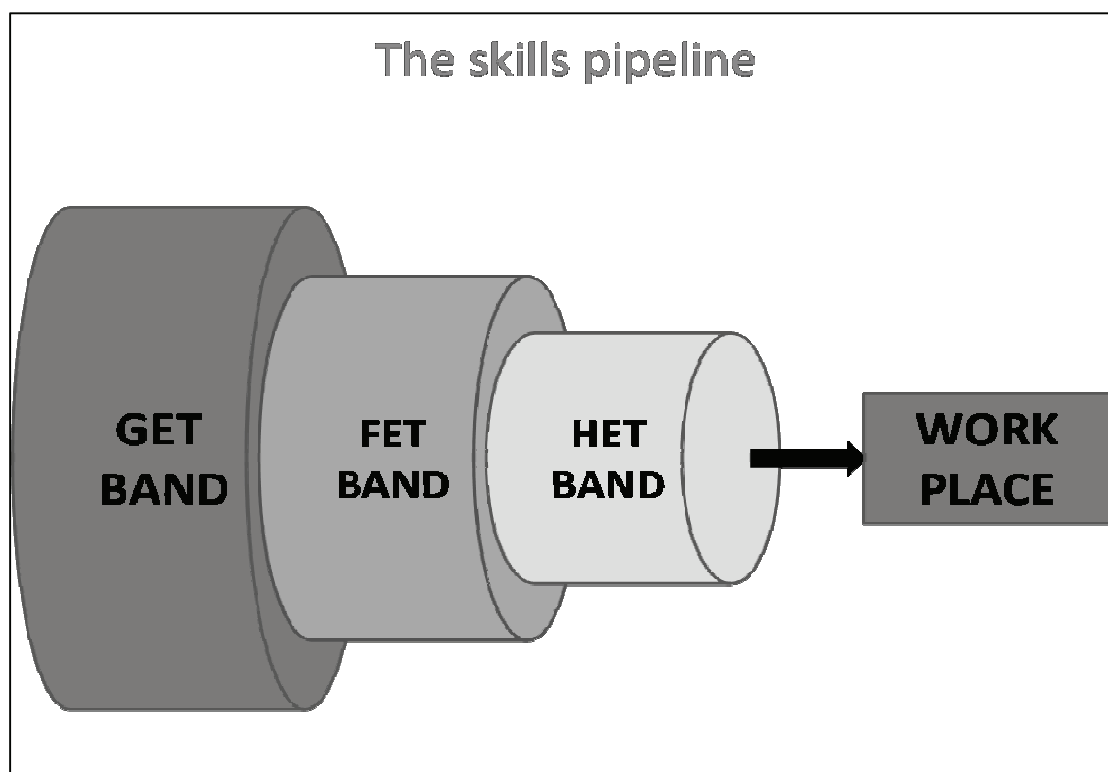


Figure 26 Skills pipeline – DWA initiative (Meyer, 2010)

General Education & Training and (Grade 0-Grade 9) – career exhibitions; curriculum development; assist educators; Further Education & Training band (Grade 10-Grade 12/National Certificates) – DWA competitions; career exhibitions; Higher Education & Training band (Post School Certificates, Diplomas & Degrees) – open days; career exhibitions; bursaries; and Work Place – Learning Academy (Meyer, 2010)

Hydrologists work on projects as varied as the collection and analysis of water-related data; soil erosion; drought and flood analysis; water chemistry; sediment transport; river channel

development; watershed (basin) management; groundwater resource evaluation; waste disposal; computer modelling (Water encyclopaedia, 2011). In order to be able to carry out all these duties, a hydrologist's academic preparation should include diverse scientific, social and economics courses.

Water professionals (Hydrologists) are normally drawn from different disciplines of university education such as civil, agricultural or mining engineering and other fields of physical sciences including geology, geography, physics, and so on. First degree courses in hydrology, hydro-meteorology, and water resources engineering are available only in large countries with enhanced water resources activities whereas most developing countries like South Africa depend more on postgraduate training courses to prepare professionals in hydrology and water resources (UN-water/Africa, 2004).

Within this broad picture, universities and other institutions of higher learning and continuing professional education are called upon to push the frontiers of innovation in both content and methodology of education. This focus does not mitigate the importance to include water and related subjects into elementary and secondary school curricula. Higher education includes the preparation of teachers and trainers to their tasks to educate the young generation. In this context the essential role of research in education and training cannot be over-emphasized. Addressing the growing complexities of integrated water resources management requires adequate research input and the continuous redefinition of the competencies knowledge and skills to be acquired during the periods of education and training, preparing for up to date competencies on the job (Schutte, 2004).

Most universities in South Africa do not have hydrology schools. Meaning, there are still no good curricula, at the undergraduate level that consider adequately topics like economics, sociology, environment, biology, laws and institutions. The focus continues to be on engineering; other aspects of water management are mostly ignored. Programmes to develop high-level expertise in hydrology are offered at post-graduate level by a number of South Africa Universities but on undergraduate level it is only three universities, this shows that there is still a huge gap to be filled. The programmes may consist of specific courses leading to an honours degree; or courses and a research project leading to a Master's degree; or a research project only leading to a masters or doctors degree. The type of training offered depends on the focus of the university or department, which could, for example be in hydrology; geohydrology; water chemistry; treatment processes; membrane processes, etc. (Schutte, 2004).

A number of universities in South Africa are said to offer hydrology or water science. These universities are: University of Pretoria, University of Cape Town, University Of Free State, and University of Rhodes only offer hydrology from postgraduate (Schutte, 2004). Whereas three South Africa Universities, *i.e.* University of Venda, University of Zululand and University of KwaZulu-Natal, are the only three that offers hydrology from undergraduate studies to postgraduate (UKZN, 2011; UNIVEN, 2011; UZULU, 2011).

Meyer (2010) indicated that DWA's input into capacity building in the water sector is through funding. Over 400 bursaries allocated since 2007 to students studying under disciplines of: water care; geo-hydrology; hydrology; GIS; environmental related qualifications; chemistry; and water resource management, just to mention few. Also DWA also plays a role in capacity building by doing experiential training – Learner Interns, Professional Development – Graduate Trainee (Meyer, 2010).

2.10 Conclusions

The literature review was structured so as to unpack integration issues pertaining to bringing together the four components of the water sector (i.e. the water business, the water information value chain, the operating environment, support services required).

The literature review has highlighted the complexity of the water business in that water managers need to consider multiple actors, multiple preferences, multiple problem perception and multiple institutional rule setting, considering collaboration across sector and organisational boundaries, with considerations of political and strategic alliances, technological improvements and natural events.

The literature review has pointed to a number of available tools that can be brought together by a unifying platform to address complexity in the water sector. However, the challenge remains to develop a unifying platform fit for the South African situation. The following chapters show how these tools were used to analyse and develop a unifying platform for the South African water sector.

3 ASSESSMENT OF TOOLS

3.1 Overview

This chapter is dedicated to describing the process followed in reviewing the tools for the purpose of developing a unifying platform. This is in line with the recommendations of Barlebo (2006). Barlebo (2006) recommends that in the process of identifying, enhancing, and developing new tools to address complexity, a review of existing tools needs to be undertaken. This is because there are many existing tools suitable for integrated water management, however, there is a challenge on how to implement them successfully for a particular country, in this case South Africa. Also, for development of tools to be sustained to the point of reliable and effective end use, it is important to bridge the gap between theory and practice, development and application, researcher and practitioner (Barlebo, 2006).

Due to limitation of resources, it was not possible to review all tools in South Africa. Therefore, the review by no means covered all existing tools, but enough to enable the creation of a unifying platform. Furthermore, the views expressed regarding the tools reviewed are those of the authors, they are subjective, and in some cases are based on limited information.

3.2 Methodology

As previously mentioned, for the purposes of this project a tool is defined as something (either tangible or intangible) used to support operational actions in performing IWRM. Hence, tools are considered to represent; guidelines, procedures, protocols, methods, techniques, an artefact, a device, an apparatus, and software programmes. This definition is broad with the intention that it should be able to embrace the different uses of the term “tool” in different scientific and professional sub-communities dealing with water management, particularly for water resources and water uses.

The review methodology was adapted from Barlebo (2006) and consists of three categories (classification, input data requirements, and output data) with various criteria. In **section 2.4**, methodologies for identifying and classifying tools were discussed. To make the assessment relevant to the project, two other criteria were added to Barlebo’s classification methodology and two categories dealing with input and output data were added. A full list of the categories and sub-categories is as follows (see **Table 3, 4 and 5** for details):

- Classification – consisting of:
 - Water business
 - Problem life cycle
 - Functionality
 - Included topics
 - Type of tool
 - Intended users/user friendliness
 - Scientific verification of tool
 - Extent of current use of tool
 - Relevance to IWRM tools as defined by GWP
- Data input requirements consisting of:
 - Catchment Mapping Data
 - Climate Data
 - Ecological data
 - Hydro geological data

- Hydrology Data
- Water Quality Data
- Water Supply Data
- Water Demand Data
- Data output consisting of:
 - Catchment Mapping Data
 - Climate Data
 - Ecological data
 - Hydro geological data
 - Hydrology Data
 - Water Quality Data
 - Water Supply Data
 - Water Demand Data

The resulting assessment methodology is multidimensional with each of the above criteria as an axis. **Tables 3, 4 and 5** shows the methodology with the different categories and criteria. It should be emphasised that although the criteria are viewing things from different perspectives, there are overlaps. A tool may be characterised by ticking in several criteria within the categories.

Table 5: Tool data output assessment method

Tool	Data and Information Requirements																															
	Data and Information Output																															
	Output Data Type																															
	Catchment Mapping Data	Climate Data	Ecologic al data	Hydro geological data	Hydrology Data	Water Quality Data	Water Supply Data														Water Demand Data											
Tool X Tool Y Tool Z etc.	topography, drainage, land use, geology and vegetation.	rainfall and evaporation monitoring and derived datasets;	macro invertebrates, fish, plants and algae; most typically collected for monitoring and evaluation of river/ wetland/ catchment/ aquifer health;	characterisation of aquifers and other geological features;	water level, volume, flow velocity or pressure that relate to the movement of water. These cover a broad range of water features such as rivers, dams, wetlands,	relating to the physical, chemical and biological condition of water;	Internal renewable water resources	Runoff data at catchment outlet (time series; if n/a:long-term average)	Renewable Ground water	Ground water recharge (natural and artificial)	Non-renewable ground water	Surface water	Desalination plants capacity	Capacity of reservoirs	Operating rules for existing reservoirs (Objectives)	A(h), V(h) relationships for reservoirs	Transfer from neighbouring regions	Water recycling/reuse	Losses in distribution system	Unaccounted for water	Water Quality	Water demand per person	Abstraction from surface water	Abstraction from ground water	Abstraction from fossil groundwater	Final water consumption	Number of licences for abstraction	Industrial water requirement (consumptive and Non-consumptive)	Agricultural water demand (consumptive and Non-consumptive)	Water demand per overnight stay	Seasonal demand pattern	WQ parameter for return flow

3.3 Tools Assessment

3.3.1 Overview

The project focused on the integration of tools that includes: mobilisation of social, economic, institutional, legal, environmental and technical expertise, in the effort to address water resources and water uses in an integrated manner. Therefore, the tools were assessed for the extent to which they incorporation of social, economic, institutional, legal, environmental and technical expertise in solving the intended problem the tool was developed for.

Tools were collected and grouped into water resources and water services. The water resources in most cases incorporate other uses; hence it was not necessary to have other uses separately. The review process was undertaken in four stages as follows: the collection of tools, grouping of tools into water resources and water services, the selection of tools to be assessed, and the assessment of the selected tools. The following sections detail the review process.

3.3.2 Inventory of Tools

3.3.2.1 Inventory of water resources tools

Tools for water resources management were gathered from different reports and stakeholders and are listed in **Table 6**.

Table 6: List of identified water resources tools

INVENTORY OF WATER RESOURCES TOOLS			
1.	WRYM (Water Resources Yield Model)	20.	AQUAWIN
2.	WRSM2000 (Water Resources Simulation Model)	21.	NACL
3.	WRPM (Water Resources Planning Model)	22.	DISA
4.	WQT (Water Quality Model)	23.	WARMS
5.	ACRU (Agrohydrological Model)	24.	National Groundwater Archive
6.	MIKE BASIN (DHI decision support system)	25.	Floods
7.	MIKE 11	26.	Property
8.	WSAM (Water Situation Assessment Model)	27.	HYDSTRA
9.	SPATSIM-VTI (Spatial and Time Series Information Modelling)	28.	GIS
10.	IMPAQ	29.	LIMS
11.	FLOSAL-M	30.	Meta Data
12.	ISIS	31.	WMS (Water Management System)
13.	DUFLOW	32.	SADC-HYCOS
14.	FEFLOW	33.	Surveys
15.	MODFLOW/ MT3D	34.	NWRS
16.	PM-WIN	35.	CMS
17.	VISUAL MODFLOW	36.	Internal Strategic Perspective
18.	GMS	37.	Pricing Strategy (Raw Water)
19.	FEMWATER	38.	NGIS (National Ground Water Information System)

3.3.2.2 Inventory of Water Services Tools

Tools for water services management were gathered from different reports and stakeholders and are listed in **Table 7**.

Table 7: List of identified water services tools

INVENTORY OF WATER SERVICES TOOLS			
1	Policy Development and Bylaws	2	Water Services Provider Arrangements
1.1	Information kit for free basic water implementation in South Africa, DWAF, 2002, Directorate: Communications comprising the following:		Delivery mechanisms / partnership materials
	Question & Answers Booklet, August 2002		Guide towards Ring-fencing the Water Services Provision Function within a Municipality, Version 1 April 2003
	A Summary Booklet For Local Authorities, August 2002		Sample Section 78 Terms of Reference
	Implementation Strategy: Version 2, August 2002	2.1	Section 78 Internal Mechanism Materials
	Financial Model User Manual, August 2002, Version 1: Spreadsheet Model	2.2	Section 78 External Mechanism Materials
	1) CD with all FBW info on, 2) website user manual, 3) Pilot Studies, 4) Rural areas: fbw implementation strategy & guidelines 5) regulations & guidelines 6) prepayment water meters and management systems 7) control devices guidelines summary. On CD is FBW	2.3	Section 78 Materials Pack
	Free Basic Sanitation Guideline		Water Service Provider Options Guideline (Parts A-D), DWAF, Draft, 2003
	Free Basic Water Brochure, September 2001		Water Services Provider Status Quo Tool, DWAF, Version 1
	Free Basic Water Implementation Guideline for Local Authorities, Version 2.3, August 2003		Water Service Provider Quick Assessment Tool, Excel, Version 1, March 2003
	Water Supply Service Levels: A Guide for Local Authorities; DWAF, November 2000		Water Services Provider Performance and Capacity Assessment Tool, DWAF, Version 1
	Sanitation Services Model (assists in the development and evaluation of investment scenarios and tariff policy)		Areas of Competence Listing (of Water Boards)
	Sanitation Services Model Version 1.1		Map of Water Boards of South Africa (illustrates areas of operation)
	Water Supply Services Model (the development and evaluation of investment scenarios and tariff policy)	2.4	Model Water Service Provider Contracts and Guidelines (examples of existing contracts are often more useful than 'models'. Municipalities must use legal expertise for developing service delivery agreements)
	Sanitation Services Model Version 1.		Water services provider contract regulations, DWAF, 2 August 2001
	Questions and Answers on the White Paper on Basic Household Sanitation, DWAF, 2002		Model Water Services Contract: District Municipality As Water Services Authority And Local Municipality As Water Services Provider, Version 1, DWAF, April 2002

INVENTORY OF WATER SERVICES TOOLS			
1.2	In model bylaws		Guideline Contract For A Partnership Between A Municipal Authority And A Water Board, Public-Public Partnership, Contract Relating To Water And Revenue Services And The Water Services System, DWAF
1.3	Model By-laws Pack; Model Water Services By-laws; Model Credit Control and Debt Collection By-laws; Version 1 Draft 2 (July 2004)		Community-Based Organisation Legal Pack (01 March 2001)
			Introduction to water services management in SAs urban areas
3	Financial Planning and Management		Alternative service delivery options for municipalities in the rural areas: Kamiesberg Local Municipality case study
3.1	Regional Water Supply Services Model (RWSSM); WRC Report No. TT118/00		Making water work for villages
	Targeting Poor Households In The Provision Of Basic Municipal Services: A Guideline For Municipalities		So you think you want to corporatise – a guideline for municipalities considering corporatised water entities
3.2	Human Resources Planning and Management System (HRPMS) – includes portions of the job analysis and planning (decision support system) component includes the employment equity, resources (benchmarking), forecasting human resource requirements and provision of data required for business plans as dictated by the Water Services Act.		The Return Flow Model has the ability to model future water requirements, water use, loses and return-flows. In essence the model provides a link to water resources management from water services management
3.3	WSSM/ SSM; developed through the WRC (Palmer Development Group, 1998) in order to assist the agencies responsible for urban water supply services to undertake the necessary investment planning and analysis.		BENCHLEAK and ECONOLEAK model were developed through the WRC in order to assist the agencies responsible for urban water supply services to undertake leakage evaluation and comparison between supply systems in a meaningful and realistic manner.
			The Water Quality Management System (WQMS) can be used by Water Services Authorities (local government), provincial/national government, etc. to guide the tracking, reviewing and improving of water quality.
3.4	Norms and standards in respect of tariffs for water services in terms of section 10 (1) of the water services act (act no. 108 of 1997) Regulations and guidelines booklet explains tariff regs.	5	Performance Management and Regulatory Capacity
	Rural Tariff Model – Cost and Tariff Model for Rural Water Supply Schemes; WRC Report No. 886/1/03	5.1	Water Service Provider standardised indicators
	Financial planning for infrastructure services at district level: A user guide to the district services model, Version 1.1, WRC, Report Number: TT 143/01		Performance management guide for municipalities

INVENTORY OF WATER SERVICES TOOLS			
	Financial planning and modelling for regional water supply service providers		Guidelines for the implementation of benchmarking practices in the provision of water services in South Africa
	- Supply pricing of urban water in South Africa (Volume 1 and 2) - Infrastructure Costing Report – Fred van Zyl DWA	6	Health and Hygiene Promotion
4	Water Services Development Planning	6.1	The KAP Tool for Hygiene. A Manual on: Knowledge, Attitude and Practices Study for Hygiene Awareness in the Rural Areas of South Africa, WRC, Report Number: TT 144/00, WRC
4.1	WSDP Overview Guide, DWAF, 2001		Hygiene awareness for rural water supply and sanitation projects, WRC, Report Number: 819/1/00
	Water Service Act WSDP Support Tool (provides extensive data / information, national, provincial and municipal), DWAF		SITPAK
	WSDP Poster	7	Asset Management and Legal Matters
4.2	WSDP Preparation Guide, DWAF, 2001	7.1	Impahla Asset Management System (Software that emanates from the project "Improved management of assets in the water supply and sanitation industry" funded by the WRC. Its aim is to assist in efficiently managing assets in the water sector.)
	Site User Manual , DWAF		- Managing community assets, by (Australian South African Local Government Partnership) ASALGP 2005 - Municipal Assistant Software System
	WSDP, Citizens Version, April 2002, Draft		Provincial Supervision: Manual for the application of Section 139 of the Constitution
		8	Transfer
4.3	Water Service Authority indicators are all being standardised	8.1	Joint Transfer Policy
	Development of a framework for the economic evaluation of water conservation/ demand management measures with specific application to decision making in Cape Town		Functional assessment tool
9	Infrastructure Development		Asset Register of DWAF Water Services Schemes (for all Provinces) March 2001
9.1	No guidelines or tools -		Model Transfer Agreement
9.2	(Integrated Development Plan Guides)		Other – to be followed up with DWAF and SALGA
9.3	MIG Project Registration Form	8.2	See Section 78 Tools
	Guideline towards Registering a MIG Project	8.3	<i>Need to check with William and Resolve what tools have been developed</i>
9.4	DWAF tabled a guide at MIT3	10	Water Service Authority Structural and Organisational Issues (Capacity Building)
9.5	Format from National Treasury format		Water Services Capacity Building Policy for Local Government, Draft 3, November 2003

INVENTORY OF WATER SERVICES TOOLS			
9.6	DWAF prepare a format and place on water services section of MIG CD	10.1	Water Services Authority Capacity Assessment and Objectives Tool, 2004 Version
9.7	Generic		Water service Authority Checklist (Draft 1)
	Alternative Delivery Mechanisms: Toolbox of Guidelines & Model Forms of Contract	10.2	Water service Authority Capacity Building Business Plan, Version 1, 2003
	Alternative Delivery Mechanisms: Toolbox of Guidelines & Model Forms of contract		Municipal Demarcation Board Capacity Assessments (DMs) 2004/05
	Guideline Document for the Toolbox on Selection of Delivery Mechanisms and Model Forms of Contract, Version 1.0: Revised June 2001		Rapid capacity building for water and waste management at local authority and district council level
	Road Map to Information on Municipal Services Partnerships		Development of generic and sectoral competencies in the water supply and sanitation training sector
	Cost Benchmarking Guide		
	Generic Model Forms of Contract	11	Powers and Functions
	Improved (Build, Operate, Train and Transfer) BOTT Model Form of Contract		Guideline for implementing the division of powers and functions for water and sanitation services, Version 1
	Groundwater		
	Intensive Construction Using SMMEs		Water and Sanitation National Policy, Legislation and Regulations
	Guideline on the role of NGOs for water services infrastructure delivery		Water Services Act, No. 108 of 1997
	Model forms of Contract for Water Boards (as Implementing Agent and as Support Services Agent)		Draft Water Services Act Amendment Bill (Comments by 30 June 2004)
	ISD Package		Strategic Framework for Water Services
	Sanitation services model manual		White Paper on Basic Household Sanitation 2001, September 2001
	An assessment of the trickle feed system as a tool for implementing the free basic water policy		Framework for a National Sanitation Strategy, 2002
	Sanitation Technology Options		The Policy of Basic Household Sanitation made easy, DWAF, February 2002, in English, Afrikaans, Ndebele, Northern Sotho, Zulu, Setswana, Sesotho, Seswati , Tsonga, Venda, Xhosa
	Guidelines on appropriate technologies for water supply and sanitation in developing communities, WRC, Report Number: 520/1/01		Norms and standards in respect of tariffs for water services in terms of section 10 (1) of the water services act (act no. 108 of 1997).
	The development of an on-site sanitation planning and reporting aid (SSPRA) for the selection of appropriate sanitation technologies for developing communities: User Manual, WRC, Report Number: 586/2/00		Regulations relating to compulsory national standards and measures to conserve water in terms of section 9 of the Water Service Act
	Handbook to guide communities in the choice of sanitation systems, WRC, Report Number: TT 104/98		Water services provider contract regulations, DWAF, 2 August 2001

INVENTORY OF WATER SERVICES TOOLS			
	• The toilet selection and maintenance guide		• An assessment of the water policy process in South Africa 1994-2003
	• The applicability of shallow sewer systems in South Africa		
	• Guidelines for the upgrading of existing small water treatment plants		
	• Guidelines for the use of septic tank systems in the South African coastal zone		
	• Groundwater contamination as a result of developing urban settlements		
	• An introduction to yard tanks Feb 2005		
	• Land based effluent disposal and use: Development of guidelines and expert systems based decision support		

3.3.3 Selected and Reviewed Tools

3.3.3.1 Overview

The purpose of this project was to develop a GICF for the integration of water resources and water uses tools with an emphasis on software modelling and database tools that are currently used in South Africa. According to Stephenson et al. (2001), the level of water services in the water industry is a function of the following measures:

- Quality of water
- Quantity of water
- Water availability
- Standard (or legislative) requirements
- Maintainability (a probability of restoration)
- Reliability and performance
- Capacity of a system
- Environmental issues
- Cost/affordability
- Comfort
- Safety.

From the water resources point of view the tools to be assessed for use in the development of a unifying platform should span: hydrological analysis, yield analysis, allocation planning, domestic demand forecasting and management, water conservation, return flow management, data management and administration. Over and above, both the water resources and water services tools should contain multiple aspects such as environmental, socio-economic, administrative and sustainable development.

From the inventory of tools listed in the previous section it is clear that there are many tools currently in use in South Africa. Therefore, in selecting the tools to be evaluated, their ability to span “hydrological analysis” to “urban returnflows”, and management that includes mobilisation of social, economic, institutional, legal, environmental and technical expertise were a priority. Also the familiarity of the tools to the research team was used as a criterion in

selecting the evaluated tools. The following sub-sections give a list of selected water services and water resources tools as well as a detailed assessment of each.

3.3.3.2 Reviewed water services tools

Water services management interacts with water resources management at two points, i.e. inlets/abstraction (with quantity, quality and reliability being of concern) and outlets/discharge (with quantity and quality being a concern) points (Smits and Butterworth, 2005). Therefore, the tools selected for review are those that were perceived to have domestic water demand forecasting & management, water conservation, urban return flow management and administration modelling capabilities integrated on multiple aspects such as environmental, socio-economic, administrative and of sustainable development. The following is a list of water services management tools selected for review:

- Return Flow model (urban component).
- WSSM/SSM (Water Supply Services Model/Sanitation Services Model).
- RWSSM (Regional Water Supply Services Model).
- HRPMS (Human Resources Planning and Management System).
- BENCHLEAK (Benchmarking of Leakage for water suppliers in South Africa).
- ECONOLEAK (Economic model for Leakage management for water suppliers in South Africa).
- WATTREAT (Water quality management model for small communities).
- IMPAHLA (Asset management for water services sector in South Africa).
- WSNIS (Water Services National Information System).
- WQMS (Water Quality Management System).

3.3.3.2.1 *The Return Flow Model*

Tool Description

The Return Flow Model was developed for the DWA as part of the Crocodile (West) River Return Flow Analysis Study (DWAF, 2004b). The model was developed to reflect the relationship between water uses and return flows, and to develop return flow scenarios up to a 20-year planning horizon. The model is capable of analysing return flows from urban, mining, industrial and agricultural land use activities at a comprehensive level of detail (Hattingh et al., 2007). The model output data is in a format compatible with the water resource planning models that are applied by DWA in water resource management planning phases.

In the design of the conceptual Return Flow model an attempt was made to achieve a balance between simplicity, availability of data and compatibility with other models used by DWA. In the Return Flow model, Sewage Drainage areas (DAs) are the main building blocks within which all the serviced land-use activities are quantified. The land-use is grouped into two main categories; (a) serviced housing, and (b) related land use and other land uses that are serviced by water supply and or sanitation systems (Hattingh et al., 2007). The serviced housing land-use is further split into seven serviced housing categories and land-use other than housing, is defined in six categories.

Allowances are made for distribution losses in the supply network that occur between the bulk water supply meter and the user. Rainfall and groundwater infiltration into the sewer network are also taken into consideration. Losses during the treatment of the sewage are

included as well as direct re-use usage, which could be for irrigation or other purposes. It is important to note that the urban return flow model was developed as a combined database/spreadsheet model (Hattingh et al., 2007).

Processes, linkages and calculations in the Return Flow Model are divided into the following ten distinct calculation processes:

- Urban population database structure.
- Normalised drainage area population.
- Land use population.
- Requirement and return flow from serviced housing.
- Requirement and return flow from other land use.
- Distribution losses.
- Infiltration through sewers.
- Total demand & return flow per DA.
- Total flow into treatment works, total losses & total direct reuse.
- Total treatment & total return flow into river system.

The Return Flow Model gives results for each DA as well as for different hydrological control points as follows:

- Distribution losses.
- Other land use requirements.
- Other land use return flows.
- Sewer system infiltrations.
- Serviced housing requirement.
- Serviced housing return flow from use.
- Serviced housing return flow from leakage.
- Total water requirements.
- Total return flows into treatment works.
- Relation of return flow to water requirement (%).

In addition:

- A summary of the total return flow flowing into the Sewage Treatment Works and the total return flow flowing into the river system Sewage Treatment Works for each Sewage Treatment Works as well as for the different hydrological control points
- A summary of the combined total return flow flowing into the river system for the urban sector as well as the irrigation sector combining these results at the different hydrological control points.

Relevance and adaptability of the Return Flow model to this project

The Return Flow Model has the ability to model future water requirements, water use, losses and return-flows. In essence the model provides a link to water resources management from water services management, therefore the model is considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools. However, it is noted that there is no explicit integration on multiple aspects such as environmental, socio-economic, administrative, etc., therefore, the model need to be adapted to account for such.

3.3.3.2.2 *The Water Supply Services Model*

Tool Description

The water supply services model (WSSM) was developed through the WRC (Palmer Development Group, 1998) in order to assist the agencies responsible for urban water supply services to undertake the necessary investment planning and analysis. More specifically, its purpose is to evaluate the impact of different investment scenarios and tariff policies on the financial viability of the water service provider. The key focus of the model is on the financial viability and sustainability of the water supply service, as international experience has clearly shown that, where service provision is not financially sustainable, it is the poor who are the major losers. The specific objectives of the WSSM are:

- To provide a practical strategic planning tool for people involved in (or who have a stake in) investment planning and tariff determination for water supply services in urban areas.
- To undertake financial viability analyses of selected investment programmes and tariff policies in urban metropolitan areas, cities or towns.
- To test the sensitivities of the input parameters on the short- and long-term viability of the agency responsible for water supply services within a unified urban or metropolitan area.
- To guide decision-makers in the development of policy and service delivery and management strategies and this will ensure adequate provision of services to all residents within a reasonable time-frame, whilst ensuring longer-term financial viability and sustainability of these services.

The model has been developed for application in urban areas, including small towns situated in rural areas. It is not applicable to rural water supply. The model should be applied to each local authority area as a whole, and not to sub-sections in isolation (Palmer Development Group, 1998).

A major advantage of the model is that it provides a transparent interface between policy-makers and technical and financial personnel in the service agency. In general, policy-setting is the function of policy-makers (political representatives), whereas the determination of policy implications is the task of the technical and financial personnel in the agency itself. The model provides a transparent tool to test financial and physical implications of desired policy options, and hence, to foster trust between policy-makers and technical personnel. The model covers an 11-year period with "Year 0" being the current planning year and "Year 1" being the first year of planned investment (Palmer Development Group, 1998). The model allows the user to:

- Provide for new residential consumer units
- Eliminate the residential backlog and upgrade existing services
- Provide for non-residential consumers
- Plan a metering programme for existing residential services
- Plan capital requirements in nominal and real terms for a five- and/or ten-year period
- Estimate total water use, with both the macro consumption estimates and the consumption estimated by the model (graphic)
- Estimate annual growth in the rate of water consumed and bought/purified by the service provider (graphic)
- Show the amount of water consumed, the amounts bought and/or purified and the physical losses on an annual basis.

Relevance and adaptability of the WSSM to this project

The key focus of the WSSM is on the financial viability and sustainability of the water supply service. The model uses water demand, losses, and services levels to arrive at the financial viability and sustainability. Therefore, this model is considered a candidate model to be used in the development of a framework for integration of water resources and water uses management tools.

3.3.3.2.3 The Regional Water Supply Services Model

Tool Description

The Regional Water Supply Services Model (RWSSM) is intended primarily for regional water services providers such as water boards. Its structure and format are similar to that of the Water Supply Services Model and the Sanitation Services Model. The key focus of the model is on financial viability and sustainability of the regional water supply service provider. It is designed as a financial planning tool with a central objective of providing financial inputs into business planning.

The model links decisions made with regard to the service level provided to consumers, to water demand, and hence to the cost of providing the service. This, in turn, is used to calculate tariff trends which can be used to assess whether the type of service offered is affordable. The implications of expanding systems to accommodate new consumers can be assessed (Palmer Development Group, 1998).

The model has been developed in Microsoft Excel for Windows and as such may be run using Excel 5.0 (or a later version).

The broad aim of the model is to assist regional water agencies such as water boards and district councils to undertake the necessary investment planning and tariff analysis inherent in their business planning exercises. More specifically, its purposes are:

- To provide a practical strategic planning tool for parties involved in (or with a stake in) investment planning and tariff determination for water supply services at a regional scale.
- To undertake financial viability analyses of existing and new operations for regions containing a mixture of settlement types and water service provision arrangements. In particular, the model aims to assess the financial impacts on a regional water agency as a result of expanding its role beyond traditional core activities (bulk water supply), to include retail water supply (normally in rural areas), or the provision of support and monitoring services to rural water services providers.
- To allow for testing the sensitivities or the financial position of regional water agencies to changes in input parameters.
- To guide decision-makers in the development of policy and service delivery and management strategies that will facilitate accelerated and sustainable provision of water services to all residents.

The model is intended to allow for inclusion of a number of urban and rural settlements in the organisation's supply area, and for the range of bulk, distribution and support activities to various demand zones.

The model has been developed for application at a regional scale, typically incorporating more than one urban area within a larger area. Target users include water boards – either as a whole, or as operating divisions defined on geographical or functional bases – and district

(regional) councils which carry the responsibility for water service provision. The model includes provision for up to 30 separate demand zones, falling into four broad categories:

- Urban local authorities which purchase water in bulk from the regional water agency
- Rural local authorities or water services providers, also purchasing bulk water
- Areas – normally rural – in which the agency undertakes retail water supply.
- Areas – usually rural – in which the agency does not supply water, but provides support and mentorship services to other water services providers.

The model consists of four sections:

- Section 1 – this section of the model contains compulsory inputs. Essential information is entered regarding water consumption, consumer units, service levels, water supply schemes, costs, tariffs, the subsidy environment and the organisation's financial position. The setting of tariff levels is a key input and impacts directly on financial viability.
- Section 2 – this section contains a number of default inputs, and the user has the option of over-riding them with more accurate local information. It is not essential for the user to change any of these variables.
- Section 3 – this section of the model contains the main outputs, including financial statements and cash flow graphs.
- Section 4 – this is the 'engine' where most of the calculations are conducted. A user would access this section to trace the model's calculations.

Relevance and adaptability of the RWSSM model to this project

The key focus of the RWSSM model is on the financial viability and sustainability of the water supply service. However the model uses water demand, losses, services levels to arrive at the financial viability and sustainability. Therefore, the model is considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools.

3.3.3.2.4 The Human Resources Planning and Management System

Tool Description

The Human Resources Planning and Management System (HRPMS) is a computer program used as a decision support and information management system, to aid human resource departments of water related institutions (Stewart Scott (Pty) Ltd, 2007). The system is used to store, retrieve and manipulate employee post, demographic and resource information in order to provide a human resource planning and management tool.

In essence HRPMS is a management tool to help managers undertake human resource planning and management of water services institutions: it focuses on the human resources required to support the infrastructure as well as support organisational structure requirements of various sizes of water services institutions. The human resource and organisational structure requirements of a water services institution related to the specific water infrastructure, population served, financial resources and the production capacity of the water service institutions. This relation between human resources and other resources is achieved through the establishment of performance indicators. The planning of human resource requirements is then facilitated through the comparison of these performance indicators with benchmarks (Stewart Scott (Pty) Ltd, 2007).

