A COMPARISON OF THE SOUTH AFRICAN APPROACH TO WATER RESOURCES MANAGEMENT AND PLANNING WITH FOUR INTERNATIONAL COUNTRIES

Report to the
WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

South Africa has, for many years, managed its water resources in an efficient and effective manner. The infrequent requirement for water restrictions of strategic users in the major systems of the country, despite the semi-arid climate, is evidence of this. For many years, however, the South African approach to manage the water resources systems has been the same. To date, this is because the methodologies and techniques have always worked well for South African circumstances. It may, however, be the case that South Africa is lagging behind other countries in terms of water resources management and planning, and this should be established.

This document compares the South African approach to water resources management with four international countries, namely: Australia (New South Wales), Brazil, England and the USA (California). The overall objective is to determine whether or not South Africa can learn from other countries with similar water resources issues and improve the current methodologies, approaches and techniques based on their experiences.

This is carried out using the following areas of comparison:

- Legislative framework;
- Required documentation and typical studies carried out;
- Institutional arrangements; and
- Modelling techniques.

As a result of today's internet capabilities, a significant amount of literature is available on-line. It became evident during the study that the topics covered were possibly too wide, and selected areas should have been focused on to gain more insight on a specific issue. It is believed that this literature review, however, does include a broad basis from which further investigations into more specific areas could be carried out if required.

The general conclusion is that South Africa, though for many still considered a developing country, currently maintains a very high standard in managing its water resources, and is comparable to some of the most developed countries in the world. It appears that, when comparing management approaches, South Africa was, for many years, leading the group. However, it appears that in recent years, a stagnation of further maintenance and development of the techniques used has allowed others to catch up and possibly even move past. It is believed that South Africa can learn from the other countries when it comes to model development, though the actual modelling approach and methodology (risked based) used are still very highly rated.

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CAP	Catchment Action Plan
COAG	Council of Australian Governments
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
CN	Curve Number
CVP	Central Valley Project
CWO	Water Resources Civil Organisation
CWYET	Catchment Water Yield Estimation Tool
DEFRA	Department for Environment Food and Rural Affairs
DLWC	Department of Land and Water Conservation
DSS	Decision Support System
DWR	Department of Water Resources
DWS	Department of Water and Sanitation
EA	Environmental Agency
ESM	Equivalent System Network
ET	Evapotranspiration
GIS	Geographic Information System
HRU	Hydrological Response Unit
ISP	Internal Strategic Perspective
IMS	Information Management System
IQQM	Integrated Quantity and Quality Model
IWR	Institute for Water Research
IWRM	Integrated Water Resources Management
LHPA	Livestock Health and Pest Authority
LIMCOM	Limpopo Commission
LP	Linear Programming
LPMA	Land and Property Management Authority
MDBA	Murray Darling Basin Authority
NCWR	National Council on Water Resources
NetLP	Network Linear Programming
NGO	Non-Governmental Organisation
NHMP	National Hydrological Modelling Platform
NRA	National Rivers Authority
NRCS	National Research Conservation Service
NSW	New South Wales
NWA	National Water Act
NWRS	National Water Resources Strategy
OFWAT	Water Services Regulation Authority
ORASECOM	Orange Senqu Commission
PET	Potential Evapotranspiration
RBC	River Basin Committee

Ref	Reference
RWA	Regional Water Authority
SCL	Stochastic Climate Library
SDL	Sustainable Diversion Limit
SMAP	Soil Moisture Accounting Procedure
SPATSIM	Spatial and Time Series Information Model
SWP	State Water Project
SWRCB	California State Water Resources Control Board
UN	United Nations
USBR	United States Bureau of Reclamation
UWMP	Urban Water Management Plans
VBA	Visual Basic for Applications
WMA	Water Management Area
WRC	Water Research Commission
WRESL	Water Resources Engineering Simulation Language
WRIMS	Water Resources Integrated Management System
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model
WSAM	Water Simulation Model
WSDP	Water Services Development Plan

1 INTRODUCTION

1.1 Background

South Africa has, for many years, managed its water resources in an efficient and effective manner. The infrequent requirement for water restrictions of strategic users in the major systems of the country, despite the semi-arid climate, is evidence of this. In addition, The Department of Water Affairs and Sanitation (DWS) has also always placed future water resources planning high on its priority list of management functions, with the aim of having sufficient time to prepare for and construct new augmentation schemes and to implement these at the required time without disruptions to major users. In recent years the focus has shifted from being primarily on infrastructure development projects to a more integrated approach where both demand side and supply side management interventions are put forward as the solution to ensure sufficient water is made available to sustain socio-economic development while also reserving water for the ecology.

For many years, however, the South African approach to manage the water resources systems has been the same. To date, this is because the methodologies and techniques have always worked well for South African circumstances. It may, however, be the case that South Africa is lagging behind other countries in terms of water resources management and planning, and this should be established.

1.2 Aims and Objectives

This study aims to compare South Africa's approach to effectively manage its water resources with other countries. The overall objective is to determine whether or not South Africa can learn from other countries with similar water resources issues and improve the current methodologies, approaches and techniques based on their experiences.

This is carried out using the following areas of comparison:

- Legislative framework;
- Required documentation and typical studies carried out;
- Institutional arrangements; and
- Modelling techniques.

1.3 Study Approach

In order to benchmark South Africa's water resources management capabilities, four other countries were selected for evaluation and comparison. The selection was carried out randomly, with factors such as water resources, language, availability of information and economic status all being considered. The study was carried out purely as a literature review through the internet. A significant amount of information is available, and as a result, significant sorting out of the information to reduce it to pertinent aspects only was required. A country representative was also selected based on knowledge of the water resources sector, and was asked to review their relevant country's information gathered for correctness. In this regard, the following people were contacted:

- New South Wales: Australia: Brian Haisman (brianhev@optusnet.com.au) Water Resources Engineer
- Brazil: No information returned

- California State: USA: Jeff Meyer (jeffmeyer@ecorpconsulting.com) Director, Water Resources Management, ECorp Consulting
- England: Rachel Evans (r.j.evans@btinternet.com) Independent Water Resources Consultant: Rachel Evans Limited

1.4 Overview of Water Resources Management

1.4.1 South Africa

South Africa is not well endowed with abundant fresh water resources. In fact, it is regarded as the 30th most water scarce country in the world (Ref: DWS 1). Despite this major challenge, the country has thus far managed to harness this resource in support of a strong economy and a vibrant society. This is achieved through effective water resources planning, infrastructure development, demand side management and effective service delivery.

It must, however, be stated that the country is facing various challenges with regard to its water resources and the management thereof. Various concerns have been raised regarding pollution and resource quality, water security for both social and economic development, protection of the ecology as well as services quality. These concerns must be addressed as they have major social, economic, environmental, legal and political impacts on the lives and businesses of the population.

1.4.2 Australia

The management of water resources in Australia is a complex process, which differs in each state and territory. There are five levels of water management in Australia, namely national, cross-border, state/territory, regional and local (Ref: NWM). Water management includes the following functions:

- water pricing and economic regulation;
- water planning and management;
- water markets;
- water supply and services; and
- water quality management.

Due to this wide variation of activities in Australia, the focus for this literature review has been narrowed down to “water planning and management” on the state/territory level, focusing on the State of “New South Wales”.

1.4.3 Brazil

Brazil is a federal republic of South America and is known as a country of plentiful water. Approximately 13% of the world's surface water resources are in Brazil (de Vasconcelos, 2006). This perceived abundance, however, delayed the realization of its scarcity and the need for it to be properly managed. Water resources management is a key element of Brazil’s strategy to promote sustainable growth and a more equitable and inclusive society. Brazil’s achievements over the past 70 years have been closely linked to the development of hydraulic infrastructure for hydroelectric power generation and more recently for the development of irrigation infrastructure, especially in the Northeast region.

Two challenges in water resources management stand out for their enormous social impacts: (i) unreliable access to water with a strong adverse impact on the living and health standards of the rural populations in the Northeast where two million households (out of a total population of 200.4 million people), most in extreme poverty, live, and (ii) water pollution in and near large urban centers, which compromises poor populations' health, creates environmental damage, and increases the cost of water treatment for downstream users.

1.4.4 England

Salient features of the water sector in the United Kingdom compared to other developed countries is the full privatisation of service provision and the pioneering of independent economic regulation in the sector. On average, only about 10 per cent of freshwater resources in England and Wales are abstracted. Water companies abstract almost half of this amount. The remainder is used for cooling power plants, other industries, fish farming and other uses. Water companies use mainly surface water (two thirds), and also groundwater (one third) (Ref: Wikipedia 1).

1.4.5 USA: California State

California's water system is large, complex, and interconnected. Most precipitation falls in the sparsely populated northern and mountainous regions of the state during the winter, whereas most human water demands occur during the late spring, summer, and early fall in the population and farming centers farther south and along the coast. Precipitation also varies greatly across years, making the state susceptible to large floods and prolonged droughts. These conditions have led to the development of vast water infrastructure systems that store and convey water to demand centers and that protect residents as well as infrastructure from flooding. (Ref: PPIC)

Effective water management requires sound information, and water management systems as complex and extensive as California's require commensurately broad and well-organized scientific and technical support. The development of the Central Valley Project, the State Water Project, and the Central Valley flood control system all involved focused and systematic development of scientific and technical knowledge and expertise over decades. The Hydraulic Era in California's water development required tremendous growth in technical expertise in all branches of government and the private sector. From this emerged one of the most complex and effective water supply and flood control systems in the world.

2 LEGAL FRAMEWORK

2.1 South Africa

South Africa's waters are governed by the Water Services Act of 1997 and the National Water Act (NWA) Act 36 of 1998. The Acts are complementary and provide a framework for sustainable water resource management while enabling improved and broadened service delivery. The strategic objectives are stipulated in the National Water Resource Strategy. The NWA promotes an integrated catchment-based approach to water resource management. The law promotes a more equitable and sustainable use of water. It is based on certain fundamental principles:

- Water is a scarce natural resource which is unevenly distributed, and occurs in many different forms all of which are part of a unitary, interdependent cycle;
- While water is a natural resource that belongs to all people, discriminatory laws and practices of the past have prevented equal access to water and to the use of water resources;
- National government is the overall authority and ultimately responsible for the nation's water resources and their use, including the equitable allocation of water for beneficial use, the redistribution of water, and international water matters;
- The ultimate aim of water resources management is to achieve the sustainable use of water for the benefit of all users;
- Protection of the quality of water resources is necessary to ensure sustainability in the interests of all water users;
- All aspects of water resources need to be managed in an integrated way, and, where appropriate, management functions need to be delegated to a regional or catchment level to enable everyone to participate.

The main purpose of the NWA is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take account of, amongst other factors:

- meeting the basic human needs of present and future generations;
- promoting equitable access to water;
- redressing the results of past racial and gender discrimination;
- promoting the efficient, sustainable and beneficial use of water in the public interest;
- facilitating social and economic development;
- providing for growing demand for water use;
- protecting aquatic and associated ecosystems and their biological diversity;
- reducing and preventing pollution and degradation of water resources;
- meeting international obligations;
- promoting dam safety;
- managing floods and droughts,

and, for achieving this purpose, to establish suitable institutions and to ensure that they have appropriate community, racial and gender representation.

The 1998 Act introduced the concept of the Reserve, and the requirement to classify water resources. Although the Act was promulgated in 1998, the Water Resource Classification System was only established in 2010 and is now been rolled out on a catchment by catchment basis. Another major change in the 1998 Act was the introduction of water use licensing which is replacing the land based permit system. This is being rolled out through the Validation and Verification processes (Section 35).

2.2 Australia

Managing New South Wales (NSW) water resources in Australia relies on a range of legislation, initiatives and cooperative arrangements with the Commonwealth and other state governments. The two key pieces of legislation for the management of water in NSW are the Water Management Act 2000 (WMA2000) and the Water Act 1912. (Ref: NSW-DPI)

The Water Act 1912 came into force at the turn of the last century and represented a different era in water management in NSW. This Act is being progressively phased out and replaced by the WMA2000, but some provisions are still in force. The object of the WMA2000 is the sustainable and integrated management of the state's water for the benefit of both present and future generations.

After an extensive period of public consultation, the WMA2000 was passed by the NSW Parliament in December 2000, establishing a completely new statutory framework for managing water in NSW. For the first time, NSW had comprehensive water legislation to guide water management activities. The WMA2000 is based on the concept of ecologically sustainable development – development today that will not threaten the ability of future generations to meet their needs. The Act recognises:

- the fundamental health of rivers and groundwater systems and associated wetlands, floodplains, estuaries has to be protected;
- the management of water must be integrated with other natural resources such as vegetation, soils and land;
- to be properly effective, water management must be a shared responsibility between the government and the community;
- water management decisions must involve consideration of environmental, social, economic, cultural and heritage aspects;
- social and economic benefits to the state will result from the sustainable and efficient use of water.

The WMA2000 was driven by the need for NSW to secure a sustainable basis for water management for (amongst others) the following reasons:

- NSW was at the limit of its available water resources – new licences for commercial purposes could no longer be issued across most of NSW and a limit had been placed on the total volume of water that could be extracted across the inland of NSW under the Murray-Darling Basin Cap.
- The decline in the health of rivers, groundwater, floodplains and estuaries was evident with increasing water quality problems, loss of species, wetland decline and habitat loss.

As a result, the WMA2000 recognises the need to allocate and provide water for the environmental health of rivers and groundwater systems, while also providing licence holders with more secure access to water and greater opportunities to trade water through the separation of water licences from land. The main tool the Act provides for managing the state's water resources are water sharing plans (expanded on in **Section 3.2.2**). These are used to set out the rules for the sharing of water in a particular water source between water users and the environment and rules for the trading of water in a particular water source.

Because of the major changes required by the legislation, the Act has been progressively implemented. Since 1 July 2004 the new licensing and approvals system has been in effect in those areas of NSW covered by operational water sharing plans – these areas cover all of the state's inland rivers and aquifers and the majority of coastal rivers and aquifers. As water sharing plans are finalised and commenced for the rest of the state, the licensing provisions of the Act are introduced, extending the benefits for the environment of defined environmental rules and for licence holders of perpetual water licences and greater opportunities for water trading.

2.3 Brazil

Brazil has had water legislation since 1934, when the Water Code was enacted. Nevertheless, the existing legislation was unable to avert water stress and pollution, or even conflicts over its use. Nor did it foster decentralized and participatory management of water resources – an absolute requirement today. After wide-ranging debates during the 1980s and 1990s, Congress passed Law #9433 in January 1997 for the precise purpose of filling the gaps in the 1934 Water Code. (Ref: Wikipedia 2)

The following basic principles underscoring Law #9433 should be emphasized.

- Adoption of catchment basins as the planning unit. The boundaries of each basin delimit the planning area in order to facilitate a comparison between water supply and demand, which are the essential parameters in determining the water balance.
- The principle of multiple water uses putting all user categories on equal footing with regards to access to water resources. In Brazil, the power sector has always been the only surface-water management agent. Such preference shows clearly the asymmetrical treatment of the central government to the various water user categories during the first half of the century. Only the rapid growth of other user categories made it possible for the principle of multiple water uses to emerge and become a major part of the new legislation.
- The acknowledgement of water as a finite and vulnerable good – a call to preserve this natural resource.
- The acknowledgement of water as an economic good induces rational use of water resources and is the foundation of water charges.
- Decentralized and participatory management of water resources. The philosophy underlying decentralized management is that anything that can be decided at the lower hierarchical levels of government should not be decided at higher levels. In other words, whatever the regional or even local governments can decide should not be dealt with in the federal or state capitals. Participatory management, in turn, is a way of empowering users, whether organized civil society, NGOs or other interested parties, to influence the decision making process.