HRPMS makes use of exogenous factors and forecasting tools using data input fields and formulas to manipulate this data. HRPMS was designed to conform to current legislation

within South Africa and there are four modules that are geared to achieving this (Stewart Scott (Pty) Ltd, 2007):

- Employment equity module – assists the user in managing and keeping track of transformation progress, and that an institution's policies are reviewed consistently. This module assists the user to comply with the reporting requirements of the Act, and also allows for the storage of data that will facilitate the analysis of conditions external to the institution, as required for planning purposes.
- Job analysis module – is the module through which the user manages the organisation structure and post details. This job analysis module provides details of the criteria for generic positions within the water services institutions with job specification, or minimum qualifications, and state the qualifications job applicants must possess to be considered for a job. The qualifications for each post within the water services institution are grouped into three categories: abilities, knowledge and competencies.
- Resources module – forms part of the integral planning system by making use of diverse calculations to calculate current and required resources necessary for the effective functioning of the organisation. The purpose of this module is to assist with the planning process via performance indicators that link human resources to other resources of the water services institution. The modules allows:
 - Input of demographic and infrastructure data such as population served, lengths of pipeline and consumer water meters
 - Input of financial data commonly available from the annual financial reports of water services institutions
 - Input of forecasted production capacities, kilometres of piping and connections for a particular year from other strategic planning exercises in order to calculate future human resource requirements
 - Calculation and display of human resource statistics relevant to the organisation as well as: the input of water production/treatment figures, performance indicators, benchmarks, and the percentage difference between current and required human resources.
- Employee Profile module – captures and stores record of the individual staff members as a digital CV. The employee's history, knowledge, skills and abilities are recorded here. The purpose of the employee profile module is to provide a pro forma or template for the entry and storage of actual employee information. The difference between the job analysis module and this module is that the former holds a database of the ideal criteria for a particular position while this module is a database of an employee's actual attributes.

Relevance and adaptability of the HRPMS model to this project

The HRPMS developed for water services institutions can be categorised within a continuum describing aspects of both a management information system as well as a decision support system. The management component of the HRPMS includes portions of the job analysis and employee profile modules. The planning (decision support system) component includes: the employment equity, resources (benchmarking), forecasting human resource requirements, and provision of data required for business plans as dictated by the Water Services Act.

The HRPMS model is considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools. However, it is noted that the model does not deal explicitly with the interaction between water services and water resources, although, the model is considered to exhibit the ability to integrate on

multiple aspects such as socio-economic, administrative, etc., therefore the model would need to be adapted to account for lacking attributes.

3.3.3.2.5 The BENCHLEAK model

Tool Description

The BENCHLEAK model was developed through the WRC (McKenzie et al., 2002) in order to assist the agencies responsible for urban water supply services to undertake leakage evaluation and comparison between supply systems, in a meaningful and realistic manner. The BENCHLEAK Model is simply an Excel spreadsheet comprising three forms that utilise certain basic information supplied by the water supplier. The information provided by the water supplier is processed in such a way that the leakage can be evaluated and compared. The model contains three parts namely:

- Summary form (1 sheet when printed)
- Detail-1 form is where most of the information required in the model is supplied by the user or water supplier
- Detail-2 form uses most of the information taken from Detail-1 form and thus minimal additional information is required.

Summary form – simply provides a one-page summary of certain key performance indicators and requires no input from the user with the exception of the reference number for the water supply system (optional). The model carries out several basic functions that can be summarised as follows:

- Estimates the current annual real leakage.
- Estimates the unavoidable annual real losses that occur from the system.
- Estimates an appropriate target annual real leakage for the system.
- Estimates the potential for savings in leakage.

The user should provide the following information:

- System name and contact details
- System data – length of mains, number of connections, percentage of time the system is pressurised, and the average operating pressure of the system
- Period over which the information refers – calendar year, financial year
- Details of water input to the system – water purchased from bulk supplier and water produced from own sources, etc.
- Details of water supplied to customers including estimates of all unmetered and unbilled water
- Estimate of apparent losses as a percentage of the total losses.

To facilitate the capture of data from water suppliers, a data request form has been created that includes only the basic information required.

Relevance and adaptability of the BENCHLEAK model to this project

BENCHLEAK models provide water suppliers with tools to assist them with leakage management, and evaluation and comparison between supply systems in a meaningful and realistic manner. The model is considered to exhibit water use efficiency management with integration to socio-economics, and is therefore considered a candidate model to be used in the development of a framework for integration of water resources and water uses management tools. However, it is noted that the model does not deal explicitly with the

interaction between water uses and water resources; therefore the model would need to be adapted to account for such.

3.3.3.2.6 The ECONOLEAK model

Tool Description

The ECONOLEAK model was developed through the WRC in order to assist water suppliers to manage and reduce their levels of unaccounted-for water. The ECONOLEAK model is based on the standard Burst and Background Estimate (BABE) procedures which were developed initially in the UK for use in the UK Water Industry. The ECONOLEAK model is aimed specifically at determining when a water supplier should invest in active leakage control for a specific zone metered area. The model complements the existing WRC SANFLOW, PRESMAC and BENCHLEAK models which together provide water suppliers with four key tools to assist them with their leakage management. The model assists water suppliers in gaining a better understanding of the main factors influencing the economics of leakage control, and enables them to identify the most cost-effective methods of reducing their system leakages. The ECONOLEAK model requires considerable factual system data in order to assess the economics of leakage in a water supply system (McKenzie and Lambert, 2002).

To use the ECONOLEAK model the user must collect certain basic information for the water supply system in question. Much of the information used in ECONOLEAK is basically the same information required in a normal minimum nightflow analysis or pressure analysis. The following information is required:

- Basic system data – length of mains, number of connections, pressure, etc.
- Water loss data – real and apparent losses
- Duration of reported bursts
- Number and leakage rates for reported and unreported bursts
- Marginal cost of water
- Costs for leak detection and repair.

The ECONOLEAK Model is designed to assess the leakage from a water distribution system based on the supplier undertaking active leakage control every two years, every year and every six months. The water losses from the three options are then compared to the costs associated with each option, and the most appropriate level of active leakage control is chosen. The model has been designed in a simple and straightforward manner to help water suppliers understand what is generally a complex issue. By developing the model in the form of an EXCEL spreadsheet, it is possible to simplify the calculations and, in this manner, the calculation processes can be understood easily (McKenzie and Lambert, 2002).

Relevance and adaptability of the ECONOLEAK model to this project

The model is considered to exhibit water use efficiency management with integration to socio-economics, and is therefore considered a candidate model to be used in the development of a framework for integration of water resources and water uses management tools. However, it is noted that the model does not deal explicitly with the interaction between water services and water resources; therefore the model would require to be adapted to account for such.

3.3.3.2.7 *The WATTREAT system*

Tool Description

WATTREAT is the name given to the suite of expert systems based decision-support software developed for the WRC project (O'H. Murphy, 2002). WATTREAT has been designed to address water treatment for small communities, and may be readily modified so that new information can be implemented into the software. Although WATTREAT has been designed to produce meaningful results, some components such as the water source protection advisor have significant scope for expansion. The expert-systems decision support programs developed include (O'H. Murphy, 2002):

- Water supply microbial sampling/ monitoring and chlorine disinfection advisors
- Laboratory determinand test selection aid
- Laboratory determinand test interpreter and water treatment advisor
- Water treatment option suitability ranking tool
- Water hardness and corrosion potential advisor
- Drinking water contaminant limits exceedance tool
- Water source protection advisor.

The functions of these components are summarised below.

1. Microbial sampling and chlorination disinfection advisor – this is a simple system designed to give advice on microbiological sampling and chlorination of a community's water supply, where a water storage and/or water reticulation system exists. It is split into two modules:
 - One module looks at when and where chlorine disinfection is done and the minimum residual chlorine concentrations in a community's water supply.
 - The other module addresses how often microbial sampling should be done, what microbes should be tested, and the need for re-sampling when results are positive.
2. The water determinand test selection aid and the treatment identification and toxicity advisor – this is designed to identify preliminary water quality test determinands based on site evidence and then to present toxicity and water treatment advice:
 - Given visual symptoms, taste and smell characteristics for on-site water samples and potential pollution sources in the vicinity of the water source, this module then identifies criteria for laboratory analysis.
 - Given specific contaminant concentrations in a water supply, this component is designed to:
 - Give comments on potential problems, toxic effects or impacts relating to the contaminant in terms of its concentration
 - Provide recommendations and warnings regarding the treatment process
 - Identify relevant treatment options for the contaminant in question.
3. Water treatment option ranking aid – this module is designed to aid in the selection of water treatment options, given the following criteria:
 - The need for restrictions on costs

- The relative importance of operational simplicity and process reliability
 - The need for effective reduction of pathogens, potentially toxic contaminants and constituents which present aesthetic problems.
4. The drinking water limits assessment tool – this decision aid estimates the extent to which constituents exceed or satisfy upper-end health related guideline limits. The ability to cost-effectively treat raw water to make it suitable for potable purposes depends on:
- The extent to which constituents exceed aesthetic and health-related guideline limits
 - How easy or cost-effective it is to treat the water for each constituent to bring it within acceptable limits
 - To what extent a suitable treatment process for one constituent is compatible with that selected for another constituent.

This information is used to help assess the importance of specific treatment process options for potential contaminants, and thus be profitably used in conjunction with the water treatment option ranking aid and the treatment identification and toxicity advisor.

5. Water supply network corrosion and aggressiveness assessment aid – this module is designed to give advice on water hardness, corrosivity and aggressiveness, the latter two, principally, in terms of chlorides and sulphates. In other words, it is designed to advise on:
- The potential aggressiveness of water on cement-based materials and potential corrosivity of water on metals, due mainly to high chloride and sulphate concentrations
 - Corrosivity of water on cement and metals given calcium, pH and alkalinity values in terms of threshold values
 - The hardness of the water and the potential effect of this on human health and on washing.
6. The water source protection assistant – this module is designed to give advice on protection of water sources for rural communities, where the community collects its water directly from the source. The principal aim being to protect the health of those using the water for domestic purposes. Given the type of water source, the existing facilities used to protect the source, the type of sanitation in the vicinity, the proximity of sanitation facilities at the source, the existence of other potential sources of pollution up-slope of the source, the depth of the groundwater table, and the type of ground in the area, the module:
- Determines the degree of risk of contamination of the water source
 - Identifies the need to get expert advice
 - Identifies appropriate mitigation measures.

Relevance and adaptability of the WATTREAT model to this project

In essence, WATTREAT attempts to provide decision support for small-scale water supplies in terms of:

- Advice on sampling water supplies for pathogens
- Advice on chlorination

- Toxicity advice and treatment option identification
- Water treatment component suitability assessment
- Comments on water hardness, potential aggressiveness and corrosivity (the latter two due principally to the presence of chlorides and sulphates in the water)
- Water sample analysis data comparisons with quality limits
- Water source protection for springs, boreholes and wells.

Therefore, the model is considered to exhibit water quality management integration, to some extent, with socio-economics and environmental issues, and is therefore considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools. However, it is noted that the model does not deal explicitly with the interaction between water services and water resources, therefore, the model may have to be adapted to account for such.

3.3.3.2.8 The IMPAHLA software

Tool Description

The IMPAHLA software package was developed as part of a research project funded by the WRC of South Africa (Stephenson et al., 2001). It is designed to implement a simple asset register for small water services institutions. It contains a number of default assets and event types, as well as many standard reports. However, it is flexible, and can be adapted to the needs of most small water services institutions, or even other institutions that have a number of assets to manage. The IMPAHLA asset management system is therefore, a guide intended to help organisations to set up an asset management system, and to implement the asset register using IMPAHLA. The management system has been designed to investigate asset management procedures according to the infrastructure asset function in relation to the complete water services cycle (i.e. from the water abstraction point to the final disposal point) (Stephenson et al., 2001).

IMPAHLA uses a three criteria classification system. Each asset is classified according to its location, its function and its type (Stephenson et al., 2001). In summary, IMPAHLA helps water services providers develop an asset management plan that helps an institution to answer the following questions:

- What do we own and manage?
- Are we meeting our customers' needs in the most sustainable, cost-effective manner?
- Where are we now?
- Where do we want to be in the future?
- How are we going to get there?

Not only will an asset management plan help to answer the above questions from a planning point of view, but the information in the plan will also help an institution manage its day-to-day activities in a sustainable, cost-effective and efficient manner.

Relevance and adaptability of the IMPAHLA tool to this project

The diversity within water services with regard to level of services cannot easily be reduced. However, with the introduction of a standard asset management software to the water services sector in South Africa, an environment of discipline and logical processes can be adopted particularly by small water service providers. The conventional technical reliability approach is no longer sufficient to keep water services systems operational, profitable and sustainable. The IMPAHLA ensures that water services infrastructures are managed within an integrated social, economic and environmental context.

The model is considered to exhibit infrastructure management and administrative capabilities that integrate, to some extent, with socio-economics and environmental issues, and is therefore considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools. However it is noted that the model does not deal explicitly with the interaction between water services and water resources, therefore the model may have to be adapted to account for such.

3.3.3.2.9 The Water Services National information System

Tool Description

The Water Services National Information System (WSNIS) is a GIS Based ArcGIS 9.2 and emanates from the requirements of the NWA, which in Chapter 14, outlines the framework on monitoring, recording, assessing and disseminating information on water resources. The information on water services is the key component of the whole future national information system. In particular, the NWA deals with the framework components as follows:

- Establishment of national information systems
- Objectives of national information systems
- Provision of information
- Access to information
- Regulation for monitoring, assessment and information.

The responsibility for the development of the National Information System (NIS) is vested with the DWA. The DWA has outlined that the NIS will be used for development, implementation and monitoring of a national policy on water services, and more specifically to provide information to water service institutions, consumers and the public to enable them to monitor the performance of water services institutions.

The NIS is based on three scenarios of population (i.e. census population, census updated population and the reference framework population). The NIS is structured to cover the following aspects:

- Demography and service levels
- Water services infrastructure
- Sanitation services infrastructure
- Associated services education/health
- Water resource management
- Year infrastructure development plan
- Water services management
- Institutional capacity
- Social awareness and customer service requirements
- Environmental status conservation and management
- Needs development plan.

The NIS is community based with a provincial programme view and a consolidated view.

Relevance and adaptability of the WSNIS tool to this project

The WSNIS is a step towards fulfilling the requirements of the Water Services Act to establish a national information system. The WSNIS covers a whole range of information from population, water services levels, backlogs, and water quality, to mention a few; and clearly the tool has the administrative abilities integrated on environmental, socio-economics issues, and is therefore considered a candidate tool to be used in the development of a

framework for integration of water resources and water services management tools. However, it is noted that the model does not deal explicitly with the interaction between water services and water resources, therefore the model may have to be adapted to account for such.

3.3.3.2.10 The Water Quality Management System

Tool Description

The Water Quality Management System (WQMS) can be used by water services authorities (local government), provincial/national government, etc. to guide the tracking, reviewing and improving of water quality. In particular, the system can be used for (Emanti, 2009):

- Monthly review of legislative compliance
- Identification of areas requiring urgent attention thus allowing effective and efficient allocation of resources
- Quarterly summary review (trend analysis, effectiveness of remedial actions, etc.)
- Reporting to stakeholders.

Water quality and other water service information is captured by authorised personnel and stored onto the central database. Water quality and other information can then be easily retrieved from the database via the internet to generate reports, tables and graphs for management review and decision making processes.

WQMS is currently being rolled-out across South Africa by the DWA and is supported by the Institute of Municipal Engineering of Southern Africa and the Water Institute of Southern Africa.

The following information can be accessed (Emanti, 2009):

- Drinking water general information.
- Abstraction, treatment, storage, reticulation and point of use, water quality monitoring and management programmes, laboratories, water related sites and news, etc.
- Reference material
- Abstraction – this section provides an overview of typical raw water sources and their protection.
- Drinking water treatment – this section provides an overview of water treatment technologies, and highlights the need for operation and maintenance, and discusses the importance of disinfection.
- Storage – this section provides an overview of typical storage systems, highlights the need for maintenance and discusses their protection.
- Reticulation and point of use – this section provides an overview of typical issues faced in distribution networks and required remedial measures.
- Drinking water quality monitoring and management programmes – this section provides an overview of legislation and regulations related to drinking water, and describes typical water quality management procedures.
- Drinking water quality parameters – this section describes typical water quality parameters and provides typical reasons for water quality failures.
- Drinking water laboratories – this section describes the types of laboratories and provides links to laboratory services.
- This model also has the facility to deal with sewerage effluent.

Relevance and adaptability of the WQMS tool to this project

The Water Quality Management System (WQMS) can be used by water services authorities (local government), provincial/national government, etc. to guide the tracking, reviewing and improving of water quality. Therefore the WQMS is considered to exhibit water quality management with integration to some extent to socio-economics and environmental issues, and is considered a candidate model to be used in the development of a framework for integration of water resources and water uses management tools. However, it is noted that the model does not deal explicitly with the interaction between water services and water resources, therefore the model may have to be adapted to account for such.

3.3.3.3 Reviewed water resources tools

The water resources tools selected for review are those that were perceived to have hydrological analysis, yield analysis, allocation planning, water conservation, return flow management, data management and administration integrated on multiple aspects such as environmental, socio-economic, administrative and of sustainable development. The following is a list of water resources management tools selected for review:

- WRSM2000 (Water Resources Simulation Model)
- ACRU (Agrohydrological modelling system)
- WRYM (Water Resources Yield Model)
- WRPM (Water Resources Planning Model)
- WQT2000 (a water quality model)
- Mike Basin (Danish Hydraulic Institute (DHI) decision support system)
- WSAM (Water Situation Assessment Model)
- HYDSTRA (a hydrological information- & data-base)
- WMS (Water Management System)
- NGIS (National Groundwater Information System)
- SAGDT (South African Groundwater Decision Tool)
- EIS (Economic Information System).

3.3.3.3.1 The Water Resources Simulation Model 2000

Tool Description

Water Resources Simulation Model 2000 (WRSM2000) is a modular water resources simulation program that runs under Windows (Middleton and Bailey, 2008). The program features five different module-types: the Runoff module, the Channel module, the Irrigation module, the Reservoir Module and the Mining module. Each of these modules contains one (or offers a choice between more than one) hydrological models that simulate a particular hydrological aspect. The modules are linked to one another by means of routes. Multiple instances of the different modules, together with the routes, form a network. By choosing and linking several modules judiciously, virtually any real-world hydrological system can be represented (van Wyk et al., Undated).

The first step in simulating any hydrological system is to set up the network of modules and routes to represent this system. The Windows version of WRSM2000 allows for much larger networks than ever before and offers interactive creation and editing of all modules, routes and networks. The program supports the user by means of extensive error checking and does away with the error prone and time consuming chore of creating data files in an editor, external to the program. Where files of older versions of the program are supplied, WRSM2000 will automatically update these files to be compatible to this latest version.

WRSM2000 simulates flows in a catchment and by comparing against observed flows, the user can analyse statistics and graphs of various water resource parameters and manipulate calibration parameters to achieve a good 'fit' between observed and simulated flows. Once this has been achieved for the network, naturalised flows can be determined (i.e. flows without any man made effects of reservoirs, industry, towns, irrigation schemes, mines, etc.). The model stores all information internally, so that any number of runs can be undertaken without terminating the program. This facility, in conjunction with the ability to look at several gauging points in a network, speeds up the calibration process considerably.

The nature of the problem that is addressed by WRSM2000 is eminently suited to be solved by means of object-oriented design and programming. Each of the real world elements (the modules and the routes) within a network can be seen as largely independent entities that can be programmed as independent classes. For historical reasons, WRSM2000 is written in Fortran, using the Fortran Compiler Lahey Fortran 90. The choice fell on the Lahey compiler largely because it could be used in conjunction with the Winteracter package. The Winteracter package allows one to create Windows style user interfaces with far less effort than it would have taken to do the same by means of either C/C++ or Pascal.

Relevance and adaptability of the WRSM2000 tool to this project

The WRSM2000 has been upgraded from being a surface water resources model to an integrated water resource model by including the groundwater : surface water interaction, streamflow reductions such as alien vegetation and afforestation, and more advanced methodology for irrigation and wetlands. The model is to be enhanced further by embracing databases and a GIS Viewer and will ultimately be incorporated into a framework which will include water quality and ecological reserve models. The WRSM2000 is considered a candidate model to be used in the development of a framework to integrate water resources and water uses management tools. However, it is noted that the model does not deal explicitly with the interaction between water uses and water resources, therefore the model would need to be adapted to account for such.

3.3.3.3.2 The ACRU model

Tool Description

ACRU is an agrohydrological modelling system in which the fields of scientific hydrology and applied engineering and water resources related hydrology are integrated and interlinked with agrohydrology in terms of the forcing functions and responses of the various components which make up the natural and anthropogenically influenced terrestrial hydrological system (Schulze, 1995).

The ACRU model has its hydrological origins in a distributed catchment evapotranspiration based study carried out in the Natal Drakensberg in the early 1970s. The acronym ACRU is derived from the Agricultural Catchments Research Unit within the erstwhile Department of Agricultural Engineering of the University of Natal in Pietermaritzburg, although it has now become the model's generic name without reference to the former unit. The agrohydrological component of ACRU first came to the fore during research on an agrohydrological and agroclimatological atlas for Natal. The ACRU agrohydrological modelling system is centred around the following aims (Schulze, 1995):

- It is a physical conceptual model, (i.e. it is conceptual in that it conceives of a system in which important processes and couplings are idealised, and physical to the degree that physical processes are represented explicitly).

- ACRU is not a parameter fitting or optimising model, and variables (rather than optimised parameters) are, by and large, estimated from physical characteristics of the catchment.
- It is a multi-purpose model which integrates the various water budgeting and runoff producing components of the terrestrial hydrological system with risk analysis, and can be applied in: design hydrology, crop yield modelling, reservoir yield simulation and irrigation water demand/supply, regional water resources assessment, planning optimum water resource allocation and utilisation, climate change, land use and management impacts, and resolving conflicting demands on water resources.
- The model uses daily time steps and thus daily rainfall input, thereby making optimal use of available data. Certain more cyclic, conservative and less sensitive variables (e.g. temperature, reference potential evaporation), for which values may have to be input at monthly level (if daily values are not available), are transformed internally in ACRU to daily values by Fourier Analysis. In routines in which sensitive intra-daily information (e.g. rainfall distribution) is required, this is obtained by synthetic disaggregation of daily input within the model.
- The ACRU model revolves around daily multi-layer soil water budgeting and the model has been developed essentially into a versatile total evaporation model. It has therefore been structured to be highly sensitive to climate and to land cover/use changes on the soil water and runoff regimes, and its water budget is responsive to supplementary watering by irrigation, to changes in tillage practices, or to the onset and degree of plant stress.
- ACRU has been designed as a multi-level model, with either multiple options or alternative pathways (or a hierarchy of pathways) available in many of its routines, depending on the level of input data available or the detail of output required. Thus, for example: reference potential evaporation, interception losses, values of soil water retention constants, maximum (i.e. potential) as well as total evaporation (actual evapotranspiration), leaf area index, components of the peak discharge estimation, hydrograph routing, reservoir storage : area relationships, or the length of phenological periods in crop growth. All may be estimated by various methods according to the level of input data at hand or the relative accuracy of simulation required.
- ACRU can operate as a point or as a lumped small catchments model. However, for large catchments or in areas of complex land uses and soils ACRU can operate as a distributed cell-type model. In distributed mode, individual subcatchments (ideally not exceeding 30 km²) are identified, discretised and flows can take place from exterior through interior cells according to a predetermined scheme, with each subcatchment able to generate individually requested outputs which may be different to those of other subcatchments or with different levels of input/information.
- The model includes a dynamic input option to facilitate modelling the hydrological response to climate or land use or management changes in a time series, be they long term/gradual changes (e.g. forest growth, urbanisation, expansion of irrigation project or climate trends), or abrupt changes (e.g. clear felling, fire impacts, construction of a dam, development of an irrigation project, or introduction of new land management strategies such as tillage practices), or changes of an intra-annual nature (e.g. crops with non-annual cycles, such as sugarcane). A dynamic input file is accessed each year with the new variable inputs to be used from that year onwards (e.g. crop coefficients, root mass distributions, planting dates or soils properties – for new tillage practices). Details of the dynamic input option are given in the ACRU User Manual.
- ACRU operates in conjunction with the interactive ACRU Utilities, which is a suite of

software tools to aid in the preparation of input information (e.g. the ACRU Menubuilder) and output information (e.g. the ACRU Outputbuilder). The ACRU Menubuilder prompts the user with unambiguous questions, leading the user into inputting, for example, complex distributed catchment information, easily. The Menubuilder contains alternative decision paths with pre-programmed decision support Systems. Furthermore, the Menubuilder includes a help facility, built-in default values as well as warning and error messages. Details of the various utilities are presented in ACRU User Manual.

Relevance and adaptability of the ACRU model to this project

Typical applications of the ACRU model are:

- Water resources assessments
- Design flood estimation
- Irrigation water demand and supply
- Crop yield and primary production modelling
- Assessments of impacts of land use changes on water resources
- Assessments of hydrological impacts of wetlands
- Groundwater modelling
- Assessments of potential impacts of global climate change on crop production and hydrological responses.

Therefore ACRU is considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools. However, it is noted that the model does not deal explicitly with the interaction between water services and water resources, therefore the model may have to be adapted to account for such.

3.3.3.3 The Water Resource Yield Model

Tool Description

The Water Resources Yield Model (WRYM) was developed by the DWA (DWAf, 2003), for the purpose of modelling complex water resource systems. It is used together with other simulation models, pre-processors and utilities for the purpose of planning and operating the country's water resources. WRYM model is used to optimise the allocation of water on a monthly basis throughout a large multi-use river system, according to a penalty structure, for a given time horizon of water demands and allowing stochastic variation of streamflows. It is used to calculate the long-term yield from a specific flow series, to examine operating rules or to develop yield-reliability curves. Flow and demands sequences are supplied to the model for specific catchment development scenarios. This allows calculation of assurance or risk of failure of the water resources yield of the system as a whole or of any of its reservoirs. Model outputs can be used to indicate the required timing of augmentation measures and schemes to maintain given assurance levels. The impact of management options on reliability of supply can also be examined (DWAf, 2003).

The WRYM uses a sophisticated network solver in order to analyse complex multi-reservoir water resource systems for a variety of operating policies and is designed for the purpose of assessing a system's long-term and short-term resource capability (or yield). Analyses are undertaken based on a monthly time-step and for constant development levels (i.e. the system configuration and modelled demands remain unchanged over the simulation period).

According to DWAF (2003) the WRYM has been created for the purpose of configuring most water resource system networks using basic building blocks. Central to the modelling approach adopted in the WRYM is the concept that the configuration of a system network and the relationships between its elements are defined by means of input data, rather than by fixed algorithms embedded in the complex source code of the model (DWAF, 2003).

The primary building blocks used in the model are channels and nodes. These are discussed below:

- Channels – channels represent conduits that convey water between nodes within the water resource system network and include river reaches, canals, pipelines (gravity or pumped), hydraulic structures and defined water requirements imposed on the system.
- Nodes – nodes serve primarily as junctions between the various channels within a water resource system network. This includes bringing flow from a tributary catchment together into a river reach, as well as providing abstraction points that represent the appropriate locality and associated resource availability for a particular water user in the system. A node can have storage, representing the capability of reservoirs to retain water over time, and can also be used to define where natural runoff, generated within catchments, enters the system network.

It should be noted that in addition to the two basic elements of channels and nodes, there is another important group of input parameters that is used to control the basic definition associated with a particular model run. This includes options relating to the run description, analysis period, type of analysis and result output formats. These aspects will be discussed later.

The starting point when building a water resource system network model is usually a geographical map showing the physical features of the system in question. The map should denote rivers, catchment boundaries, reservoirs, abstraction works, water discharge infrastructure, water transfer conduits (canals, tunnels or pipelines) as well as the location of water users. The catchment delineations that is required for defining the way in which hydrological data will feed into the network model has to be determined from the map. The selection of incremental sub-catchment boundaries within the system is dictated by the resolution to which modelling needs to be undertaken, the position of existing infrastructure, as well as the location of potential new water resource development options that need to be assessed.

The next step in the process of building a water resource system network model is deciding on the implementation of rules that will control the way in which the system is operated. System operating rules address aspects like the supply priority amongst water users, prioritisation of the use of water sources, inter-reservoir and inter-basin support rules, as well as reservoir operational levels and drawdown rules. The selection of operating rules are of great importance because, as is the case with the physical characteristics of a system, operating rules have a direct impact on the capability, assurance and sustainability of a system's water resources, as well as the costs associated with its operation.

The procedure for developing operating rules involves a number of steps, which represents an iterative process that can be repeated as many times as required:

- Selection of an initial set of operating rules based on chosen objectives with regard to the behaviour of the system. This step is probably the most difficult and relies greatly on the intuition and experience of the water resource system analyst.
- Implementation of the selected operating rules in the network model and undertaking of a model run.

- Evaluation of the level of achievement of selected objectives based on the behaviour of the system as exhibited in the simulation results.
- Usually, selection of an alternative set of operating rules followed by repetition of the above steps.

Relevance and adaptability of the WRYM tool to this project

WRYM is used to optimise the allocation of water and therefore is considered to exhibit socio-economic and environmental issues as well as a link to water services. Thus, WRYM is considered a candidate model to be used in the development of a framework for the integration of water resources and water services management tools. However, it is noted that the model does not deal explicitly with the interaction between water uses and water resources, therefore the model may have to be adapted to account for such.

3.3.3.3.4 The Water Resource Planning Model

Tool Description

The Water Resource Planning Model (WRPM) was developed from the WRYM for the DWA. The purpose of the WRYM is to quantify the yield capability of a system under a fixed development level (constant level of water requirements and fixed system configuration). The WRPM has been designed to simulate a changing system allowing for growing demands. In general the purpose of the WRPM is to analytically quantify the capability of dynamic changing water resource systems, determine operating rules and schedule the implementation of development options using a practical curtailment strategy (DWAF, 2008a).

According to DWA (2009), the WRPM is a decision support system with the ability to evaluate the capability of existing and proposed water resources systems. This is achieved through simulation of the physical, statistical, operational and quality variables that influence the capability of a water resource system. WRPM is used to optimise the allocation of water on a monthly basis throughout a large multi-use river system, according to a penalty structure, for a given time horizon of water demands and allowing stochastic variation of stream flows. It allows various sub-systems to support each other during deficit periods and is used as a planning tool to explore augmentation or restriction strategies, against increasing demand scenarios. Flow and demands sequences are supplied to the model for specific catchment development scenarios. This allows calculation of assurance or risk of failure of the water resource yield of the system as a whole or of any of its reservoirs. Model outputs can be used to indicate the required timing of augmentation measures and schemes to maintain given assurance levels. The impact of management options on reliability of supply can also be examined. Salinity management through freshening releases can be allowed to play a role in WRPM (DWAF, 2003).

Relevance and adaptability of the WRPM tool to this project

WRPM is used to optimise the allocation of water and therefore is considered to exhibit socio-economic and environmental issues as well as a link to water services and is thus considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools. However it is noted that the model does not deal explicitly with the interaction between water uses and water resources, therefore the model may have to be adapted to account for such.

3.3.3.3.5 The WQT2000 model

Tool Description

WQT2000 is a coarse to medium-scaled model for salinity (total salt load) production and transport in large multi-user, multi-reservoir catchments, specially designed to be driven by the same natural flows that drive the WRYM and WRPM system analysis models outlined above. The free standing version of WQT2000 is used to determine salinity model parameters by calibration. These parameters are then input to the WRPM model, which incorporates an integrated version of WQT2000, to generate salt loads/concentrations during multiple stochastic optimisation runs in large river systems (User-support, 2009d).

The model presents a powerful tool for the initial assessment of the impact of proposed development options and can also be used to provide a regional overview of salinity conditions. It has been designed to complement the WR90 water resources manual and database (recently updated to WR2005). WQT2000 incorporates a simple to use but versatile interface that links the user to an extensive database and to the comprehensive WQT monthly hydro-salinity model. It incorporates powerful and flexible “What if?” capabilities for assessing proposed new developments (User-support, 2009d).

The initial implementation is for the 192 quaternary catchments of the Vaal River, ranging from undeveloped areas to some of the most developed catchments in South Africa. The database contains 70 year monthly time series of rainfall and naturalised and urban catchment runoff. It also includes calibrated WQT hydro-salinity model parameter values. The characteristics of each quaternary catchment are stored along with default present day catchment development data such as (User-support, 2009d):

- Urban area
- Irrigation areas
- Wetland area
- Channel bed loss
- Minor (typically farm) dam Full Storage Capacity and Full Storage Area
- Major dam Full Storage Capacity and Full Storage Area
- Reservoir storage-area shape factor
- Release from major dam
- Mine pumpage and Total Dissolved Salts concentration
- Effluent discharge and Total Dissolved Salts concentration
- Abstraction from major dam and minor dam
- Proportions of catchment runoff upstream of supported and unsupported irrigation and downstream of major dam.

Relevance and adaptability of the WQT2000 tool to this project

The WQT2000 is considered to exhibit water quality management including to some extent socio-economics and environmental issues, and is therefore considered a candidate model to be used in the development of a framework for integration of water resources and water uses management tools. However it is noted that the model does not deal explicitly with the interaction between water uses and water resources, therefore the model may have to be adapted to account for such.

3.3.3.3.6 The Mike Basin system

Tool Description

Mike Basin is a decision support system and can be considered to be a more comprehensive tool. Developed by the Danish Hydraulic Institute (DHI) as a versatile decision support tool for integrated water resources management and planning, Mike-Basin has been integrated into the ArcView GIS environment. This ensures to maintain the full functionality of the Esri Tool and apply its standard facilities to water resource modelling (WaterStrategyMan, 2003).

Mike Basin studies by default the water distribution within the basin. However, a water quality option and a module for simulating groundwater can be selected as well. The first step in building a Mike Basin project consists of the basin schematisation as a network of nodes and branches. As in large river basins the description of numerous individual demands and features takes a lot of time and effort. Some networks can be simplified according to objectives of the modelling and availability of information. For instance, smaller rivers can be lumped into a single branch upstream an intake point, small irrigation sites scattered in an area can be represented by a single scheme with one intake point, and civil and industrial supply can be lumped into one entity. However, MB leaves the alternative to either draw a simplified schematic scheme, or keep the details of a basin (WaterStrategyMan, 2003).

The schematic network can be drawn on a geographic map showing the hydrography of the area of interest. At first the user manually digitises the main river and its tributaries in terms of a polyline following the trace on the map. Then he places the nodes in the following order: river nodes, reservoirs, hydropower nodes, and water demand nodes. River nodes are placed on the river polyline and are of simple or catchment type. The former defines confluences, diversions, upstream end of tributaries and the outlet of the river system, whilst the latter is the outlet of an upstream catchment area. Mike Basin has an Access database but data for each network element is easily edited or viewed from the Network View (WaterStrategyMan, 2003).

In fact in Mike Basin each connection between a user node and a source node must be consistently defined in the property boxes of both of them. This means that whenever a user is specified for a source node, the same node must be specified for that user. The Check Topology, the tool is responsible to sweep the network connections and validate the basin schematisation before starting the simulation (WaterStrategyMan, 2003).

If the Mike Basin's user connects an off-take node to multiple water demanding users, the order followed in selecting them is significant: it represents the sequence in which connected user nodes will be fed and their water demands fulfilled. Each demand node will receive the minimum between its entire water demand and the water available at the off-take node after upstream user nodes have been fulfilled. On the other hand, if a demand node receives water from more than a source node, the order of the source identifiers listed in the property box represents the sequence in which extractions are requested from the connected supply nodes. The first node in the list will supply the entire demand (if available) before the second node is considered. This second node will supply the remaining demand (if any) after the first node has supplied 'its' water, and so on for the subsequent supply nodes. This is the Local Priority principle of Mike Basin and it is at the basis of the allocation algorithm of Mike Basin (WaterStrategyMan, 2003).

Mike Basin has another principle for managing water distribution, namely Global Priority Rules and consists of a set of rules affecting any node in the network that is involved in the

water allocation process. Multiple rules can be defined with a priority rank given to each. With the global priority algorithm any distribution of water is governed by rules only. Global Priority Rules concern extractions, minimum flows, reservoir storage and reservoir target level (WaterStrategyMan, 2003).