Law #9433 of 8 January 1997 also establishes the following five political instruments for the sector.

- Water Resources Plan. A set of water resources programs for each basin, i.e. in-depth collection and updating of the regional information that influences decision-making in a catchment basin, in addition to defining clearly the division of the flow among the various users.

- The classification of watercourses into categories associated with prevailing water uses is extremely important in establishing a surveillance system that focuses on the water quality of existing sources. This classification also makes it possible to link water quality and quantity management.
- Users are granted an authorization or concession to use water. Granting water rights and charging for water use are essential elements to control and help discipline water use.
- Water charges are very important in creating a balance between supply (water availability) and demand. Charging also fosters harmonious relations among competing users and helps redistribute social costs, improve effluent quality and fund the sector.
- The purpose of the National Water Resources Information System is to collect, organize, analyze, and disseminate the database on water resources, diverse uses, and water balance of each source and basin. The system provides managers, users, civil society, and other interested parties input on which to base their opinions and decisions, as well as their participation in the decision-making process.

2.4 England

In England, the Water Act 1989 established privatisation of the sectors. Four Acts of Parliament were then passed to consolidate existing water related legislation (including the Water Act 1989). (Ref: Ofwat). The four Acts were as follows:

- The Water Industry Act 1991 set out the powers and duties of the water and sewerage companies, thus replacing those set out in the Water Act 1989, and defined the powers of the Director General of Water Services (now Ofwat).
- The Water Resources Act 1991 set out the functions of the National Rivers Authority (now the Environment Agency) and introduced water quality classifications and objectives for the first time.
- The Statutory Water Companies Act 1991 applied specifically to the former statutory water companies.
- The Land Drainage Act 1991 transferred the functions of previous internal drainage powers of local authorities to the National Rivers Authority.

Subsequent Acts have modified the framework. These include the following.

- The Competition and Service Utilities Act 1992 increased Ofwat's powers to determine disputes and increased the limited opportunities for competition in the industry.
- The Environment Act 1995 led to restructuring of environmental regulation and placed a duty on the companies to promote the efficient use of water by customers. It consolidated the functions of the National Rivers Authority, Her Majesty's Inspectorate of Pollution, the waste regulation functions of local authorities and certain elements of the Department of the Environment to a new body, the Environment Agency.
- The Competition Act 1998 prohibits any agreements between businesses that prevent, restrict or distort competition. It also prohibits any abuse of a dominant market position. Ofwat shares investigative powers in the water industry with the Office of Fair Trading under the Act.

- The Water Industry Act 1999 made several important amendments to the Water Industry Act 1991.
- The Water Act 2003 amended the framework for abstraction licensing, made changes to the corporate structure of economic regulation, and extended the scope for competition in the industry to large users.
- The Enterprise Act 2002 amended the Water Industry Act 1991 to include a duty to refer certain mergers between water companies to the Competition Commission.
- Among other things, the Flood and Water Management Act 2010, removed the automatic right to connect to sewers, changed the list of activities that can be restricted by water companies in a drought, amended the Water Industry Act to clarify who is responsible for paying a water bill, and made it easier for water companies to offer lower tariffs to certain groups.
- The Water Act 2014 introduces markets for non-household customers in England as well as making provisions for flood insurance and drainage boards

In 2011, the Government published two white papers – The Natural Choice, a Natural Environment White Paper which set out the benefits of healthy rivers, lakes, groundwater, estuaries and wetlands, and Water for Life, the Water White Paper. Water for Life sets out the Government‘s objectives for providing secure, sustainable and affordable supplies of water. It outlines the challenge that climate change and population growth present for future water resources, and the case for action to build resilience and ensure a good quality water environment. The Environment Agency‘s Case for Change – current and future water availability, published alongside the White Paper sets out new scenarios for water availability in the 2050s to illustrate the scale of the challenge, and the level of uncertainty involved in planning for this changing future. The Water White Paper sets out the Government‘s objectives for the water sector, and how it will work with others to drive change, support economic growth and protect the environment. It emphasises the importance of a stable regulatory environment for the water sector to ensure it remains attractive to investors. It also sets out the Government‘s vision for greater choice, innovation and efficiency in the water sector to deliver better outcomes for customers.

The Water White Paper emphasises the importance Government attaches to the water resources management planning process, and its intention to strengthen the planning guideline to reduce costs to customers and improve benefits for the environment. In particular, it is looking to companies to:

- reflect the longer term supply challenges through to 2050;
- more accurately reflect the cost of abstraction to the environment;
- set ambitious goals for reducing average water consumption, supported by detailed implementation plans;
- consider the scope for improved interconnection; and
- make greater use of water trading and options provided by other parties.

The Water White Paper emphasises the importance of companies considering all options to balance their supply and demand including water trading. It also set out reforms to make it easier for non-household customers to switch their retail supplier and to make it easier for parties with their own water resources to use water companies’ networks to provide that water to eligible customers.

In addition, England also needs to consider the European Union Water Framework Directive, the requirements of which are becoming increasingly important in shaping what UK water companies can and cannot do with their water resource systems.

2.5 USA: California State

California water law is informed not only by California laws but also by federal environmental laws that restrict their application; this amalgam of California and federal law is the product of California's – and the nation's – unique development and experience (Walston, 2015). California water law has substantially changed from the early days when miners diverted water to their mining claims – and unwittingly created the foundational principles of water law that prevail in California and the West today. In the modern age, California no longer allocates water among competing users – like the miners – based on "first in time, first in right" principles. Rather, California allocates water based on the public interest, as that public interest is defined through the state's institutional processes. The public interest takes into account the needs of those who depend on water supplies for their sustenance – the large cities and farming communities that provide the backbone of California's economy – and the competing need to preserve water in its natural state for various environmental uses, such as the preservation of fish and wildlife.

The Legislature has specifically spelled out the public interest as it applies in certain situations. Under the Water Code, domestic water uses have the highest priority among competing uses, followed by agricultural water uses for irrigation purposes. The Water Code also provides that water users in watersheds or areas of origin – that is, where the water supply originates – have a priority to the use of such water, and shall not be deprived of their prior rights to its use. The Delta Protection Act provides that water uses in the Sacramento-San Joaquin Delta are entitled to special protection, although the specific nature of the protection is not clear.

The statutory water rights system authorizes the State Board to approve water appropriations for out-of-stream consumptive uses, but not for instream, environmental uses, such as protection of fish and wildlife. Other states, such as Alaska and Colorado, allow the appropriation or reservation of water for instream flows; once the water is appropriated or reserved for this purpose, the water cannot be diverted to serve out-of-stream consumptive uses elsewhere. Thus, some western states authorize appropriation of water for instream uses and other states, such as California, do not. In California, however, the State Board must fully consider the public interest – including the need to protect environmental interests, such as fish and wildlife – in deciding whether to issue appropriative permits, and in imposing conditions in the permits. Thus, although California does not authorize the appropriation of water for instream, environmental uses, California requires such uses to be fully considered through the appropriative permit process.

As California's population has dramatically grown while its water supplies have remained relatively static, the California courts and the Legislature have required water supply agencies and local land use agencies to better coordinate their planning functions. The courts, interpreting the California Environmental Quality Act, have required development projects to demonstrate a reasonable likelihood of obtaining necessary water supplies as a condition for their approval. The Legislature has enacted statutes requiring water supply agencies to engage in long-term water supply planning, and requiring them to identify specific water supplies for proposed development projects that will depend on such supplies.

The effect of these judicial and legislative developments is to provide for more coordination of water supply and land use planning.

3 TYPICAL STUDIES AND DOCUMENTATION

3.1 South Africa

3.1.1 Catchment Management Strategies

The management of water resources is to be detailed in Catchment Management Strategies (CMS) that must be developed for each of South Africa's Water Management Areas (WMA). Section 10(1) of the NWA makes provision for the drafting of guidelines to facilitate the development of these strategies. A Catchment Management Agency (CMA) must, by notice in the Gazette, establish a CMS for the protection, use, development, conservation, management and control of water resources within its water management area.

A CMS is a statutory document which provides the vision and the strategic actions to address integrated water resources management. It is based on the best available information. A framework for the CMS is given by the National Water Resource Strategy (NWRS, 2004). In the process of developing this strategy, a CMA must seek co-operation and agreement on water related matters from the various stakeholders and interested persons.

The CMS must:

- not be in conflict with the NWRS;
- be reviewed from time to time;
- include a water allocation plan. In this respect, a CMS must set principles for allocating water to existing and prospective users, taking into account all matters relevant to: the protection, use, development, conservation, management, and control of water resources.
- take into account the class of water resources and resource quality objectives contemplated in Chapter 3, the requirements of the Reserve and, where applicable, international obligations;
- take into account the geology, demography, land use, climate, vegetation and waterworks within its WMA;
- contain water allocation plans which are subject to S 23, and which must set out principles for allocating water, taking into account the factors mentioned in S 27(1);
- take account of any relevant national or regional plans prepared in terms of any other law, including any development plan adopted in terms of the Water Services Act, 1997 (Act No. 108 of 1997);
- enable the public to participate in managing the water resources within its water management area;
- take into account the needs and expectations of existing and potential water users; and
- set out the institutions to be established.

3.1.2 Reconciliation Strategies

In the process of compiling the Internal Strategic Perspectives (ISPs) for all the Water Management Areas (WMAs) in the country, the DWS identified the need to develop strategies that will ensure adequate future reconciliation of water requirements and water availability in the main metropolitan areas, as well as in smaller municipal areas and towns. Some basic reconciliation options were addressed as part of the ISPs, but at the time it became clear that more detailed strategies needed to be developed. This would ensure effective and efficient management of the water resources supplying the economic hubs and smaller urban areas in the country, while at the same time managing their water requirements to ensure water use efficiency. These Reconciliation strategies are currently bridging the gap whilst the country is waiting for the CMAs to become operational. Once this occurs, and the CMSs are developed, the Reconciliation Strategies will become part of the CMSs.

3.1.3 Water Resource Classification

It is recognised that some water resources by virtue of their ecological importance may require a high level of protection, whereas other water resources may serve the country's developmental and economic growth needs. In keeping with the Constitutional requirement for sustainable development, all water resources must be able to sustain their use. Chapter 3 of the National Water Act is devoted to the comprehensive protection of water resources and provides a series of measures intended to achieve this protection such as: Classification of water resources, determination of the Reserve and the Resource Quality Objectives (RQO's). In response, the DWS has established a Water Resources Classification System (WRCS) that is formally prescribed by Regulation 810 in terms of section 12(1) of the NWA, dated 17 September 2010. The WRCS is a step-wise process whereby water resources are categorized according to specific classes that represent a management vision of a particular catchment by taking into account the current state of the water resource and defining the ecological, social and economic aspects that are dependent on the resource.

The WRCS defines three classes referred to as Water Resource Classes, reflecting a gradual shift from resources that will be minimally used, to resources that are heavily used by taking into consideration the social and economic needs of all who rely on the water resource. The subsequent classification of water resources represents the first stage in the protection process and will result in the determination of the quantity and quality of water required for ecosystem functioning as well as maintaining economic activity that relies on a particular water resource.

The RQO's are numerical and narrative descriptive statements of conditions which should be met in the water resource, in order to ensure that the water resource is protected. The purpose of determining the RQO's is to establish clear goals relating to the quality of the relevant water resource. The RQO's are intended to give effect to the Water Resource Classes determined in each water resource.

The RQO's may relate to the Reserve, the in-stream flow, the water level, the presence and concentration of particular substances in the water, characterizes the quality of the water resource, in-stream and riparian habitat, the characteristics and distribution of aquatic biota, the regulation or prohibition of in-stream or land-based activities which may affect the quantity or quality of the water resource, and any other characteristic of the water source in question. In South Africa water resources management, the acceptable level of impact hinges on the concept of RQO's as the balance between resource protection and resource development and utilization.

3.1.4 Water Services Development Plans

The Water Services Act (No. 8 of 1997) of South Africa states that water service delivery is the responsibility of local government as Water Services Authorities. The principal legal responsibility is to complete a Water Services Development Plan (WSDP) every 5 years with annual review. The WSDP encapsulates all the responsibilities and tasks required in water service delivery. However, it does not spell out local government's role in water resource protection or its responsibilities as far as integrated water resource management is concerned.

3.1.5 Annual Operating Analyses Studies

In an attempt to carefully manage South Africa's water resources, annual operating analyses studies are undertaken in most of the crucial catchments throughout the country. Unlike Strategic studies, the annual operating analyses studies focus on short term planning and operations. At the beginning of the dry season each year, the relevant dam storages are obtained and included into the modeling tool used to manage the system. Short term (usually 5 year) demand projections from all the major users are obtained and also included into the models. In addition, the user priority classification method is discussed and agreed on with the Stakeholders from various user groups. This method involves the division of each user's demand into categories that ultimately determine the timing and size of restrictions. For example, higher priority users, such as strategic industries, may have a significant portion of their demand in a high class (for example restrictions may occur only once in 100 years) whereas lower classes would include users that can accept more risk of failures, for example irrigators. Simulations are then carried out, the results of which guide operators as to whether or not any restrictions need to be implemented in the system, whether there is surplus water that can be allocated to strategic users and finally how to operate in terms of when to transfer water between catchments. These studies have saved the country millions of rands in terms of pumping costs by utilizing short term surpluses in systems rather than transferring from neighbouring catchments. By carrying out these studies, operators have been able to prevent major water shortages by timeously implementing restrictions on lower priority users. Stakeholder Participation is encouraged, and results are presented to key users. By so doing a transparent approach in managing the catchment's resources is carried out.

3.2 Australia

3.2.1 Water Resource Assessments

Through the Commonwealth Water Act 2007, the Bureau of Meteorology is responsible for producing regular reports on the status of Australia's water resources and how they are used. Australian Water Resources Assessments assist understanding of the impact of past and present water management practices. This informs the design of water resource policies and plans, supporting the goals of the National Water Initiative. (Ref: BOM)

The Australian Water Resources Assessments provide consistent, scientifically robust water information on:

- climatic conditions and landscape characteristics;
- patterns and variability in water availability over time;
- surface water and groundwater status;
- floods, streamflow salinity and inflows to wetlands; and
- urban and agricultural water use.

The assessments highlight patterns in the water situation at regional to national scales and over time periods of months to decades.

Australian Water Resources Assessments are published regularly by the Bureau of Meteorology.

3.2.2 Water Resource Plans

Current policy in Australia requires that all States are to prepare State water management plans, based on a guideline titled “The Basin Plan” which sets out what must be contained to enable the Plans to be accredited by the Commonwealth Minister. Water resource plans are therefore a key driver in implementing the outcomes of the Commonwealth Basin Plan 2012 at both a local and Basin wide level. By 2019 all the Water Resource Plans will provide a consistent Basin-wide approach to the management of water resources. (Ref: MDBA)

The plans set out how water resources will be managed – usually for a ten year period – for each Water Resource Plan area. Depending on the jurisdiction the water management plans are sometimes referred to as:

- Water sharing plans;
- Water allocation plans; or
- Water resource plans.

At the heart of the Basin Plan are limits on the quantities of surface and groundwater that can be taken from Basin water resources for agriculture and other consumptive purposes. These limits are known as sustainable diversion limits (SDLs). Water resource plans have a fundamental role in ensuring that SDLs are implemented from 2019 and beyond. Water resource plans set out arrangements to share water for consumptive use. They also establish rules to meet environmental and water quality objectives and take account of potential and emerging risks to water resources.