Once the river basin schematisation has been completed, the data entered and the rules defined, some parameters characterising the simulation must be specified. The simulation window asks for the starting and ending dates of the simulation period and to choose between a monthly or a daily time step. Some options related to the result presentation can be selected as well: some results views can open automatically when simulation is terminated, or output can be visualised for a specific sub-set of nodes (WaterStrategyMan, 2003).

As far as water quantity is concerned, the calculation of water flows and their distribution in the basin is performed on the basis of the local or global rules. Mike Basin integrates a rainfall-runoff module that allows the computation of the runoff time series given the initial conditions, a set of necessary parameters and time series of evaporation and precipitation. The user is asked for this kind of information in the rainfall-runoff modelling dialog box that is accessed from the generic catchment node box. In the same box he can choose among three different rainfall-runoff models that are part of another DHI software package named Mike 11 (WaterStrategyMan, 2003).

The water quality module within Mike Basin simulates transport and degradation of significant substances affecting water quality issues in reservoirs and rivers. The substances modelled are: the total organic matter expressed as Biological Oxygen Demand, Ammonia, Nitrates, Dissolved Oxygen, Chemical Oxygen Demand, Total Phosphorus and *E. coli* bacteria (WaterStrategyMan, 2003).

The groundwater module of Mike Basins consists of a simple physical model of an aquifer that is conceptualised as a linear reservoir exchanging water with water users and surface water bodies. The terms of the water balance comprise: pumping, recharge, seepage from rivers and discharge to rivers (WaterStrategyMan, 2003).

Simulation results consist of performance of reservoirs and hydropower units, water balance and water quality status at the user nodes, and river flows at each river node.

Information is displayed in three different formats (WaterStrategyMan, 2003):

- As time series and related graphs
- Summary Hypertext Markup Language (HTML) tables
- On the geographic layer.

Relevance and adaptability of the Mike Basin tool to this project

According to the developer Mike Basin should facilitate sustainable management of surface and groundwater resources and water quality (WaterStrategyMan, 2003). The system concentrate on the physical and optimisation aspects of water resources, without taking into account socio-economical impacts and impact analysis techniques, and is therefore considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools. However it is noted that the model does not deal explicitly with the interaction between water services and water resources, therefore the model may have to be adapted to account for such.

3.3.3.3.7 The Water Situation Assessment Model

Tool Description

The Water Situation Assessment Model (WSAM) is a coarse-scaled model which allows assessment of cascading water balances for quaternary scale catchments in South Africa for prescribed scenarios of human related water use. The water balances are based on prior estimates of the annual natural stream flow during a 1:50 year "drought". The model database includes water use data as well as default values for many model parameter settings. The model was developed to support decision-making regarding the NWRS (User-support, 2009a).

The NWA has transformed water management in the country, in line with the principles of the new constitution of 1994. The NWA recognises the integrity of the hydrological cycle, and requires that water resource management proceed in an integrated fashion, ensuring that the resource is developed in a sustainable manner (User-support, 2009a).

Macro scale reconnaissance level planning provides a platform whereby one can evaluate, as well as effectively communicate and involve stakeholders in the various strategy development processes related to water resource management. This, combined with the fact that macro scale planning is an integral part of the planning process in terms of obtaining an understanding of the status of the water resources on a national scale, led to the development of the WSAM with a combined investment in terms of data and software in the order of R15 million (User-support, 2009a).

WSAM combines simplicity of use and the ability to obtain results with a level of accuracy, which is eminently sufficient for macro scale reconnaissance level planning within seconds. Its conceptual structure makes it possible to comprehensively account for the many factors that affect water resources planning. It also provides a useful aid in communicating general ideas, thoughts and opinions concerning options for strategic water resource planning. Other models are, however, still needed for final design purposes and for the preparation of operating rules for daily water resource management (User-support, 2009a).

The WSAM is a versatile and effective decision-support tool that empowers stakeholders to get involved in water resource management decision making. Its roles within the Department include (User-support, 2009a):

- Strategy development
- reconnaissance level planning for scoping and situation assessment
- Support for water resource managers with macro-scale planning
- Serve as a warning mechanism for identifying possible future areas of concern
- A communication tool for conveying study results
- A training tool for the purpose of introducing these water resource concepts and their interrelationships to less experienced individuals.

Relevance and adaptability of the WSAM tool to this project

WSAM's sound structure and speed makes it suitable for use in a workshop environment, yet it is comprehensive and sufficiently accurate for national or regional water resources analysis. It is also a useful communication tool that can empower water resource managers and other stakeholders to make well-informed decisions and understand the processes that affect water resources management. It encourages stakeholders to share information and to improve the existing national database (User-support, 2009a). WSAM is considered a candidate model to

be used in the development of a framework for integration of water resources and water services management tools. However it is noted that the model does not deal explicitly with the interaction between water services and water resources, therefore the model may have to be adapted to account for such.

3.3.3.3.8 The HYDSTRA system

Tool Description

HYDSTRA is a software for managing large amounts of time-series data in the hydro power, water resources and wastewater industries (Kisters, 2009). HYDSTRA offers a complete solution to environmental data management with unrivalled capability in:

- Data acquisition
- Data management
- Data analysis
- Modelling and simulation
- Automated task scheduling
- Providing quick and easy access to all data.

HYDSTRA stores data efficiently, reducing the amount of storage required and improving the speed at which it can be processed. HYDSTRA can keep tens of thousands of station years of data on a local hard disk and analyse a year of continuous data in under three seconds on a Pentium. HYDSTRA can import data from a variety of sources including any data logger, digitised charts, telemetry systems and spreadsheets. It can easily import data on a one-off basis or set up the system to routinely import data. HYDSTRA allows combining time-series data, water quality data, groundwater bore information and geographical information into a single integrated archive (Kisters, 2009)

In a perfect world, data would always be clean and accurate, but in reality data needs to be reviewed after it is collected and often edited. HYDSTRA provides a powerful tool for editing and reviewing data. Facilities include freehand editing, rescaling, zooming, cut & paste and stretching. When making multi-million dollar decisions based on data, one needs to know how good the data is. HYDSTRA allows for guarantee of the quality of data by storing quality information with each data point. HYDSTRA also includes facilities for routinely performing data audits and highlighting potential problems in your archive (Kisters, 2009).

HYDSTRA provides a wide range of outputs that can be automatically assembled to publish in Microsoft Word format or on the World Wide Web. HYDSTRA stores supporting information including: station details, rating tables and shifts, gauging measurements, instruments, cross-sections, variable descriptions, variable conversions, data quality descriptions, etc. HYDSTRA makes it easy to retrieve data from the archive to use with other packages. With HYDSTRA data can be extracted from the archive in text format, dBase III database format, CSV format for spreadsheets as well as through a Dynamic-link library (Kisters, 2009).

Relevance and adaptability of the HYDSTRA tool to this project

HYDSTRA is a software for managing large amounts of time-series data in the hydro power, water resources and wastewater industries and is considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools.

3.3.3.3.9 The Water Management System

Tool Description

The Water Management System (WMS) is a water quality management information system that has been developed to support the objectives of the NWA (DWAf, 2007b). WMS addresses and manages the monitoring systems component of the National Water Act and then captures the data collected from monitoring to be used for assessing and disseminating information. WMS is a working computer programme that assists the Water Quality Manager in making decisions that are scientifically sound by:

- Firstly – assessing the impact through the position of the site, and other activities and the water resources in relation to that site.
- Secondly – implementing a monitoring programme and ensuring that it is integrated into other existing monitoring programmes. To manage that monitoring programme to ensure that the required monitoring actions, frequency of monitoring, prescribed analytical methods are followed and that data with a high level of integrity is collected.
- Thirdly – setting resource quality objectives for the resource, and standards for water users (e.g. discharges), and then determine the extent of compliance of these objectives and standards.

The WMS contains three sub-systems:

1. The water resource management sub-system – this is used to achieve the sustainable use of water, protection for the quality of water resources is necessary to ensure sustainability of the nation's water resources in the interests of all water users. The water network defines all the geographical features and the human factors necessary to achieve the given objectives. The Water Resource Management sub-system deals with the following sub-modules:
 - Master lists (used to create and maintain standard reference information and standard processes in WMS)
 - Water network management (used to register stakeholders participating in managing the water resources, define management areas, water resources, transfer facilities, water use sites, water use, and the setting of objectives and standards)
 - Stakeholder management (used to register functional structures and geographical feature stakeholders)
 - Result management information (used to set parameters, and extract reports and graphs in order to accurately manage water resources)
 - Multimedia.
2. The monitoring management sub-system – this is used to effectively and efficiently manage resource quality operational monitoring, on a national basis. The Monitoring management sub-system deals with the following main modules:
 - Peripheral information (used to create and maintain standard reference information for monitoring management)
 - Monitoring programmes (used to register the requirements for recurring monitoring and associated information)
 - Sample and results registration (used to capture monitoring samples and results into the WMS system)
 - Sample and results administration (used to ensure the correct monitoring information is gathered through quality control).
3. The Water Management System GIS sub-system – this is used to geographically display water resource information, in order to assist in interpreting and determining

the quality and status of water resources. Water resource information that can be obtained and viewed via this system includes the geographical location and representation of water features, as well as the orientation and context of one water feature in relation to other water features.

To provide additional customised functionality for the integration of the geographical aspects of water resource features and water resource information, the WMS GIS sub-system also makes use of ArcView GIS. WMS Geographical information is stored in the database as layers, and these layers provide a means to distribute and share geographical information with all users of the WMS.

Relevance and adaptability of the WMS tool to this project

The WMS is a water quality management information system that has been developed to support the objectives of the NWA and is considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools.

3.3.3.3.10 The National Groundwater Information System

Tool Description

The National Groundwater Information System (NGIS) is a portfolio of projects designed to meet increasing demands for groundwater information in a rapidly changing water business environment. The system is distributed among regional offices and caters for the integration of spatial and non-spatial data and information. It also accommodates increased visualisation and analytical functionality (DWA, 2009).

The portfolio of the NGIS project includes several applications, namely (DWA, 2009):

- The National Groundwater Archive – is a web-based system that allows capturing, viewing, modifying and extraction of groundwater related data by registered users. Currently it is focusing on data related to points known as geosites (boreholes, wells, springs, etc.). Line and polygon related data will be made available in future.
- Open-NGDB – this is presently the national database system for managing the groundwater data and is accessible to trained users. It is available at the national office and all Regional offices, although not all these offices are actively capturing groundwater data. Currently there are approximately 244 700 records on the Open-NGDB.
- REGIS-Africa – REGIS-Africa is an acronym for Regional Geohydrological Information System. It is a complete hydrogeological information system, in which all relevant hydrogeological and related data are stored, managed, manipulated and queried in a uniform way. REGIS-Africa can be used for the evaluation of (geo) hydrological situations on a national and regional scale. The application is available at the national office and all regional offices.
- CHART-(C) HydroGeochemical Analysis and Reporting Tool (CHART) – is a combination of a management information system and decision-support system which integrates geohydrological and hydro chemical data in order to establish more effective and efficient monitoring management.
- Geohydrological Reports System – this is a database that contains groundwater related technical reports. Approximately 2600 technical reports are available in the library at the national office. These reports reflect the hydrogeological investigations done by DWA officials or consultants. A web based system allows one to inquire about the availability of specific documents and are made available in PDF format.

- Geodatabase – This is an Arcgis Geodatabase storing all cleaned and verified spatial hydrogeological data. From here data is fed into other applications, such as the REGIS-Africa.

Relevance and adaptability of the NGIS tool to this project

The NGIS is a portfolio of projects designed to meet increasing demands for groundwater information in a rapidly changing water business environment and is considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools.

3.3.3.3.11 The South African Groundwater Decision Tool

Tool Description

The purpose of the South African Groundwater Decision Tool (SAGDT) is to incorporate appropriate groundwater science and technology into a management platform, to make informed decisions when considering groundwater options, and, as a result, open new horizons for better water use in South Africa (User-support, 2009c).

The SAGDT is a groundwater assessment and planning tool, rooted firmly within the Water Research Commission. The DWA modified the software to an easy to use, risk-based decision support tool. It is an interactive tool that can be used by various user groups, solving day to day groundwater related matters, with the flexibility to solve more complex hydrogeological scenarios. It includes a much needed groundwater dictionary with illustrative graphics and animations of groundwater concepts (User-support, 2009c).

SAGDT is designed to provide methods/tools to assist groundwater professionals and regulators in making informed decisions concerning groundwater use, management and protection, while taking into account that groundwater forms part of an integrated water resource. The SAGDT is spatially-based software, which includes (User-support, 2009c):

- A geographic information system (GIS) interface to allow a user to import shape files and geo-referenced images.
- The GIS interface which allows spatial queries to assist in the decision-making process. The GIS interface contains a default set of shape files depicting various hydrogeological parameters across South Africa.
- The SAGDT introduces fuzzy logic based risk assessments to assist in decision making by systematically considering all possibilities. Included risk assessments relate to the sustainability of a groundwater resource, contamination of a groundwater resource, human health risks associated with a contaminated groundwater resource and the impacts of changes in groundwater levels on aquatic ecosystems.
- Third-party software includes a shape file editor, an interpolator and a groundwater dictionary, which includes a definition, a description of why the term is important, when considering groundwater. Graphics are used to assist in understanding the terminology.
- A report generator, which automatically generates documentation concerning the results of the risk assessment performed and the input values for the risk assessment.
- A scenario wizard is available for the novice to obtain step by step instructions in setting up a scenario.

The SAGDT allows problem solving at a regional or local scale, depending on the problem at hand (User-support, 2009c).

Relevance and adaptability of the SAGDT tool to this project

The SAGDT is designed to provide methods/tools to assist groundwater professionals and regulators in making informed decisions concerning groundwater use, management and protection, while taking into account that groundwater forms part of an integrated water resource. The SAGDT is therefore considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools.

3.3.3.3.12 The Economic Information System

Tool Description

The Economic Information System (EIS) was developed in order to provide a user-friendly means to access and analyse the database of freely available economic indicators assembled by the Department for the Water Resource Situation Assessment Studies (User-support, 2009b). In this way, information on the economic status of provinces and water management areas was generated for 1995. The EIS provides a means to carry out rapid economic overviews at national and regional scales, and support more detailed studies.

Since the EIS was developed, the framework for the collection of social and economic information has been reoriented to meet the needs of the recently demarcated district, local and metropolitan councils; and, important new data sets such as Census 2001 have now become available. The importance of incorporating socio-economic considerations in water management and planning is emphasised in the NWA (User-support, 2009b).

Relevance and adaptability of the EIS tool to this project

The EIS was developed in order to provide a user-friendly means to access and analyse the database of freely available economic indicators assembled by the DWA for the water resource situation assessment studies and is considered a candidate model to be used in the development of a framework for integration of water resources and water services management tools.

3.4 Conclusions

A generic method for assessment of tools has been developed and applied on selected tools used both in water uses and water resources management. The focus has been given to those tools integrated on multiple aspects such as environmental, socio-economic, administrative and of sustainable development while ensuring that they span the water management cycle from hydrological analysis, yield analysis, allocation planning, domestic demand forecasting & management, water conservation, return flow management, data management and administration.

It has been observed that in most of the tools reviewed there is a general lack of integration on multiple aspects such as environmental, socio-economic, administrative and sustainable development. Further the tools presented lack a framework for defining strategies and allowing the water managers (instead of specialists) to evaluate options. Nevertheless, some support the visualisation of results both in graphical and table format but leave to the technical user or the decision maker the further step of drawing conclusions and imagine suitable strategic measures.

The assessment has shown that there a number of tools that qualify as Level II Frameworks and in most cases this are at their maturity stage. However, there are gaps, and of particular

concern are those Level II Frameworks that the authors regard as key to integration, and this are there coordination, monitoring and compliance, and the data and information management integrated frameworks.

4 INTERNATIONAL EXAMPLES

4.1 Overview

South Africa is both a reforming and a developing country and it is therefore necessary to benchmark itself with other countries in improving its water management. South Africa is hailed to have the best water legislatures which were in part inspired by Australian changes for example. To date it is argued that Australia can now look to the new South African legal and constitutional framework for inspiration for reforms more geared towards sustainable environmental and social outcomes (Godden, 2005). This is an example of how South Africa managed to learn from other countries and come out even better.

This chapter gives examples from other countries who have been involved in integration issues, and these examples are intended to inform South Africa's path towards integration. The chapter looks specifically on integration frameworks and institutional setups.

4.2 Integration Frameworks and Systems

As already stated, there are no generic integrated frameworks which have received wide acceptance and uptake with open access to the framework components internationally. However, there are efforts towards integration, internationally, and though not guided by a framework like the GICF developed in this project, they are based on the same principles, and builds towards a complete system as envisaged with the WATERGRAL. These developments are guided by priorities of the particular countries and are centred on data and information management as a priority. The following are some of the examples:

4.2.1 The CUAHSI Hydrological Information System

The Consortium of Universities for the Advancement of Hydrologic Science Hydrologic Information System (CUAHSI HIS) – is an organization representing 122 US universities, which is supported by the Earth Sciences Division of the National Science Foundation to develop infrastructure and services to advance hydrologic science in the nation's universities. One component of CUAHSI's activity, also funded by the National Science Foundation, is a Hydrologic Information System (HIS) project, which is developing infrastructure and services to improve access to hydrologic data. The project started in April 2004 and ran for a period of two years (Tarboton, 2010). CUAHSI HSI is an internet-based system for sharing hydrologic data, **Figure 27**. It is comprised of databases and servers, connected through web services, to client applications, allowing for the publication, discovery and access of data (CUAHSI, 2011).

The CUAHSI (HIS) project was conducted by a group of academic hydrologists collaborating with the San Diego Supercomputer Centre as a technology partner. The HIS project was intended to produce a prototype Hydrologic Information System to perform the most critical functions needed to advance hydrologic science in US academic institutions, and to define the scope and extent of a more complete CUAHSI Hydrologic Information System that could be created with further investment by NSF after the end of this project (CRWR, 2005).

CUAHSI-HIS has three key components: (i) HIS Central — contains copies of metadata which facilitates searches; works like a search engine, in that it harvests

metadata from the data servers and allows it to be efficiently searched by the clients; (ii) HydroServer — stores, organizes and publishes data; allows metadata to be harvested by HIS

Central and data to be shared with clients and (iii) Clients (such as HydroDesktop) — gives users a convenient interface to access data; retrieves metadata from HIS Central and retrieves data from HydroServers (CUAHSI, 2011).

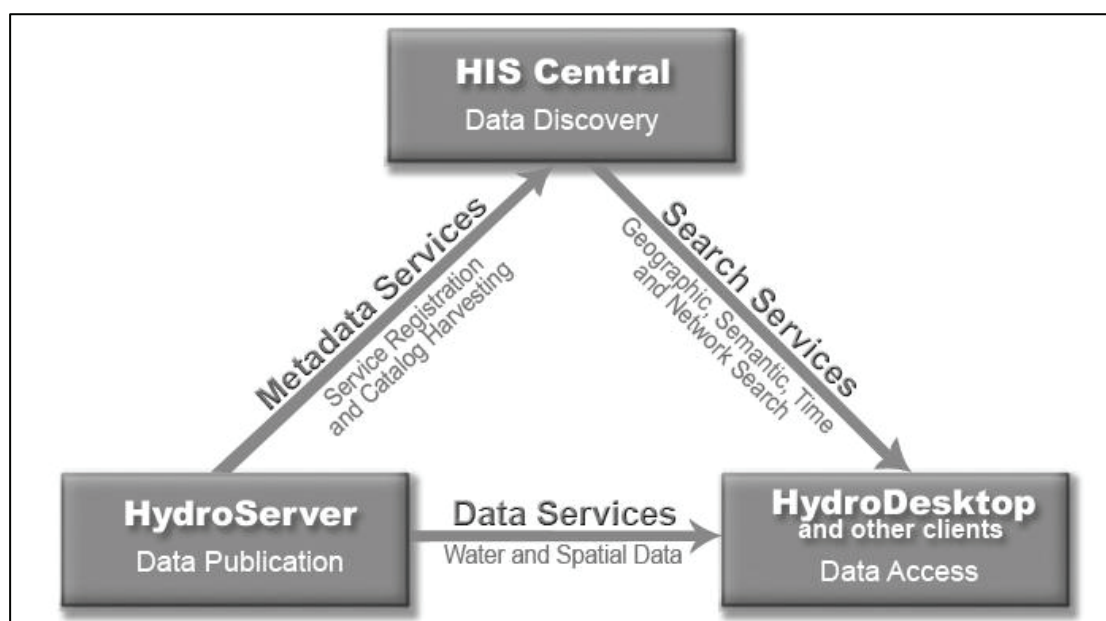


Figure 27: Three key components of CUAHSI-HSI

Maidment DR was funded \$964 218 US to defined how cyberinfrastructure should be developed for the hydrologic sciences, and developed a prototype community hydrologic information system using web services through the Consortium of Universities for the Advancement of Hydrologic Sciences (CUAHSI); Tarboton DG was funded \$964 218 US for the User Needs Assessment Survey and Hydrologic Observations Data Model Design; Piasecki M was given \$181 007 US to developed a basic community metadata profile and also conceptual representations for vocabulary taxonomy and processes using ontologies; and Zaslavsky I was given \$1 059 352 US for the development and deployment of cyberinfrastructure components of the prototype CUAHSI hydrologic information system, the Hydrologic Data Access system in particular (CUAHSI, 2011)

4.2.2 The Australian Water Resources Information System

The government through the Bureau of Meteorology is building the Water Resources Information System (AWRIS) which is to be a powerful information system capable of receiving, standardising, organising and interpreting water data from across the nation. The project commenced in August 2007 and the first phase of AWRIS development has been completed and has delivered the first water information products, water storage information, during 2010. The total cost of the project is \$10 million US plus applicable GST (NWC, 2011).

From 2008 to 2013, this water information research and development alliance will deliver most of the scientific and research innovation required by the Bureau to fulfil its national water information mandate. Through a strategic investment of \$50 million over five years, more than 40 CSIRO researchers are focussing on data interoperability (the compatibility of different data systems), earth observation, hydrologic modelling, water accounting, water

resource assessment and water forecasting. The Sustainable Water Information Models' tools and methodologies are already being explored in the context of soils, geosciences, meteorology, and through partnerships with the Australian Research Data Commons project, as part of the Spatial Information Services Stack (CSIRO, 2010).

4.2.3 The European Water Information System

Europe is developing a Water Information System for Europe (WISE) which is to manage information on projects, tools, documents or any other information relevant for the WFD implementation. WISE is a partnership between the European Commission (DG Environment, Joint Research Centre and Eurostat) and the European Environment Agency. The WISE viewer is a central location where geographically-mapped information on water-related issues can be found for the whole of Europe. This includes data on water quality and soon on water quantity, and information on implementation of EU water legislation (WISE, 2011).

At the water Director's meeting in November 2003, EU bodies and the EU25 member states agreed on the development of a new, comprehensive, European data and information management system for water, including river basins' and thus WISE was Launched on the 22nd of March 2007 (European commission Environment, 2011). In 2010-2011, the WISE-RTD Web Portal will be extended with the Flood Directive in the FLOOD-WISE project. FLOOD-WISE is an INTERREG IV C project in which water managers from various European countries exchange experiences with flood risk management. The objective of the project FLOOD-WISE is to improve cross border flood risk management in European river basins that cross national borders (WISE, 2011)

4.2.4 The American National Water Information System

America through the U.S. Geological Survey has developed the National Water Information System (NWIS) which provides access to water-resources data collected at approximately 1.5 million sites in all 50 States the District of Columbia, Puerto Rico, the Virgin Islands, Guam, American Samoa and the Commonwealth of the Northern Mariana Islands (USGS, 2011).

The National Water Information System is a tool that can provide timely information to decision-makers and planners and, if used to its potential, can drastically improve their ability to address water resources and land use challenges. The U.S. Geological Survey's (USGS) National Water Information System (NWIS) is a comprehensive and distributed application that supports the acquisition, processing, and long-term storage of water data. NWISWeb serves as the publicly available portal to a geographically seamless set of much of the water data maintained within NWIS. Many types of data are stored in NWIS, including comprehensive information for site characteristics, well-construction details, time-series data for gage height, streamflow, groundwater level, precipitation, and physical and chemical properties of water. Additionally, peak flows, chemical analyses for discrete samples of water, sediment, and biological media are accessible within NWIS (USGS, 2011).

The National Water Information System (NWIS) has been in existence in some IT-Based form since 1975. The initial system was a mainframe system called WATSTORE, which later became a network of distributed systems called NWIS in 1984. Since 1984 several improvements have been made to NWIS, including the release of the publically available NWIS web system, NWISWeb and associated web services. The current annual operations

and maintenance cost for the NWIS is \$7.8 Million, which includes both server and software costs, and the federal personnel costs for staff that support the operations (USGS, 2011).

4.2.5 The SADC Hydrological Cycle Observing System

The World Meteorological Organization has developed the WHYCOS Guidelines to provide for a common approach to the development and implementation of Hydrological Cycle Observing System (HYCOS) components. To date three WHYCOS component have been funded and implemented, MED-HYCOS, SADC-HYCOS phase I and II, and AOC-HYCOS Pilot phase (WHYCOS, 2011).

The overall objective of SADC-HYCOS was to develop and/or strengthen the national and regional capacity in the fields of water resources assessment, monitoring and management. This called for the provision of water resources data and information in the form needed for decision making on all aspects of integrated water resources development and management (Rutashobya and Wellens-Mensah, 2002)

The first phase of the SADC-HYCOS project was implemented between 1998 and 2001. Eleven countries from the Southern African Development Community participated in the project. The Pilot Regional Centre (PRC) was hosted by the DWA of the Republic of South Africa. It was funded by the European Commission (EC) with a grant of 1.96 million Euros (WHYCOS, 2011).

The second phase of SADC-HYCOS project aims at the consolidation/redesign of the regional observation network established during the first phase, further development of the sub-regional and national water resources information systems, identification and development of hydrological products of regional interest, training and awareness building. Funding has been secured through the Dutch Government and the European Commission who together committed 4, 50 million Euros. The European Commission has already entered into an agreement with DWAF for funding the PRC with € 1.50 million while the Dutch Government and SADC signed an agreement for funding field activities with € 3.00 million. WMO's role will be to "oversee and facilitate the implementation of the project, and to provide technical assistance where required" (WHYCOS, 2011)

The primary benefit of the SADC-HYCOS (Phase I and II) is improved and reliable water resources data and information availability and dissemination for regional and national water resources management. Sectors benefiting will be flood control and disaster mitigation, drought forecasting and management, irrigation management, protection of aquatic ecosystems, and the monitoring of international agreements for shared and transboundary rivers. The secondary benefits of the SADC-HYCOS project include capacity building, institutional strengthening, and improved institutional linkages. For example, the regional and national capacity and competency of the National Hydrological Services will be improved. Their ability to operate and manage systems for water resource monitoring, data management, data exchange and information dissemination in both a national and regional context will be strengthened (SADC HYCOS, 2002)

4.2.6 The OpenMI-Life Project

The European Commission has funded the OpenMI-Life project aimed at developing a unified approach to linking applications which it promotes as the OpenMI Standard. OpenMI is a data and model integration framework, designed to take independent data and computing

systems and provide a standard means of describing how time series are communicated between the systems. It has been developed from the need to answer integrated hydrological catchments management questions within the EU 5th framework program project HarmonIT. Since the release of phase one early 2006 the OpenMI is well applied in the hydrological domain (Knapen et al., 2009).

The OpenMI saw a significant increase in the number of applications that lead to new requirements. For example integration of non-model components like the web-based hydrologic information system HydroDesktop or the decision support system AM-DSS was possible but required some effort. To improve the OpenMI and advance it to the next version several European research institutes bundled activities and, after a modelling community review period, released the OpenMI standard version 2 in December 2010. Future extensions could support compliance with the standards of the Open Geospatial Consortium (OGC) or request and deliver data in terms of dictionaries or ontologies. (Schade et al., 2011)

4.3 Institutional Arrangements

The international movements have demonstrated the need to have integrated water management systems managed by public entities instead of government departments. For example:

- The AWRIS is being developed and managed by the Bureau of Meteorology which is an equivalent of the South African Weather Services. The Australian Government has given the Bureau this water information role under section 7 of the Australian Water Act 2007.
- The OpenMI is being developed and managed by the OpenMI Association. The OpenMI Association is a not-for-profit, open, international organisation of people and institutions which was established during the first year of the LIFE project to ensure the necessary stability, maintenance and promotion of the standard during but most importantly after the end of the project.
- The WISE is being developed and Managed by WISE-RTD Association. The WISE-RTD Association has an objective to manage the comprehensive disclosure of existing scientific and technical knowledge with direct relevance to WFD implementation and all other Water Related Water Directives and Guidelines (national, regional ...) in Europe.
- The American NWIS is being developed and managed by the Water Resources Discipline (WRD), one of four science disciplines of the U.S. Geological Survey (USGS). USGS is the American largest water, earth, and biological science and civilian mapping agency, the U.S. Geological Survey (USGS) collects, monitors, analyses, and provides scientific understanding about natural resource conditions, issues, and problems.
- CUAHSI – HIS is been developed and managed by hydrologic scientists from the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) and computer scientists from the San Diego Supercomputer Centre, and supports a larger strategy at NSF to develop cyber infrastructure for the environmental and earth sciences.
- SADC HYCOS project has been implemented by a Pilot Regional Centre (PRC) hosted by the DWA, Pretoria, South Africa, and Technical Assistance by the Centre for Ecology and Hydrology (CEH), Wallingford, UK (formerly known as the Institute of Hydrology). WMO played the supervisory role and provided technical and scientific support to the PRC and to the participating countries.

4.4 Conclusions

The international examples found have shown a development towards integration of the value chain (hydrological information) component of the developed GICF which, itself, brings together four components. The GICF can draw a lot from these experiences as it operationalise the highly regarded South African water legislation framework.

While the discussed examples illustrate the data and information management approach, the CUAHSI-HIS, AWRIS and OpenMI in particular bring together decision support capability, Knowledge management, Integrating Models and Policy, and aspects of interoperability on board. There are other developments towards bringing DSS and knowledge capabilities into the information systems and this have been demonstrated by the Waterware, Strategyman, NOVIWAM, SWITCH, NHI projects, etc.

5 CONCEPTUAL FRAMEWORK DEVELOPMENT

5.1 Overview

The development of the GICF is seen as a first and a necessary step towards complete integration between water resources and water usage. In essence, the GICF is required to provide an optimal direction, applicable to all actors in the water sector, leading to complete integration. From the literature review and assessment of tools, it became clear that the unifying platform should be extensible with the following properties:

- Plug and Play
 - Common understand of what a tool is
 - Common understand of what integration is
 - Common objectives, interaction principles and performance measures
- Evolutional in Nature
- Representativity of the problem (Technocrats, Sociocrats)
 - Multisector integrality
 - Flexibility/Adaptive
 - Accessibility

Hence, in developing the GICF it was necessary to build an understanding of the water management process evolution over the years, the circumstances driving the evolution, the water sector building blocks, as well as the different water management philosophies that shaped the water sector. The previous three chapters have laid the foundation conducive for the development of the GICF by reviewing the literature and assessing the tools, the current management philosophies and their challenges.

In this chapter the understanding gained through the work done in the first three chapters is synthesised and combined to come up with a unifying platform representative of the water sector.

5.2 Development Approach

The key to building systems that provide high level of flexibility is to use a component-based design meeting current requirements and flexible enough to meet future needs. This requires a dynamic architecture that allows for easy modifications of existing functionalities and easy adoption of new ones (Papajorgji, 2004). Hence the approach in developing the GICF was based on developing the three required properties of the GICF into usable components in the GICF. The following sections detail how the properties were developed to establish the basis for the development of the GICF.

5.2.1 Plug and Play

An architecture that is designed to minimize the impact of future changes is the “plug and play” architecture (Papajorgji, 2004). According to the definition provided by Webopedia (2011), the “plug and play” architecture refers to “the ability of a computer system to automatically configure expansion boards and other devices”. The plug and play property was established by unpacking the tools and the integration hierarchy, the water business objectives, and by developing a cause-effect-cause framework to represent interaction of entities in the water sector.

5.2.1.1 **Tools and the integration hierarchy**

A tool has been defined as something (either tangible or intangible) used to support operational and strategic actions in performing water management. This include a guideline, a procedure or protocol, a method or technique, a device, an apparatus and a software program dealing with all levels in relation to transition to integrated water management.

Also, integration in this project is defined as a “continual process, rather than a goal, of logically quantifying both the short term and long term effects of the decision process (governance and the tools) in water management ,on the water balance equation in a single platform”. There are three levels of framework forming the integration hierarchy on a water sector level, and this are:

1. Level I Frameworks – this type of integration frameworks refers to a collection of tools that have been combined in order to represent a specific system/issue or a domain (examples of Level I Frameworks are ACRU, SFWS, WRYM, WRSM2000, etc.). These can be referred to as just “Frameworks” or “Integrated Tools”.
2. Level II Frameworks – these integration frameworks refers to a collection of tools which have traditionally been used within their own separate systems, each consisting of similar tools to prepare input data, write input files and analyse model output. (Examples of Level II Frameworks are the WRIMS, WSDP, SPATSIM, WSNIS, HYDSTRA, WMS, WULATS, etc.) These can be referred to as “Integrated Frameworks”.
3. Level III Frameworks – the level III integration frameworks refers to open frameworks for linking integrated tools and/or frameworks focusing on generic linkages and functional modularity. These can be referred to as “Generic Integrated Frameworks”.

In essence, the objective of Level I Frameworks is usually to provide a new tool, the objective of a Level II Frameworks is to provide a mechanism by which existing tools can be linked or organised in a consistent manner, and the objective of Level III Frameworks is to reduce duplication of effort between the different domains/silos, and to facilitate tool use and development by providing optimal direction. In fact Level III Frameworks is like a loose ‘wrapper’, which ensures consistency both in the tools themselves and in their use, and delivers greater utility and value than the simple sum of the constituent parts (HarmonIT, 2002; Marston et al., 2002; Argent et al., 2004).

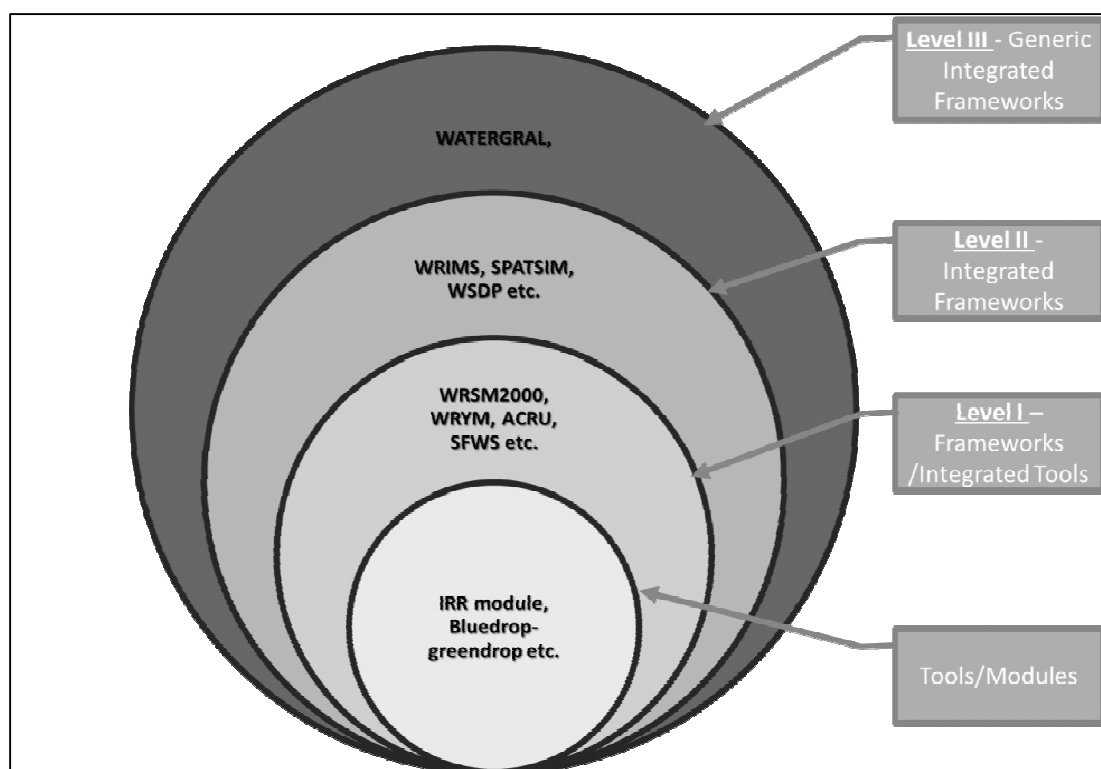


Figure 28: Water sector integration hierarchy

On a Level III Frameworks, relationships with other sectors need to be established, and **Figure 27** depicts such relationships for the water sector to the other sectors.

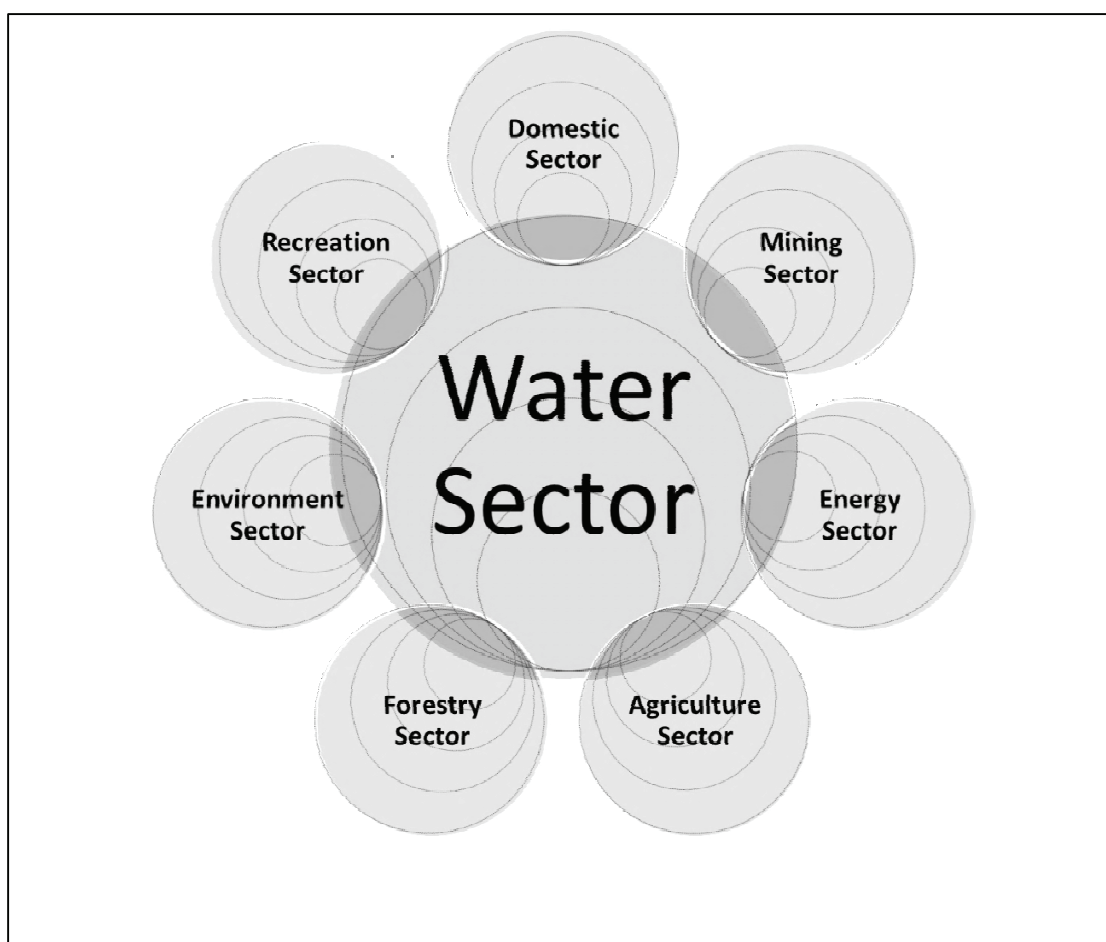


Figure 29: Water sector's relation to other sectors

5.2.1.2 Water business objectives

This sub-section is aimed at unpacking the objectives of the water sector and defining a generic objective function applicable to all actors in the sector.

The reviewed literature has broadly pointed to the fact that the water sector exists so as to balance the demand for and the supply of the water resource. Therefore it can be said that the objective function of the water sector is the water balance equation. To illustrate this concept, and to frame the generic equation, the water balance approach, as discussed in **Chapter 2.5.4**, is used.

An initial step in performing a water balance is to identify a domain of interest and affected parties by specifying spatial and temporal boundaries of the domain. IWRM is said to be a management philosophy aimed at striking a balance between sustainability, equity and efficiency in the provision of reliable quantity of good quality water. This indicates that the actors in the sector will one way or the other act in a way that affects one or more of the IWRM key elements, and this is reflected in the resulting quantity, quality, efficiency, equity and sustainability of the water resource. Hence, sustainability, equity, efficiency, water quantity and water quality are seen as the five highest variables of the water balance equation. These variables represent both the socio-political and technocrats domains. Plotting these variables in a spider diagram (**Figure 30**) shows the area inside the graph as the resultant water balance; the state of the water balance changes depending on the behaviour of the five

variables which are themselves dependant on the management options of the water sector, the user's preferences and government interventions.

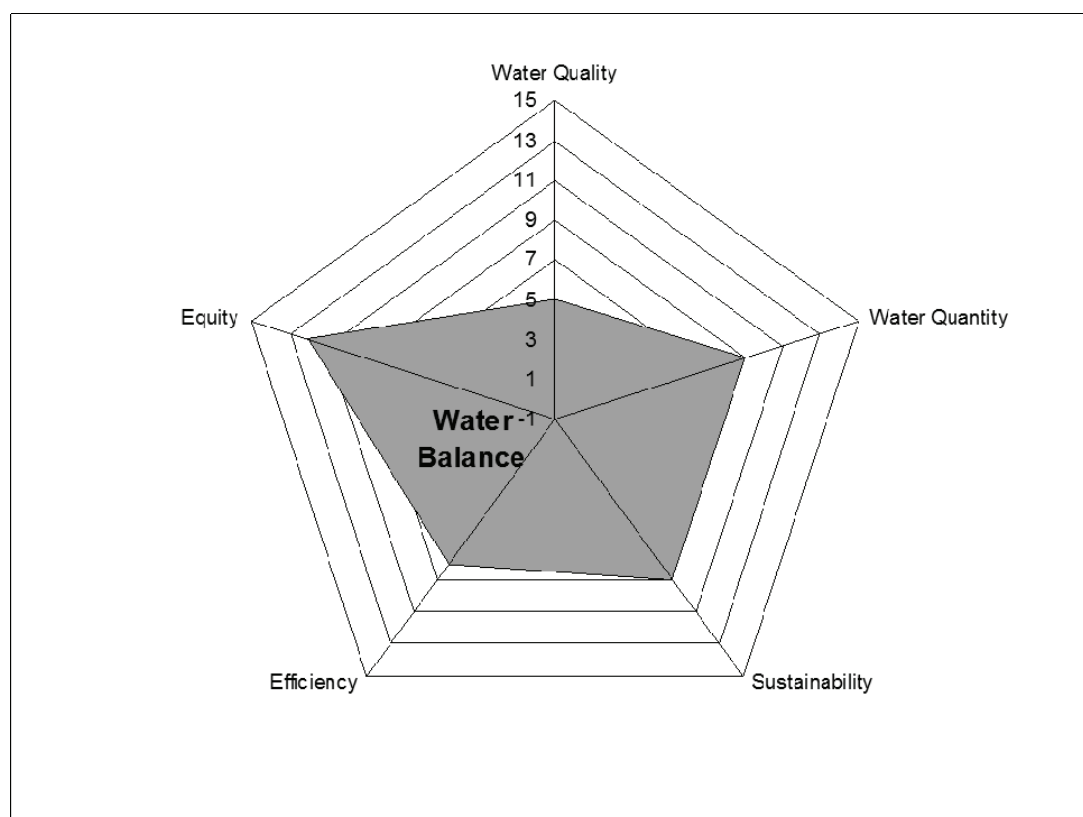


Figure 30: The water balance driven by the five variables

Figure 31 depicts a water balance with the different actors responsible for the elements of the water balance. This is based on an understanding that water resources are finite and can be reduced by a number of factors (i.e. climate change, pollution, inefficiencies, poor management), and can also be increased (the benefits of use can be increased) by a number of factors, (i.e. technological innovation, proper allocation and management, etc.) the capability or availability of the water resources will have to be quantified (yield on an annual basis) and development will have to be undertaken in line with the needs for a particular time.

Figure 32 shows the water balance with the possible relation to the different functional areas to demonstrate how the different actors come into the water balance. The different actors, in this case the six functional areas as defined by the NWA (i.e. protect, develop, use, conserve, manage, and control), will have to identify the key drivers on a high level, responsible for the changes in the water balance.

What is important to realise at this stage is that fewer parameters are required on the highest level of a water balance, however a drill down is allowed for whereby the underlying parameters driving the highest parameters can be accessed and assessed. I.e. in the case of water services it may be important on a high level to know the water requirements while on the next lower level it may be necessary to know the infrastructural requirements, and due to priority in allocation of funds, also the backlog that exists and other water supply problems.

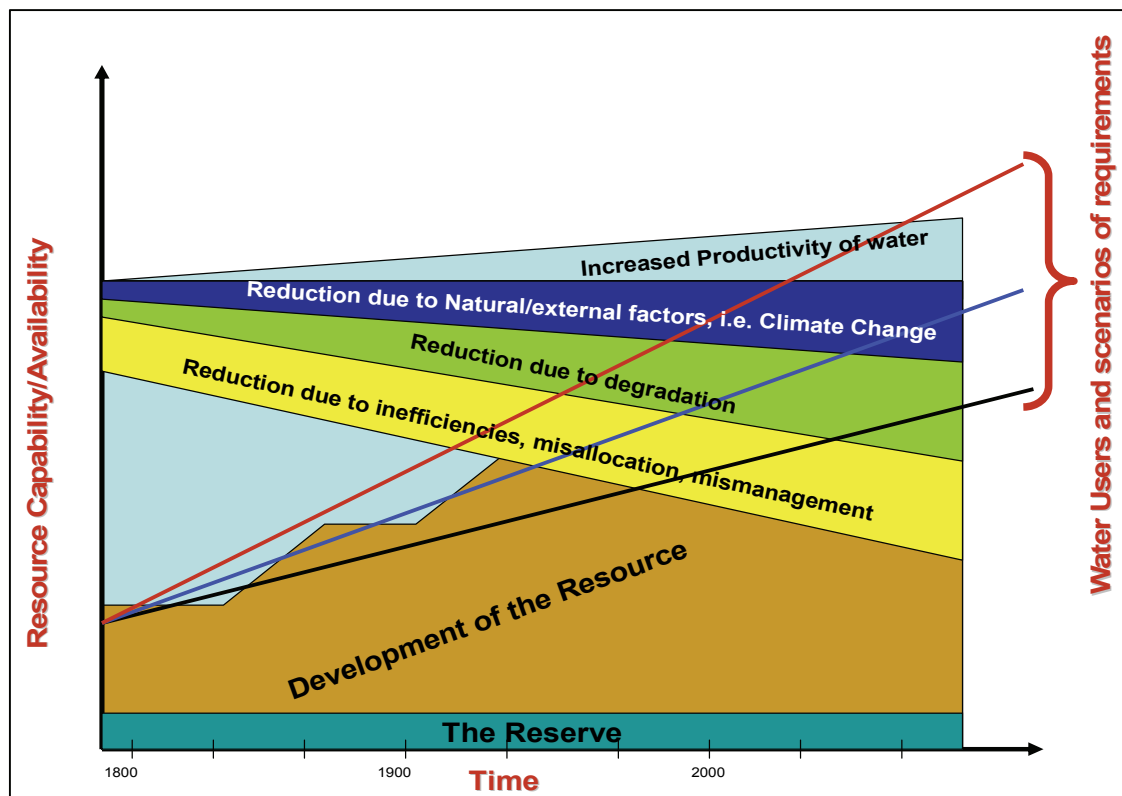


Figure 31: The water balance

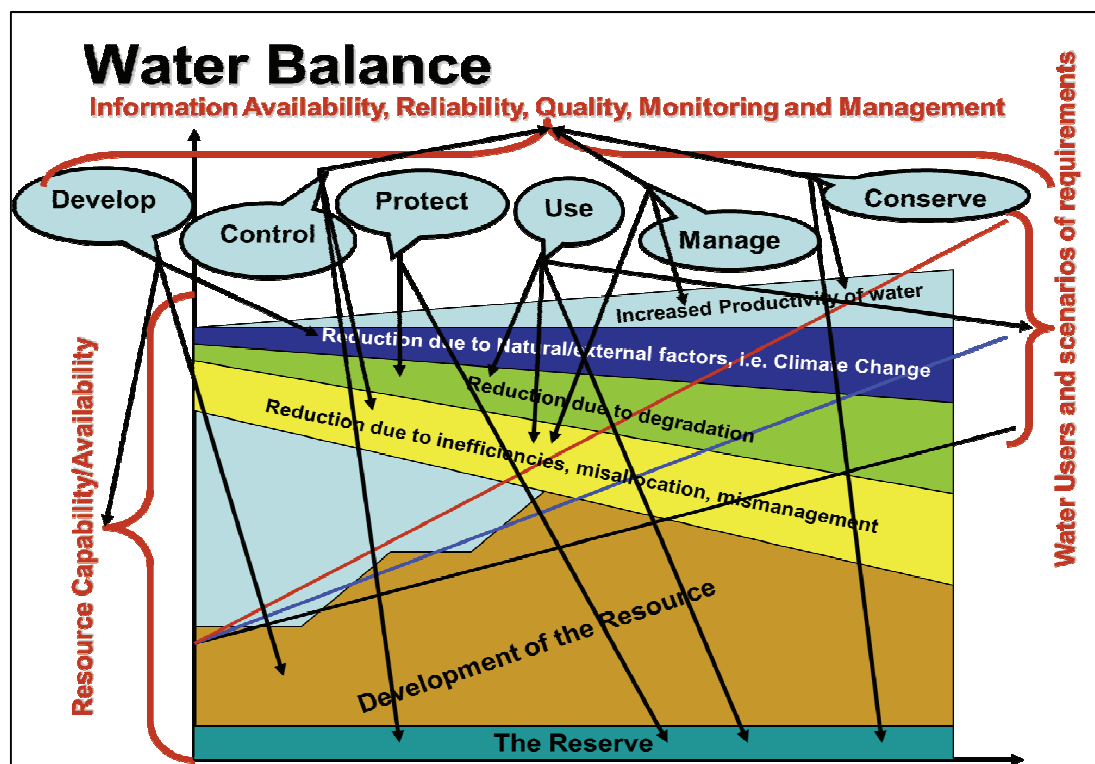


Figure 32: The water balance with some actors

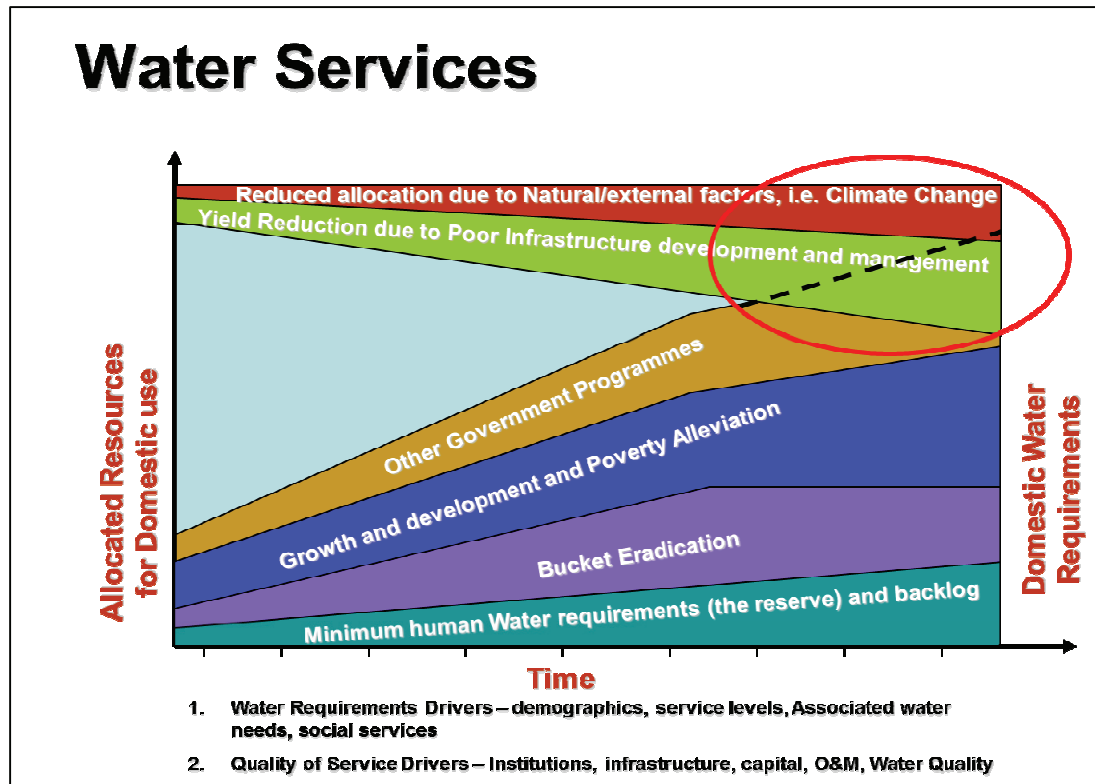


Figure 33: Example of water services activities on the water balance

5.2.1.3 Cause-effect-cause Framework

The application of the water balance equation as defined in the previous sub-section depends on the understanding of the management structure and the interrelations between the different actors. While the traditional water balance would consider volumes of inflows and outflows, the water balance equation (as defined in this project) integrates the inflows and outflows with the required quality, equity, sustainability and efficiency. These parameters depend on the decision process (i.e. end goal to be defined and agreed upon and then trade-offs to take place between the variables in line with the end goal). This enables the comparison of different scenarios.

The decision process recognises the different levels of management (i.e. strategic, tactical and operational levels). These management levels must be mapped against the three governmental management fields of legislative governance, administrative (resource) management, and service delivery management, as discussed in **Chapter 2.6.1.2**, and this is shown in **Figure 34**. Although **Figure 34** shows the fields according to national, provincial and local government, the same fields can still be applied with for example the national government.

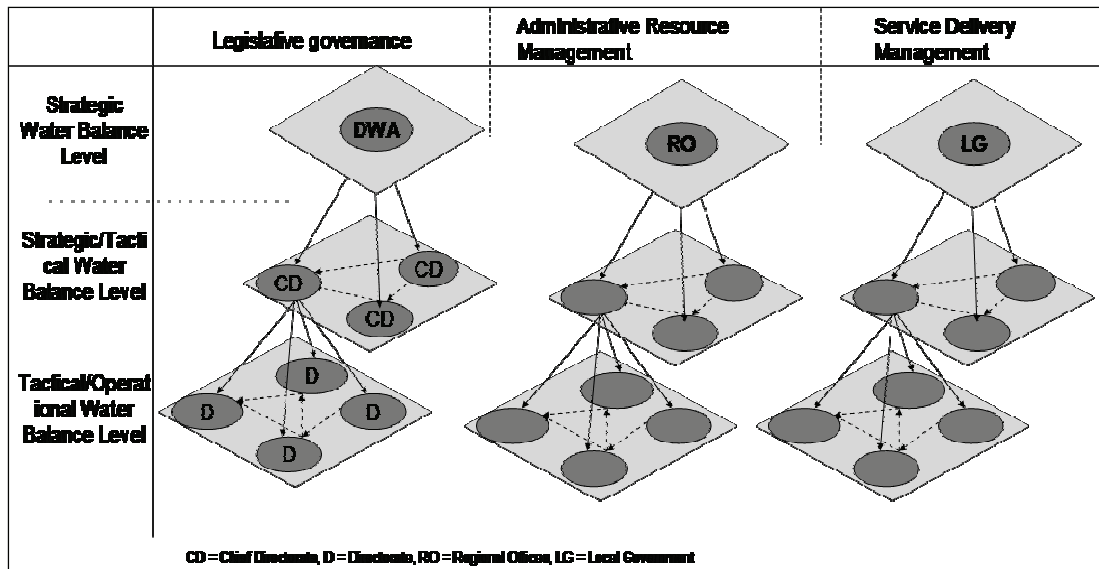


Figure 34: Management structure

The actors in the sector have certain impacts on the water balance, and to understand their actions and the resulting impacts, the DPSIR is used to depict the interrelations. This helps define the interactions and consequently define the management structure. The actors are seen as residing in one or more of the functional areas (protect, conserve, develop, use, control and manage) and hence are represented by these functional areas. In essence, each actor is required to bring forth a mandate, vision, decision process and required data, and must also indicate the drivers, pressures, states, impacts and responses relevant to their mandate as well as the preferred factors between equity efficiency, sustainability, water quantity and quality such that all the five factors add up to 100%.

To visualise this process the functional areas are plotted against the water balance equation parameters and the DPSIR parameters. See **Figure 35** for details.

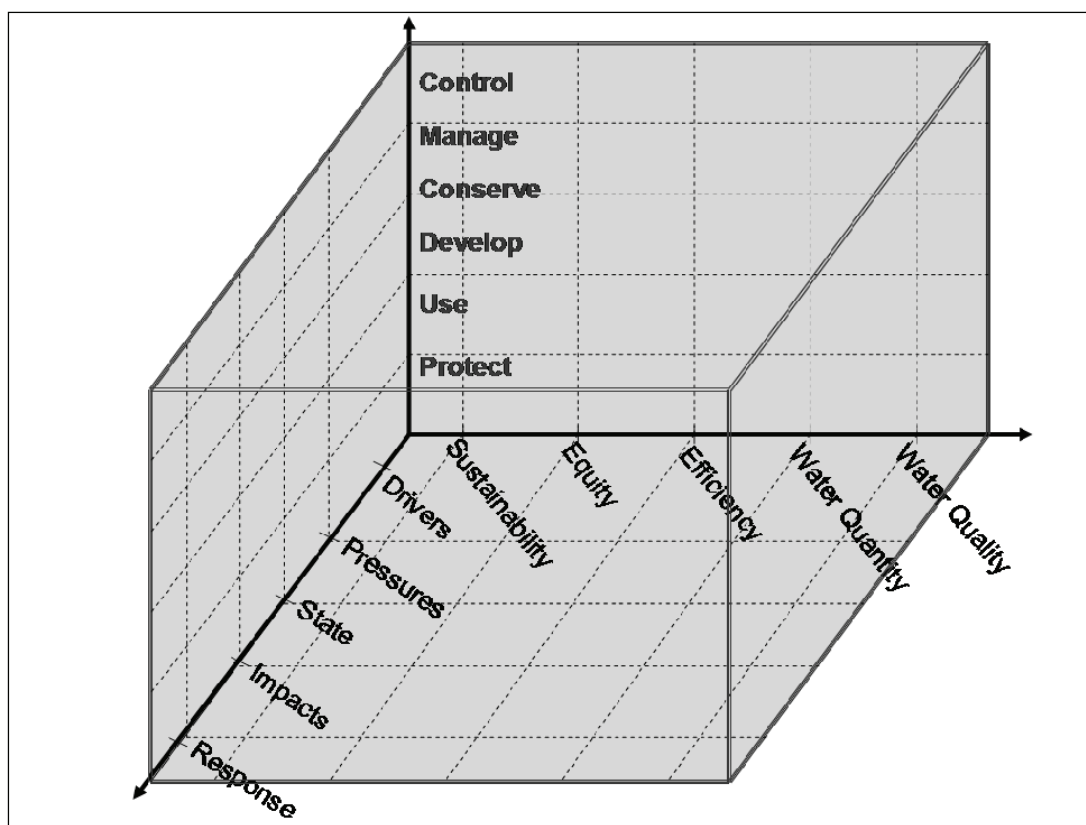


Figure 35: Cause-effect-cause framework

All criteria (indicators) need to be determined with care by stakeholders (i.e. experts such as researchers, governmental officials, the public, etc.) on the basis of the concept of the DPSIR framework, since this process requires discussion and refinement.

5.2.2 Evolutional Nature

The literature review has pointed to the water management evolution process that took place over the past 100 years. It has shown that water management progressed from the Sectoral Age through Cooperative Age, to IWRM and Adaptive Management Age. For example, in the 1820s the sectoral approach was the norm, and as the approach grew and received recognition in the 1960s, it was no longer sufficient due to competing uses and the need for conjunctive use, and that is when the IWRM approach surfaced. IWRM was met with some resistance and it only peaked in the 80s, and as it matured in the 2000s, the need to account for risk and uncertainty arose, and a new water management approach was born (i.e. adaptive water management).

To be able to understand this evolution and its dynamics, the S-Curves model, as discussed in **Chapter 2.9.1.3**, was used to depict the evolution process. The S-Curves are plotted with the water management performance index being on the *y-axis*, and time being on the *x-axis* as shown in **Figure 36**. The water management index represents the measure of the water sector's performance as a whole, and is made up of quantity, quality, equity, efficiency, and sustainability parameters.

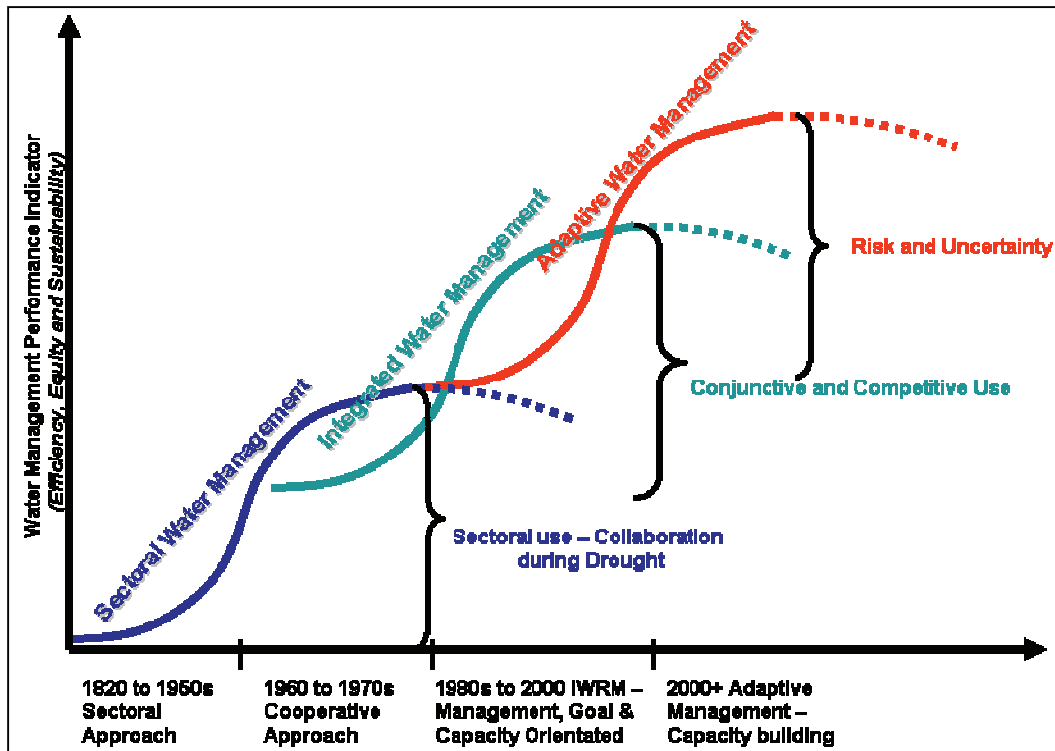


Figure 36: Water management evolution and paradigm shifts

As shown in **Figure 36**, when management philosophies are discovered, little recognition is received at first; this is shown by the curve's gradual rising slope (i.e. as on the Sectoral Water Management curve). Over time the philosophies receive recognition and they are adopted for full use, and this is shown by the rapid rising slope of the curve. However, as with technology, the philosophies become obsolete with time and new problems surface that cannot be dealt with; and this is shown by the gradual fall in slope of the curve. At this point a new philosophy is required to address the new problems. Typically a new management philosophy would be discovered before the current one is obsolete; however, it would be met with resistance as people hold onto the current one. As a result the new philosophy goes through the same stages as the previous one (i.e. gradual rise, rapid rise and gradual fall as shown by the Integrated Water Management curve). These stages are called the (1) invention/conception, (2) improvement/growth and (3) maturity stage, respectively.

What is important to note is that although a new philosophy is usually greeted with resistance, it eventually becomes imperative to adopt it as the current philosophy becomes obsolete. Therefore, transition/change becomes the norm and then the question arises as to how the transition/change should be made? To be able to make such a decision, given this behaviour of evolution, it becomes clear that integration will have to be seen in the context of both short and long term goals. Thus integration will have to be achieved in a framework of the following three stages of the Incorporation-Convergence-Evolution (ICE) Process (see **Figure 37**):

- Incorporation – this is in the short term where the ideas of one section are embraced by the others and vice-versa without formal structures in place, and this reflects the willingness to work together towards a common good, therefore this is nothing but a change of attitude.
- Convergence – in recognising that integration is a way of thinking rather than the end itself, the authors believe it important to map the path of convergence in the light of the future goals. This requires the first stage (incorporation) to have happened, and

consists of planning and setting future goals for the whole sector, taking into cognisance anticipated changes/threats; and in light of the set goals, a map of convergence of the different ideas/sections can be drawn.

- Evolution – this is a transition stage where minimal changes are undergone in any one stage to ensure that short term goals are not compromised. This requires proper sector knowledge management to ensure that only fit genes are moved to the next generation in light of the future goals.

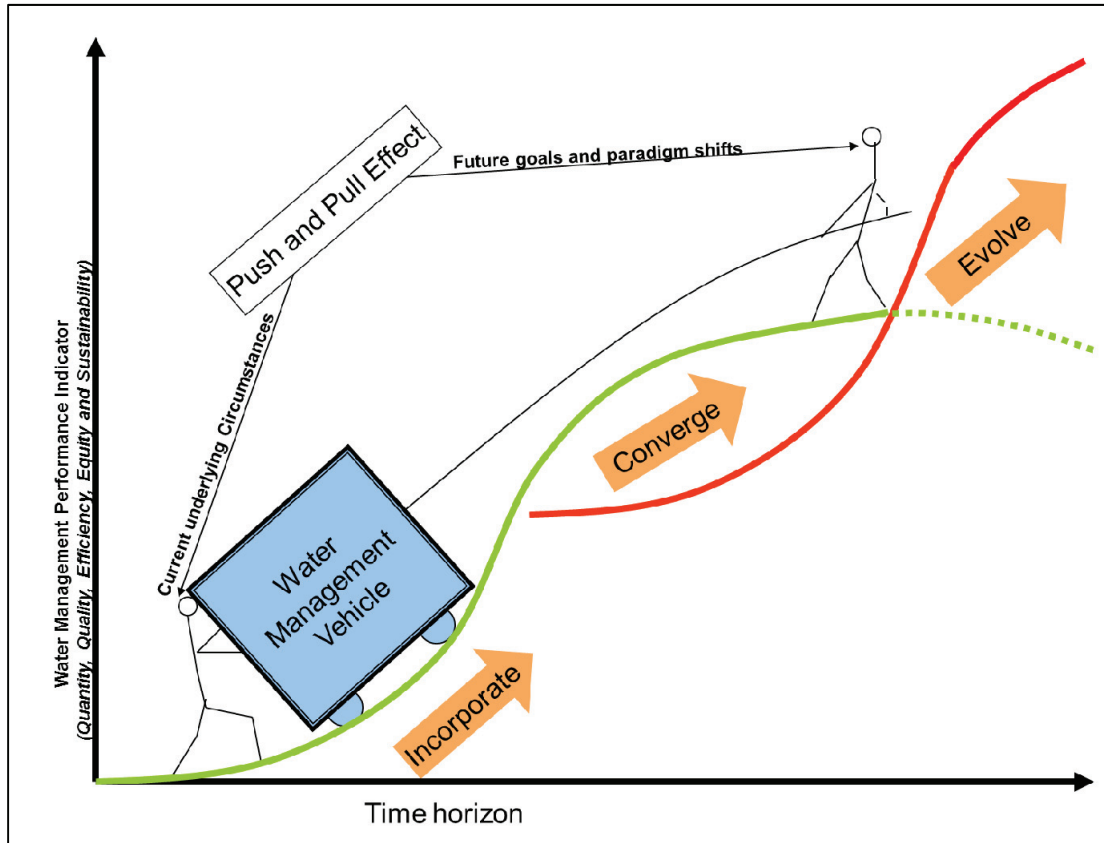


Figure 37: Combination of short term and long term goals (ICE Process)

Figure 37 gives a view of the ICE process. The ICE process shows that in the current/short term some activities, even if they are not so in line with the management objectives must be pushed/accommodated as long as they address current problems. However, there must be a long-term view that seeks to address the problems in a sustainable manner, and this is represented as a push and pull mechanism in the ICE process.

The ICE process is meant to represent a way of thinking and should be undertaken at any point in time. I.e. at any point in time the sector must ask such questions as “1) what needs to be done in the next 3-5 years? (Incorporation Stage); 2) how does the future look and what elements can be put together at that stage in preparation of the future changes? (Convergence Stage); 3) what elements can only come together over time to ensure that they are relevant for the future, and what should be let go and what should be adopted in transit? (Evolution Stage)”.

5.2.3 Representativity

In making decisions in terms of the transition to integrated water management, it is important to understand the base elements propelling the water sector. These elements should be maintained throughout as they define the nature of the sector. Three such elements were identified as follows:

- The water business – which must be properly defined and streamlined
- The operating environment – which is the operating environment of the water sector and informs the reporting requirements, this must be properly defined and streamlined
- The institutional arrangements – which depicts the value chain and must be properly defined and streamlined.

These elements must, however, be supported by support services, (i.e. IT, human resource, finance, etc.). Therefore these elements can be depicted as the three corners of a prism, with the support services being the fourth, **Figure 19**. The ICE process emphasises that the benefits of the fourth element/corner of the prism (support services) can only be realised once the three base corners have come together. Therefore, support services should not be seen as the drivers. **Figure 38** brings together the ICE process and the water management base elements, and shows the progressive move to integration by initially bringing together the three base elements in each transition.