Water resource plans should set out the inter-related water management arrangements for each plan area. The plans should build on existing State water planning arrangements, and can be made up of a range of documents, such as State plans, State strategies and technical reports. Water resource plans should also address the following:

- ensure environmental watering rules are consistent with the Environmental Watering Plan and the Basin-wide environmental watering strategy;
- the management of water quality outcomes are in line with the Water Quality and Salinity Management Plan;
- water trading
- the sustainable management of water, including recognising local impacts of take and water accounting;
- identifying water dependent Indigenous values and uses based on consultation;
- risks to the water resources;
- taking into account potential and emerging threats to the water resource including extreme events;
- recognising compliance requirements;
- monitoring, reviews of the water resource plans and using the best available data.

Water resource plans may impose requirements on the management of water interception (water captured for use before it reaches a river, for example, by farm dams and plantation forests) but they do not directly regulate land use or land use planning.

3.2.3 Annual Water Assessment

In NSW, water access from streams is based on a system of entitlement volumes. In each water year, the available resources are continuously assessed. This estimates the water available at various times during the water year, based on current storage conditions, expected inflows, and losses. Based on this resource assessment, each user in a river system is allocated a percentage allocation based on their entitlement volume. Frequently, because of the conservative nature of the resource assessment process, an allocation of less than 100% at the beginning of a water year can increase during the year depending on rainfall and inflows to the system. IQQM models (see **Section 5.2.1**) this resource assessment process in a detailed fashion. (Marino, 2000)

Access to water from NSW streams is controlled by a system of licences. In regulated river systems, these licences have an annual volumetric entitlement. A user's regulated water availability is expressed as a percentage allocation relative to their licensed volume. Two classes of licences, high and normal security, are issued. High security licences (such as town water supplies, permanent plantations, environmental needs and industrial requirements) receive 100% allocation except during extended droughts, when their allocations may be reduced. The normal security licence holders have their allocation set based on a resource assessment. This assessment takes into account the volume in storage and expected minimum inflows during the year. The volume reserved for high security licences is subtracted from this volume, together with expected evaporation and transmission losses within the system. A reserve volume is set aside for the following year. If the remaining volume is insufficient to satisfy the licence requirements of the normal security users then they are allocated a percentage share of their licensed volume. This allocation may increase during the year depending on rainfall and inflows to the system, but will never decrease. IQQM performs resource assessment calculations at the start of the year and at regular intervals to determine the allocation level, which may not decrease during the year.

3.3 Brazil

State Water Resources Plans are seen as necessary instruments to orient sustainable development and institutional action to improve integrated water resources management, although their implementation at the sub-national level is still very slow. Water resources plans allow diagnosing and guiding specific actions for water transfer to different users. Furthermore, they identify constraints and opportunities for development of productive activities that use water as basic input. The National Water Resources Plan constitutes the basic programming document for the water sector and is a comprehensive document updating and consolidating the Water Resources Master Plans, which are drawn for each catchment basin (or set of basins).

The **National Water Resources Information System** is a system for collecting, processing, storing and retrieving information on water resources and the factors involved in their management. The objectives of this system are to collect, standardize and disseminate data on the quality and quantity of water resources in Brazil, to update information on the availability and demand for water throughout the country and to provide subsidies for the preparation of Water Resources Plans. There is guaranteed access to the data and information in this system for the "whole society".

The **classification of water bodies** according to uses is a powerful tool in water quality management. The classification systems of water bodies are usually established according to legal standards. Subsequently, in each watershed, the reaches of the rivers are classified accordingly. This provides a firm basis for protecting water quality and to provide improvements where required.

One of the fundamental guidelines for implementing this instrument is that it should not be based on the current state of the water body, but on the quality levels necessary to meet needs. This concept reinforces the classification should be within a context of wide watershed planning. In Brazil, the classification of the water bodies according to uses was established by resolution n° 20 of (CONAMA) Conselho Nacional do Meio Ambiente on 06/18/1986 and in several Brazilian states it has served as standard in monitoring and controlling water pollution. According to it, waters were classified as fresh water (special, 1, 2, 3 and 4 classes); brackish waters (classes 7 and 8), and saline waters (classes 5 and 6). For each class, conditions and standards limits of several water quality variables were also established.

Water body classification by use is also one of the instruments provided for in federal law no. 9433/97, which defined the National Water Resources Policy for Brazil and created the National Water Resources Management System. Water quality evaluations and comparisons with legal classification norms are crucial for identifying the critical locations and providing subsidies for decision making, and thus facilitating selection of priorities in adopting corrective measures.

3.4 England

3.4.1 Water Resources Management Plans

Water Resources Management Plans should ensure an efficient, sustainable use of water resources. They should focus on delivering efficiently the outcomes that customers want, while reflecting the value that society places on the environment. The legislative requirements for water companies to prepare and maintain a water resources management plan are set out under sections 37A to 37D of the Water Industry Act 1991, (as amended by the Water Act of 2003). These provisions set out the procedures companies must follow when developing their plans. The Water Resources Management Plan Regulations provide further detail on the process, particularly around:

- consultation requirements;
- handling representations and the statement of response to representations;
- the power of the Secretary of State and Welsh Ministers to hold an inquiry or hearing;
- publication requirements.

The law says that water companies have to supply potable (good to drink) water to all homes in England and Wales. Water companies are also legally obliged to produce a plan every 5 years showing how they will:

- manage the needs of future populations;
- deal with climate change; and
- develop – where needed – new water supply resources such as reservoirs

Most water companies have published the final version of their latest plans (covering 2015 to 2040). The companies will begin consulting on their next plans in 2018 (EA et al., 2012).

3.4.2 Regional Water Resource Planning

The WRSE Group comprises six water companies, the Environment Agency, Ofwat (Water Services Regulation Authority), Defra (Department for Environment, Food and Rural Affairs), the Consumer Council for Water and Natural England. The supply area is split into 34 discrete water resources zones, which serve a population of 18 million. (Ref: WRSE)

A regional water strategy is needed for the South East of England to find the best solutions for customers and the environment in the region. The development of a regional strategy, to inform individual water company plans, can maximise the benefits of sharing of water resources, reduce the need for new water abstractions from the environment, and facilitate reduction of existing abstractions. Many of the 34 water resource zones across the South East currently, or in the future will, experience shortfalls in water availability in periods of prolonged dry weather. However, there are also areas that have adequate water availability and can provide supplies for short or long periods to areas with a shortfall.

The central activity in the WRSE project has been the development and application of a regional model that will provide a selection of future options for water resources planning. The model works to “least cost” optimisation principles, using data provided by water companies concerning the forecast supply-demand balance, and options that could be chosen to maintain that balance. The modelling has been carried out to produce a regional water resources strategy, which will contain a range of strategic options in order to develop the best solutions for customers and the environment in the South East of England. The options that form the strategy can then be considered by individual water companies when developing their draft WRMPs.

3.5 USA: California State

3.5.1 Urban Water Management Plan

Urban Water Management Plans (UWMPs) are prepared by California's urban water suppliers to support their long-term resource planning, and ensure adequate water supplies are available to meet existing and future water demands. (Ref: CA)

Every urban water supplier that either provides over 3,000 acre-feet (3.7 million m^3) of water annually, or serves more than 3,000 urban connections is required to assess the reliability of its water sources over a 20-year planning horizon, and report its progress on 20% reduction in per-capita urban water consumption by the year 2020, as required in the Water Conservation Bill of 2009 SBX7-7.

The plans must be prepared every 5 years and submitted to the Department of Water Resources (DWR). DWR staff then reviews the submitted plans to make sure they have completed the requirements identified in the Water Code, Sections 10608-10656, then submits a report to the Legislature summarizing the status of the plans.

For each round of UWMPs, DWR provides guidance for urban water suppliers. This includes preparation of a Guidebook, workshops, and program staff to assist in preparing comprehensive and useful water management plans, implementation of water conservation programs, and understanding the requirements of the Act.

The UWMP, which must be updated every five years, must describe the agency’s water supplies, and evaluate whether the supplies are sufficient to meet the agency’s projected water demands over a 20-year planning horizon, taking into account the agency's existing and planned future uses.

3.5.2 Water Supply Assessment

In 2002 the Legislature enacted two statutes, SB 610 and SB 221, that require public water supply agencies to provide information regarding the availability of water supplies for proposed projects.

SB 610 provides that public water agencies must prepare a "water supply assessment" describing the availability of water supplies for a proposed project. The assessment must describe whether sufficient water supplies are available to meet the project's needs over a 20-year period, taking into account the water supplier's "existing and planned future uses." The assessment must describe the availability of future water supplies under different scenarios – normal years, dry years and multiple dry years. In determining the sufficiency of *existing* water supplies, the assessment must describe the specific authority for the supplies – entitlements, contracts, water rights, permits and approvals, funding programs, and so forth. In determining the sufficiency of *future* water supplies, the assessment must describe the plans for acquiring the supplies, including estimated costs and how they will be financed. The assessment may incorporate information from the relevant UWMP, if the UWMP provides adequate information for this purpose. For groundwater supplies, the assessment must determine whether the groundwater basin is "sufficient" to meet the project's future demands over a 20-year period, and must specifically consider past, present and future projected pumping by the water supplier. If the water supplier is a city or county, the city or county must prepare the assessment. SB 610 applies only to large projects, such as residential projects of more than 500 units and large commercial projects.

3.5.3 Obtaining water use data

Although DWR has made greater efforts in recent years to quantify and document gross and net water use by sector in different parts of California, these efforts are hampered by a lack of local reporting of water use. Estimating gross use is less difficult where water deliveries are quantified for billing purposes, e.g. surface water deliveries to contractors of the CVP and SWP and metered household water deliveries. But measurement is problematic for self-supplied surface water and groundwater, which have few if any reporting requirements. As a result, DWR must essentially back out estimates of agricultural groundwater use from crop production estimates, themselves imprecise. Net water use is even more approximately estimated. Water use reporting is a highly charged issue, and water users – particularly agricultural users – have successfully resisted legislative efforts to strengthen reporting requirements for groundwater withdrawals and stream diversions. Yet without better reporting, California's water accounting and water rights enforcement will remain approximate at best – an increasingly difficult handicap for policy discussions and water management in a water-scarce state. (Ref. PPIC)

4 INSTITUTIONAL ARRANGEMENTS

4.1 South Africa

4.1.1 Department of Water and Sanitation

The Minister of Water Affairs is responsible for managing and administering water resources as the public trustee, ensuring that the country's water resources are managed for the benefit of all, that water is allocated equitably, and that environmental values are promoted. General water management functions are delegated to the Department of Water and Sanitation (DWS). The DWS is responsible for implementing the two major legal instruments relating to water: the Water Services Act No. 108 of 1997, and the NWA No. 36 of 1998.

The DWS consists of a number of Directorates, all performing different functions. The purpose of the Chief Directorate "Integrated Water Resource Planning" (IWRP) is to ensure availability of adequate water which is fit for use through holistic planning for the management and development of water resources and systems.

The IWRP function is under the Department of Water Affairs Sub-programme of Integrated Planning which develops comprehensive plans that guide all initiatives and infrastructure development within the water sector; taking into account the water needs of all users and identifying the appropriate mix of interventions, that will ensure a reliable supply of water in the most efficient, sustainable and socially beneficial manner. The purpose is to ensure that the country's water resources are protected, used, developed, conserved, managed and controlled in a sustainable manner for the benefit of all people and the environment through effective policies, integrated planning, strategies, knowledge base and procedures. Four Chief Directorates fall under IWRP.

- National Water Resource Planning develops national strategies and procedures for the reconciliation of water availability and requirements to meet national social and economic development objectives including strategic requirements, resource quality objectives and international obligations.
- Options Analysis identifies and evaluates water resource management options/projects to meet future water requirements and for multi-disciplinary project planning to implement these options, including the development of applicable procedures and guidelines.
- Water Resource Planning Systems evaluates strategic water resource management challenges, provides expert planning related support and develops planning and management decision support systems (DSS) with regard to operating rules, water quality, integrated hydrology (including geohydrology) and socio-economic aspects of water resources
- Climate Change contributes to water related policies and develops appropriate adaptation strategies for the water sector in response to climate change.

4.1.2 Catchment Management Agencies

In South Africa, a vital component of Integrated Water Resources Management is the progressive devolution of responsibility and authority over water resources to Catchment Management Agencies, or CMAs. The initial scale of operation for the CMAs is that of Water Management Areas, or WMAs (National Water Act (NWA); Act 36 of 1998). In terms of the National Water Resource Strategy, 19 WMAs are delineated in South Africa, with CMAs in various stages of establishment. More recently, a change in approach has seen some CMAs cover more than one WMA, with the intention that nine CMAs will be formed throughout the country.

The NWA S80 describes the initial functions of a CMA as: to investigate and advise interested persons on the protection, use, development, conservation, management and control of the water resources in its water management area; to develop a catchment management strategy; to coordinate the related activities of water users and of the water management institutions within its water management area; to promote the coordination of its implementation with the implementation of any applicable development plan established in terms of the Water Services Act, 1997 (Act No. 108 of 1997); and to promote community participation in the protection, use, development, conservation, management and control of the water resources in its water management area.

4.1.3 Water Service Authorities

Local government, being strategically located between the national policy-making level and water consumers, has a significant role to play in water management and in engaging local communities to participate in Integrated Water Resources Management (IWRM) processes.

According to the South African Constitution (Act No. 107 of 1996) and the Water Services Act (Act No. 108 of 1997) water service delivery is a core responsibility for local government, whether as a water services authority or as a water services provider. Carrying out this responsibility faultlessly and lawfully should be the goal. IWRM would require a general review of management practices. Municipal officials tend to function within their directorates without sufficient cross-directorate interaction. Municipal officials are traditionally pre-occupied with delivering water and sanitation to households and generally do not consider the health of rivers and wetlands as part of their sphere of responsibility. In order to practice IWRM, they will have to adopt a holistic and integrated approach to water service delivery and water resource management.

4.1.4 International Commissions

A few International Commissions exist for management of catchments whose boundaries fall outside the borders of South Africa. Examples of these are the Orange River Basin (Orange Senqu Commission: ORASECOM) and Limpopo Basin (Limpopo Commission: LIMCOM). These Commissions include representatives from all countries that share in the basin. They are responsible for the planning and managements of these basins.

The Orange-Senqu River Commission (ORASECOM) was established by the Governments of Botswana, Lesotho, Namibia and South Africa through the "Agreement for the Establishment of the Orange-Senqu Commission" on 3 November 2000 in Windhoek, Namibia. The Preamble to the Agreement recognises the "Orange-Senqu River System as a major water resource in the Region", committing the four Member States "towards the realisation of the principle of equitable and reasonable utilisation, as well as the principle of sustainable development with regard to the River System". It also recognises the following rules and agreements:

- Helsinki Rules (1966)
- UN Convention on the Non-Navigational Uses of International Watercourses (UN Convention; 1997)
- The Protocol on Shared Watercourse Systems in the Southern African Development Community (Original Protocol)

ORASECOM is an international organisation that possesses an international legal personality within the legal systems of each member country, and has the capacity to enter into international agreements. The objective of the Council is to serve as a technical advisor to the member countries and perform other functions assigned by the member countries on matters pertaining to the development, utilisation and conservation of water resources in the Orange-Senqu River System. Parties shall fully cooperate with and support the implementation of this Agreement and recommendations of the Council. Parties shall utilise resources of the River System in an equitable and reasonable manner, take all appropriate measures to prevent causing significant harm to any other Party, exchange available information and data on the River System, and, notify the Council of any project, programme or activity related to the River System which may adversely affect other Parties.

4.2 Australia

4.2.1 Council of Australian Governments

The Council of Australian Governments (COAG) is the peak intergovernmental forum in Australia comprising the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association (Ref: AG). The role of the COAG is to develop and monitor the implementation of policy reforms that are of national significance, including water policy. COAG has released a number of communiqués dealing with national water reform and policy.

4.2.2 State Governments

Basin States have a major water management role. The water entitlement regime is defined and managed under state legislation. State water agencies manage storages, river flows and water deliveries. In the case of New South Wales, water management is carried out as defined in the following table (Ref: NWM).

Table 1: Australian Institutions deal with water resources

Water Management Function	Organisation	Key responsibilities
Water pricing and economic regulation	Independent Pricing and Regulatory Tribunal	Price determination functions for the urban water sector and recommendation of licensing guidelines to the minister.
Water planning and management	NSW Office of Water	Administer the Water Management Act 2000 & Water Act 1912. Lead agency for preparation of water sharing plans.
Water markets governance	NSW Office of Water Land and Property Management Authority (LPMA) Irrigation corporations	Administer the Water Management Act 2000 & Water Act 1912. Assess all water dealing applications for consistency with the Access Licence Dealings Principles Order and any additional rules that are specified in the relevant water sharing plan.
Rural/ Bulk water supply and services	StateWater Private irrigation companies Private irrigation schemes	Urban water utilities provide water to towns and cities and take responsibility for disposal of urban and industrial wastewater. Rural water utilities are responsible for supplying water for non-urban water uses, particularly irrigation, stock and domestic supply. They also manage public reservoirs and supply water to urban water authorities.
Water quality management	NSW Office of Water	Administer the Protection of the Environment Operations Act 1997. Issue environment protection licences under the Protection of the Environment Operations Act 1997 that set operating and waste discharge limits for all scheduled activities.

The NSW Office of Water is responsible for the strategic management of the State's freshwater resources. This involves:

- setting water policy;
- developing statutory water sharing plans;
- negotiating interstate and national water agreements;

- determining how available water is allocated to water users, particularly during times of drought;
- approving the extraction, use and trade of water;
- monitoring the quantity and quality of water extractions; and
- monitoring the ecological health of aquatic ecosystems.

A key component of managing the state's water resources is ensuring water users comply with the rules set out by NSW water management legislation. In its regulatory role, the Office of Water works to prevent, detect and stop illegal water activities by promoting, monitoring and enforcing compliance with the legislation and associated regulations.

4.2.3 Catchment Management Authorities / Local Land Services

Catchment Management Authorities were responsible for the management of water catchments in the state of New South Wales, Australia until 2013. From January 2014, the NSW Government established Local Land Services to replace the CMAs. The eleven Local Land Services Regions are established within the NSW Primary Industries portfolio (Wikipedia 3).

Local Land Services bring together agricultural production advice, biosecurity, natural resource management and emergency management into a single organisation. Local Land Services Boards are accountable for

- administering and delivering local land services;
- developing and implementing appropriate governance arrangements for the delivery of local land services;
- preparing a State Strategic Plan and Local Strategic Plans;
- providing and facilitating education and training in connection with agricultural production, biosecurity, natural resource management and emergency management;
- making and managing levy rates, levies and contributions on rateable and other land;
- providing and administering grants, loans, subsidies or other financial assistance for local land services; and
- communicating, consulting and engaging with the community, including the Aboriginal community, to encourage participation in the delivery of local land services.

Information available appears that the transfer of water management to Local Land Services has come with problems. From January 1, the organisation merged the Department of Primary Industries' extension arm, Catchment Management Authorities (CMA) and Livestock Health and Pest Authorities (LHPA). It has been controversial from the start, with farmers concerned about a loss of services because of a reduction in staff numbers, especially extension staff. The establishment of Local Land Services coincided with state budget cuts which saw 300 jobs slashed from the Department of Primary Industries. The LLS restructure means the state is now split into 11 management regions. Each of those regions has a board which is responsible for the day-to-day operations of LLS.

Many of the LLS boundaries do not follow the previously determined catchment boundaries. Former Namoi CMA board member and former director of the New England Livestock and Pest Authority, Brian Tomalin, is critical of the new structure and says federal funding of catchment action plans (CAPs) is under threat. He says he can foresee problems with the way LLS has been set up.

"The splitting up of the new areas and the dividing of the new catchment action plans, and the investment programs which go with that and how that's managed, is going to be very difficult in the way that it's been proposed. It's going to pose some problems for the Commonwealth Government funding arrangements. If the Commonwealth isn't happy with the way the LLS model is working, the funding is at risk." Mr Tomalin says the Commonwealth has only guaranteed funding for NSW catchment projects for one year, instead of the four-year funding guarantees secured by other states.

4.2.4 The Murray Darling Basin Authority (MDBA)

The MDBA undertakes activities that support the sustainable and integrated management of the water resources of the Murray-Darling Basin in a way that best meets the social, economic and environmental needs of the Basin and its communities. They lead the planning and management of Basin water resources, and coordinate and maintain collaborative long-term strategic relations with other Australian Government, Basin state government and local agencies; industry groups; scientists and research organizations. The Murray-Darling Basin Authority's roles are diverse and include:

- The independent Authority responsible for implementing a Plan for the Basin;
- A facilitator of Basin States and communities to identify common interests and support reform;
- An advisor using knowledge and evidence to formulate policy and set standards;
- An enforcer of effective Basin governance – the frameworks and institutional arrangements which enable Basin-wide decisions and compliance; and
- A professional manager of the rivers and river assets (on behalf of Basin States) with a high degree of technical and scientific capability.

All of these roles and responsibilities aim for one major outcome – together we achieve a healthy, working Basin that will benefit the Australian community for many years to come.

The Basin Plan was adopted on 22 November 2012 and provides for the MDBA to enter into an agreement with a Basin State with respect to any implementation obligation the Plan imposes on a Basin State. Implementation agreements exist with all Basin States. The co-operation of the Basin States remains an integral element of water reform and its effective implementation.

4.3 Brazil

In Brazil the 1988 Constitution established a distinction between federally controlled water, for rivers, lakes, and lagoons across state boundaries (article 20), and state-controlled water, for rivers and groundwater that remain completely within state boundaries (article 26). This definition of state-controlled water complicates the effective management of some of the country's important rivers since the main stem of a federally controlled river cannot be effectively managed without controlling water resource development on the state-controlled tributaries of the river.

The National Water Resources Management System is a combination of organized public organizations, private entities, and civil society representatives which make the implementation of the water resources management instruments possible, in accordance with the principles established in the law. The institutional framework consists of the following:

The **National Council on Water Resources** (NCWR) is the highest organization in the system's hierarchy. It aims at promoting the integration of water resources planning at the national, regional, and state levels and between user sectors. The NCWR consists of representatives of the Federal Government ministries as well as representatives designated by the State Councils on Water Resources and representatives of water users and civil organizations concerned with water resources management. The Chairman of the National Water Resources Council is the Minister of the Environment.

The **National Water Authority** (Autoridade Nacional da Agua – ANA) is in charge of implementing the National Plan for Water Resources formulated by the NCWR. ANA consists of ten functional *superintendence's* with implementing and administrative functions headed by a president and four directors. ANA is under the Ministry of the Environment but has administrative and financial independence.

The **River Basin Committees** (RBC) are connected organizations that bring together stakeholders to discuss and decide on their own problems with the objective of protecting water resources in the river basin region. Under Brazilian law, they do not have legal status. RBCs include representatives of the Federal Government, the states, or the Federal District in which they are located (even if only partially), the municipalities, the water users and the water resources civil organizations that have a demonstrated record of action in the basin. The numbers of representatives from each sector mentioned, as well as the criteria for their appointments, are defined in the regulations of the Committees.

The **River Basin Water Agencies** act as the executive secretariats of the River Basin Committees. Although there is a close relationship between the committees and the agencies, the latter are very different from the former. The main difference is in their nature and organization: while the Committees act as what is called in Brazil "water parliaments," the Water Agencies operate more like executive organizations.

The **Water Resources Civil Organizations** (CWO) should be represented on the National Water Resources Council and should participate in the decision-making process. CWOs can be any of the following: (i) inter-municipal consortia, (ii) river basin associations, (iii) regional, local, or sectoral associations of water users, (iv) technical, academic, and research organizations, and (v) nongovernmental organizations (NGOs).

More recently, the advent of river basin or **sub-basin commissions** has changed the terms of the debate over the "ideal scale" of water services provision. The creation of Users' Commissions, such as COGERH (created in 1993) in the Lower Jaguaribe/Banabuiú, and a (short-lived) similar organization in Curú, have served the overlapping goals of public participation, decentralization, and transparency. Such Users' Commissions have effectively mobilized "multidisciplinary" teams of experts – including sociologists, geographers, agronomists, and engineers – "not as organizers but as facilitators," for more participatory decision-making processes.

The river basin committees represent a "new decision-making" arena which has begun to challenge the "closed and technocratic" bureaucracy that Brazil inherited from its pre-democratic past. For example, COGERH's recommendation to reduce water consumption voluntarily came as a shock to the traditional water policy-making establishment. The Piracicaba, Capivari, and Jundiaí River Basin Committee (created by Law No. 7663/1991, formalized by November 1993) pioneered a shared decision-making model between users and state and local officials, which has been used as a model by several other committees in the state of São Paulo.

4.4 England

4.4.1 National Rivers Authority

Water privatisation was undertaken in 1989 by the government of Margaret Thatcher which partly privatised the ten previously public regional water authorities (RWAs) in England and Wales through the sale of assets. The regulatory arm of the RWAs, including pollution control and water resource management, was hived off to the newly created National Rivers Authority. The National Rivers Authority (NRA) was one of the forerunners of the Environment Agency of England and Wales, existing between 1989 and 1996. Before 1989 the regulation of the aquatic environment had largely been carried out by the ten Regional Water Authorities (RWAs). The RWAs were responsible for the supply and distribution of drinking water, sewerage and sewage disposal, land drainage and flood risk management, fisheries, water quality management, pollution prevention, water resource management and many aspects of the management of aquatic ecology and some aspects of recreation. With the passing of the Water Act 1989, the 10 Water Authorities in England and Wales were privatised by flotation on the stock market. They took the water supply, sewerage and sewage disposal activities into the privatised companies. The remaining duties remained with the newly created National Rivers Authority.

The assets and the staff of the RWAs were divided up at privatisation between the new water companies and the NRA. However, all the assets relating to water supply reservoirs were transferred to the newly created private water companies, even in those cases where there were strong recreational and fisheries interests in the reservoirs. Complex charging arrangements were also put in place whereby the newly created companies paid abstraction charges to the NRA for water removed from surface and ground waters but the NRA then had to pay to have such waters released into rivers. In circumstances where reservoirs had been built to control river flow and thus independently support drinking water abstractions, this could entail the NRA paying out more to have the water released than it had charged for its abstraction. It also meant that some releases of water from reservoirs, which in the past had been made principally for ecological or recreational interests, were now made with economic interests as the principal driver. In 1996, the NRA ceased to exist when it was subsumed into the Environment Agency together with HMIP and the local authority waste regulation functions.

4.4.2 Environment Agency

The Environment Agency (EA) is a non-departmental public body, established in 1996 and sponsored by the United Kingdom government's Department for Environment, Food and Rural Affairs (DEFRA), with responsibilities relating to the protection and enhancement of the environment in England (and until 2013 also Wales). Additional money is raised from the issuing of licences and permits such as abstraction licences, waste handler registrations, navigation rights and rod (fishing) licences and from licensing data for which the Agency is owner.

The Agency manages the use and conservation of water through the issue of water abstraction licences for activities such as drinking water supply, artificial irrigation and hydro-electricity generation. The Agency is in charge of inland rivers, estuaries and harbours in

England. Its remit also extends into Scotland in the River Tweed and River Solway catchments where special arrangements exist with SEPA to avoid duplication but retain management on a catchment basis.

4.4.3 Water Companies

Water supply and sanitation in the United Kingdom is provided by a number of water and sewerage companies. Twelve companies and organisations provide drainage and sewerage services, each over a wide area, to the whole United Kingdom; and supply water to most customers in their areas of operation. There are also 'water only' companies which supply water in certain areas. Some companies are licensed to supply water or sewerage services using the networks of other providers.

4.4.4 Water Resources of South England Group

The WRSE Group comprises six water companies, the Environment Agency, Ofwat (Water Services Regulation Authority), Defra (Department for Environment, Food and Rural Affairs), the Consumer Council for Water and Natural England. The six water companies are: Affinity Water (Central and Southeast areas), Portsmouth Water, Southern Water, South East Water, Sutton and East Surrey Water and Thames Water. The Group's aim is to develop a regional water resources strategy which contains a range of options to find the best long term solutions for customers and the environment in the South East of England. This strategy is a public document, and the options explored within it – which are based on an objective set of company data and assumptions – form the 'building blocks' of the individual water companies' next set of water resources management plans (years one to five) and their preferred option strategy (years six to 25).

The Group considers all possible proposals, including those to share existing or future resources through increased or improved interconnection within or between water company resource zones. Further options, such as demand management, raw water trading or other cross-boundary solutions, are also explored.

4.5 USA: California State

In the United States, most water management is local, and California is no exception. Although state and federal legislatures, agencies, and courts have roles in all aspects of water management, thousands of local entities have the frontline responsibility for serving customers, complying with water quality regulations, and raising revenues to cover the operations, maintenance, and capital investments needed to support these tasks. The governance of water in California also involves many nongovernmental interest-based organizations and many large and small private groups, including business interests and ultimately the general public, which make water-related decisions in homes, in businesses and farms, and at the ballot box. Table 2 presents the role-players in the California Water Field.

Table 2: California Water Sector

Agency	Responsibility
STATE	
State Water Resources Control Board	Permits and administers state surface water rights, regulates water quality(along with nine regional boards)
California Department of Water Resources (California Natural Resources Agency)	Administers the State's Water Projects: oversees state flood control operations and overall state water planning.
California Department of Fish and Game (California Natural Resources Agency) and Fish and Game Commission.	Implements California fish protection laws and the state Endangered Species Act.
California Department of Public Health	Regulates drinking water quality (utilities, devices.)
Central Valley Flood Protection Board	Permits construction and modification of levees within the Central Valley.
California Public Utilities Commission	Regulates water rate structures for private water utilities (~20 percent of urban customers)
FEDERAL	
U.S. Department of the Interior	Acts as watermaster for the Colorado River
U.S Bureau of Reclamation (USBR) (U.S. Department of the Interior)	Administers the Central Valley, Klamath River, Colorado River, and other projects.
U.S. Fish and Wildlife Services (U.S. Department of the Interior)	Administers federal Endangered Species Act for salmon, steelhead trout, and other species that spend at least part of their lives in the ocean
National Marine Fisheries Service National Oceanic and Atmospheric Administration (U.S. Department of Commerce)	Regulates water quality through the Clean Water Act, Safe Drinking Water Act, Resources Conservation and Recovery Act, and other federal laws.
U.S. Environment Protection Agency (EPA)	Builds and oversees flood control systems and flood operations of most reservoirs
U.S. Army Corps of Engineers (U.S. Department of Defense.)	Operates the National Flood Insurance Program (including levee certification and regulation of land use in the floodplain) and provides flood disaster assistance.
Federal Emergency Management Agency (U.S. Department of Homeland Security)	Licenses and regulates dams that produce hydropower.

4.5.1 Department of Water Resources (DWR)

In 1956, the Legislature passed a bill creating DWR to plan, design, construct, and oversee the building of the nation's largest state-built water development and conveyance system. Today DWR protects, conserves, develops, and manages much of California's water supply including the State Water Project which provides water for 25 million residents, farms, and businesses.