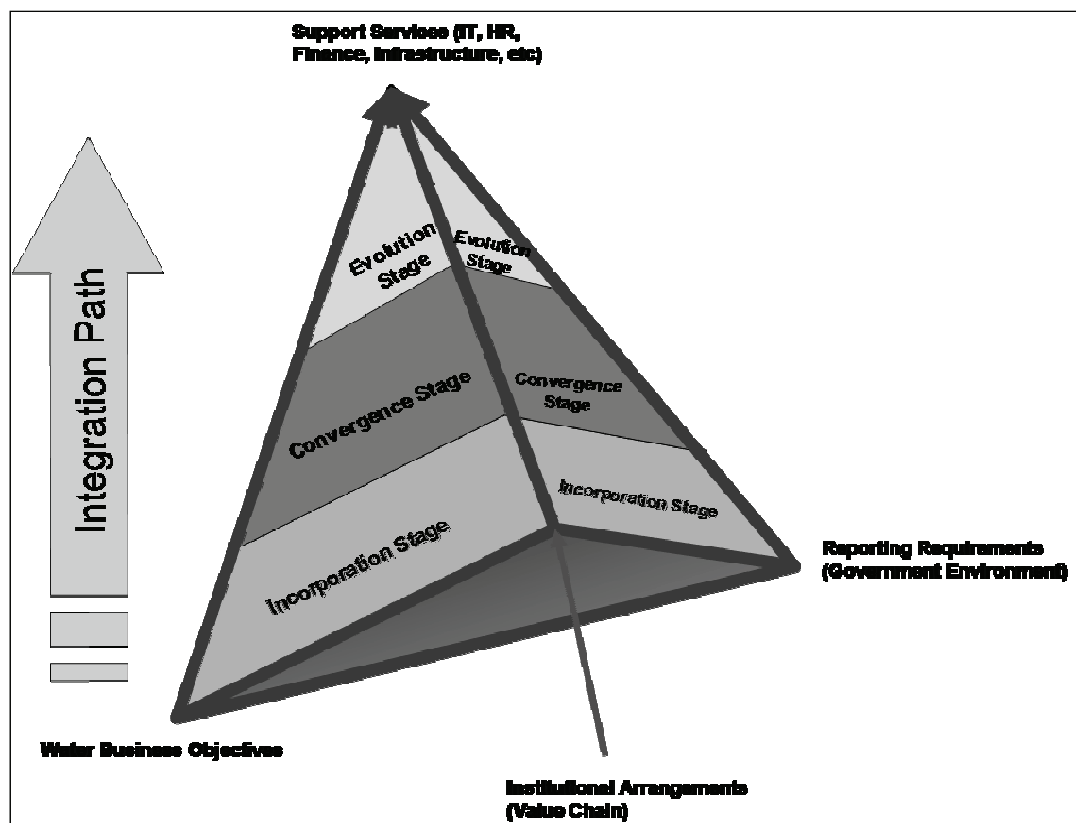


Figure 38: The integration prism

5.2.4 What to Integrate?

According to Nelson (2005), integration takes place within the context of organisational maturity. This means that organisations must mature through the stages of integration, fulfilling the requirements at each stage, before an organisation can move to more advanced stage of integration.

An integration hierarchy has been shown to consist of three levels whereby the objective of this project is to develop the third level of the integration hierarchy. The third level of integration entails bringing together the matured Level II Frameworks.

Ten Level II Frameworks were identified and can be represented as building blocks in grouped into the “pillarly” and “foundational” blocks. The foundational blocks are those Level II Frameworks that are a necessity to the existence of the GICF, while the pillarly blocks do not need to be all in existence at once, but a sufficient number of them must be in place. The Level II Frameworks are as follows in their groups:

- Foundational – this consists of the:
 - Coordination and conflict resolution integrated framework – IWRM requires the participation of all units of government and stakeholders in decision-making through a process of coordination and conflict resolution.
 - Monitoring and compliance integrated framework – IWRM is not a goal but a process which requires continual monitoring and ensuring compliance to agreed objectives.
 - Data and information management integrated framework – data/information is the medium through which integration takes place, and before any discussion/decision can take place, some form of data/information must first be presented. This is true for IWRM, and a structure for data management is a prerequisite for a successful integration.
- Pillarly – this consist of :
 - Water resources assessment and development integrated framework – this is to enable interdisciplinary understanding of the dynamic linkages between the ecological, social and economic components of human-environment systems associated with water resource management, over time. This can be used to inform the CMS.
 - Regulatory integrated framework – IWRM requires devolution of powers to appropriate levels and this inherently requires a regulatory framework. The framework would go a long way in facilitating the transition of DWA to being a regulator.
 - Water management financing integrated framework – implementation of the IWRM requires financial resources and an appropriate framework to guide sustainable funding. The framework can be used to guide the pricing strategy.
 - Water allocation and use integrated framework – IWRM requires water to be allocated and used equitably, efficiently and sustainably; this requires a framework that brings together the different uses (i.e. water services, industry, energy, etc.) and in understanding the national benefits of their uses, draw an allocation plan.
 - Capacity building integrated framework – IWRM is a new way of doing things and requires human capacity equal to the task. This requires capacity building initiatives that embrace the principles of IWRM.

- Research and development integrated framework – IWRM is not a goal but a process requiring continual improvement through research, and this requires a guiding framework to ensure that research produced adds value to the IWRM process.
- Domain/field specific integrated frameworks – the water sector is a multidisciplinary field combining different expertise which has its own framework (i.e. integrated hydrological modelling, integrated ecosystem modelling, integrated sediment modelling, integrated water quality modelling, etc.), this needs to be managed and brought together through a framework.

Therefore the integration at the third level of integration can structurally be depicted as the roof bringing together the Level II Frameworks grouped into the foundational and the pillarly frameworks as shown in **Figure 39**.

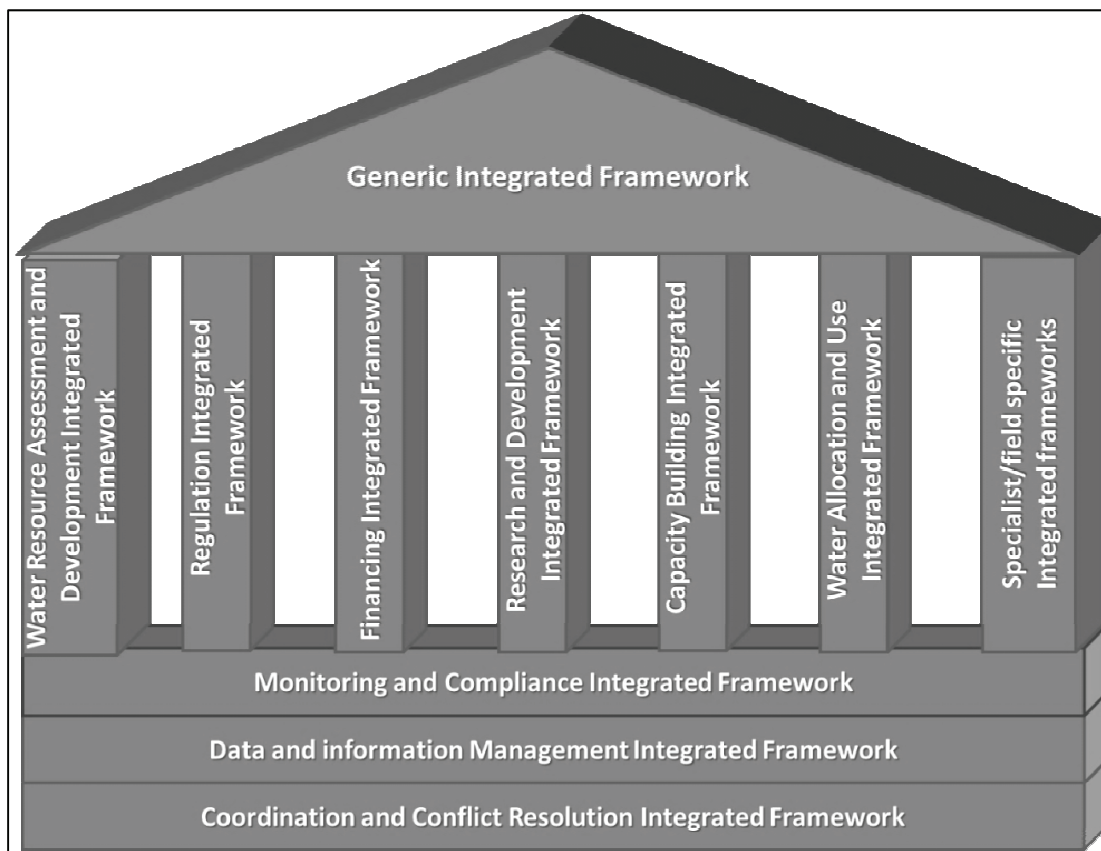


Figure 39: Integration structure of water management frameworks

Each of the building blocks (Level II Frameworks) are made of the four layers of the business prism and have been divided into the three levels of management as shown in **Figure 40**.

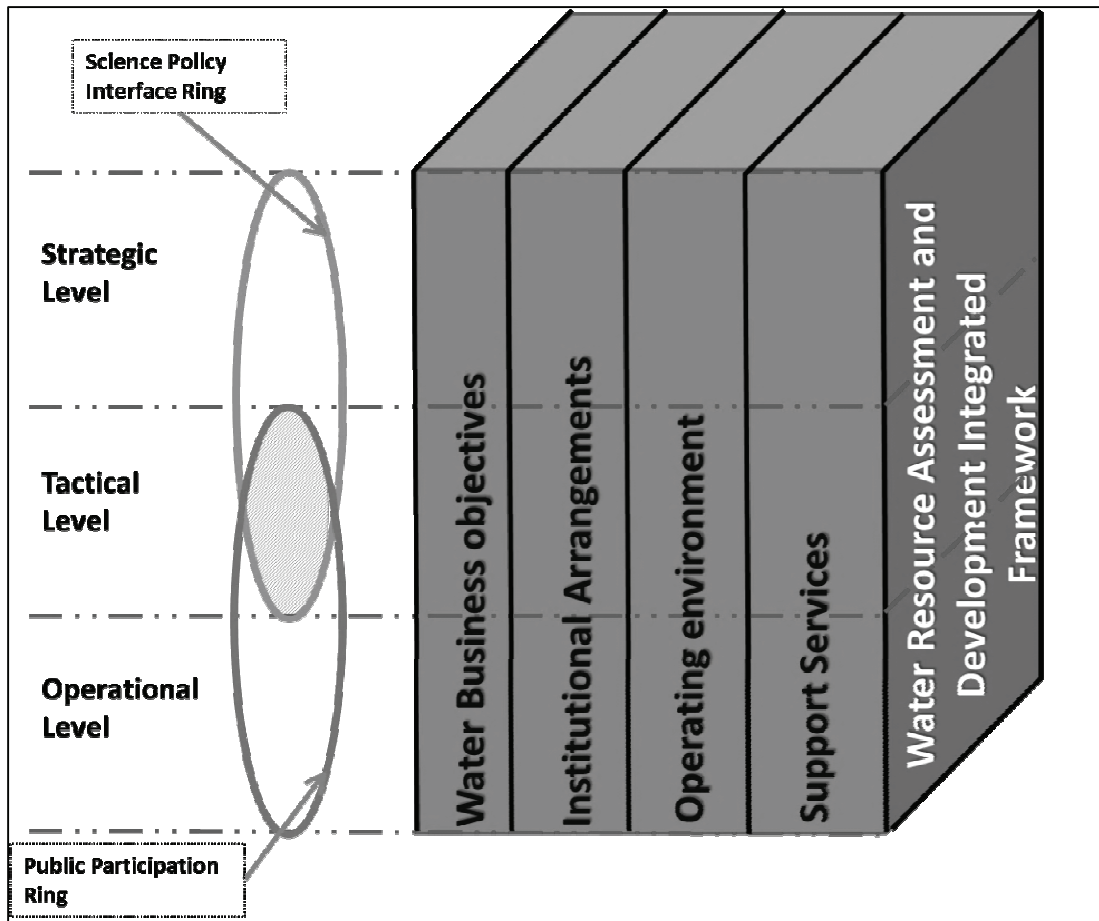


Figure 40: Level II Frameworks with the layers and management levels

5.3 The Generic Integrated Conceptual Framework

In essence, the unifying platform is required to assist organisation to make decisions in a coherent and consistent manner, based on existing knowledge and information using the tools at their disposal. This requires the organisations to actively and continuously identify the decision processes, manage knowledge, manage data and information, and develop and manage tools appropriate for the sustainable management of water. Therefore, the unifying platform, the GICF in this case, should consist of modules capable of supporting management in decision making, knowledge management, information and data management, and tools development and management with an interactive interface. Hence the GICF has been developed to contain five main modules as follows (**Figure 41**):

1. Integrated Decision Support System module (IDSS) – this module allows the user to combine results from the different tools as well as from the database to come up with a holistic picture of the analysis. The module also allows for different scenario analysis which may not be built into any of the tools or data, and this will rely on the knowledge management module to ensure consistency with the assumptions underlying each tool. The IDSS brings together the three levels of the decision process:
 - a) Strategic level DSS – this level of the IDSS is mainly concerned with political decision making and factors in all issues of political nature to the water business.
 - b) Tactical Level DSS – this level of the IDSS is mainly concerned with technical/facts decision making, and factors in the science (including social sciences) surrounding the water business.

- c) Operation Level DSS – this level of the IDSS is mainly concerned with stakeholder involvement in decision making, and factors in the stakeholder preferences to the water business.
- 2. Integrated Database-access (Data Mart) module – integration requires a common database where all tools interact and exchange information. In addition, the development of necessary surrogate tools/systems requires the development of a mechanism for linking the tools, for a two-way information exchange with a visualising (communicating) tool. Therefore, data integration and standardisation is seen as core to integration and the integrated data mart ensures that data requirements for planning purposes and data produced by the tools are compatible, and that there is no duplication of efforts.
- 3. Knowledge management system module – the failure to learn from and to incorporate key elements from the past paradigm of thinking about water management could seriously hinder the effectiveness of new approaches. This module ensures that as integration happens, the knowledge and purpose of the individual tools are also appropriately incorporated. This module also provides a platform for further development giving guidance on how to best identify which past tools best apply, and, which parts of those tools have the most relevance to current and near term future water management settings.
- 4. Tools management module – this module allows for management and evaluation of tools for their applicability and maturity. The module consists of two sub-modules as follows:
 - Integrated surrogate tools module – the surrogate tools act as a simplified replica of detailed physically-based tools, they are less complex and computationally less expensive when compared to the physically-based tools, but are able to produce reasonably accurate outputs for strategic planning purposes. Therefore, this sub-module ensures that tools can be simplified to represent fewer parameters and be user friendly for strategic planning purposes while supported by the detailed complex tools where necessary with the help of the specialists.
 - Tools inventory and management module – this sub-module allows the users to put together all tools at their disposal with an ability: to compare different tools, search for an appropriate tool for a particular assignment, classify and categorise tools, undertake gap analysis, and ensure that tools development is coordinated.
- 5. User interface module – this module allows the user to interact with all the above mentioned modules and sub-modules, to choose the type of analysis to be performed and the tools to be used.

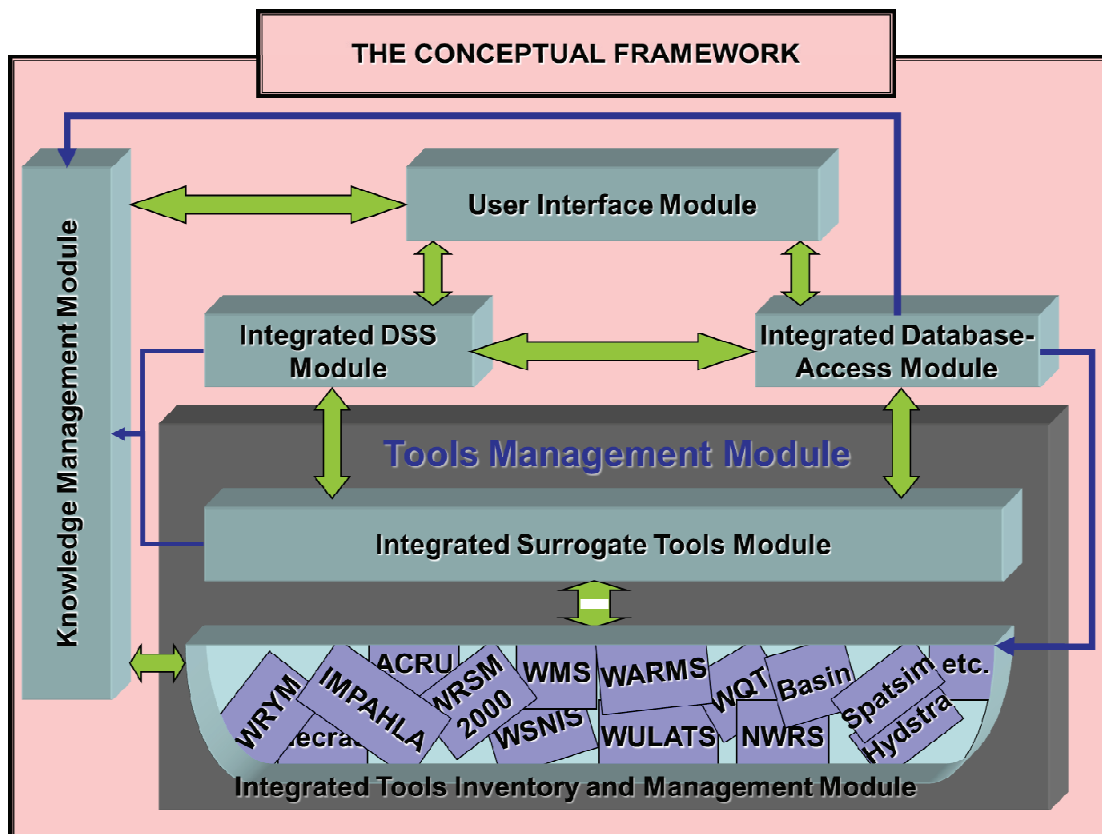


Figure 41: The Generic Integrated Conceptual Framework

5.4 Using the Generic Integrated Conceptual Framework

5.4.1 Application Process

The GICF is applicable at different levels of an organisation and it must be applied in a hierarchical manner building up to the highest level of interest in an organisation. Application of the GICF can be undertaken through several mechanisms. Therefore, the GICF can, for example, be used by managers using their own observational experiences to identify different elements of their organisation/departments within the GICF. In doing so, managers in one functional area can compare their evaluation to those of managers in the other functional areas and engage in discussion around the points where there are gaps and overlaps. Managers might also consider gaining a wider range of input to the evaluation, including a sample of staff at different reporting levels from different departments and/or specialists' inputs. This could be done through a short survey instrument or perhaps as part of a staff meeting or focus group.

Once an organization identifies its mandate, objectives, required tools and data, stage of maturity of tools, the integration issues can be addressed at an appropriate level. The application procedure to guide the use of the GICF has been divided into nine steps, grouped according to the GICF modules as shown in **Figure 42**. The nine steps are as follows:

- Step 1 – Identify the high-level mandate of an entity.
- Step 2 – Identify actors and their objectives.
- Step 3 – Identify the decision process and indicators.
- Step 4 – Identify required tools and their maturity levels to achieve the objectives as per the indicators.

- Step 5 – Identify the required data.
- Step 6 – Identify the data sources and point of contact on the value chain.
- Step 7 – Bring the actors with their objectives and data requirements to the unifying platform using the appropriate Level II Frameworks.
- Step 8 – Identify overlaps and gaps on objectives, tools and data.
- Step 9 – Streamline the processes accordingly.

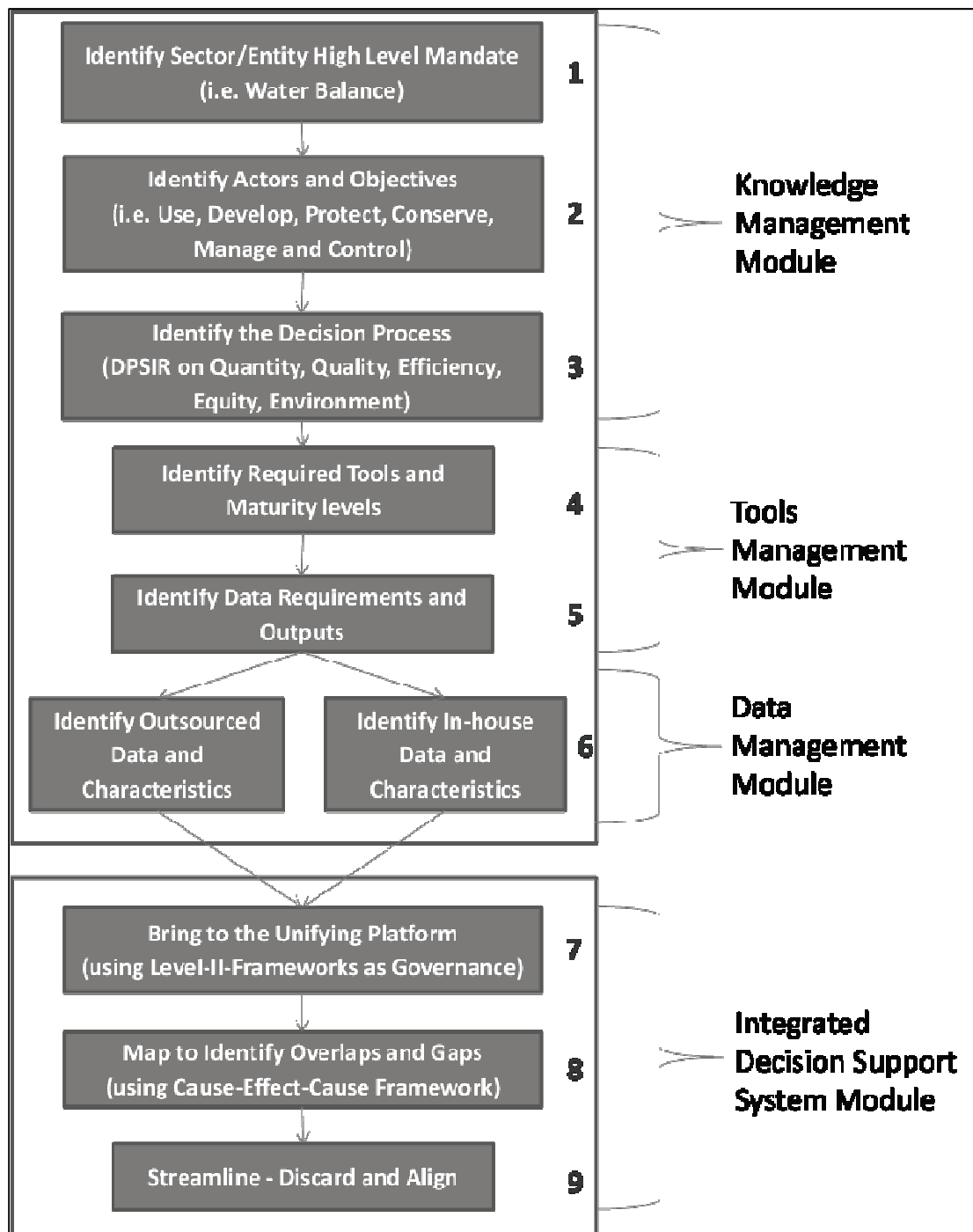


Figure 42: GICF application procedure

5.4.2 IT Perspective

From the IT perspective **Figure 43** shows the current setup whereby information request is made individually to the data sources. **Figure 44** shows the setup as proposed by the GICF whereby request can be made to multiple heterogeneous data sources simultaneously regardless of semantic or structural differences. This integration requires a semantic mediator and **Figure 45** shows the GICF from the IT perspective, where Area A shows the traditional integration which is IT driven and has failed in many cases, while Area B depicts integration which is business objectives driven. Area B is the core of the GICF which emphasises that for integration to be achieved there must be a thorough understanding of the business objectives as well as the operating environment. Hence, Area A can be classified as the noise area in which decision makers can obtain information to inform their decision making, however, decision makers need Area B to filter the noise from Area A and present them with the relevant information they need for decision making. **Figure 46** shows the proposed detailed IT process including the water business model (filter) of the GICF.

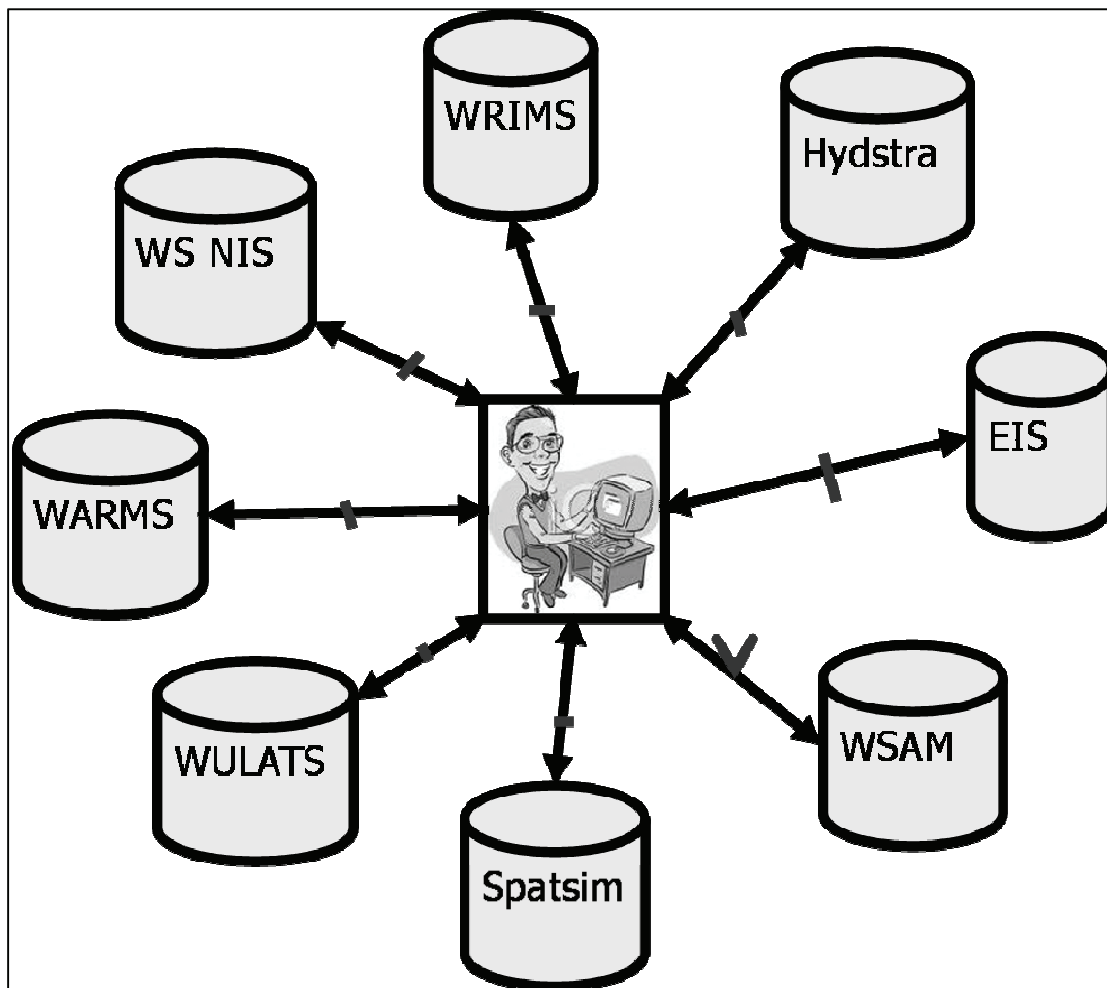


Figure 43: Current IT setup (adapted from Maidment (2007))

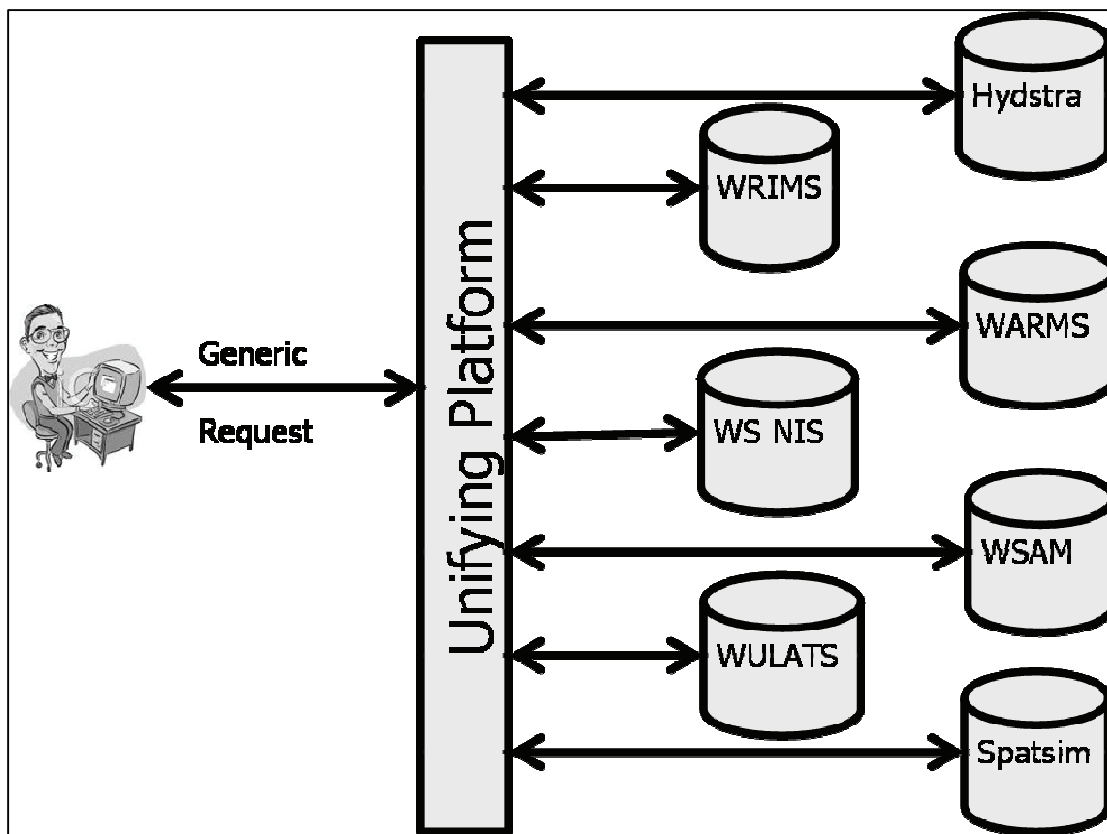


Figure 44: Envisaged future IT setup (adapted from Maidment (2007))

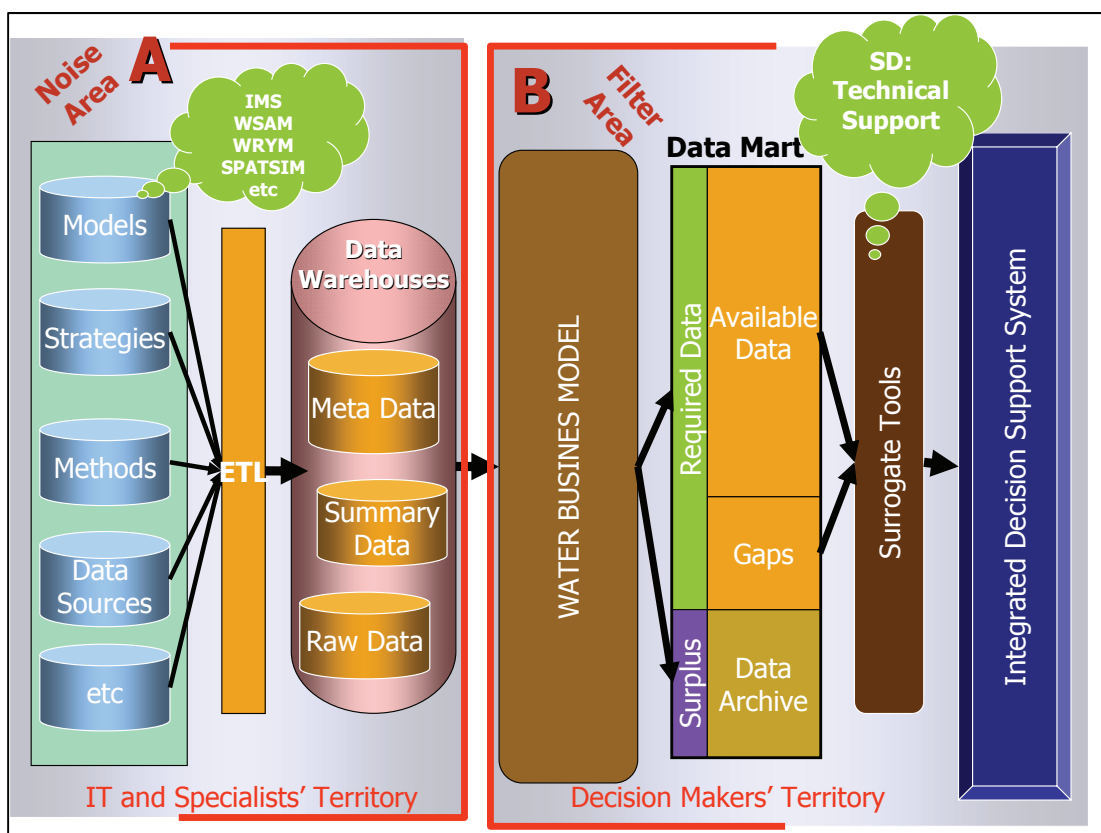


Figure 45: The GICF from the IT perspective

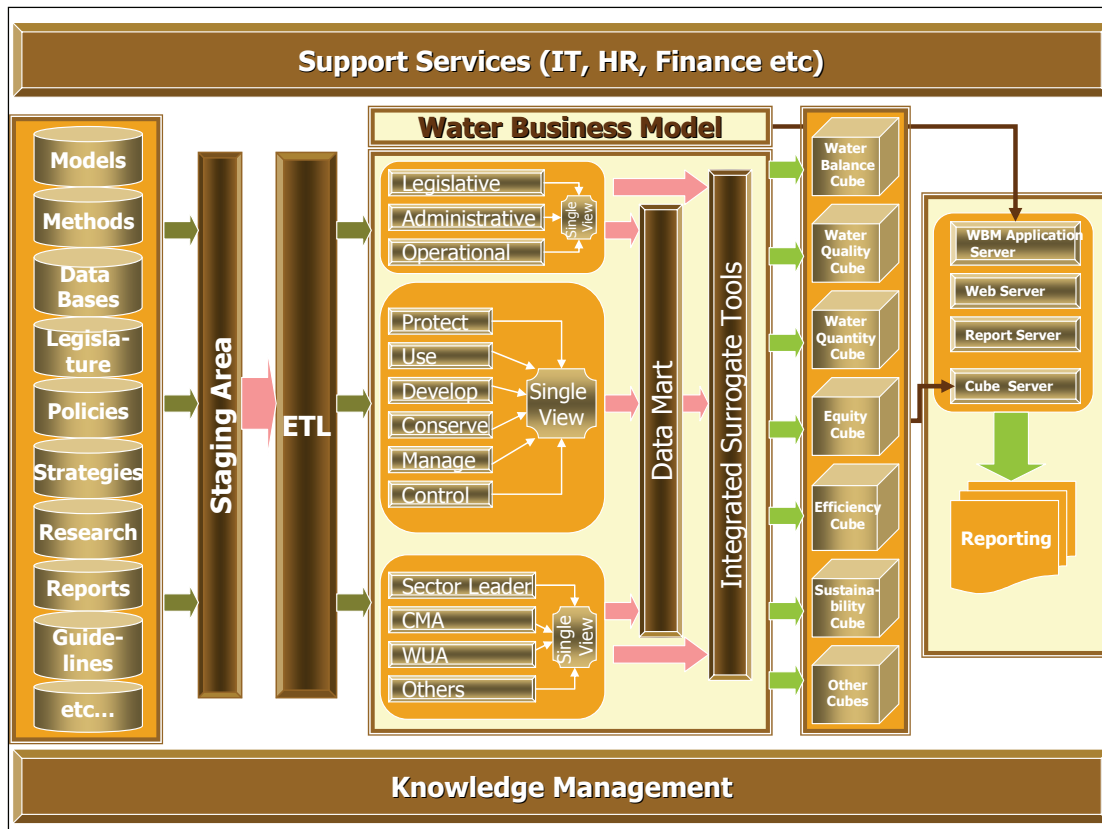


Figure 46: The GICF's water business model detailed

6 THE WATERGRAL SYSTEM

6.1 Overview

The GICF has been developed around the principles of extensibility with three basic characteristics (i.e. (a) Plug and play, (b) Evolutionality and (b) Representativity of the problem), and also around characteristics necessary for adaptive water management as follows:

- Ability to analyse ambiguities and mental frames that may hinder agreement on a common goal or a desired future state that should be achieved.
- Ability to develop scenarios or design monitoring programmes that can help analyse the possible changes in water availability. For the former tools, factors that influence sectoral water demand are also important.
- Ability to support analysis and evaluation of different management strategies and experimental approaches.
- Ability to support the implementation of an integrated research-policy process that is transparent as to who decides, based on what evidence, why to change a management practice.
- Ability to support the learning process where learning encompasses a wide range of processes.
- Ability to include and support analysis of uncertainty.
- Ability to retain, preserve and review knowledge embedded in data, algorithms and information.