Working with other agencies and the public, DWR develops strategic goals, and near-term and long-term actions to conserve, manage, develop, and sustain California's watersheds, water resources, and management systems. DWR also works to prevent and respond to floods, droughts, and catastrophic events that would threaten public safety, water resources and management systems, the environment, and property. Balancing the State's water needs with environmental protection remains a long-term challenge.

4.5.2 California State Water Resources Control Board

The California State Water Resources Control Board (SWRCB) is one of six branches of the California Environmental Protection Agency. The State Water Board has never had the luxury of advocating protection of just one water need, such as the environment or agriculture or that of large cities. Their charge is to balance all water needs of the state. Some call it a superhuman task, but through the years this Board, aided by its excellent staff, has accomplished that mandate despite the intensive historical, political, and economic pressures that always accompany California water issues.

The State Water Board oversees the allocation of the state's water resources to various entities and for diverse uses, from agricultural irrigation to hydro electrical power generation to municipal water supplies, and for safeguarding the cleanliness and purity of Californians' water for everything from bubble baths to trout streams to ocean beaches.

The State Water Board is separate from and has different responsibilities than the Department of Water Resources (DWR), which manages state-owned water infrastructure, such as dams, reservoirs and aqueduct. DWR, like any other water user, must apply for water rights permits from the State Water Board.

Under the Federal Clean Water Act and the state's pioneering Porter-Cologne Water Quality Control Act the State Water Board has regulatory authority for protecting the water quality of nearly 6,500 km^2 of lakes, 5,300 km^2 of bays and estuaries, 340,000 km of rivers and streams, and about 1,800 km of exquisite California coastline.

The State Water Board also provides financial assistance to local governments and non-profit agencies to help build or rejuvenate wastewater treatment plants, and protect, restore and monitor water quality, wetlands, and estuaries. It also administers a fund to help underground storage tank owners and operators pay for the costs of cleaning up leaking underground storage tanks.

The State Water Board coordinates the state's nine Regional Water Quality Control Boards (Regional Water Boards), which serve as the frontline for state and federal water pollution control efforts. Together, the State Water Board and the nine Regional Water Boards are referred to as the California Water Boards.

4.5.3 Regional Water Boards

The nine semi-autonomous Regional Water Boards were created in 1949 by the Dickey Water Pollution Act and have been responsible for protecting the surface, ground and coastal waters of their regions since then.

In adopting the Dickey Act the Legislature was acknowledging that California's water pollution problems are regional, and are affected by rain and snowfall, the configuration of the land, and population density, as well as recreational, agricultural, urban and industrial development, all of which vary from region to region.

The Regional Water Boards develop basin plans for their natural geographic characteristics that affect the overland flow of water in their area, govern requirements for and issue waste discharge permits, take enforcement action against dischargers who violate permits or otherwise harm water quality in surface waters, and monitor water quality.

The Regional Water Boards are unusual in this state because their boundaries follow natural mountain chains and ridges that define watersheds rather than political boundaries.

5 MODELLING APPROACHES

The complexity of modelling approaches can vary from very simple conceptual models through to very detailed and data rich approaches. Models can be applied at scales varying from very small scale specific sites or study levels, through to regional scales. The utility of any of these models is constrained by basic limitations in our knowledge and the availability of data to build the model. Models cannot generate knowledge; they only combine what we know into useful forms. This section describes various modeling approaches used in the focused on countries.

5.1 South Africa

The technology methods that are described in this sub-section in terms of the South African approach to managing the water resources are the following models:

- Pitman Rainfall-Runoff Model;
- Water Resources Yield Model; and
- Water Resources Planning Model.

These models have been developed by the DWS and are regarded as the standard modeling tools used to manage the countries water resources.

5.1.1 Pitman Rainfall-Runoff Model

The Pitman model is a mathematical model to simulate the movement of water through an interlinked system of catchments, river reaches, reservoirs, irrigation areas and mines. The Pitman model is of a modular construction (running under Windows), with five different types of modules (runoff, reservoir, irrigation, channel and mine) linked by means of routes. The routes represent lines along which water flows, such as river reaches.

The model was first developed in 1969 and has been subject to numerous enhancements over the years. The Pitman model has been used to analyse the hydrology on a monthly time scale for a number of diverse applications ranging from very small to very large catchments varying in complexity from being totally undeveloped to highly developed. It has been used throughout South Africa, SADC countries and even in certain overseas countries.

Some common uses of the model are:

- to calibrate streamflow records taking land-use changes over time into account by comparing the observed flows against those simulated by the model;
- for broad regional assessment of water resources;
- to produce naturalised flow records, i.e. take out man-made land-use effects;
- to estimate flows in ungauged catchments by transferring parameters:
    - when the density of flow gauges is insufficient to cover all catchments,
    - when record periods are too short and/or
    - when records show changes in land-use over time;
- simple reservoir yield analysis;
- input to complex system models of water resources (e.g. WRYM, WRPM and WSAM);
- input to water quality studies and
- input to Ecological Water Requirement models.

The model is not appropriate for flood design and for determining yields of dams in a complex system of competing water users. Each of the 5 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.

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 the Pitman model 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. The Pitman model 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.

5.1.2 Water Resources Yield Model

The WRYM is a monthly stochastic yield reliability model used to determine the system yield capability at present day development levels. The model allows for scenario-based historical firm and stochastic long-term yield reliability analysis. In addition, short term reservoir yield reliability can be determined, given current starting conditions.

The WRYM was developed by the South African Department of Water Affairs (SA-DWA) for the purpose of modelling complex water resource systems and is used together with other simulation models, pre-processors and utilities for the purpose of planning and operating the country’s water resources.

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- 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. The major strength of the model lies in the fact that it enables the user to configure most water resource system networks using basic building blocks, which means 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.

Recently, SA-DWA has developed a software system for the structured storage and utilisation of hydrological and water resource system network model information. The system, referred to as the WRYM Information Management System (IMS), serves as a user friendly interface with the Fortran-based WRYM and substantially improves the performance and ease of use of the model. It incorporates the WRYM data storage structure in a database and provides users with an interface which allows for system configuration and run result interpretation within a Microsoft Windows environment.

5.1.3 Water Resources Planning Model

The WRPM is similar to the WRYM, but uses short term yield reliability relationships of systems to determine for a specific planning horizon what the likely water supply volumes will be, given starting storages, operating rules, user allocation and curtailment rules. The model is used for operational planning of reservoirs and inter-dependant systems, and provides insight into infrastructure scheduling, probable curtailment interventions and salt blending options.

A unique feature of the analysis methodology is the capability of the WRPM to simulate drought curtailments for water users with different risk requirements (profiles) receiving water from the same resource. This methodology makes it possible to evaluate and implement adaptive operating rules (transfer rules and drought curtailments) that can accommodate changing water requirements (growth in water use) as well as future changes in infrastructure (new transfers, dams and/or dam raisings) in a single simulation model. By combining these simulation features in one model gives the WRPM the ability to undertake risk based projection analysis for **operation** and **development** planning of water resource systems. The WRPM therefore simulates all the interdependencies of the aforementioned variables and allow management decisions (operational and/or developmental) to be informed by results where all these factors are properly taken into consideration.

5.1.4 Other

Other, less widely used models in the South African water resources sector are briefly described as follows:

- **ACRU**: ACRU is a multipurpose model that integrates water budgeting and runoff components of the terrestrial hydrological system with risk analysis, and can be applied in crop yield modelling, design hydrology, reservoir yield simulation and irrigation water demand/supply, regional water resources assessment, planning optimum water resource allocation and utilization, climate change, land use and management impacts, and resolving conflicting demands on water resources. The ACRU model uses daily multilayer soil water budgeting and 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.
- **WReMP**: Water Resources Modelling Platform can be operated in various modes in order to analyse a water resource, namely: Reconnaissance, System Analyses, Reservoir Operation and Future scenarios. The model performs many of the same functions as the WRYM, and its use is fairly limited to the model developer and studies on which he operates.
- **SPATSIM**: SPATSIM (SPAtial and Time Series Information Modeling) software package has been developed by the Institute for Water Research (IWR) of Rhodes University in South Africa over a period of 1999-2002. The package has been developed using ESRI Map Objects as a tool for managing and modeling the data that are typically associated with water resource assessment studies. It contains an integrated database management system that uses GIS Shape files as the main form of data access. It also has a number of built-in data analysis and processing tools (such as for generating catchment average rainfall data from gauged station data or generating monthly and annual frequency tables from time series data), as well as a wide range of external models that can be setup and integrated seamlessly with the database (i.e. the models access their data requirements from the SPATSIM database and store their results in the database without any intermediate data transformation).

The models include Design Flood, Spatial Interpolation of Observed Flow Records, Monthly Rainfall-Runoff Simulation Model, Desktop Model for Environmental Flow Assessment, etc.

- **MIKE SUITE**: The internationally known Mike models developed and commercialized by DHI of Denmark are also used in some catchments in the country. The real time operation feature is slowly being adopted, however, the limited uptake appears to be the costs involved. In addition, the other models in the suite do not perform any additional required functions that the WRYM and WRPM are already carrying out.

5.2 Australia

The New South Wales Office of Water uses a range of modelling techniques to understand how the river and groundwater systems behave. The resultant models help predict what will happen in a variety of scenarios, including water sharing, compliance and the effects of climate change, and factors that affect water availability.

5.2.1 Integrated Quantity and Quality Model (IQQM)

The main surface water model used for water sharing and management is the Integrated Quantity and Quality Model (IQQM). IQQM has been developed to assess the impacts of different management strategies on all water users. The models have been developed to simulate the major hydrological processes in river valleys along with relevant management rules. These models have been calibrated to match reservoir levels, diversions and flows over the calibration periods. The models are set up in such a way as to reproduce the average long term behaviour of the river system for planning purposes and not specifically to reproduce individual daily flow behaviour in any particular year, or to forecast any future year.

Until the early 1990s, The Department of Land and Water Conservation (DLWC) used monthly flow simulation models to investigate water-sharing issues and to evaluate alternative water resource management options for planning purposes. Many of the current water management issues are concerned with the interaction between water quality and quantity, and the restoration of natural flow variability. Monthly models cannot adequately address these issues because the modelling of the short-term variability (e.g. of flows within the month) is important. DLWC recognized that it would need a model that could take into account both the short-term variability and integration of water quantity and quality issues, and be able to run on any river system. Hence the generic model IQQM was developed.

IQQM models have been developed for most inland river basins and some coastal river valleys. The models can be used to obtain a range of information on simulated river system behaviour ranging from average summary statistics to specific event or sequence details.

These models are used in different water management areas such as:

- Water sharing plans
- Auditing NSW compliance with the Murray-Darling Ministerial Council Cap
- Estimating the baseline salinity condition of NSW rivers in the Murray-Darling Basin
- Strategic and operational hydrologic matters

IQQM operates on a continuous time basis and can be used to simulate river system behaviour for periods ranging up to hundreds of years (DLWC, 1995). It is designed to examine long-term behaviour under various management regimes, which include environmental flow requirements. IQQM is based on a node-link concept. Each important feature of a river system is represented by one of thirteen node types. The movement and routing of water between nodes is carried out in the links. Normally the model is run on a daily time step but for adequate representation of certain water quality and routing processes, the model can run down to an hourly step. In a regulated river system, IQQM makes three passes of the river system. The first pass starts from the bottom of the system and totals water demands along the river up to the supply reservoirs. These orders take into account the water requirement of the different users along the river, and consider transmission and evaporation losses as well as tributary flow contributions. The second pass determines water user shares of surplus unregulated flow and how this is to be distributed within the system. The order pass and unregulated flow sharing is carried out with a daily time step. The final pass routes the reservoir releases and tributary inflows down the system at a user defined time step, between one hour and a day. The extractions from the system also take place in the final pass.

The water quantity module of IQQM simulates all the processes and rules associated with the movement of water through the river system. The major processes include: (a) flow routing; (b) on and off river reservoir modelling; (c) harmony rules for reservoir operation; (d) town water and other demands; (e) hydropower modelling; (f) effluent and irrigation channels; (g) crop water demands, orders and diversions; (h) wetland demands and storage characteristics; (i) water sharing rules among regulated and unregulated river systems; (j) resource assessment and water accounting; and (k) interstate water sharing agreements. The model applies hydrological flow routing for the simulation of the different ranges of low and high flow conditions.

There are a variety of options available to model the different operating procedures of both on and off river storages. The options include Puis' routing, gated storage operation and target rule curves for flood mitigation and water conservation. IQQM can be configured for systems operating single or multiple reservoirs and multiple reservoirs can operate in series or parallel.

The irrigation module in IQQM includes features for soil moisture accounting, simulating decisions of farmers regarding area of crop to plant and irrigate, water ordering and usage, taking into account on-farm storage operation where appropriate, and accounting for water use in relation to water license and access rules conditions.

The model can also simulate fixed demands (e.g. urban water supplies and power stations), riparian and minimum flow requirements, flood plain storage behaviour, wetland and environmental flow requirements, distribution of flows to effluent streams, and transmission losses. It is also capable of simulating water quality processes such as salinity, temperature, and other constituents. In addition, the Sacramento rainfall-runoff and climate generation models are available as separate modules within IQQM.

In a case study, IQQM was configured to assess the effect of various operational rules. The model was set up with more than 200 nodes to describe the dominant processes within the Lachlan River system. The calibration process required extensive data collection, validation, and processing. These data were subsequently used in a staged process to calibrate the model. Each stage of the calibration focused on calibrating a sub-set of parameters with the other parameters being fixed to observed data. The objectives of the calibration were to match the relevant observed data. The various stages of calibration are: (a) flow routing parameters, losses and effluent flow; (b) crops and irrigation demand; (c) unregulated flow usage; and (d) storage behaviour. The model was then set up for the specific valley operational rules and resource assessment. The model was initially configured for two benchmark cases: Natural and 1993/94 MDB Cap Case. This was done so that future options could be measured against these benchmarks. The model was run over a climatic period from 1894 to 1997.

Various operational rules were trialed to meet the environmental objectives. It became clear that rules related to passing particular inflow events through storages achieved the best compromise near the end of the system. The model was used to determine the size of events that would be useful. This set both a lower and an upper limit of events that would be passed through the river system, including storages. Trade-offs between event size, losses, and localized flooding determined the upper limit. The model also identified critical times within a year to make these releases for the environment. It also identified critical water resource constrained years where this release should not be made.

After more than 100 combinations of various flow rules had been considered, the option was agreed upon that maximized the environmental benefits while limiting the impact on consumptive users. In the agreed option, flow events are to be released through Wyangala Dam from 1 June to 31 October, up to a maximum of 350 Gl total volume released. Specified mid-river flows at Brewster are to be achieved subject to Wyangala storage volume conditions. As compared to the Baseline (MDB Cap) Case, the annual average diversions in the agreed option were reduced by 3.7%.

IQQM has demonstrated the usefulness of a daily water balance simulation model in developing water management rules within a river system. The model allowed government bodies, irrigators, environmentalists, and others to have a clear understanding of the impacts of the various rules. This allowed these groups to reach agreement on an option that would benefit river health while minimizing the impact on consumptive users. It also made these groups aware of how all water users within the valley interact with each other.

5.2.2 Stochastic Climate Library (SCL)

The effects of climate variability and climate change have been a particular focus of the New South Wales Office. They have used a range of climate and hydrological modelling approaches to help translate estimates of rainfall and evaporation changes from climate change scenarios into impacts on the surface water regimes of river basins across NSW. The Stochastic Climate Library (SCL) is a library of stochastic models for generating climate data.

Stochastic climate data are random numbers that are modified so that they have the same characteristics (in terms of mean, variance, skew, long-term persistency, etc.) as the historical data from which they are based. Each stochastic replicate (sequence) is different and has different characteristics compared to the historical data, but the average of each characteristic from all stochastic replicates is the same as the historical data.