To be able to test the GICF, a software prototype system (called the WATERGRAL) was designed based on the GICF. The WATERGRAL is an illustrative system depicting the end results of the GICF. The WATERGRAL cannot exist fully in reality until data warehouse system is up and running properly. The WATERGRAL provides the following features in order to present the GICF successfully:

- Self Service Tools Administrator – a website that list and describes all the tools, their input parameters, descriptions as well as the output. This module allows the user to save their data files after running their tools.
- ETL – Extract, Transform and load feature. Deals with data dimensions from various tools
- Data warehouse and or data repository. Data dimensions storage.
- OLAP – Retrieve metadata, decision support making information and summary data.

6.2 The Approach

Full integration and the development of a fully integrated system require that all tools as well as institutional arrangements conform to requirements for such integration. Such a change would require more effort, time and money, and therefore it should be noted that the development of the WATERGRAL only refers to a prototype system which was used to test the GICF. **Figure 46** depicts the GICF from an IT perspective with a water business model, meta tools to specify the requirement, a sourcing component to acquire data from source, a calculator framework in which to plug-in specialised modules, a reporting component to produce information outputs, a front end delivery tool through which to deliver Information to business users, an automated interface with workflow through which to deliver the data to external parties (Regulators) and build the best of breed record – taking the best components from multiple data sources and building a single super-record.

To achieve the Information Delivery platform as depicted in **Figure 46**, a combination of methodologies and approaches is required. Not a single approach can bear result without sourcing the help of the other. The functional model, object orientated as well as service orientated architecture and best of breed data modelling technique were used.

To be able to manage the development process appropriately, the Rational Unified Process was used. In the Rational Unified Process software lifecycle is broken into cycles, each cycle working on a new generation of the product. The Rational Unified Process divides one development cycle in four consecutive phases as follows (Rational Software Corporation, Undated):

- Inception phase
- Elaboration phase
- Construction phase
- Transition phase

For the purposes of this project only the inception and the elaboration phases were undertaken as depicted in **Figure 47**. Therefore it was not possible to develop the calculations methods into the WATERGRAL.

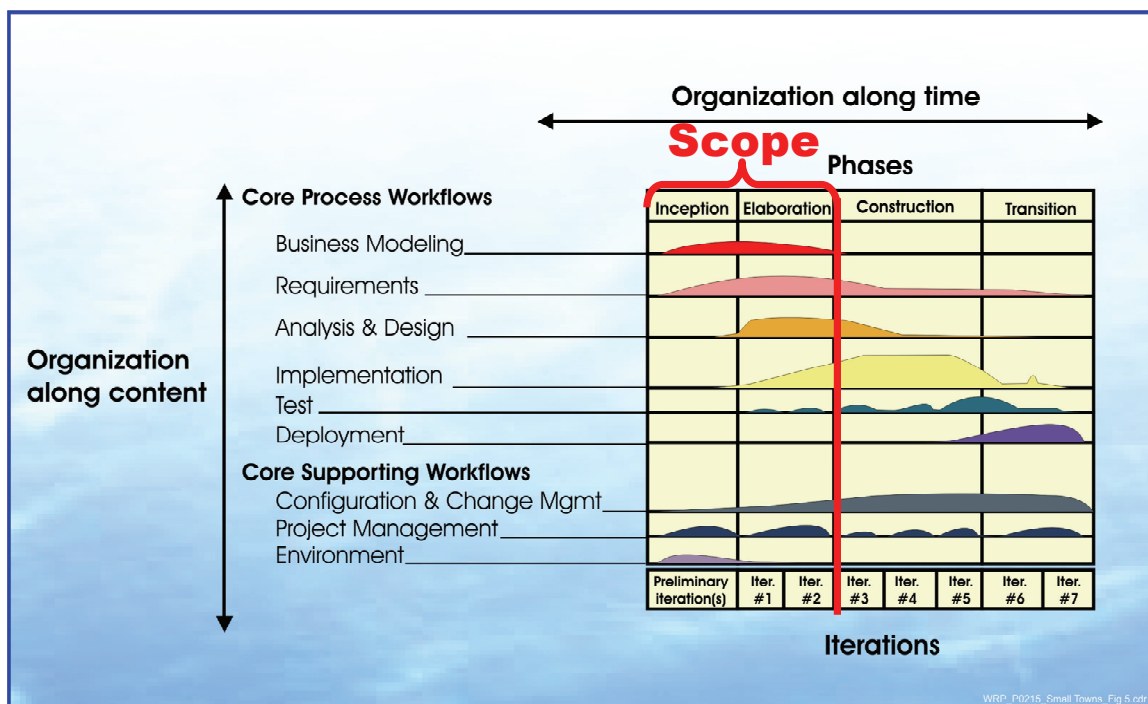


Figure 47: System development process (Rational Software Corporation, Undated)

The WATERGRAL was developed into two systems as follows:

- The web based system – this was aimed at establishing the web based online system with the ability to load and store reports and the tools.
- The Microsoft Spreadsheet based system – this was aimed at undertaking calculations required in decision making mainly focused on a linear water balance (i.e. yield vs. requirements)

Quality Assurance is the optimal methodology that ensures repeatable success in design, construction and operation of data warehouse and decision support systems environment. The

following is a short list of quality assurance principles used in developing the WATERGRAL:

- Test and Quality Assurance activities start early in the software development life cycle.
- Quality is built into the solution: “Do it right the first time. “
- Each step or phase is validated before moving ahead to the next step or phase.
- Repeatable processes are established and used by all like modules.
- Processes are continuously reviewed and improved.

Software Quality Assurance involves the entire software development process. Monitoring and improving the process, making sure that any agreed-upon standards and procedures are followed, ensuring that problems are found and dealt with and it is oriented to “prevention” (SoftwareQATest, 2011).

To be able to optimise the changes introduced in the process the Project Life Cycle took into consideration in a prioritised order the:

- **Re-Use** of existing software where possible, because it is already implemented and paid for and then only improve and fix it as necessary. Unless of course the software becomes obsolete.
- Using **E-Services** when available and feasible since it is the easiest manner to add capability, by only subscribing, interfacing and testing for a full implementation.
- **Outsourcing** when the application and support services provided of high quality, affordable, and non-strategic (not differentiated).
- **Buying**, where it sense. Packages must provide the features required, be available and supported by local Vendors, and bring stability and capability to the Business.
- Bespoke development (**Build**) only when the functionality is not provided by a package; the package is unaffordable; or where the client can develop a better or more sophisticated solution that would differentiate him better from the competition. In some cases a one-of-a-kind solution is required. Here it would be difficult to use a package.

Important in the development of the WATERGRAL was the choice of the enterprise architecture which is key to managing complexity and change. The Zachman framework was used to establish architecture at all levels i.e. Business architecture, Application architecture and Platform architecture by modelling the dimensions of the business by asking the following:

- **what** must be done (function)?
- what **data** must be collected (data)?
- **who** must do it (responsibility)?
- **when** it must be done (time)?
- **where** it must be done (locality)?
- and in **what format** with what (diagrams, text, etc.) (object)?
- **how** it must be done (process)?

6.3 The WATERGRAL Software Design

6.3.1 Water Business model and Data warehousing architecture

A data warehouse architecture is primarily based on the business processes of a business enterprise taking into consideration the data consolidation across the business enterprise with

adequate security, data modelling and organisation, extent of query requirements, meta data management and application, warehouse staging area planning for optimum bandwidth utilisation and full technology implementation (Toolbox for IT, 2009). A data warehouse is a repository of an organisation's electronically stored data. Data warehouses are designed to facilitate reporting and analysis.

Datawarehousing arises in an organisation's need for reliable, consolidated, unique and integrated reporting and analysis of its data, at different levels of aggregation.

The practical reality of most organisations is that their data infrastructure is made up by a collection of heterogeneous systems. For example, an organisation might have one system that handles customer-relationship, a system that handles employees, systems that handles sales data or production data, yet another system for finance and budgeting data, etc. In practice, these systems are often poorly or not at all integrated and simple questions like: "How much time did sales person A spend on customer C, how much did we sell to Customer C, was customer C happy with the provided service, Did Customer C pay his bills" can be very hard to answer, even though the information is available "somewhere" in the different data systems (Article Alley, 2010).

Another problem is that Enterprise resource planning (ERP) systems are designed to support relevant operations. For example, a finance system might keep track of every single stamp bought; When it was ordered, when it was delivered, when it was paid and the system might offer accounting principles (like double bookkeeping) that further complicates the data model. Such information is great for the person in charge of buying "stamps" or the accountant trying to sort out an irregularity, but the Chief Executive Officer (CEO) is definitely not interested in such detailed information, the CEO wants to know stuff like "What's the cost?", "What's the revenue?", "did our latest initiative reduce costs?" (Article Alley, 2010).

Yet another problem might be that the organisation is, internally, in disagreement about which data is correct. For example, the sales department might have one view of its costs, while the finance department has another view of that cost. In such cases the organisation can spend unlimited time discussing who's got the correct view of the data manner (Mitra, 2010).

It is partly the purpose of Datawarehousing to bridge such problems. It is important to note that in Datawarehousing the source data systems are considered as given: It is not the task of the datawarehousing consultant to figure out, that since the problem is that the CRM system identifies a person by initials, while the Employee-Time-Management system identifies a person by full name while the ERP system identifies a person by social security number; and since a person can change his name: things do not work and the organisation should invest in and implement one or two new systems to handle CRM, ERP, etc. in a more consistent manner (Mitra, 2010).

Rather, the datawarehousing consultant is charged with making the data appear consistent, integrated and consolidated despite the problems in the underlying source systems. The datawarehousing consultant achieves this by employing different datawarehousing techniques, creating one or more new data repositories (i.e. the datawarehouse) whose data model(s) support the needed reporting and analysis manner (Mitra, 2010).

6.3.2 Self Service Tools Administrator

It is a web enabled interface to add descriptions of each tool that were developed by DWA, for a brief understanding of what each tool is capable of delivering. Stakeholders get the facility to save their output data.

It is very clear from the diagram above shows that, data flows from left to right. DWA Data from various tools will be extracted into a single storage (preferably MS SQL Server Integrated Service) by off the shelf ETL mechanism. OLAP tubes would be used to present the data into the dashboard. Google maps API is very useful to drill down/up data in the web enabled GIS presentation.

Tool Admin			
Tools	Input	Brief Process Description	Output
WQT Geo Area Scenario 1 Scenario 2 Scenario 3 WRPM Geo Area Scenario 1 Scenario 2 Scenario 3	File 1 File 2 File 56	This process Add file 1 and File 56 together, and multiply the sum by file 2 contents	Water Quantity summary File

Figure 48: Web page of a Self Service Tools Administrator

Officials responsible for the tools will get a URL and they can register and start adding, editing (for latest versions of data/tool) and removing the tools.

6.3.3 ETL – Extract, Transform, Load Layer

ETL is the functions performed when pulling data out of more than one database or file(s) and placing it into another of a different type. The general outcry from the executive summary for a surrogate tool is easily answered by this layer.

The most commonly used tool is the Business Objects and has been acquired by SAP. DWA runs SAP applications therefore there is a need to investigate their implementation. RDBMS provide ETL capability of lately e.g. Oracle and Microsoft's SSIS can set up a great data warehouse. Open Source also provide many ETL tools. ETL layer does validate data for quality, prepared and deliver it in dimensions and facts.

Load cycle management must be introduced, i.e. the frequency of replicating data, is it daily,

or weekly or monthly.

6.3.4 OLAP – Online Analysis Process Tubes

OALP provides a historical view of data, although useful when used by itself, OLAP analysis becomes truly powerful when combined with predictive analysis from automated discovery of patterns in data.

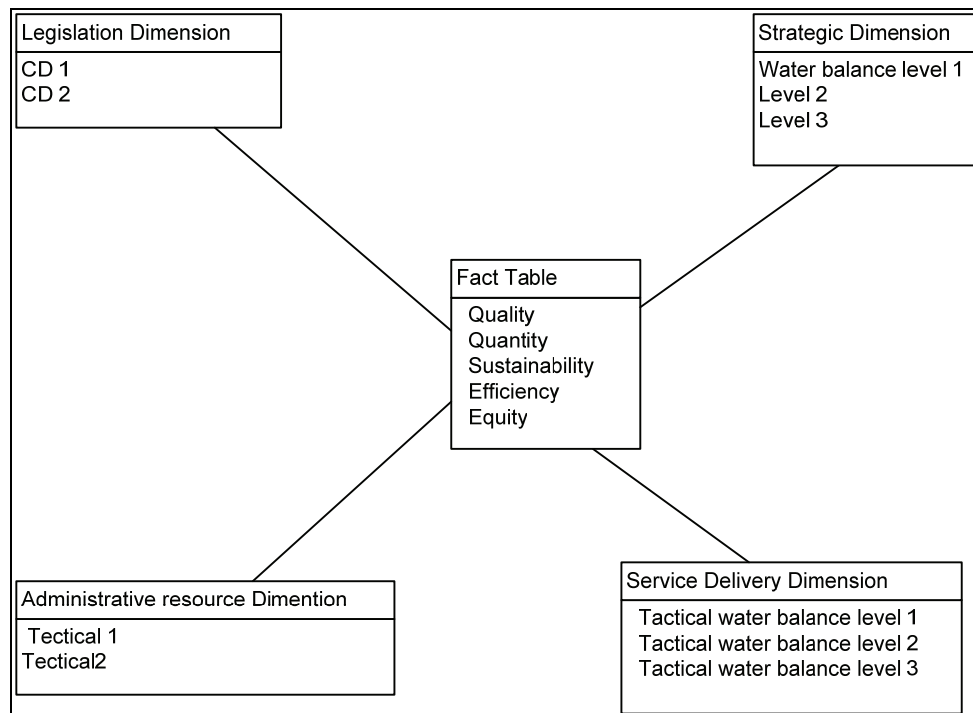


Figure 49: Star Data Model for OLAP

The central table in an OLAP start data model is called the fact table. The surrounding tables are called the dimensions. Using the above data model, it is possible to build reports that answer questions such as:

- The supervisor that gave the most contracts.
- The water quantity flow on a particular date, month, year or quarter.
- In which Geo Area did water quality fail the most?

To obtain answers, such as the ones above, from a data model OLAP cubes are created. OLAP cubes are not strictly cuboids – it is the name given to the process of linking data from the different dimensions.

6.3.5 Development technologies used

The system was primarily developed in a php custom developed Framework to facilitate further enhancement and development and uses the object oriented side of the language. Technologies used for development:

- Php
- Ajax
- MySql
- Javascript
- HTML

- CSS

File Structure is as follows:

- Images: All the images used in the system are stored in this folder.
- Includes: This contains files such as the settings to the database, the headers and footers of the system and a folder called classes. This folder contains the classes used in the crating of objects within the system.
- JavaScript: The javascript folder contains all the javascript files included in the application and framework
- Webservices: The webservises folder contains all the webservises that were called on by the Ajax functions to perform seamless searches.
- Admin: The admin folder contains all the files used for the functionality of the system.

6.4 WATERGRAL's User Manual

6.4.1 WATERGRAL System Description

The WATERGRAL System is a web-based system, with the main graphical user interface opening with the Navigation Panels on the left, **Figure 50 to 53**. This panel is always loaded, whatever functionality or sub-module is running, and presents the Base Case and the list of management boundaries (i.e. Water Management Areas, Water Management Schemes and Settlements).

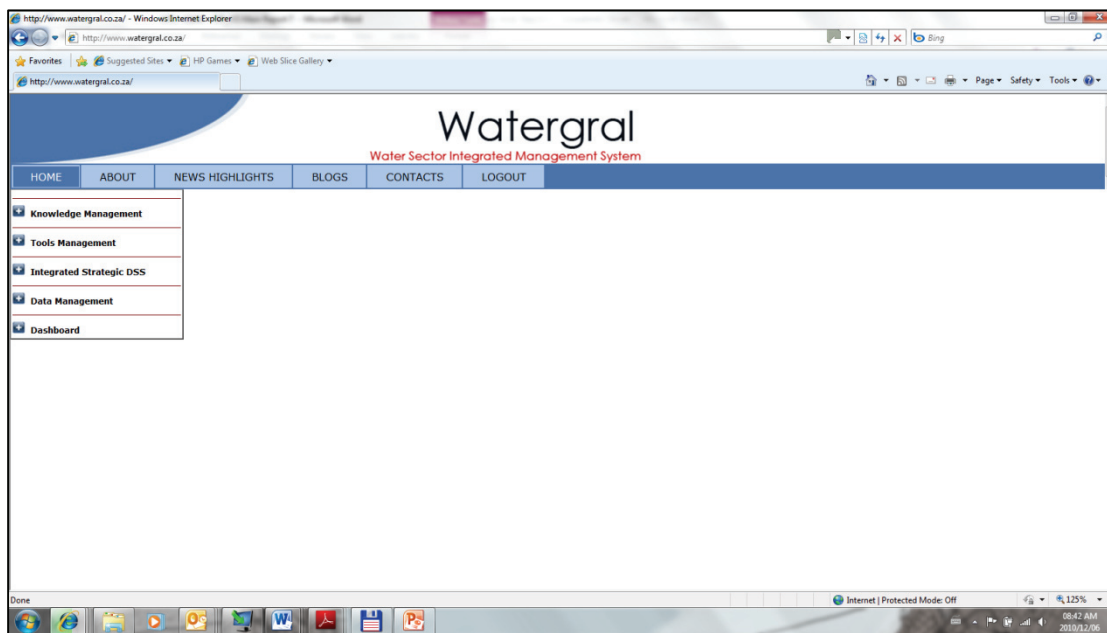


Figure 50: WATERGRAL home page

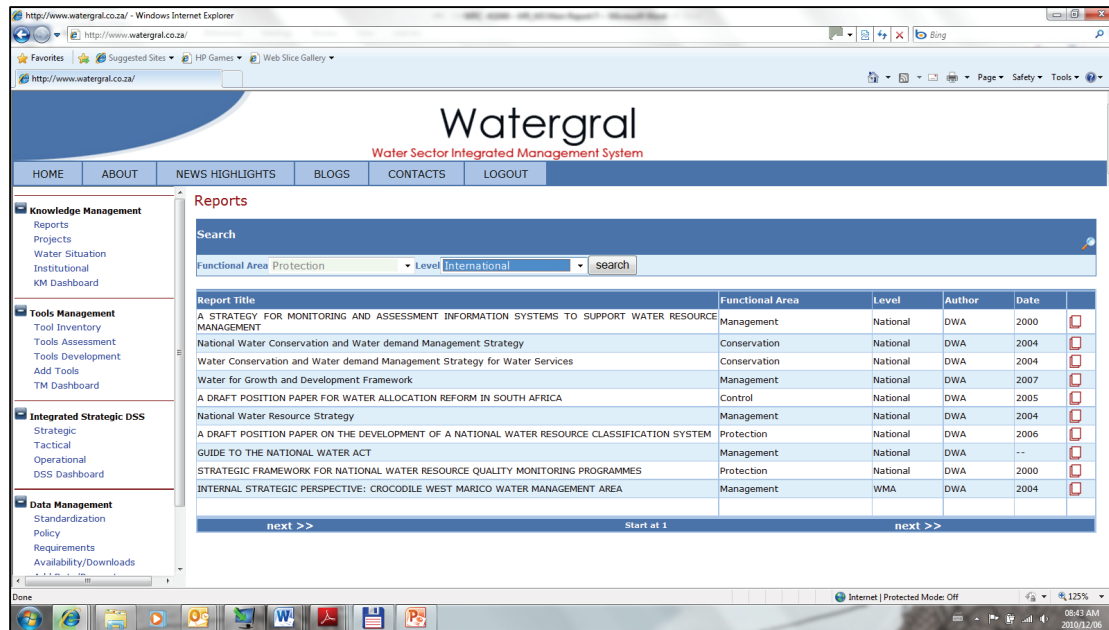


Figure 51: Knowledge management reports Page

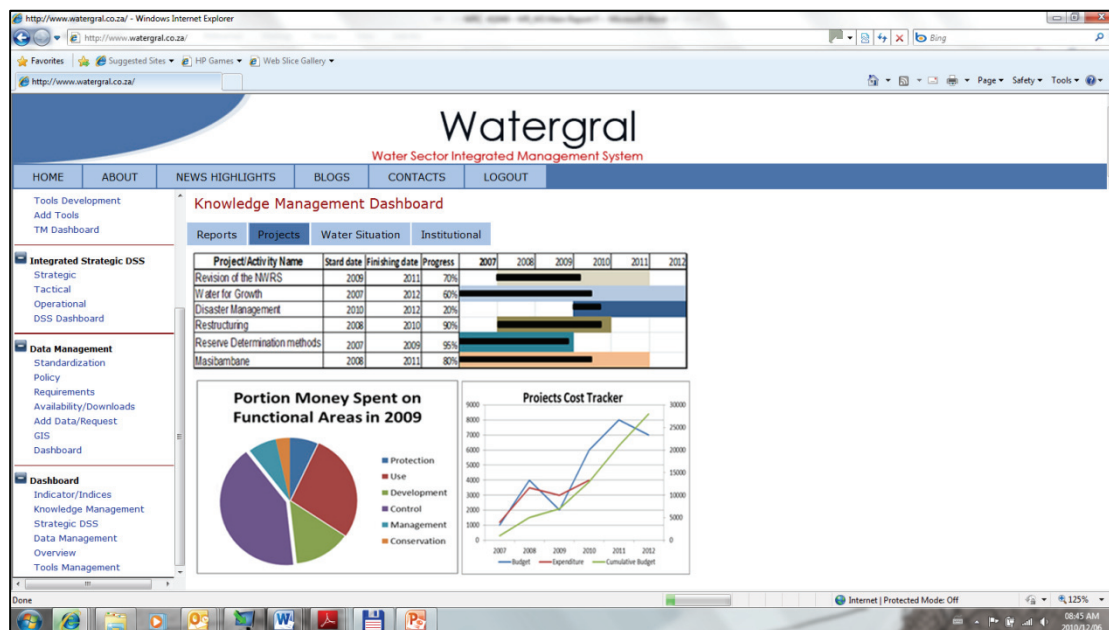


Figure 52: Knowledge management dashboard page

The Base Case represents the regional case study as it is when loaded during the case study or when entered for the first time. So, its geodatabase contains all the most recent data that characterise the current water situation of the case study or first time use. The Base Case is not simulated within the WATERGRAL; however it can be edited to update the available information and the conceptual network of nodes and links which schematise the water system of sources, demand uses and treatment plants. The data entry or network modifications can be done in the relevant windows.

The Water Management Boundaries are based on the Base Case, in the sense they are created as copies of it, and are the actual object of the WATERGRAL analysis. For each boundary, the water allocation from sources to demand sites will be simulated under user-generated

scenarios of water availability and/or demand, and strategic options selected and applied to particular time periods. Each Water Management Boundary works with the data of the base case at the beginning (when created), but both data and the water network can be modified, thus customising the scheme according to the type of analysis and objectives of the Decision Maker.

The Object Manager is also a tree view form, opening next to the Navigation Panel. It presents the nodes and the links of the water network, classified by type, firstly according to their water function with respect to the allocation (e.g. demand nodes, supply nodes or treatment nodes) and secondly according to their specific water use or resource type (e.g. industrial, domestic, aquifers, storage reservoirs, etc.). Categories can be expanded by click on the plus sign or collapsed, by clicking on the minus sign, according to the desired level of detail. The Object Manager is used to navigate through the network in order to get node or link-specific data or information when used in combination with the Data and Map Editors of the WATERGRAL.

As already said in the Navigation Panel description, the Data Editor presents the data characterising the elements of the water resource network in the region under study. Those network elements represent available water resources, such as groundwater, river reaches and reservoirs, water uses, among which settlements, irrigation sites and other farming, of treatment and transshipment plants and structures, and the connections such as canals and pipelines, linking them all conceptually and physically.

The Tools management module allows the user to define the business objective they are interested in, define the tools requirements, define the actors management level as well as the government level they are acting in and the institutional level. It further allows the user to enter a brief description of the available tools linked to the objective, the data requirements of the tools, the data outputs of the tools. With this information in the system for a number of tools, the user can then map tools to each other either through the business objective, the data requirements or the data outputs. This type of search allows the user to link their particular tools to others there by synchronising the value chain either from the data point of view or the business objective point of view.

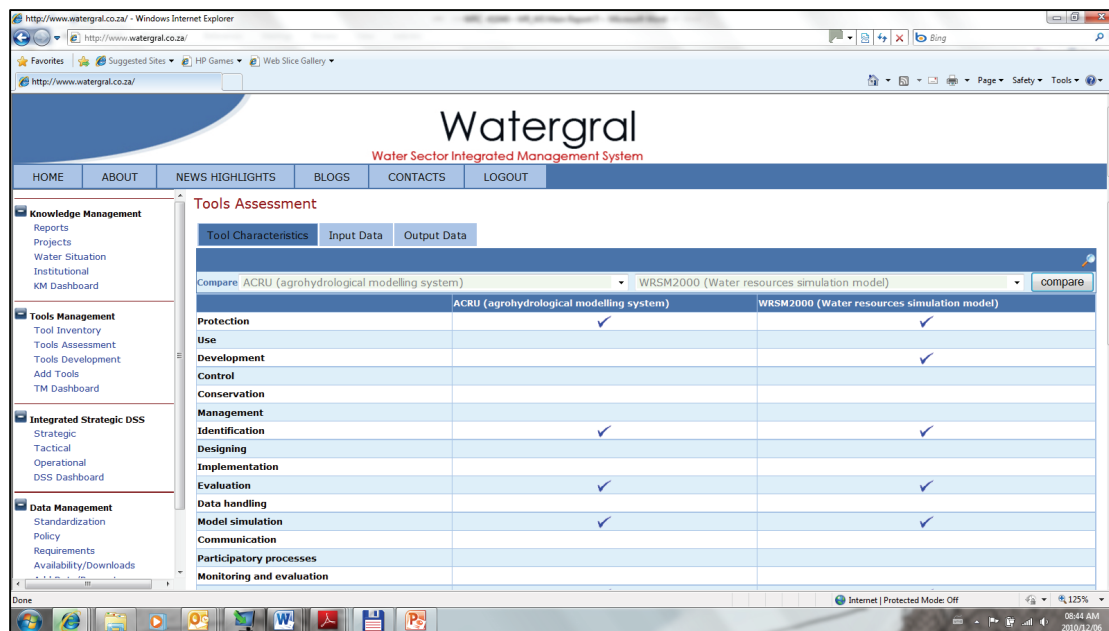


Figure 53: WATERGRAL window of tools mapping page

6.4.2 System Installation Requirements and Procedures

The web-based WATERGRAL System is accessible online (www.watergral.co.za). Users are required to register before they can be able to use the system. Upon login in, the system take users to the WATERGRAL homepage and users can navigate to the required modules, **Figure 50**. The spreadsheet based WATERGRAL System can be opened by directly opening the spreadsheet file named “watergral.xls”. The system contains five sheets namely (National Water Balance, Olifants WMA Water Balance, Croc_West WMA Water Balance, Nokeng Local Municipality Water Balance, and Tools Management). The first four “Water Balance” ones have each an input screen and a graph display, and as the parameters are changed in the input screen the graph changes accordingly, **Figure 54**. The Water balance modules allow different management scenarios to be analysed at the three different levels of management. The Tools Management Module shows the tools entered and the relevant areas of capability of the tools marked, **Figure 55**.

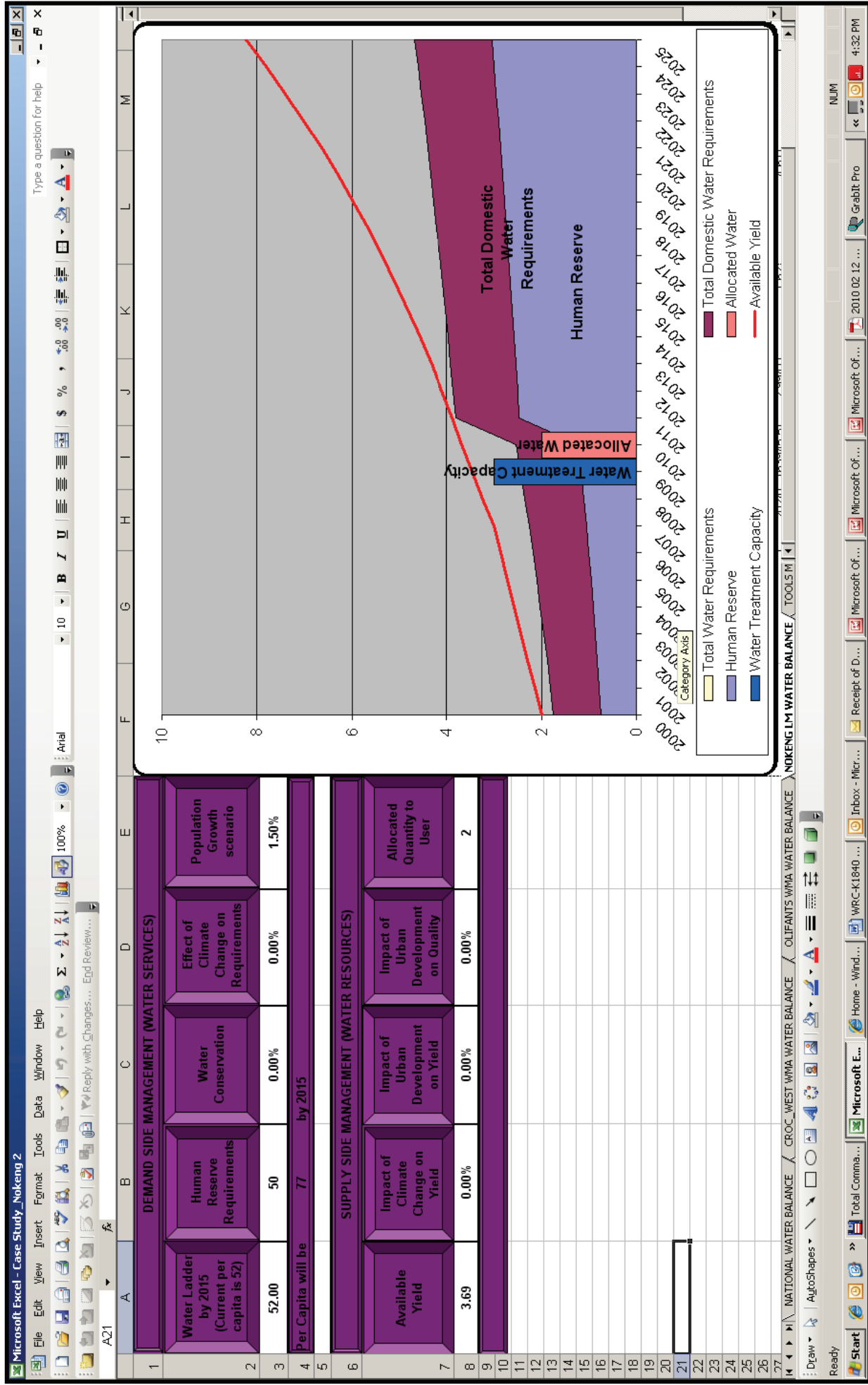
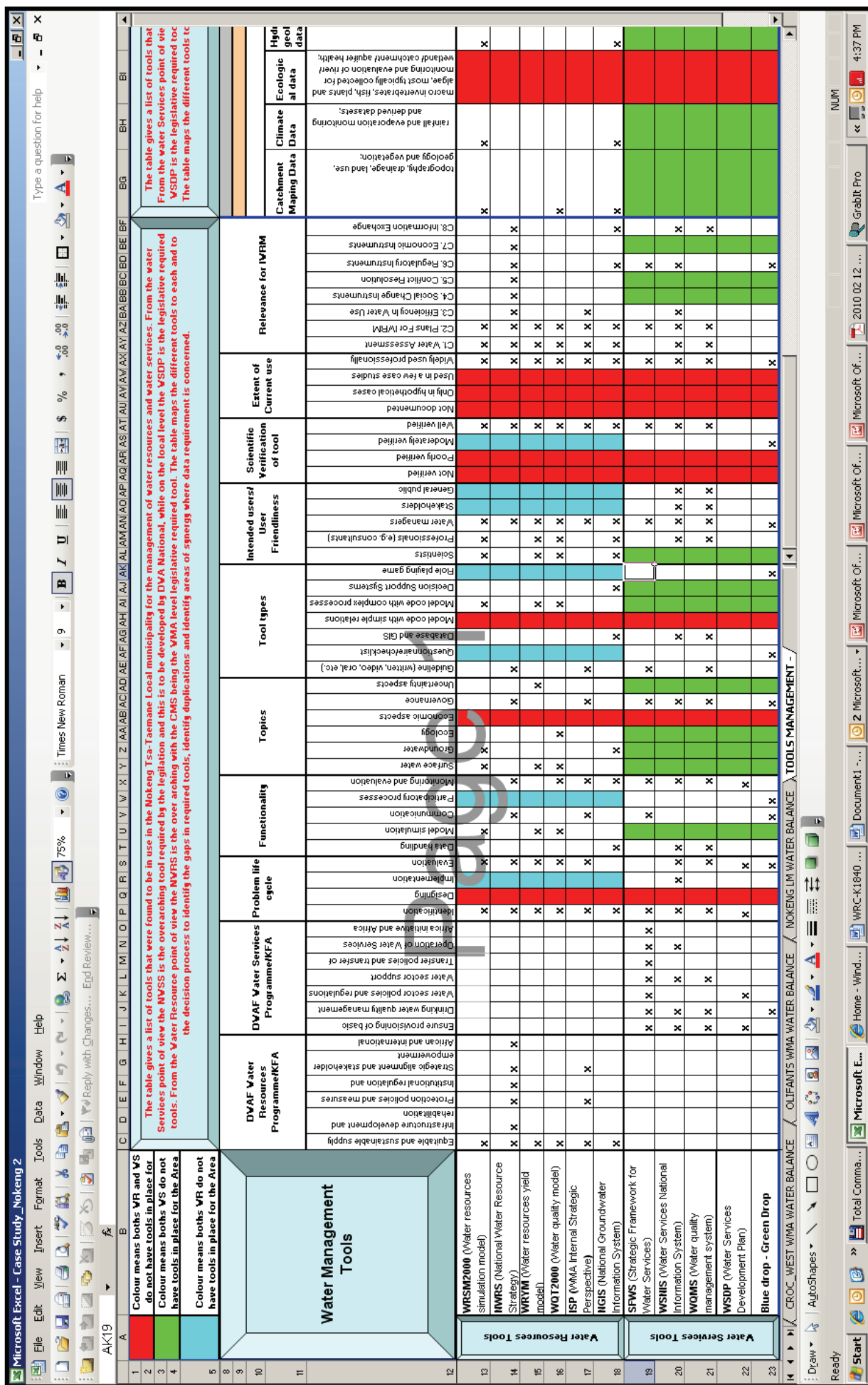


Figure 54: Spreadsheet Based WATERGRAL system – Water Balance Module



7 CASE STUDY APPLICATION

7.1 Overview

The study area selected is the Nokeng Tsa-Taemane Local Municipality in the Gauteng province. The municipality was selected due to its size, proximity to the study team and the complex water institutional arrangement, i.e. the municipality is a medium size municipality, is about an hour's drive from Pretoria, has a combination of both rural and urban settlements, has both domestic and other water uses, it straddles two water management areas, and as small as it is, it has six water services providers.