Using historical climate data as inputs into hydrological models provides results that are based on only one realisation of the past climate. Stochastic climate data provide alternative realisations that are equally likely to occur, and can therefore be used as inputs into hydrological and ecological models to quantify uncertainty in environmental systems associated with climate variability. Stochastic climate data are traditionally used in storage yield analysis to estimate reservoir size for a given demand and reliability, or to estimate system reliability (number and levels of water restrictions) for a given storage size and demand characteristics. Stochastic climate data can also be used as inputs into water resources models (like REALM and IQQM) to estimate system reliability (e.g. water allocation amounts for competing users) for alternative allocation rules and management practice.

The SCL has stochastic models for generating single site rainfall at the sub-daily, daily, monthly; and; annual timescales as well as single site climate (Rainfall, Evaporation, Maximum temperature) at the following daily; monthly; and annual timescales. In addition, multi-site rainfall can be generated at a daily timescale.

Features of the SCL include:

- Allows easy use of stochastic climate data generation models;
- Runs quickly;
- Supports various time series input data formats;
- Displays input time series and stochastically generated data graphically;
- Allows easy retrieval of the stochastically generated climate data;
- Provides a graphical display of the empirical distribution of stochastically generated data and historical data. These plots allow quick easy comparison of the distributional shape at various aggregation levels. For the daily models annual maxima curves are also produced – providing Depth-Frequency-Duration curve validation.
- Displays the mean and percentiles of various statistics of the generated data and the corresponding values in the historical data (as tabulated values, scatter plots and whisker plots) – values can also be written to a file.
- Provides statistical summary and assessment of the quality of the stochastically generated data.

SCL is designed for hydrologists, environmental scientists, modellers, consultants and researchers to facilitate the generation of stochastic climate data. SCL is easy to use and is based on relatively robust stochastic climate data generation models.

5.2.3 SOURCE

eWater Source – Australia's National Hydrological Modelling Platform (NHMP) – is designed to simulate all aspects of water resource systems to support integrated planning, operations and governance from urban, catchment to river basin scales including human and ecological influences. Source accommodates diverse climatic, geographic, water policy and governance settings for both Australian and international climatic conditions.

Source provides a consistent hydrological and water quality modelling and reporting framework to support transparent urban, catchment and river management decisions. Fundamental to this design is the flexibility which makes it readily customisable and easy to update as new science becomes available. New capabilities can be incorporated via plugins developed to suit particular needs while maintaining the overarching consistent decision and policy framework.

eWater and its Australian government and industry partners have completed more than 100 Source applications, and inform on water policy, water sharing plans and catchment management.

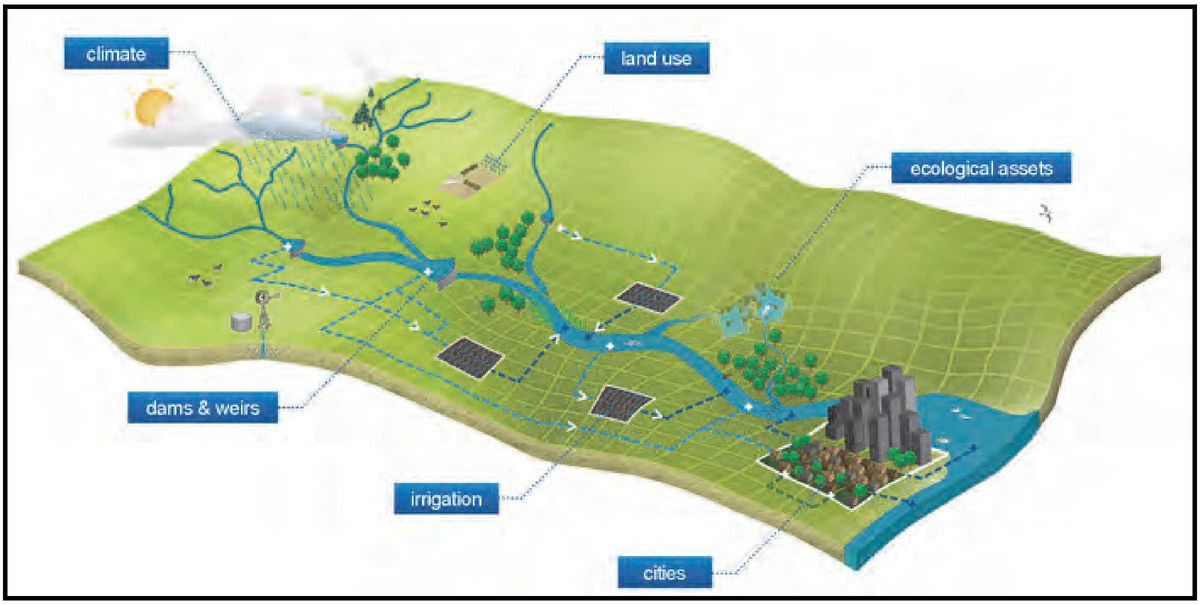

Figure 1: Catchment representation (Ref: eWater)

Source is a nationwide collaboration effort backed by the Australian government, with over 20 years of scientific research, development and applications. As Australia's national hydrological modelling platform, backed by The Council of Australian Governments, Source will gradually replace the current range of Australian river models used in various jurisdictions as they are retired.

The open software architecture of Source means new capabilities can be incorporated via tailored plug-ins, and it also permits users to incorporate existing models, saving development time and the need to establish the credibility of the model. Source includes a high-level graphical interface based on a conceptual view of the watershed or river, allowing the user to quickly and easily explore with stakeholders the practical way a river basin operates, without significant data requirements.

The software provides a framework for modelling the amounts of water and contaminants flowing through a catchment and into major rivers, wetlands, lakes, or estuaries. eWater Source can be used in planning and operations modes for river management and has been developed to address water sharing and savings for entire river and connected groundwater systems. It offers important new features and capabilities dealing with water reform, climate change and environmental water. Source can be used for urban water supply management at the town, city, and regional scale. It can assess a full range of supply and reuse options including desalination. This allows users to incorporate towns and cities into water management models for river systems.

Source has been developed to address water sharing and savings for entire river and connected groundwater systems.

It allows users to:

- share water between environmental and irrigation demands;
- consider what impact climate change will have on water security;
- manage multiple water owners in storage and in transit in the river system;
- link existing models to build on current approaches.

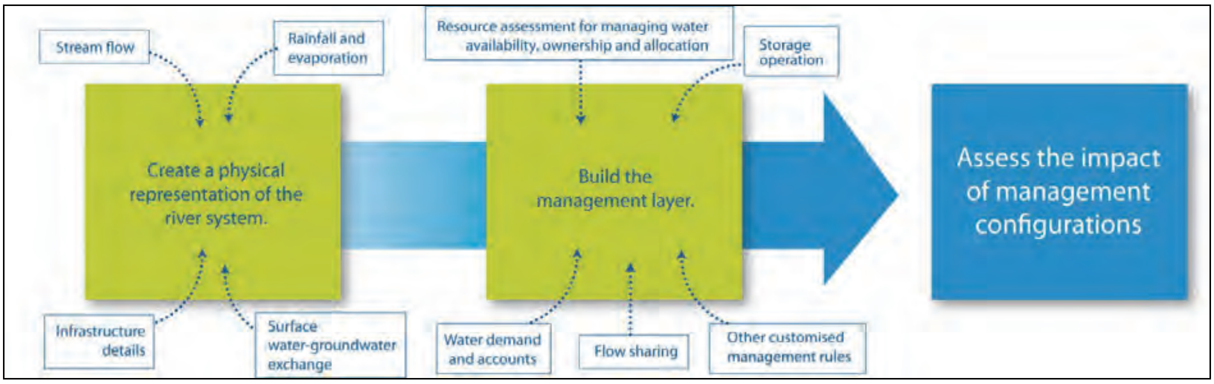

Figure 2: Source steps (Ref. eWater)

The Source modelling package can be run in one of two inter-changeable modes: 'Operations' to inform day-to-day operational decisions; and 'Planning' to inform policy decisions relating to the long-term impacts on water and environment resources. This means that managers dealing with daily operations, water accounting and long term planning will be able to efficiently and accurately compare analyses using a common platform and river system model.

Source (Planning) is designed to:

- determine which management rules will best meet planning objectives;
- explore the impact of changes in management, land-use and climate on river behaviour and water availability;
- model the supply, demand and use of water at a range of time scales;
- simulate complex management rules, such as continuous sharing;
- accommodate the needs and conditions of different river catchments across Australia;
- track and account for water shares and ownership;
- assess current and future water availability across entire river systems; and
- interact efficiently with river operations.

Source (Operations) is designed to:

- inform decisions on how the system should be operated to deliver water in the short and medium term to consumptive and environmental users;
- inform decisions on water transfers between catchments, rivers and reservoirs as specified in operation and management plans;
- inform changes in water delivery requirements as a consequence of external drivers, such as water trading;
- decide on the optimum storage and weir operations to meet target watering regimes for consumptive and environmental demands; an
- interact efficiently with long-term river system planning.

Building the Source software engine has involved a major research and development effort. This has included the development of new lumped groundwater models and enhanced algorithms for modelling the supply of water down multiple supply paths. Many of the algorithms for addressing Australia’s water management rules (such as accounting and ownership) are unique to this software.

Using Source to manage rivers:

- develop, implement and monitor robust and defensible water sharing plans
- make daily operation decisions and develop seasonal operating plans
- predict the combined impacts of climate, land use, farm dams, irrigation, water savings, and groundwater development
- model water availability – historical, present and future – across the whole country using models that are consistent at catchment, regional and continental scales
- assess the impact of land use and water management on water quality
- use with existing models or develop plug-ins as required
- share knowledge by joining a community of practice.

Source has a unique range of capabilities. Users are able to simultaneously answer catchment management and river modelling questions, including the ability to handle complex policy and management rules at a system-wide scale.

Key features include the ability to:

- model water sharing and accounting using a selection of resource assessment systems dealing with water sharing plans in place in different catchments and jurisdictions;
- assign, track, manage and reassign an owner's (such as a state or 'the environment') share of water as it moves through the river system;
- support both rules based and optimised solutions to manage the delivery of water from multiple supply storages via multiple paths;
- track the concentration of salinity and other 'conservative constituents' through the river system;
- take explicit account of fluxes between the river and the groundwater aquifer along entire river reaches at any time step;
- predict inflows from rainfall and runoff using a collection of available models; and
- select from a range of 'water user' demand models, including urban, environmental and irrigation demand, to inform storage releases.

Source provides a management layer that interacts with storages, links and water users to allocate shares of regulated and unregulated water supplies.

Source provides the following accounting functionality:

- Different levels of security;
- Annual accounting where stored resources and losses are socialised and allocated on an annual basis;
- Annual accounting with carry over where an amount of water can be carried over to successive water years;
- Continuous accounting where there are individual shares in storages and losses are socialised;
- Continuous sharing where there are individual shares in storages and losses are reconciled against users; and
- Unregulated flow sharing where events in the system are shared amongst water users.

The management of water in the system is controlled by a range of nodes such as:

- Minimum flow node that orders water to meet in-stream targets;

- Maximum flow node that constrains regulated orders to ensure maintenance of
- maximum flow targets;
- Customisable rules via the expression editor; and
- Water users.

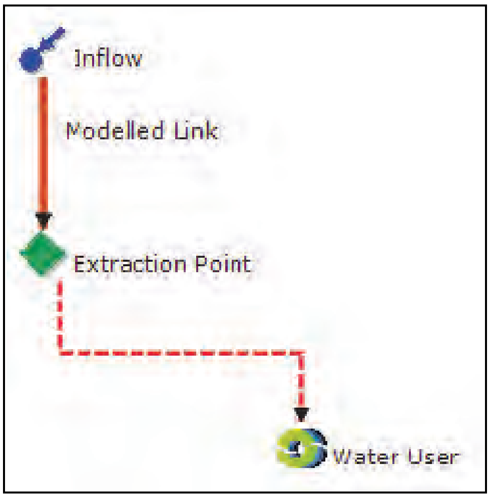

Figure 3: Example of components in a Source network

Water users control the ordering of water and the allocation to different licences. Water users can extract from multiple sources including groundwater. They have an optional inbuilt storage and can select from a range of demand models that include patterns, time series, crops and environmental demands. They can also return water from the inbuilt storage and demand models to the river system.

Source utilises a selection of nodes and links to represent how water moves through, and is managed in the river system. Nodes and links provide the 'building blocks' for re-creating the river system. Nodes represent locations along the river where flow and water quality constituents enter or are stored, extracted, lost or measured. Links are used to model the movement of water between nodes.

Overlying the physical network is a water management rules 'engine' that provides Source with an additional layer of management complexity. This 'engine' allows for complex management rules to be modelled at a system-wide scale to support water sharing arrangements between states, water ownership in the system, water accounting, and ordering to meet demand.

Physical nodes represent the hydrology of the system and include the:

- Inflow node to define flows into the model such as from rainfall, runoff, tributaries and water
- Confluence node to represent the joining of two tributaries
- Gauge node for entering recorded flow and water level details
- Loss node to represent water removal from the model, including evaporation and seepage or even error associated with flow-measurement uncertainty.

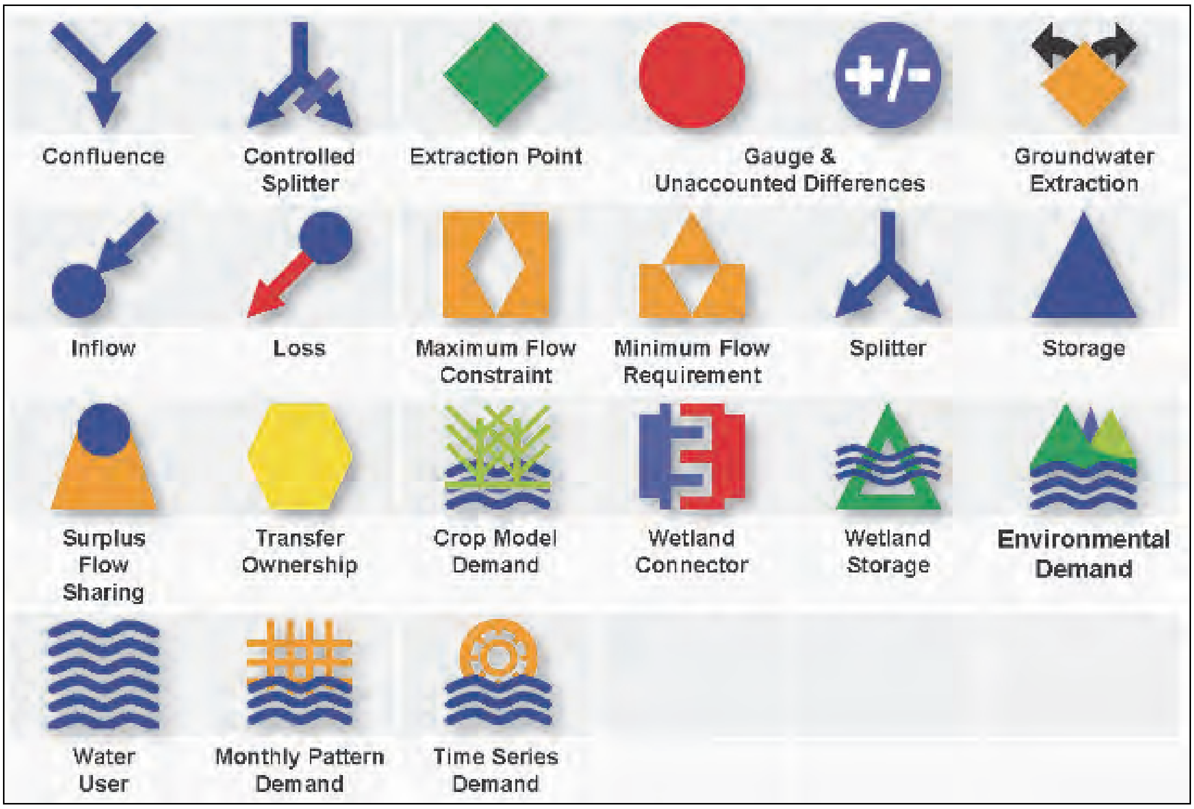

Figure 4: Source components (Ref. eWater)

Management nodes are used to regulate the river. They allow water to be owned, ordered, accounted for, tracked and extracted by users. They include:

- Water User node to represent demand in the system. This includes environmental needs, such as a wetland, and irrigation demand.
- Transfer Ownership node to change ownership of flows.
- Minimum Flow Constraint and Maximum Flow Constraint for managing river flow in order to meet demand requirements and consider channel capacity limitations.