The WATERGRAL System is at this stage a prototype, i.e. the research has established that integration will be achieved in the context of defining and bringing together the water business model, the institutional setup (Value Chain) and the operating environment(government) on both a short and long term perspective through the ICE process; hence the demonstration of the WATERGRAL system in this task concentrated its effort on populating the WATERGRAL system with data for the settlements in the Municipality, the two water management areas and the institutional information, the purpose being to demonstrate how the Framework would bring about integration assuming the actors involved would have aligned themselves with the recommendations of the GICF. Therefore, the main product of this exercise is a populated WATERGRAL prototype with information from the case study.

7.2 Background on the Case Study Area

7.2.1 Nokeng Tsa-Taemane Local Municipality

The Nokeng Tsa-Taemane Local Municipality is situated on the north eastern part of Gauteng Province and is one of the two Local Municipalities within Metsweding District Municipality-the other being Kungwini Local Municipality, **Figure 56**. Metsweding District Municipality was established as a category C municipality in terms of section 155 (1) (c) of the Constitution of the Republic of South Africa and demarcated into this category in terms of the Local Government Municipal Demarcation Act of 1998. The Nokeng Tsa-Taemane Local Municipality Area includes various communities with different water needs and requirements, ranging from urban areas such as Rayton, Cullinan and Refilwe, rural residential areas such as the Roodeplaat Area, agricultural land, conservancies, and areas having tourism potential. The area's diversity, one of its strengths, contributes to its unique character, and the Gauteng Spatial Development Framework characterised the Nokeng Tsa-Taemane Area, as being predominantly rural in nature with lack of services, few employment opportunities, high levels of poverty and unemployment, large areas of potential agricultural and recreation and tourism areas.

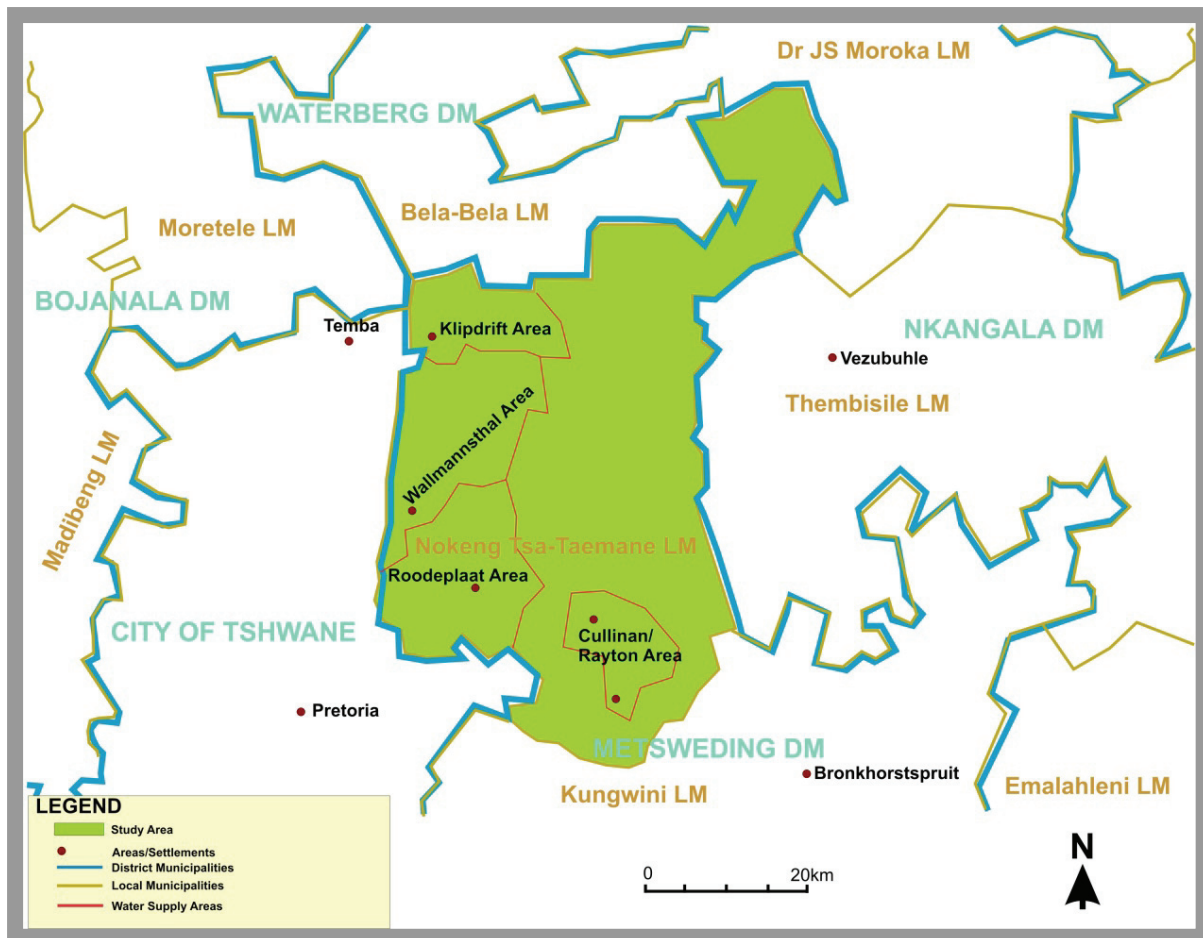


Figure 56: Municipal boundary of Nokeng Tsa-Taemane Local Municipality

From the water management perspective the Nokeng Local Municipality straddles two water management areas i.e. the Olifants and the Crocodile West Water Management areas, **Figure 57**. The Municipality receives and returns water from and to both the Olifants and the Crocodile West Water Management Areas. Nokeng Tsa-Taemane is primarily rural in nature with a significant but somewhat underdeveloped agricultural base. The Nokeng Tsa-Taemane Area is however a global centre for diamond mining, and Cullinan has developed as a result of the diamond mining activities, which produced the world's largest diamond and the world's largest cut diamond. Nokeng Tsa-Taemane has a very limited manufacturing with Industrial companies in the area producing a variety of goods and a significant number are engaged in downstream processing of agricultural products such as wood, maize and eggs.

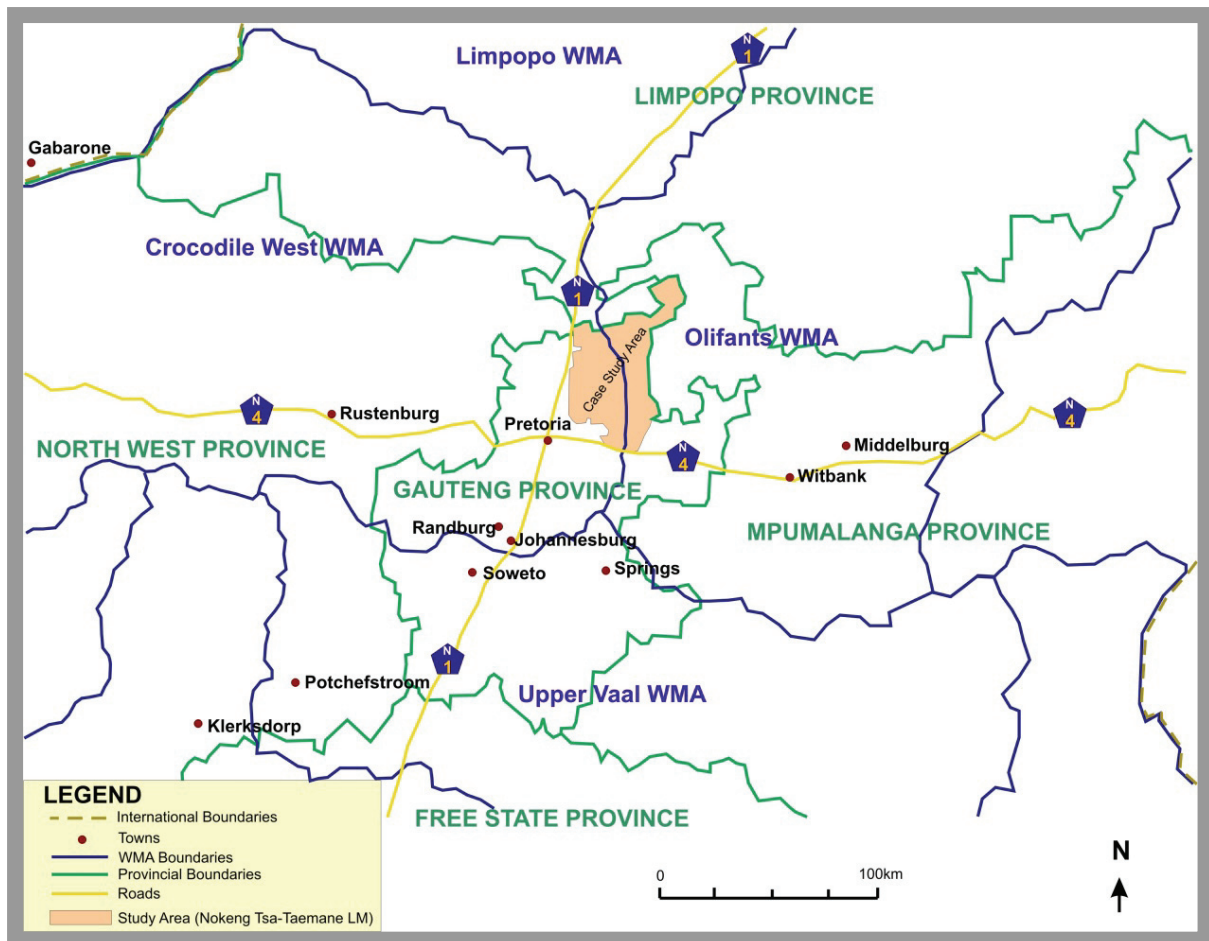


Figure 57: WMAs cutting through Nokeng Tsa-Taemane Local Municipality

The Water Services Development Plan (WSDP, 2008/9) (Clark et al, 2009) indicates that the Area's main water resource is the Roodeplaat Dam, Bronkhorstspuit Dam, abstractions from the Apies/Pienaars Rivers and ground water. The provision of water services can be summarised per area as follows:

- Roodeplaat Area – Water supply in the Roodeplaat Area is provided by a number of service providers, such as the Municipality, Rynoue Water Supply Company, Kameeldrift Water Supply Company and Magalies Water. Magalies Water is a bulk supplier of water in the area and only supplies water where the Water Services Authority is not able to supply. The Roodeplaat area mainly uses on site sanitation systems (septic tanks and soak ways).
- Cullinan Area – Cullinan water is abstracted from Bronkhorstspuit Dam in the Wilge River and purified at the Cullinan treatment works. Cullinan water scheme supply Nokeng, Rayton, Refilwe, Kekana Gardens, Cullinan Diamond Mines, Zonderwater Correctional Services and other consumers in Cullinan water supply area.
 - Wallmannsthal Area – The Wallmannsthal water is abstracted from Roodeplaat Dam and the Apies/Pienaars rivers, and purified at Wallmannsthal water treatment works. The system supplies Nokeng Tsa-Taemane Local Municipality, SANDF, Baviaanspoort correctional services, Government institutions such as Department of Public Works, Agricultural Research Council and various household supplied along the pipeline.
- Klipdrift Area – Klipdrift water is abstracted from Apies/Pienaars River system and purified at Klipdrift purification works.

- The Rural Areas – The rural areas use groundwater and on-site sanitation of which septic tanks with soakways and self-constructed pit toilets are the most common. The basic sanitation requirements are not always met.

The Crocodile West and Marico WMA have a complex water infrastructure network. With the exception of the northernmost region, most of the water management area is covered by the supply area of the three water boards mentioned above. As a result, an extensive network of reservoirs and pipelines has developed in the Crocodile West and Marico WMA in order to deliver water to the consumers. Most of the urban areas are supplied by surface water, although Pretoria, Thabazimbi, and towns situated in the Groot-Marico and Upper Molopo catchments utilise groundwater in addition to surface water (DEAT, 2005).

Rand Water is the largest water board in South Africa and supplies purified water to the Greater Johannesburg region, Greater Pretoria, Rustenburg and other smaller consumption centres. The water is drawn from the Upper Vaal catchment, and is transferred over the catchment divide to the southern region of the Crocodile catchment. All return flows from consumers north of the catchment divide therefore supplement the yield of the Crocodile River system substantially. This transfer of water has a significant impact on the water resources of the Crocodile West and Marico WMA. Magalies Water and the North West Water Supply Authority are the other two water boards that cover a significant area of the WMA. The Magalies Water supply area covers the central and eastern regions, and the North West Water Supply Authority covers the western regions. The only other significant inter-basin transfer is the Tswasa Water Supply Scheme, which transfers water from the Molatedi Dam in the Groot-Marico catchment to the Gaborone Dam in Botswana. This scheme is managed by the North West Water Supply Authority (DEAT, 2005).

The natural water resources of the WMA are predominantly surface resources, with a natural surface mean annual runoff of 850 million m³/annum. The groundwater resource has a total exploitable potential of 200 million m³/annum while the current actual water supply from groundwater is estimated at 111 million m³/annum. The total available resource in the WMA in 1995 is estimated at 786 million m³/annum. This includes both surface and groundwater components of the resource as well as imports into the catchment but does not include reusable return flows (DEAT, 2005)

7.2.3 Olifants Water Management Area

The Olifants River originates in the Highveld of Mpumalanga. The river initially flows northwards before curving in an easterly direction through the Kruger National Park and into Mozambique. The Olifants WMA falls within three provinces via Gauteng, Mpumalanga and the Limpopo provinces, **Figure 59**. The topography is characterised in the southern part by gently rolling hills before the river cuts through the Drakensberg to enter the relatively featureless lowveld region. The rainfall is strongly seasonal occurring mainly in summer. The mean annual precipitation varies from 500 mm in the Lowveld region, reaching 1000 mm in the mountains and reducing to 700 mm in the south in the Mpumalanga Highveld. The potential evaporation is well in excess of the rainfall. The WMA has been divided into 4 sub-areas for the purposes of discussing the issues and developing the strategies for the WMA. The sub-areas are the Upper Olifants, Middle Olifants, Steelpoort and Lower Olifants Sub-areas (DWAF, 2004d).

The Upper Olifants Sub-area is the most urbanised of the four sub-areas with the majority of the urban population located in Witbank and Middelburg. The population in these urban centres is projected to grow in the future. There are extensive coal mining activities in the sub-area both for export through Richards Bay and for use in the six active coal fired power

stations in the sub-area. The presence of coal also led to the establishment of the steel manufacturing industries located in Middelburg and Witbank (DWAF, 2004d).

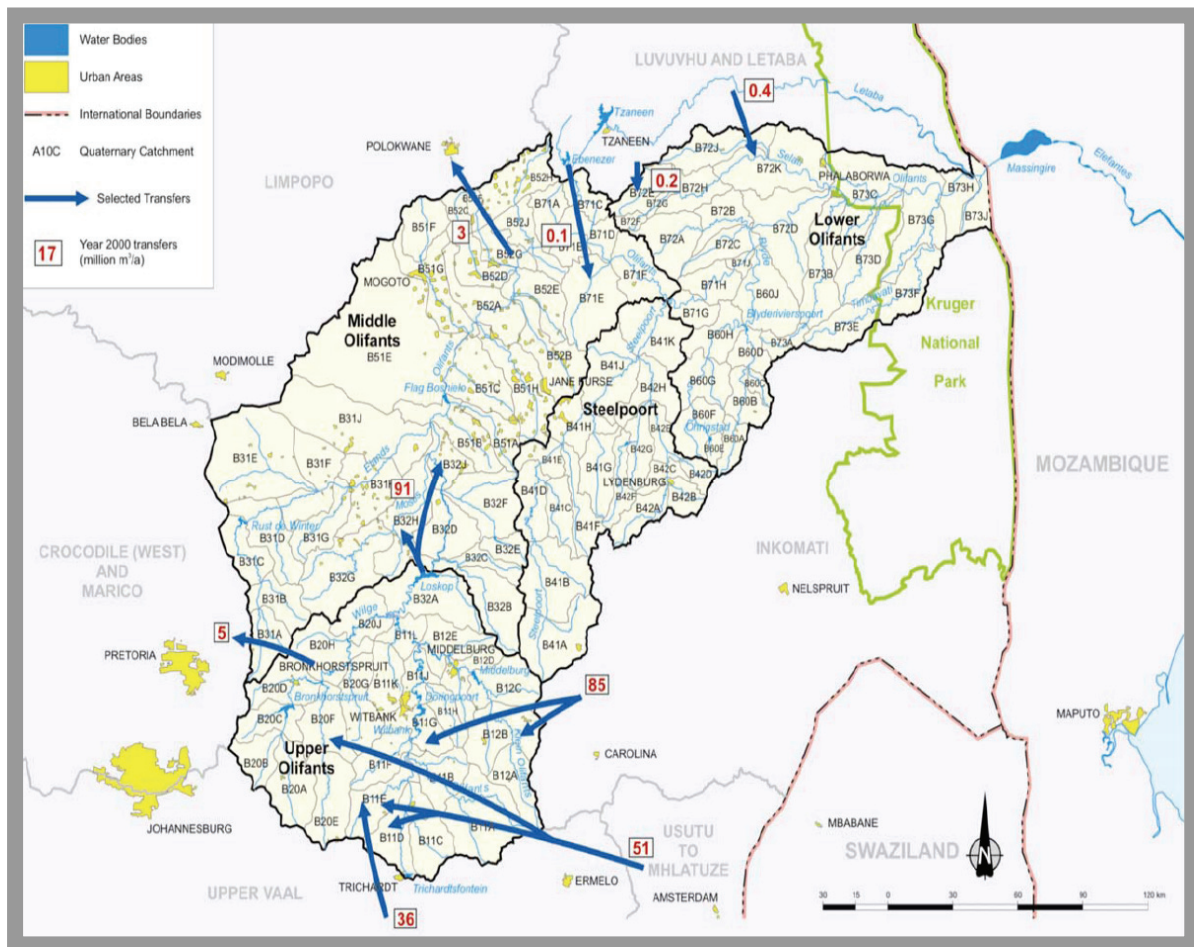


Figure 59: Olifants WMA and the water transfers (DWAF, 2004d)

The population in the Middle Olifants Sub-area is largely undeveloped with scattered rural settlements. The predominant land use is agriculture with extensive irrigation taking place from Loskop Dam. There are a number of platinum and chrome mines being developed in the Middle Olifants Sub-area. The mines have increased the water requirements in the area both due to direct water use and the influx of people into the area to work on the new mines. The Steelpoort Sub-area is largely rural with agriculture the predominant land use (DWAF 2004d).

There is vanadium and chrome mining and mineral processing taking place in the sub-area. The demographics of this sub-area are also affected by the new mining developments in the WMA with the population of Burgersfort projected grow. The Lower Olifants Sub-area is also rural in character with the main urban centre being Phalaborwa. Extensive irrigation takes place along the Olifants River, in the Blyde River catchment and in the upper reaches of the Ga-Selati catchment. Ecotourism is an important industry with a number of private game parks and the Kruger National Park located in the sub-area. There is mining with the main mining activity being the copper and phosphorus mining taking place in the vicinity of Phalaborwa (DWAF, 2004d).

The surface hydrology in the Upper Olifants Sub-area has been modelled. The Water Resources Yield Model (WRYM) and the Water Resources Planning Model (WRPM) have been set up for the sub-area. Although the WRPM and the WRYM can be used to determine the water availability of the large management units set up for the sub-area, there is some uncertainty related to the availability of groundwater and surface water at the local level for which more detailed hydrological models are required. There are substantial sewage treatment plant return flow volumes in the Klipspruit, Witbank Dam and Witbank and Middelburg Dam to Loskop Dam catchments. The return flows contribute to the base flow into Loskop Dam and have been cited as a cause of eutrophication in the upper reaches of the Loskop Dam and the Klein Olifants River. The WRYM has been set up for this region (DWAF, 2004d).

The groundwater resources in this sub-area vary from limited to good. The high yields are located in the Springbok Flats. The groundwater in the Springbok Flats is used extensively for irrigation and domestic supply. The full potential of the groundwater resource as a source of supply is not well known and needs to be accurately quantified as it has been earmarked as a source of supply for many of the rural communities in this sub-area in particular the Nebo Plateau. Groundwater is an important source of supply in this sub-area for irrigation and domestic use (DWAF, 2004d).

Several major dams have been constructed in the WMA. The Olifants River is highly regulated. The most significant dams in the WMA are the following (DWAF, 2004d):

- The Witbank and Middelburg Dams, which meet the urban and industrial demands of the Witbank and Middelburg centres.
- The Bronkhorstspuit Dam which supplies Bronkhorstspuit and the Western Highveld Region in the Elands River catchment with water for domestic and industrial use. There is also a supply for irrigation.
- The Renosterkop and Rust De Winter Dams are used to supply water for domestic use to the Western Highveld Region and for irrigation.
- Loskop Dam is used primarily to supply irrigation water to the Loskop Irrigation Board. Some water is supplied to the Western Highveld Region for domestic use.
- Flag Boshielo Dam was constructed to mainly supply water for irrigation, domestic use and support the transfer of water to Polokwane for domestic use. Many of the irrigation schemes have fallen into disrepair. Some of the irrigation schemes are in the process of being revitalised. The water allocation from Flag Boshielo Dam to the schemes that are in the process of being revitalised is being temporarily used to supply the growth in the mining demand. The dam is to be raised by 2005 and the increased yield will then supply the mines while the yield of the original dam will revert back to the revitalised irrigation schemes.
- Blyderivierspoort Dam, which supplies water for irrigation, local industrial and domestic demands and supports the supply from the Phalaborwa Barrage to the urban and industrial centre at Phalaborwa.

7.3 Methodology and Results

As already outlined in the approach section, the main activity for this task was to populate the WATERGRAL System with available information and dummy information where information is not available, with an aim of demonstrating how integration can be achieved using the proposed GICF.

Data was collected from previous studies, see **Table 8 and 9**. Data availability was, as expected, a challenge, however through the experience of the team members, assumptions were made where data was not available. This approach was used to arrive at a base case scenario, while allowing users to be able to update information as information becomes available.

The WATERGRAL System architecture consists of five modules i.e. Integrated DSS, Data Mart, Tools management, Knowledge Management and User Interface modules, and hence as part of the case study the information was collected for each module as follows:

1. **Integrated DSS** – this module is organised according to management levels i.e. Strategic, Tactical, and Operational where on the:
 - Strategic level – where the actors can have a view of the National strategies on a National level, Water Management Area level and the Municipal level, as well as the stages the strategies are in terms of implementation, and hence the required information was as follows:
 - The National Water Resource Strategy
 - The Strategic Framework for Water Services
 - Government Goals and Targets
 - International Agreements and paradigm shifts
 - Water balance indicators
 - Tactical Level – where the actors can have a view of the of activities of the different actors on a WMA level and Scheme level in line with the water business model and the following information was required and collected:
 - Water Management Area Strategies
 - Water Business Model's Pillars Strategies
 - Activities of the actors in line with the Water business Model as well as the water balance indicators
 - Required tools and their availability
 - Operational Level – where actors can have a view of users and their sources of water on a scheme and settlement level and the following information was required and collected:
 - Water users
 - Water sources
 - Water use and categories
 - Water allocation and licensing
2. **Tools Management** – in this module actors can have a view of required tools to fulfil the objectives of the water business, the available tools as well as the gaps on required tools. The following information was required and collected:
 - Water business objectives and the required tools
 - Tools inventory and their data requirements
3. **Knowledge Management** – in this module actors can have a view of the water sector knowledge and the following information was required and was collected:
 - Knowledge management initiatives and Strategies (i.e. defining the direction the water sector want to take)
 - People, the 'knowers' and learners who make or break the process
 - Sector knowledge.

4. **Data Mart** – the data mart stores all the information to support the activities of the above modules and information housed were as collected for the modules.
5. **User Interface** – the user interface helps users interacts and interrogates the above mentioned modules and hence no specific data was required.

Table 8 and **Table 9** gives a list of Tools and projects/activities that were collected and were included as part of the case study.

Table 8: Case study – tools inventory

TOOL NAME	PURPOSE	LEVEL OF USE	DATA INPUT TYPE	DATA OUTPUT TYPE
WSDP	Planning	Local Level	General	General
Blue Drop	Assessment	Local Level	Water Quality	Status indicators
WRYM	Yield Assessment	Regional	Flows	Yield
WRPM	Allocation Planning	Regional	Flows/Yield	Allocation/Operational Plan
NWRS	Strategic Direction	National	General	General
SFWS	Strategic Direction	National	General	General
Water Quality Management System	management	Regional/Local	Water Quality	WQ indicators
WULATS	Application Tracking	National/Regional	general	Licences
WARMS	Water Use Registration	National/Regional	Water users	Water users and use
WRSM2000	Flow Assessment	Regional	Rainfall	Flows

Table 9: Case study – list of projects and activities

PROJECT/ACTIVITY NAME	PURPOSE	LEVEL OF USE	WATER BUSINESS OBJECTIVE
Water Situation Assessment	Assess Water Situation	National	Manage
Internal Strategic Perspective	WMA Strategic Direction	National/Regional	Manage
Reconciliation Strategies	Water Reconciliation	National	Manage
Operating rules	Scheme Operation	National/Regional	Manage
Reserve Determination	Setting reserve	National/Regional	Protect
Regional bulk Infrastructure Grant	Infrastructure Development	Regional/Local	Develop/Manage/Use
Water Conservation	Conservation and Demand Management	National	Conserve
Water Use Licensing	Licensing	National	Control
Validation and Verification of water use	Clarifying water use	National/Regional	Manage

With the information collected a number of GIS layers can be produced in line with the activities required under the Water business Model. These layers can be overlaid on each other and analysed for different scenarios according to the user's requirements. The following two sections give the detailed results of the analysis undertaken for Nokeng Tsa-Taemane Local Municipality. The analysis focused on the “management of tools”, and the “strategic

assessment” components of the GICF, as it is on these two modules where integration of tools can be demonstrated, and the other modules (knowledge management, data-mart and user interface) are just support modules to ensure continual functioning of the system.

7.3.1 Tools Management Module

Water management requires different tools for the managers to undertake analysis of the different components of water management. However, for the managers to arrive at decisions that will satisfy the water balance equation as constrained by equity, efficiency and sustainability, it is very important that the tools can complement each other in the decision value chain. This section was concerned with the evaluation of the required tools for decision making, the availability of such tools as well as the extent in which tools for water management in the Nokeng Tsa-Taemane compliments each other. In line with the developed methodology for the “Management of tools” the Business Objectives, Decision Process, Required Tools and the Required Data were unpacked for the Nokeng Tsa-Taemane Local Municipality.

Table 8 and 9 lists the projects/activities and the tools that the municipality is aware of, and either uses the tools or the results of the tools. **Table 10** gives the results of the analysis of the available tools and identify gaps in terms of the ability of the combined tools to address issues of water management holistically. The assessment showed in general that the tools that were being used in the municipality were not enough to deal with the issues relating to water management. From **Table 10**, the areas highlighted in **RED** shows areas where both tools for water resource and water services being used were not sufficient to deal with the water management issues, i.e. the combined tools in use were not capable of helping the managers in “designing”, “assessing economic aspects”, “assessing ecological aspects” etc., of the water management programmes. The areas highlighted in **GREEN** indicate the areas where the water services tools came short, i.e. the tools could not “simulate water requirements”, “address uncertainty”, etc. when making water management related decisions. And finally the areas indicated in **BLUE** indicates the aspects which the water resource tools could not deal with, i.e. “implementation”, “participatory processes”, etc. when making water management related decisions.

There are, however, tools available in the sector that can deal with the short comings as highlighted in this assessment, it is the failure of the actors in the sector to adopt this tools, and mainly because of the lack of the platform to identify gaps and tools that can fill the gaps. Using the developed GICF, the following are some of the tools that the municipality could identify to meet the requirements for decision making: “Urban water retunflow model”, “IMPAHLA”, “Benchleak”, etc. **Table 11** and **12** gives the assessment results for the tools with respect to both data input and output.

Table 11: Case study tools assessment – input data requirements

		Colour means both WR and WS do not have tools in place for the Area		Colour means both WS do not have tools in place for the Area		Colour means both WR do not have tools in place for the Area																											
		Water Management Tools																															
		Data and Information Requirements																															
		Data and Information																															
		Input																															
		Input Data Type																															
		Catchment Mapping Data	Climate Data	Ecological data	Hydro geological data	Hydrology Data	Water Quality Data	Water Supply Data						Water Demand Data																			
		topography, drainage, land use, geology and vegetation.	rainfall and evaporation monitoring and derived datasets;	macro invertebrates, fish, plants and algae, most typically collected for monitoring and evaluation of river/wetland/ catchment/aquifer health;	characterisation of aquifers and other geological features;	water level, volume, flow velocity or pressure that relate to the movement of water. These cover a broad range of water features such as rivers, dams, wetlands, groundwater, storm water or industrial effluent;	relating to the physical, chemical and biological condition of water;	Internal renewable water resources	Runoff data at catchment outlet (time series: if n/a-long-term average)	Renewable Ground water	Ground water recharge (natural and artificial)	Non-renewable ground water	Surface water	Desalination plants capacity	Capacity of reservoirs	Operating rules for existing reservoirs (Objectives)	A(h), V(h) relationships for reservoirs	Transfer from neighbouring regions	Water recycling/reuse	Losses in distribution system	Unaccounted for water	Water Quality	Water demand per person	Abstraction from surface water	Abstraction from groundwater	Abstraction from fossil groundwater	Final water consumption	Number of licences for abstraction	Industrial water requirement (consumptive and Non-consumptive)	Agricultural water demand (consumptive and Non-consumptive)	Water demand per overnight stay	Seasonal demand pattern	WQ parameter for return flow
Water Resources Tools	WRSM2000 (Water resources simulation model)	X	X		X		X						X										X										
	NWRS (National Water Resource Strategy)													X									X	X	X	X							
	WRYM (Water resources yield model)						X						X			X	X	X	X			X	X	X	X								
	WQT2000 (Water quality model)	X					X						X	X		X	X	X	X			X	X									X	
	ISP (WMA Internal Strategic Perspective)												X										X										X
	NGIS (National Groundwater Information System)	X	X		X		X																	X	X	X							X
Water Services Tools																																	

7.3.2 Strategic Decision Support System Module

While the Tools Assessment can highlight the gaps in the tools being used as well as map the data, the strategic assessment ensures that assessments and decisions taken at the different levels of management are coherent, and gives a sector wide view of performance rather than a particular perspective. To be able to demonstrate the usefulness of the developed framework, the water balance, the human reserve and the water ladder concept were put into the test taking into consideration the impacts of climate change, water conservation, population growth and urbanisation.

The water ladder comes from the Strategic Framework for Water Services of DWA, where it is stated that “National government is committed to eliminating the backlog in basic water services and to progressively improving levels of service over time in line with the original aims of the Reconstruction and Development Programme in 1994. The first step up the water ladder is the provision of at least a basic water and sanitation service to all people living in South Africa. This is the most important policy priority and government will commit adequate funds to make this possible within the next few years. The next step is an intermediate level of service such as a tap in the yard. Water services authorities are expected to assist communities to achieve intermediate and higher levels of service wherever practical, affordable and sustainable without compromising the national policy priority of universal access to at least a basic level of service. National government will increase its commitment of grant funds over time to support households to step up the services ladder. Basic levels of service will also be reviewed in future to consider increasing the basic level from 25 to 50 litres per person.”

To be able to test against the stated parameters there was a need to first develop surrogate models in line with the conceptual model. Therefore, very simple surrogate models of linear relationships between the parameters in question were developed to account for changes in population, policy on human reserve, government development goals, climate, urban development, etc. **Figure 60** gives a screen of the strategic assessment spreadsheet-module showing the water supply side and demand side parameters that were considered.

DEMAND SIDE MANAGEMENT				
Water Ladder by 2015 (Current per capita is 52)	Human Reserve Requirements	Water Conservation	Effect of Climate Change on Requirements	Population Growth scenario
52.00	50	0.00%	0.00%	1.50%
Per Capita will be 77 by 2015				
SUPPLY SIDE MANAGEMENT				
Available Yield	Impact of Climate Change on Yield	Impact of Urban Development on Yield	Impact of Urban Development on Quality	Allocated Quantity to User
3.69	0.00%	0.00%	0.00%	2

Figure 60: Integrated Decision Support parameters tested

Nokeng Tsa-Taemane currently has a population of about 133000 with a total water use of about 2.53 million m³/annum; this translates to an average per capita use of 52 l/p/d. The municipality falls into the Crocodile west and the Olifants WMAs, and the Crocodile west has an average per capita use of 155 l/p/d and the Olifants on the other hand has an average per capita use of 180 l/p/d. the same analysis shows that on a national level in South Africa the average per capita use is 209 l/p/d. The following **illustrative** scenarios were tested and the results are presented in **Figure 61** to **Figure 65**:

- Scenario A – the base scenario (as is currently) where the human reserve is 25 l/p/d and the average per capita use is 52 l/p/d in Nokeng Tsa-Taemane Local municipality.
- Scenario B – the scenario where there human reserve is increased to 50 l/p/d.
- Scenario C – a scenario where climate change's negative impact on the yield is 5%, increases basic human requirements by 5%, urban development increases runoff by 2%, urban development reduces available clean water by 1.5% due to pollution
- Scenario D – as in Scenario C with a 15% saving achieved through water conservation and water demand management.
- Scenario E – as in Scenario D with development goal being to have an average per capita use of 150 l/p/d by 2015 in the municipality.