Links are used to connect nodes in order to simulate the movement of water. When configured with routing they represent flow within river reaches.

Hydrological attributes for a gauge node can be configured by uploading time series files of observed flow and rating table information. Physical attributes can be configured for storages by entering details on storage characteristics such as dimensions, outlets for releasing water, and evaporative losses.

The eWater Source software has been designed as an integrated river system modeling software in the TIME framework, based on the E2 modelling approach, and supports catchment, river management and operations modeling scenarios. There are seven major components within the Source simulation engine: i) catchment runoff; ii) River system network; iii) Interactions between river and groundwater systems; iv) Water quality; v) River regulation and storages; vi) Demands (urban, irrigation and environmental) and vii) Complex river management rules. Subcomponents comprehensively represent the underlying processes, rules and regulations. A river system is schematised into a simplified river network using a node-link structure. The river network begins and ends with a node, and all nodes are interconnected by links. Runoff from gauged or ungauged tributaries or local contributing areas between two nodes is fed into the network as an inflow at the relevant location in the network. Links represent a length of stream, which can be zero for near coincident processes, and are used for the transfer of flow and constituents between nodes, with or without flow routing and transformation. Nodes represent physical locations along a river where flow either enters or leaves the system, or is stored, extracted, lost or measured. Nodes are also used for the application of management rules that regulate the river and keep account of the water ordered and extracted by users.

Source sequentially implements two phases in each time-step: the ordering phase then the flow distribution phase. The ordering phase predicts the behaviour of operating structures such as storages and regulators in response to water orders and system regulation (e.g. minimum flow rules and maximum flow constraints). The flow distribution phase releases water, routes flows and distributes water through the river network. In the ordering phase, the calculation of the movement of water released from reservoirs to meet demands through a network of river branches is reasonably complex and operators must ensure that the river system is run efficiently. Source offers two ordering methods, heuristic (or rules-based) and NetLP-based, to calculate how water should be released from storages to meet demands. Flow in the system during the flow phase can be different from the ordering phase solution (both rules-based and optimised) because during the ordering phase calculations, the Source application must make assumptions about the state of the system during the flow phase. For example, results can be affected by flow routing, unexpected inflows, storage spills, and operational and other losses (e.g. evaporation). These differences are resolved in the flow phase using the ordering phase solution as the minimum target.

Network linear programming (NetLP) optimisers solve a class of problems called network flow problems, which consist of supplies and demands, together with multiple ways of transporting the supplies to the demands. A network is a set of vertices (called nodes) and a set of edges (called arcs) that connect certain pairs of nodes. There is a unit cost for each arc associated with the transport of the supply through the arc from one node to another node. In river system modelling, the objective when solving a network flow problem is to find the best way of supplying water from the reservoirs to meet the demands where there are one or more alternative paths from the reservoirs to the demand sites. The network contains nodes with supplies or sinks, and arcs with upper and lower bounds of flow and unit costs for flow.

There are many algorithms for solving NetLP. Two optimisation algorithms used in Source for NetLP problems are: RELAX IV Network Linear Optimiser and PPRN. The RELAX IV solver uses a sequential/auction algorithm to find an initial solution then a dual ascent algorithm to find an optimal solution. The PPRN solver is for solving the multi-commodity network flow problem with a linear or non-linear objective function considering additional linear side constraints that link arcs of the same or different commodities. For linear systems, PPRN uses a primal-dual interior point method. The constraints on an arc-node network with RELAX and PPRN are:

- All arcs are directional; they have a minimum flow of zero.
- The source quantity must equal the sink quantity.
- There must be a single network.
- There must be a way for flow to travel from source to sink (e.g. the upper bound flow constraints and side constraints (if applicable) must allow a path from source to sink).

The network flow problem is designed to maximize the equitable supply of water to consumers. Different system setups have been described for maximizing hydropower generation or minimizing pumping costs. Since the problem is typically non-linear, several solutions of a NetLP are necessary to converge to an acceptable solution. For implementing a NetLP ordering method, the simulation engine translates different elements of a node-link setup of a river system network into an Equivalent System Network (ESN) that an optimiser can solve.

In the rules-based ordering phase of a regulated river system model, orders are accumulated starting from the end point of the system, which is a node with an upstream link but no downstream link. Water order requests are accumulated from downstream to upstream, and consider the average travel time for water in the regulated river system from the reservoir to the demand.

Source has improved on existing rules-based approaches in two ways.

- Orders directed to the system
- Supply path constraints

In Source, irrigation district and urban centre place orders for water that can be sourced from any storage (rather than from a pre-specified storage). The ordering system then determines the delivery path subject to delivery rules stipulated by the user. A water user in a regulated river system might have water allocations in multiple upstream reservoirs on multiple flow paths, therefore there can be multiple options to supply the downstream water order. In such a system, a water order could be met within a range of average regulated travel times bounded by a minimum and maximum. The model forecasts orders over the range of average regulated travel times. The minimum order time is estimated as the average regulated travel time to the nearest upstream storage; the maximum travel time is estimated as the average regulated travel time to the furthest upstream storage. The model calculates the minimum and maximum order times for each model component from upstream to downstream, in the same order as in the flow phase.

5.2.4 CWYET

The Catchment Water Yield Estimation Tool (CWYET) aims to provide a common modeling framework for estimating catchment water yield and daily runoff characteristics across Australia. It predicts how catchment water yield is affected by influences such as climate variation and land use change, which includes afforestation and the building of farm dams (Ref: eWater 2).

CWYET supports managers to explore the following types of questions:

- What is the long-term catchment yield and runoff characteristics from a catchment?
- What is the impact of climate change on catchment water yield and runoff characteristics?
- What is the impact of land use change on catchment water yield and runoff characteristics?

The catchment processes modelled by the CWYET tools are illustrated below and include:

- Spatial and temporal variability in rainfall
- Spatial and temporal variability in potential evaporation
- Impact of plantations on water

- Impact of groundwater processes on surface runoff

The CWYET framework is integrated into the Source Rivers and Source Catchments models. CWYET generates a daily time series of stream flow at a catchment outlet, which can be used as an input to a Source Rivers “inflow node”

There are three components within the framework, which when used with appropriate climate data, can estimate daily runoff series for catchments. This can be used for catchment planning or as inflow information for the river models. These components are:

5.2.4.1 Rainfall-runoff algorithms – models for estimating catchment water yield and runoff

The CWYET framework includes six daily rainfall-runoff models, all of which have been applied in numerous studies both within Australia and internationally. All the models have been used in regionalisation, landuse and climate change impacts on runoff studies. The rainfall-runoff models are: 1) Sacramento, 2) SIMHYD, 3) SMARG, 4) GR4J, 5) IHACRES and 6) AWBM. These models are configured to allow the user to either run a 5 km^2 grid across the catchment, thus making the inputs and outputs of rainfall, evapotranspiration and generated runoff spatially explicit or run the rainfall-runoff models at a lumped catchment scale.

5.2.4.2 Calibration Tools

The CWYET framework includes a state of the art optimisation toolset. Stakeholders requested a high level of flexibility in expressing objectives for calibration purposes and multi-objective optimization capabilities. The high-level optimization features include:

- Availability of SCE-UA, MOCOM-UA, Rosenbrock and other optimisation algorithms.
- Availability of a list of predefined objective functions.
- Definition of custom optimization problems such as regional calibration.
- User defined custom objective functions, through a scripting environment.

5.2.4.3 Guidelines to support implementation of algorithms

Guidelines have been developed to support consistent implementation of the CWYET framework as a stand-alone tool or within the Source Catchments / Source Rivers applications. The guidelines provide information on:

- Applicability of the CWYET tools for stream flow simulation.
- Selecting the appropriate CWYET option for simulating runoff.
- Selecting an optimisation method(s) and choice of different objective functions.
- Selecting appropriate regionalisation method for predicting runoff in ungauged areas.
- Impact assessment for climate change, plantations and farm dams.

5.2.5 WASP

WASP is a mass-balance quasi-simulation computer package developed to facilitate analysis of the performance of the headworks and transfer components of a water supply system under different operating policies and changes to system configuration (Kuczera, 1988). Its generality is due to the use of a network linear program (LP) which allows system components to be connected in virtually any configuration. The user defines an operating policy in terms of easily understood rules which guide the network LP when it makes seasonal assignments of water within the water supply system. WASP is based on a network LP to take advantage of computer codes up to 100 times faster than standard LP codes.

5.3 Brazil

5.3.1 SNIRH-hydrological model

Brazil has made several advances in the last 10 years regarding water resources planning and management. In terms of hydrological simulations, three distinct phases can be identified: development of models, integration of these models into Decision Support Systems (DSSs), and the coupling of Geographic Information Systems (GISs). Nowadays, according to demands of the Brazilian Water Resources Information System, the new challenge is to consolidate all the available knowledge into a Spatial Decision Support System (SDSS). Hence the Brazilian Water Resources Information System (SNIRH) was developed and integrated to several hydrological models (Celso et al., 2010).

It was decided to adopt a free and open source GIS platform because the Brazilian National Water Resources Policy stated that the code of this software should be accessible to anyone. In this situation, OpenGIS, i.e. an Open Source Free GIS, was selected and OpenJUMP was chosen as the underlying program, which would be integrated with the hydrological models. This OpenGIS has been developed by the Geography Department of the University of Zurich in Switzerland, and it uses the JUMP core.

The OpenGIS has many advantages such as (a) the OpenJUMP can access maps remotely through the standard services of the Open Geospatial Consortium. The SNIRH map database can be accessed through the WMS (Web Mapping Service), (b) it allows new applications (plugins) to be integrated into the system and this was how the selected models were integrated to OpenJUMP, and (c) the OpenJUMP was developed in the Java language, based on concepts of Object Oriented Programming, which provides several additional advantages.

The SNIRH-hydrological model was made up of a set of three applications: an access module to the Hydro database of the Brazilian National Water Agency (ANA, in Portuguese); hydrological models built as plugins; and a robustness analysis module. All applications of this system are based on the OpenJUMP software, since some of the applications work with spatial entities. The first module is the software to access the ANA database, in which the Web Services technology was used. This technology allows interaction between applications developed on different platforms. In addition, it is possible for newly developed applications to communicate with those that already exist without the need for major changes. Through Web Services, it is possible to get rainfall, runoff and other data. The application accesses the ANA database, returning a collection of objects with the required information, which are then available in a graphical-user interface. OpenGIS is used to manage input information as well as to present the resulting simulations, in order to promote an integrated view of the basin and its elements. The chosen models were the hydrological lumped models IPH2, MODHAC and SMAP, and the distributed models MGBH and Kineros (Runoff-erosion).

Once the OpenGIS is opened, the user can select the SNIRH option in the main menu bar. The user chooses the option “models” and then they can click on the model that they want to use for their study. The integration between the OpenGIS and models was done through an interface for exchanging data, thus data stored in the GIS layers are converted into input files for a particular model. The interface is also responsible for the model execution, and again to transfer information to the GIS layers where the simulation results are presented. In this way, GIS plays an important role for the pre- and post-processing of data. After model execution, the user is able to compare all of the executed simulations within the same system. Several statistical parameters are available for this and the user does not need another software program to analyse and compare the simulation results. Several statistical measures are available such as average, deviation, variance, covariance, minimum value, maximum value, autocorrelation, BIAS, MSRE, Nash Coefficient, Pearson's Correlation, and Coefficient of Determination.

The integration of hydrological models within SNIRH allowed the development team to create an open source and free software that can be run on any operational system that has a Java Virtual Machine. The way that the hydrological models were integrated into the OpenJUMP software means that it was not necessary to implement them in Java language. Nevertheless, the use of an OpenGIS avoids the issue that new GIS functions need to be implemented. The distributed hydrological models allow separate simulation in each discretized element, and the system developed takes advantage of this to provide a graphical visualization of the results in order to facilitate the understanding of the spatial response of the basin to a rainfall event.

5.3.2 Rainfall-Runoff Model SMAP (Soil-Moisture Accounting Procedure)

The SMAP model is currently applied at FUNCEME for hydrological studies and water resources management in the state of Ceará (Alves et. al, 2012). SMAP uses two linear reservoirs to represent the surface reservoir (soil surface layer) and the underground reservoir. For each precipitation event (P), the water balance is evaluated, and a parcel of P is transferred to the surface reservoir, which is estimated using the Soil Conservation Service TR_55 procedure. The remaining parcel is divided between evaporation and infiltration. SMAP needs eight parameters to evaluate the water budget and to estimate the river discharges at the basin outlet. Two parameters are computed from basin physical characteristics:

- the National Research Conserve Service (NRCS) curve number (CN) derived from land use, vegetation cover, soil classification, hydrologic conditions and antecedent runoff conditions, and
- the initial abstraction as function of CN in the standard coefficient recommended by NRCS.

Two other parameters are arbitrated as zero from hydrological and climate peculiarities of the region:

- the initial discharge, and
- the initial soil moisture.

The four remaining parameters must be calibrated, i.e.

- the soil saturation capacity,
- the basin recession constant,
- the underground recharge capacity, and
- the soil field capacity.

SMAP is a conceptual, lumped model containing two reservoirs (subsurface and ground water) and four parameters: soil saturation capacity, surface flow, a recharge coefficient, and a base flow recession coefficient. The rainfall-runoff component is founded on the Soil Conservation Service equation and utilizes basin average precipitation and evapotranspiration.

5.3.3 ABCD Model

ABCD is a nonlinear watershed model, which represents soil moisture storage, groundwater storage, direct runoff, groundwater outflow to the stream channel, and actual evapotranspiration (Singh & Frevert, 2010). Inputs include precipitation and potential evapotranspiration. Its performance in comparison with other monthly water balance models has lead to its recommended use.

The ABCD water balance model is a simple hydrologic model for simulating streamflow in response to precipitation and potential evapotranspiration developed by Thomas in 1981. The model is comprised of two storage compartments: soil moisture and groundwater. The soil moisture gains water from precipitation and loses water to evapotranspiration (ET), surface runoff and groundwater recharge. The groundwater compartment gains water from recharge and loses water as discharge. The total streamflow is the sum of surface runoff from the soil moisture and groundwater discharge.