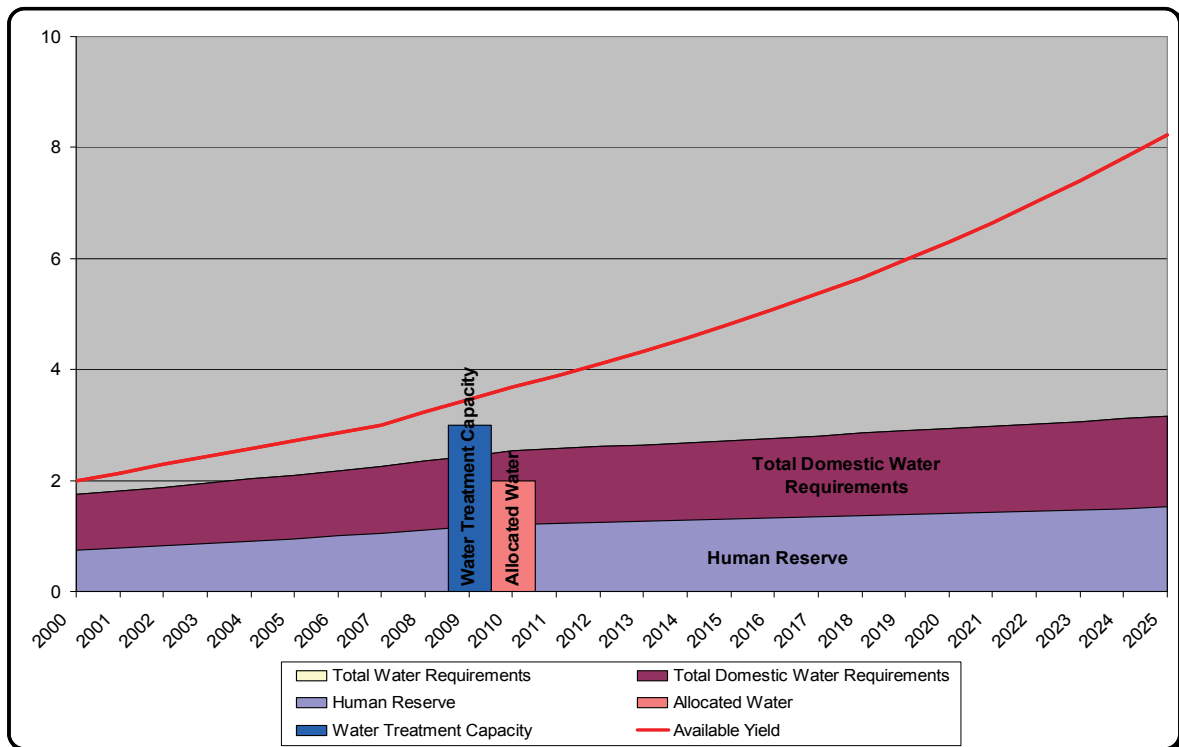


Figure 61: Results for Scenario A on an local municipality level (Illustrative)

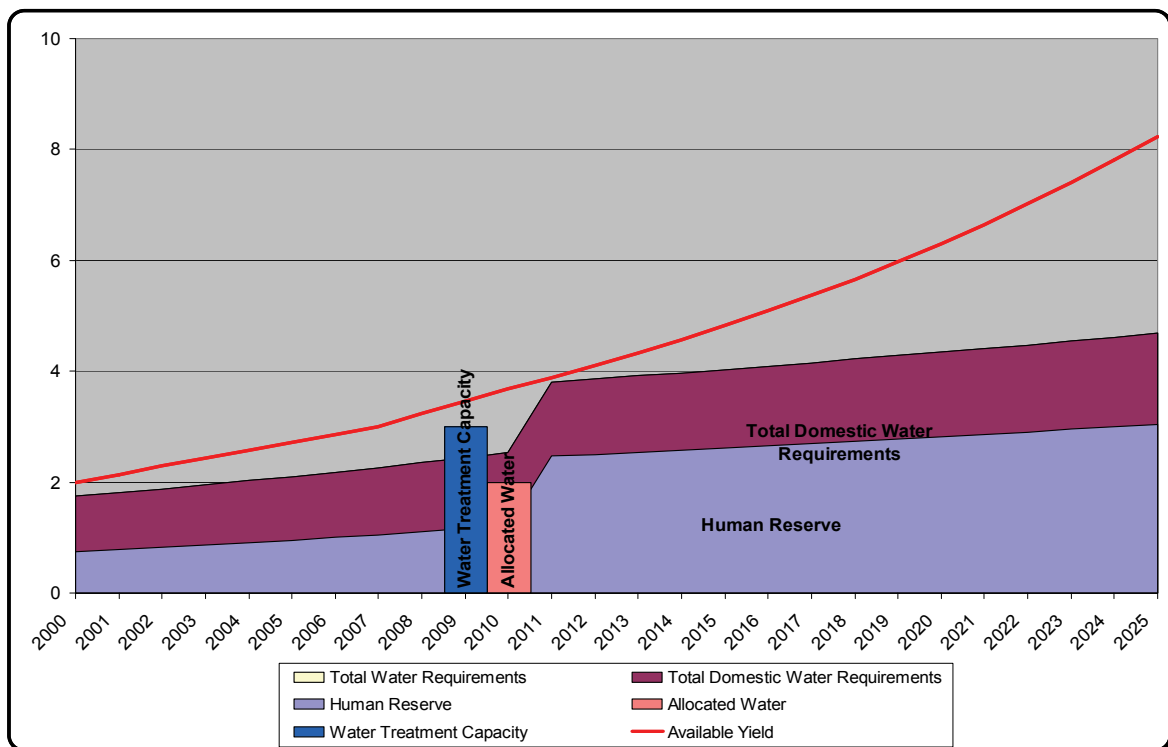


Figure 62: Results for Scenario B on an local municipality Level (Illustrative)

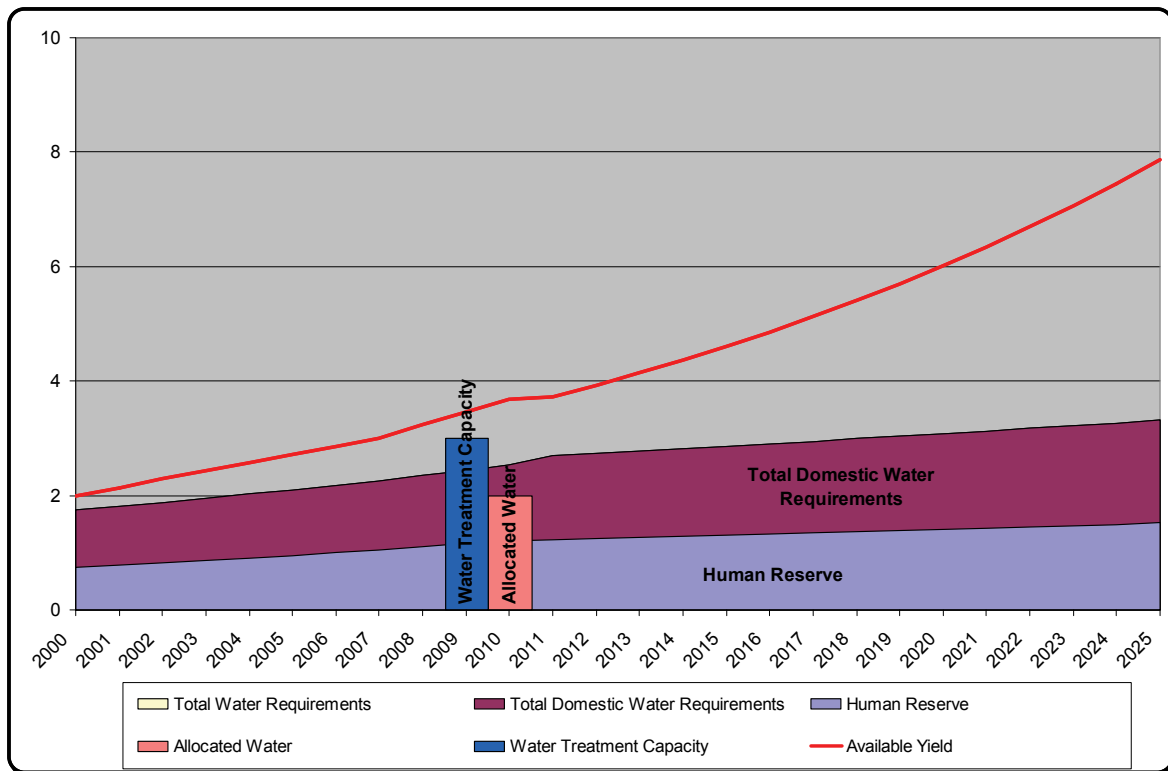


Figure 63: results for Scenario C on an local municipality level (Illustrative)

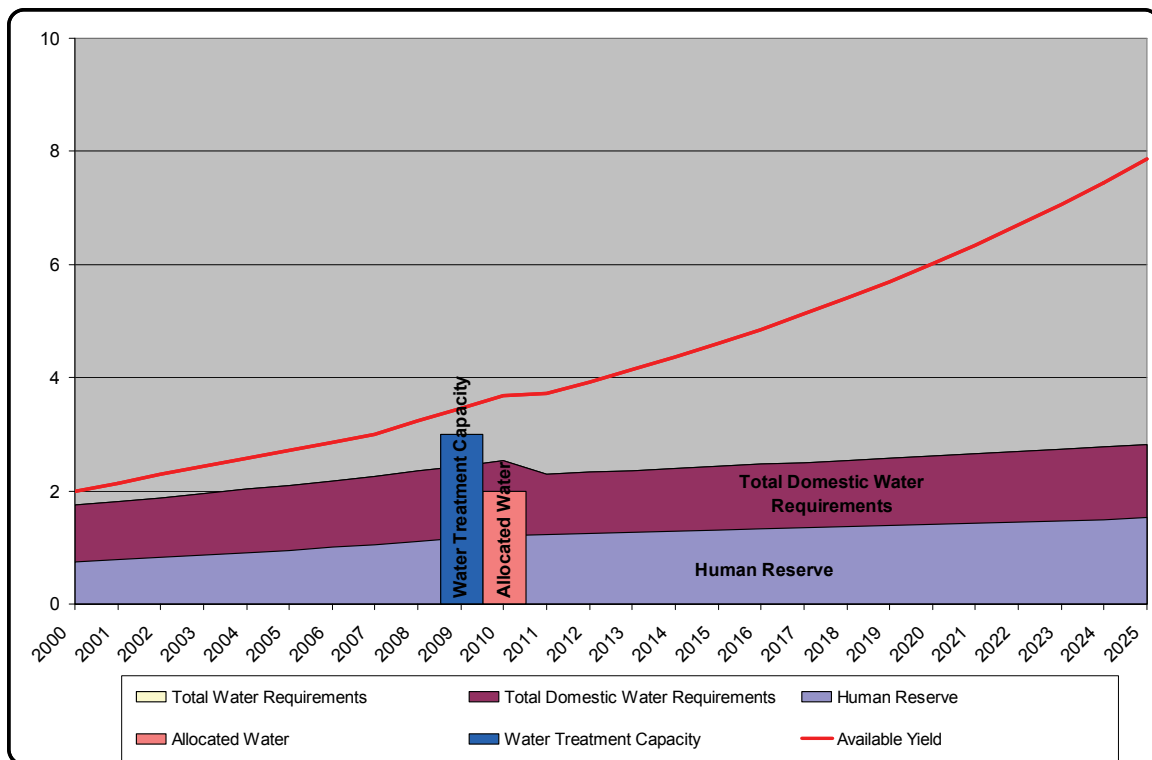


Figure 64: Results for Scenario D on an local municipality level (illustrative)

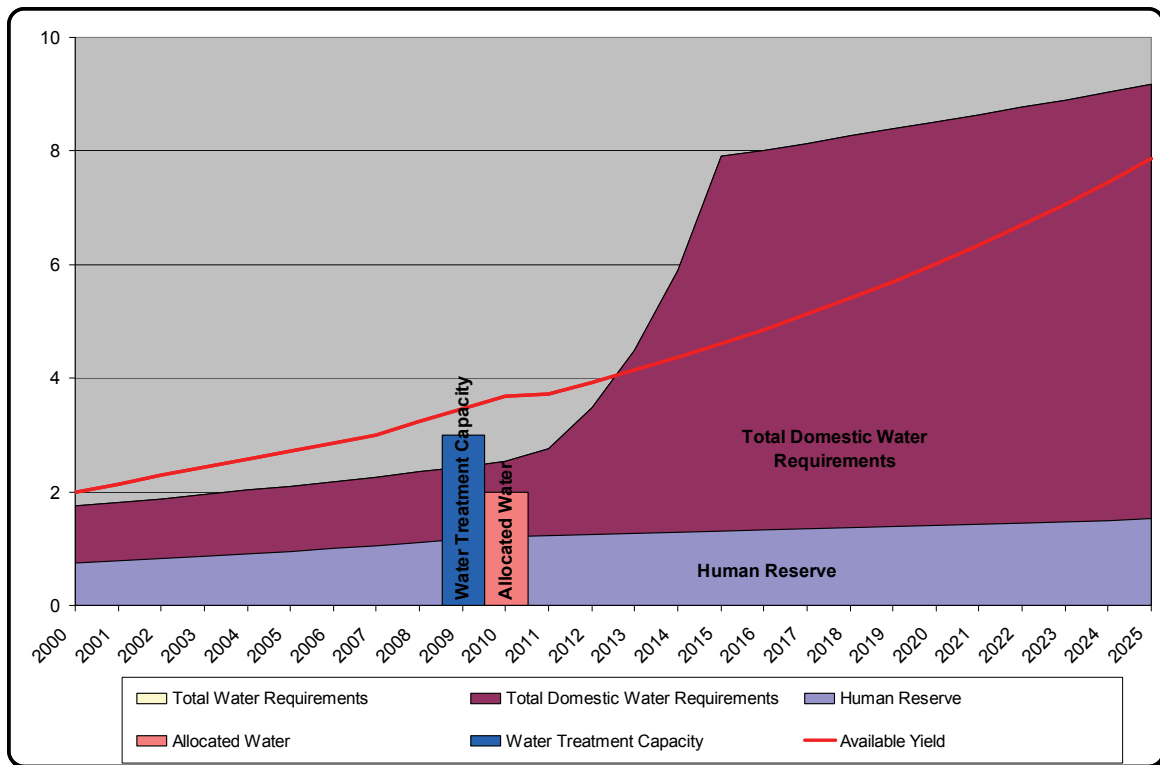


Figure 65: Results for scenario E on a local municipality Level (Illustrative)

The analysis shows that increasing the human reserve to 50 l/p/d has a potential to bring the average per capita use to 77 l/p/d in the municipality, and this will merely correct the imbalance in water distribution. However this may have other effects on the reserve in a bigger picture. While scenarios A to D shows a balance in the available water to demands, scenario E shows a water shortage by 2013.

Scenarios A to E were analysed for the WMA level as well as the National level. And from the results it is clear that equity is still far from being achieved. **Figure 66** and **Figure 67** shows Scenarios A for both the national and the WMA level. The results also showed that on a national level a development goal of an average per capita use of 150 l/p/d would not be effective while on a local level the goal would be effective. And this demonstrates how the development of policies should be driven from both the national and the local level and the importance of managing water resources in an integrated manner. It should however be noted that the test was done for changes in water resource and water services factors only, hence the results does not give a complete picture of the actual movements as one would also need to bring in the other water users. This tool however allows the managers to view the effects of their actions from both the national and the local level.

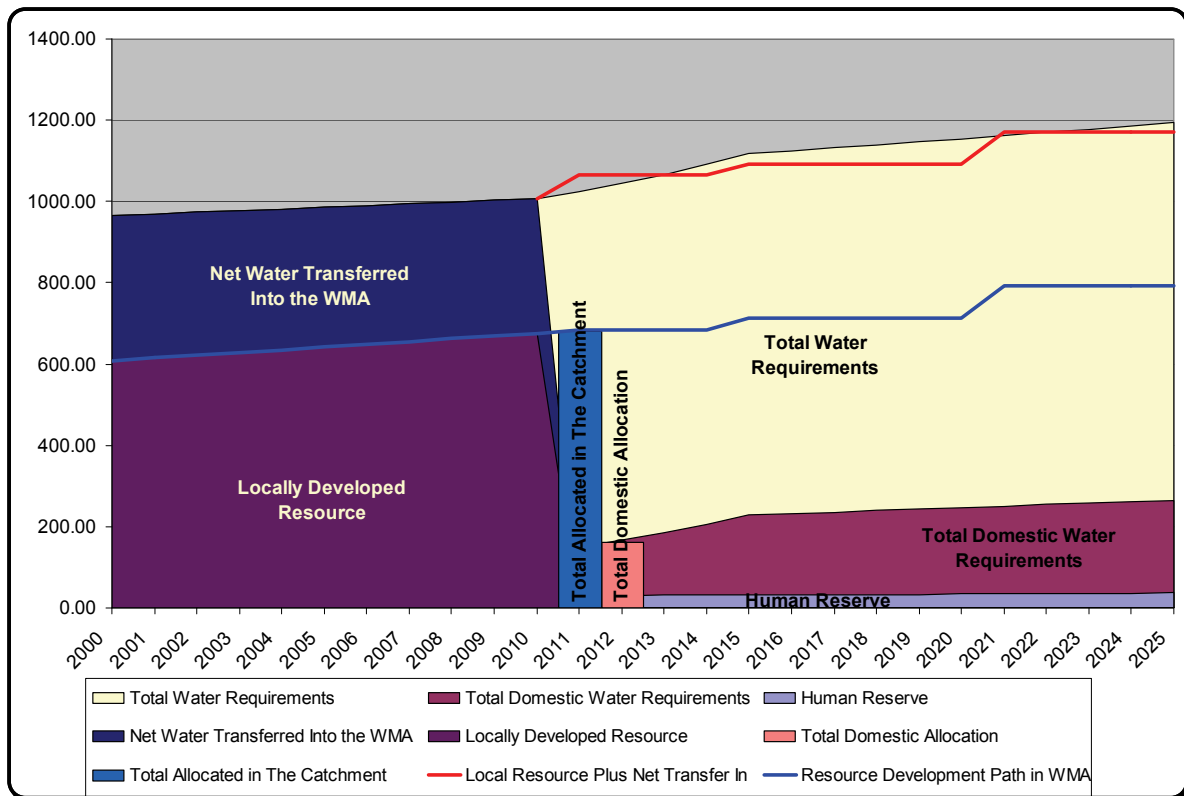


Figure 66: Results for Scenario A in the Olifants WMA (Illustrative)

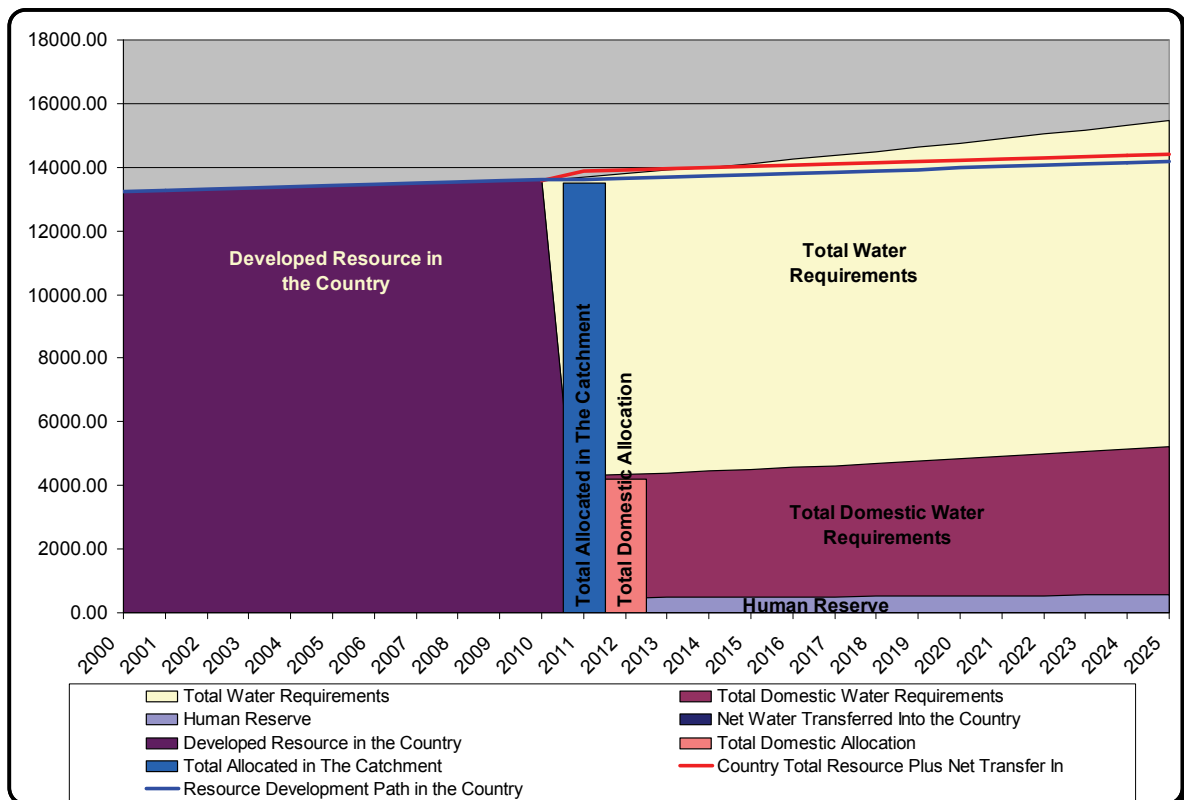


Figure 67: Results of Scenario A on a national level (illustrative)

Figure 68 shows the knowledge acquisition composition based on five criteria i.e. push strategy, pull strategy, competency, databases, and master-apprentice.

- Push strategy makes a decision on what information is to be allocated to whom and automatically alert users of changes.
- Pull strategy is based on user requests and needs.
- Competence strategy entails learning in a structured manner.
- Databases strategy entails using documented knowledge, such as reports, journals, books and on-line databases.
- Master-apprentice tends to occur in face-to-face situations, and by the use of example, metaphor and narrative.

Nokeng is more reliant on the pull strategy and is very low on the master-apprentice; this means that overtime the internal knowledge will be lost.

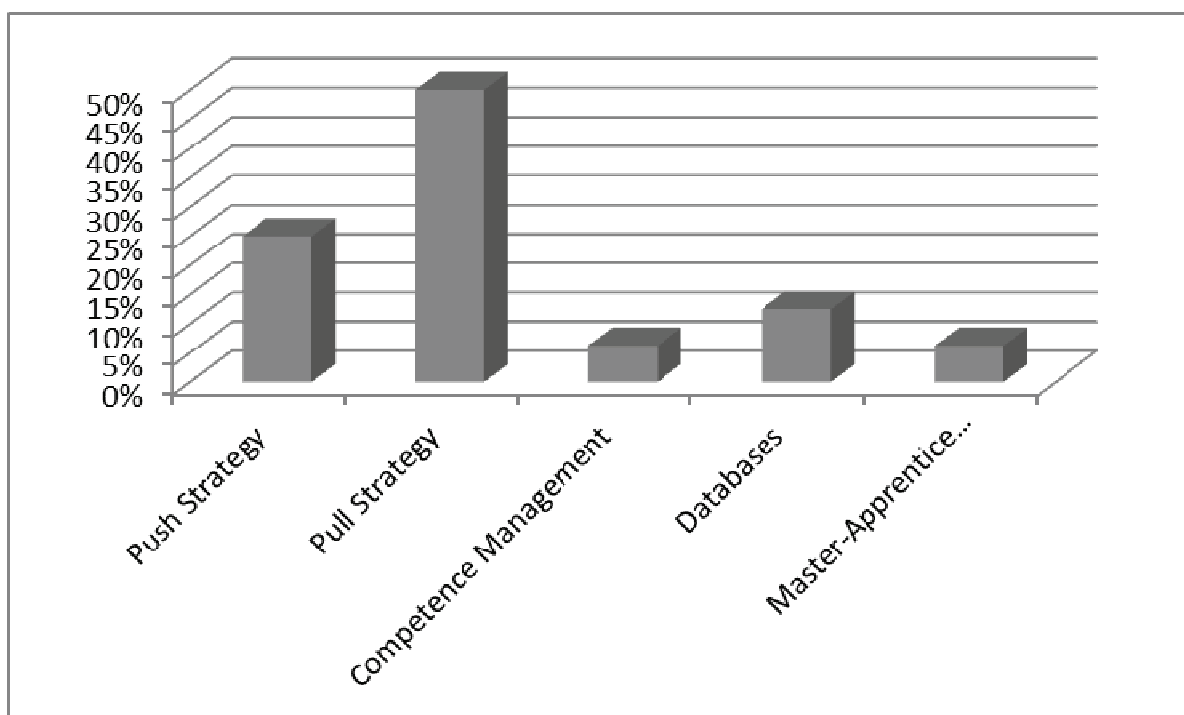


Figure 68: Case study knowledge acquisition assessment (illustrative)

8 CONCLUSIONS

The research project was commissioned to address the integration of management tools specifically for water resources and water services. Recognising that integration of tools cannot be achieved in isolation from other uses' management tools, the reference group recommended that the literature review be undertaken for the integration of tools for water resources and all water uses rather than just water services.

The project has developed a GICF, aimed at guiding the integration process in a holistic manner, and this was implemented into a prototype software system called the WATERGRAL. The WATERGRAL was developed and demonstrated in a case study in the Nokeng Tsa-Taemane Local Municipality. With the case study it was possible to demonstrate the use of the GICF. Noting that the system was for illustration purposes, it can be said that it performed well, i.e. it was possible to highlight the gaps in the tools required by the managers to be able to make decisions, the inability of the tools to complement each other either because of the missing tools or the data elements that can be produced by the missing tools. The system also demonstrated how managers can focus their energy on issues that are related to their mandate and be able to phase out tools that are no longer of use due to i.e. change of mandate or changes in underlying circumstances.

From the outcome of the project it is concluded that many of the water management tools in the South African water sector supports the principles of IWRM within their respective domains. However, it is also concluded that the tools, as a collective, do not embrace the principles of IWRM, and to enable a transition to IWRM, a unifying framework is required. The project has also identified that many of the domain specific Level II Frameworks have reached their maturity level, and that efforts are being made to integrate with other Level II Frameworks on an ad-hoc basis, this could result in systems procured and developed to solve a specific problem, characterized by a limited focus and functionality, and containing data that cannot be easily shared with other systems.

The project has shown that there are efforts towards integration, internationally. Although most of the efforts are not guided by a framework like the GICF developed in this project, they are, however, based on the same principles, and build towards a complete system as envisaged with the WATERGRAL. These developments have indicated the need for a long term perspective and a need for substantial investment in an effort to integrate water resources and water uses management.

Noting that the policy-making process is a conservative attitude of policy-makers, where they prefer simple constraints (precautionary principle) and flexible negotiations (delegation) to complex assessment and decision-aid methodologies, the Case study has showed that the GICF is a platform where policy-makers, scientists/researchers and managers can interact in a transparent manner.

It is almost impossible to deploy an integrated management system that delivers real and lasting business value without spending money – unless of course, the organisation has already invested in a BI and data management infrastructure that can deliver the right information to the right user at the right time in the right format, and has already modelled and loaded a majority of data required in the system. Hence the implementation of the WATERGRAL System will require the sector to commit resources to ensure that the system is properly implemented.

It is hoped that the GICF, if implemented, will foster greater awareness of the issues affecting integration, and focus attempts and resources to address disintegration problems. The GICF represents a means to an end, rather than an end in itself, and what is ultimately required is for all the actors in the water sector to align with the GICF's optimal direction leading to complete integration. It is therefore not expected that the GICF will be implemented all at once, but that it will be used to guide prioritisation on programmes that should be undertaken.

9 RECOMMENDATIONS

The GICF as implemented in the WATERGRAL is currently a concept, and the case study results have emphasised that integration requires both a short term and long term view, and that the water sector, particularly the DWA as a sector leader will have to act accordingly to:

- Undertake a benchmarking and cost benefit analysis exercise of implementing the GICF.
- Identify appropriate institutional model for implementing the GICF.
- Develop a long term plan and a funding model for implementing the GICF.
- Develop the three prerequisite foundational Level II frameworks, i.e. the coordination, monitoring and compliance, and the data and information management integrated frameworks.
- Streamline the sector in line with the GICF.

The water sector, particularly the functional areas must act accordingly to:

- Investigate and identify a suitable drivers and local hosts of the integrated system,
- Develop a data standardisation policy to ensure consistency and interoperability,
- Outline their data supply and value chain,
- Streamline their tools and tools requirements in line with Water sector's strategic objectives or the allocated KPA,
- Outline their tools' capability and applicability with changes in circumstances as well as a strategy to ensure that the tools remain relevant,
- Develop their own data-warehouse,
- On a WMA indicate relevant indicators and characteristics they are responsible for and how they affect the water balance.

In acting on the above the sector on a functional area basis will arrive at the following recommendations:

- Required Tools to support Strategic Objectives for the functional area,
- Inventory of tools and their linkages to the strategic objectives,
- Gaps and Needs on required tools, and a recommendation on how to fill the gaps,
- Method to identify redundant tools and how to phase them out seamlessly,
- The Decision Process and the required data/information for decision making as well as its Supply-Value Chain,
- Data management standardisation policy and data warehousing strategy,
- Proposed approach for the development of functional area's Water Management Model to link their activities and those of other sections together with respect to the water balance,
- Requirements for the development of a functional area specific Dashboard.

A three phased approach is proposed for the implementation of the GICF and the deployment of the WATERGRAL system as follows:

Phase 1: Focused on Sector Wide Objectives on a strategic level – top Management (Minister to Deputy Director General and/or Chief Director and other decision makers)

The WATERGRAL System has been designed to afford different management levels to access information and make decision relevant to their reporting requirements. The System recognises that top management must be involved in the development and execution of the

strategic plan, but line and functional managers must also be included in its development. Hence, this phase should be concerned with unpacking the mandate and reporting requirements on a strategic level (i.e. Top Management) as follows:

- Clearly outline and streamline their mandate and reporting requirements both from the water business point of view and government point of view on a strategic level.
- Clearly outline and streamline the functional roles of the water sector and their reporting requirements both from the water business point of view and government point of view on a tactical level.
- Develop a framework for a data standardisation policy to ensure that data value add is streamlined and consistent, and also ensure interoperability of the systems in the water sector.
- Explore prerequisites for sustaining effective integration as well as their temporal inter-relationships and develop a “cause-effect-cause” model to identify constraints and improve effectiveness in the water sector.
- Outline required elements and functions of a data Mart as well as plot the approach to be followed in the development of the data-mart.
- Plot a way forward in rolling out the reporting requirements to the rest of the water sector agents.

Phase 2: Focused on Functional Areas on a Tactical and Operational level (Middle and Lower Management in the Water Sector)

In this phase the reporting requirements as identified in phase 1 will be rolled down to middle and lower management on functional bases, and the following activities are envisaged:

- Development of a data standardisation policy to ensure consistency and interoperability,
- Outline and streamline their data/information supply-value chain,
- Streamline their tools and tools requirements in line with the water sector’s strategic objectives,
- Outline their tools’ capability and applicability with changes in circumstances as well as a strategy to ensure that the tools remain relevant,
- Identify temporal inter-relationships and develop a “cause-effect-cause” model to indicate relevant indicators and characteristics they are responsible for and how they affect the water balance.
- Develop a data mart, and functional area specific data-warehouses,

The result of this phase will be a document detailing a proposed approach towards achieving the above on a functional area basis for the water sector indicating the:

- Required Tools to support the water sector’s Strategic Objectives for the different functional and line areas as well as their data requirements,
- Inventory of tools and their linkages to the strategic objectives as well as their data requirements,
- Gaps and Needs on required tools, and a recommendation on how to fill the gaps,
- Method to identify redundant tools and how to phase them out seamlessly,
- The Decision Process and the required data/information for decision making as well as its Supply-Value Chain,
- Data management standardisation policy and data warehousing strategy,
- Proposed detailed approach for the development of “cause-effect-cause” Water Management Model to link their activities and those of other sections together, with

- respect to the water balance,
- Requirements for the development of a functional and line areas specific Dashboards.
- Detailed approach for the development of a data mart and functional and line areas specific data-warehouses.

Phase 3: Implementation of the WATERGRAL System

The developed WATERGRAL System is based on the principles that IT is a support service and its full benefits can only be fully realised once the business aspects (i.e. water business, Governance and institutional) have been streamlined. Therefore the implementation of the software WATERGRAL is seen as the last phase dependent on the success of the two initial phases and it cannot at this stage be fully defined, however the implementation principles are as follows:

- There is a need to identify the custodian of such a system as well as champions in each Functional areas who will together ensure the continual function of the system.
- The system should be accessible to and be able to serve the needs of all three levels of management and should be accessible online.
- The functional areas must be responsible for the data elements in the system's data mart in line with their strategic objectives.
- The system is not intended to replace the current data/information management systems, but to streamline them.
- The system is output/result oriented and hence no direct link nor a need to run tools/models on the system, but there is a need to feed the results and the assumptions to the system.

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APPENDIX

FIGURE 67: SYSTEM MODEL FOR WATER MANAGEMENT (SCHENK ET AL., 2008)

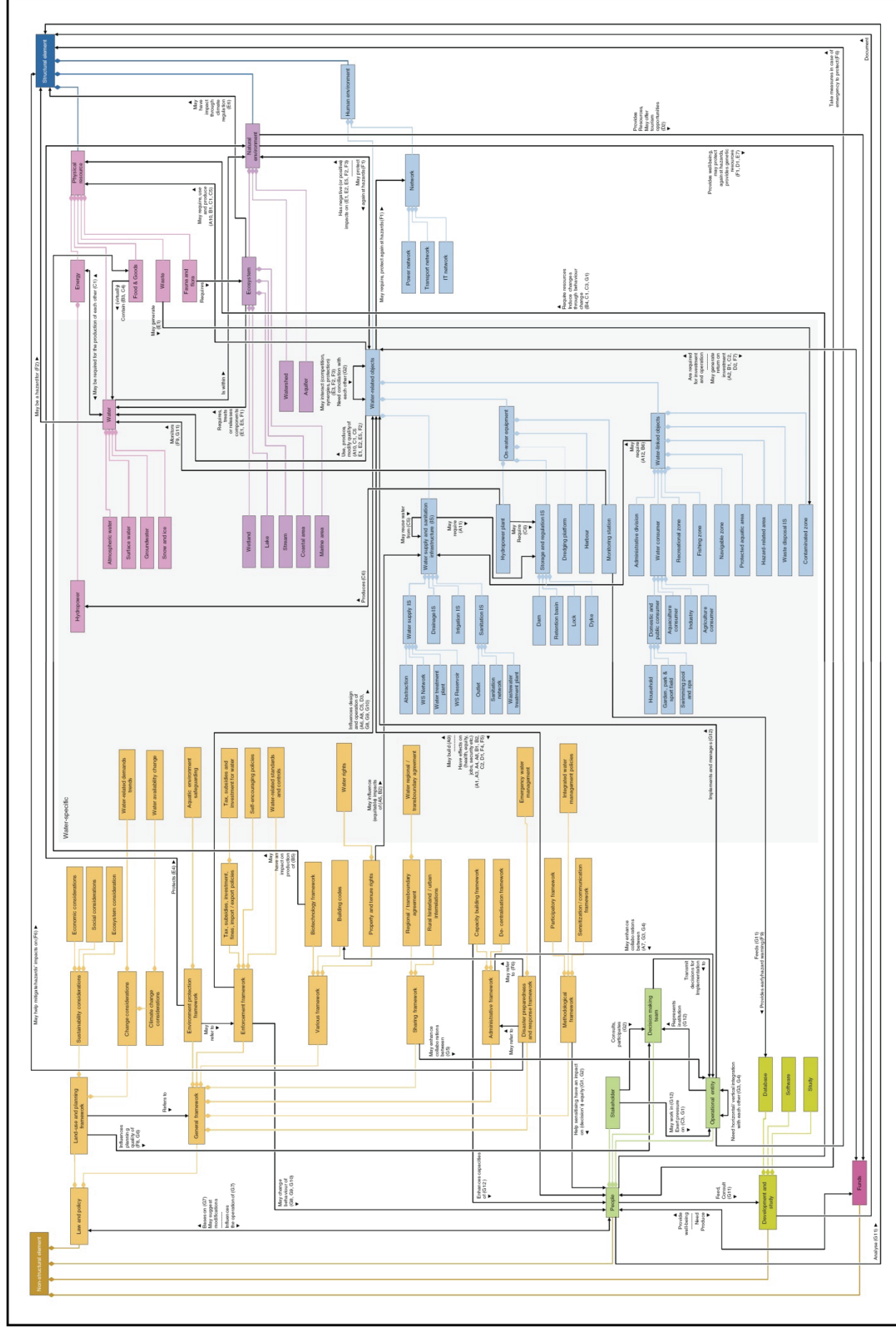


Figure 69: System Model for Water Management (Schenk et al., 2008)