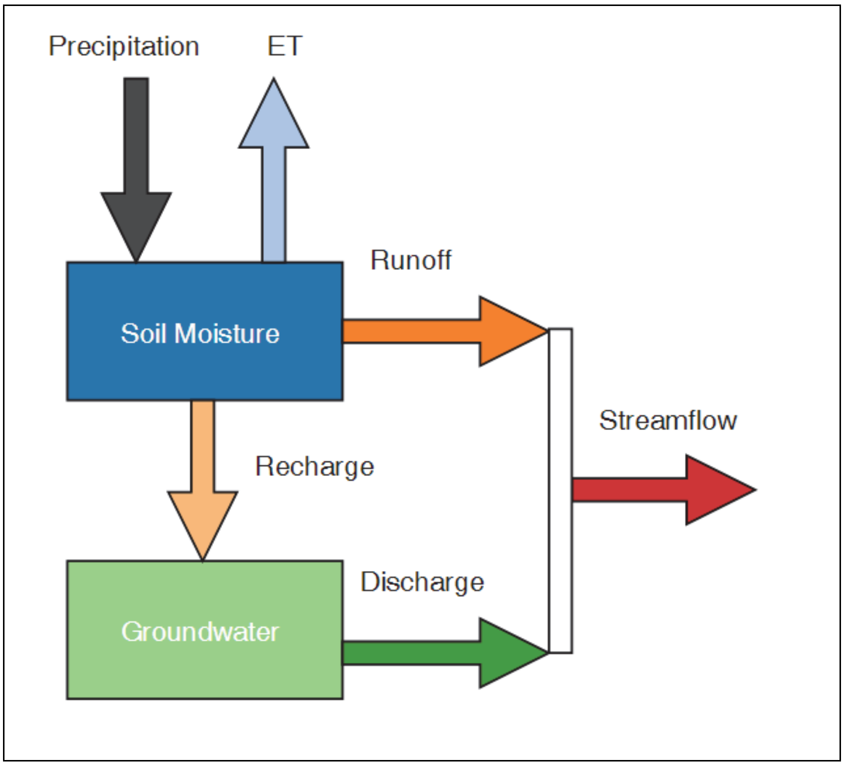

Figure 5: ABCD water balance approach

The model runs on a daily time step and requires input time series of precipitation, minimum and maximum air temperature, and observed streamflow. The air temperature data are used to compute PET.

There are four parameters governing the model behavior:

- controls the amount of runoff and recharge that occurs when the soils are under-saturated.
- controls the saturation level of the soils.
- defines the ratio of groundwater recharge to surface runoff.

- controls the rate of groundwater discharge.

5.3.4 MODHAC

MODHAC (the Portuguese acronym for "Self Calibrated Hydrological Model") is a rainfall-runoff lumped model (Neto et al., 2014), whose input variables are mean rainfall, potential evapotranspiration and streamflow. Three reservoirs represent the main processes responsible for rainfall-runoff transformation: interception, evapotranspiration and runoff generation, i.e. determination of the volume of water that will either be infiltrated into the soil or flow on the surface. The model has 14 parameters that can be calibrated automatically using four options of objective functions. MODHAC has performed hydrological simulations well in several basins located in the semiarid lands in Northeast Brazil. In addition, MODHAC can run either monthly or daily time step simulations and it needs few input data (rainfall, PET and observed streamflow). The MODHAC is similar to other models widely used for synthetic runoff generation such as Soil Moisture Accounting (SMA) present in the HEC-HMS model, SMAP present in the MIKE 11 model and the Tank model. All these models, including MODHAC, use reservoirs which represent the main processes responsible for rainfall-runoff transformation.

5.3.5 Hydrologic Engineering Center Model – HEC-HMS

The HEC-HMS (Hydrologic Modeling System) is designed to simulate the precipitation-runoff processes of dendritic watershed systems (Ref: Wikipedia 4). It was developed by the Hydrologic Engineering Center of the US Army Corps of Engineers. The model has been applied in the solution of a number of problems in a wide range of basins with different characteristics. The HEC-HMS is able to either accomplish event-based simulation (few hours to days) or continuous simulation encompassing rain and drought seasons. This is possible due to a set of models, formulations and equations that may be chosen to represent each part of the continental phase of the hydrological cycle: i) soil-plant interface water balance; ii) run-off routing; iii) baseflow routing; iv) channel routing in rivers and reservoirs.

5.3.6 MGB-IPH Model

A large scale hydrological model called MGB-IPH, from the Portuguese "Modelo de Grandes Bacias" which means "Large Basins Model", and "Instituto de Pesquisas Hidráulicas" according to the institution in Brazil where this model was developed is also used. MGB-IPH is distributed by cells and runs on daily or hourly time steps. Each cell is divided into blocks, patches, which are formed by the combination of land use, vegetation, and soil type. Each block has a uniform hydrological response to meteorological forcing, in the same way as in the case of Hydrologic Response Units (HRU's). MGB-IPH uses the Xinanjiang model formulation to calculate the soil water balance. Three linear reservoirs are used to represent independent routing of surface, subsurface and groundwater flow through the cell. Flow propagation in the rivers is based on the Muskingum-Cunge method. The potential evapotranspiration is calculated by the Penman-Monteith equation. The soil in the Una River basin is defined according to the SCS-CN hydrologic soil groups.

5.4 England

5.4.1 Aquator

Aquator is a powerful application for building and running water resources computer models (Ref: OSS). It is used by some of the largest water utility companies in the UK to model their water resource systems. These range from models of small systems with hydropower in mountainous terrain to large, conjunctive use networks supplying urban populations from groundwater sources and large river basins. Some Regional Offices of the Environment agencies use Aquator to model river basins to check on water company abstraction and develop abstraction licensing policy. One can build simple models with a few components or large, complex models with over 1000 components. With reduced cost of developing models and flexibility to deal with the challenges posed by climate change, users who adopt Aquator find it to be their water resource modelling software of choice.

River basin modelling features include: river regulation, forecasting, travel times, use of different catchment models and differentiation of river flow at any point into 'natural', 'cumulative abstraction' and 'release' components. On the supply side, water is used to meet demand using a linear optimisation algorithm that seeks to minimise cost, but also to preserve the state of resources on a daily basis.

The inclusion of Microsoft Visual Basic for Applications (VBA), the same macro language used in Excel, allows any degree of customisation that one requires, meaning that Aquator can model complex systems more accurately than other commercial modelling software. Additionally one can incorporate Aquator into other VBA-enabled applications to provide water resources data. For example, an Excel spreadsheet macro can start Aquator, run a model, abstract the results, undertake further analysis and display results in the format you require.

Features include:

- Drag and drop model construction from over 40 types of components;
- Full conjunctive water use optimised each day on cost and resource state;
- Step-by-step execution displays flows on schematic for easy problem diagnosis;
- Animated schematic shows reservoir levels change and when supplies fail;
- Customisable operation using Microsoft Visual Basic for Applications (VBA);
- Facilities to manage time series data with transfer from & to Microsoft Excel;
- Internal water balance checks;
- Daily time step;
- Open architecture allowing third parties to add new components and features;
- Multiple projects can be loaded simultaneously or run in parallel;
- Context-sensitive HTML help with 500-page manual in PDF format.

The usual way of specifying river catchment flows is by applying time series data to a standard Aquator Catchment component. An alternative way is to use a catchment model component developed for use with Aquator.

One example is the Aquator HYSIM catchment component, which incorporates the HYSIM catchment model. Users with a compatible version of HYSIM will automatically find this component on the Aquator toolbar. This component may be used to supply river flows anywhere in the project. HYSIM groundwater storage can be adjusted with VBA to simulate abstractions.

Another example is the Aquator TW Aquifer component, which was developed for Thames Water. This component simulates the behaviour of chalk and limestone aquifer units in the Thames basin where abstractions from these components reduce river flows from the aquifer.

5.4.2 HYSIM

HYSIM is a hydrological simulation model (rainfall-runoff model) which uses rainfall and potential evaporation data to simulate the hydrological cycle (surface runoff, percolation to groundwater and river flow) on a continuous basis (Ref: WATRES 1). HYSIM's parameters define in a realistic way the hydrology and hydraulics of the whole river basin (watershed). Such a model is likely to perform well in climatic conditions more extreme than those in its calibration period. The diagram below shows the conceptual basis of the hydrological component of the model.

HYSIM can use data on rainfall, potential evaporation (PET), snow melt and abstractions from, or discharges to, both groundwater and surface water. Only rainfall and PET are essential. The data can be daily or any time step less than a day. The simulation time step can be daily or less than a day.

Not only is HYSIM flexible in its data requirements, it is also flexible in terms of sub-catchments and the reaches for flow routing can be either channels or reservoirs. Flow routing uses the kinematic method. Typical uses of HYSIM have included:

Using long-term rainfall and PET data to produce long-term flow records

- Flow naturalisation
- Studying the effects of climate change
- Flood studies
- Effects of improved drainage
- Groundwater recharge

The output from the model includes: overland flow, impermeable area runoff, snow storage, soil moisture storage, interflow, groundwater recharge, groundwater storage, total surface runoff, routed flow and actual evapotranspiration. Output from HYSIM can go directly into Modflow (as recharge) or ISIS (either runoff to channels or routed flow at the upstream boundary).

Complex river basins (catchments, watersheds) can be simulated as a series of linked sub-basins. To represent hydrological or climatic variations within a sub-catchment, up to three zones, each with its own parameters and data, can be defined. In addition to the simulation model HYSIM includes facilities for plotting data and simulated and observed flows and tools for data manipulation.

HYSIM uses a physically realistic approach to modelling the hydrological cycle. It simulates seven natural storages. These are: snow, interception, upper soil horizon, lower soil horizon, transitional groundwater, groundwater and minor channels.

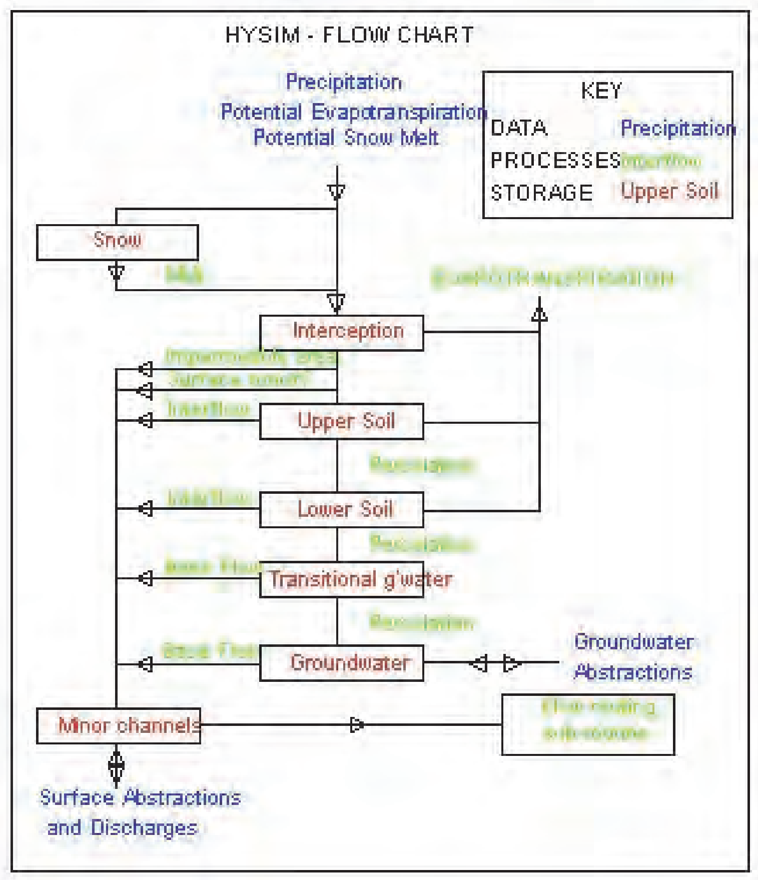

Figure 6: Hysim flow chart

The catchment being simulated can be divided into any number of sub-catchments. The sub-catchment can be divided into up to three hydrological zones, each of which should be reasonably homogeneous with respect to soil type and meteorology.

The five types of input data which the model can use are:

i) Precipitation. This is given as catchment area average.

ii) Potential evapotranspiration rate. Estimates based on an empirical relationship.

iii) Potential melt rate. This can be based on the degree day method or a more complex one.

iv) Sewage flow/direct abstractions. The net figure for these is used.

v) Groundwater abstractions.

None of the types of data is compulsory.

Snow storage. Any precipitation falling as snow is held in snow storage from where it is released into interception storage. The rate of release is equal to the potential melt rate.

Interception storage. This represents the storage of moisture on the leaves of trees, grasses, etc. Moisture is added to this storage from rainfall or snowmelt. The first call on this storage is for evaporation which, experiments have shown, can take place at more than the potential rate. This can be allowed for in the model. Any moisture in excess of the storage limit is passed on to the next stage.

Impermeable area. A proportion of the moisture in excess of the interception storage limit is diverted to minor channel storage to allow for the impermeable proportion of the catchment.

Upper Soil Horizon. This reservoir represents moisture held in the upper (A) soil horizon, i.e. top-soil. It has a finite capacity equal to the depth of this horizon multiplied by its porosity.

Lower Soil Horizon. This reservoir represents moisture below the upper horizon but still in the zone of rooting (i.e. the B and C horizons). Any unsatisfied potential evapotranspiration is subtracted from the storage at the potential rate, subject to the same limitation as for the upper horizon (i.e. capillary suction less than 15 atmospheres). Similar equations to those in the upper horizon are employed for interflow runoff and percolation to groundwater.

Transitional Groundwater. This is an infinite linear reservoir and represents the first stage of groundwater storage. Particularly in karstic limestone or chalk catchments many of the fissures holding moisture may communicate with a stream rather than deeper groundwater and the transitional groundwater represents this effect. Its operation is defined by two parameters: the discharge coefficient and the proportion of the moisture leaving storage that enters the channels. Being a linear reservoir the relationship between storage and time can be calculated explicitly.

Groundwater. This is also an infinite linear reservoir, assumed to have a constant discharge coefficient. It is from this reservoir that groundwater abstractions are made. As in the above case the rate of runoff can be calculated explicitly.

Minor Channels. This component represents the routing of flows in minor streams, ditches and, if the catchment is saturated, ephemeral channels. It uses an instantaneous unit hydrograph, triangular in shape, with a time base equal to 2.5 times the time to peak.

5.4.3 Hydro

HYDRO and HYDRO 10 are programs to simulate the operation of a reservoir on a monthly or 10-day time step (Ref: WATRES 2). They simulate hydropower generation, irrigation supply, water supply and compensation flow either individually or in combination, as well as reservoir operation for flood control.

After specifying reservoir geometry, hydropower installations and historical or synthetic series of inflows and losses, the user can define demands for water, energy and peak power, set options and priorities, minimum head criteria and rule curves that govern the way the reservoir is operated. Numerical and graphical output can be displayed for rapid appraisal of each simulation.

Written in Fortran 90 and MS Visual Basic, the programs operate under Windows95 or Windows98. The user sees only the Visual Basic screens and is able to navigate rapidly through all the pages where program operation, data input and review of results are carried out. Data and results are saved in a series of Run Files and the user can rapidly work through a series of reservoir trials in which alternative operating strategies can be examined.

5.4.4 WEAP

Allocation of limited water resources between agricultural, municipal and environmental uses now requires the full integration of supply, demand, water quality and ecological considerations. The Water Evaluation and Planning system, or WEAP, aims to incorporate these issues into a practical yet robust tool for integrated water resources planning. WEAP is developed by the Stockholm Environment Institute's U.S. Center (Ref: WEAP).

WEAP is a software tool for integrated water resources planning that attempts to assist rather than substitute for the skilled planner. It provides a comprehensive, flexible and user-friendly framework for planning and policy analysis. Conventional supply-oriented simulation models are not always adequate for exploring the full range of management options.

WEAP places demand-side issues such as water use patterns, equipment efficiencies, re-use strategies, costs, and water allocation schemes on an equal footing with supply-side topics such as stream flow, groundwater resources, reservoirs, and water transfers. WEAP is also distinguished by its integrated approach to simulating both the natural (e.g. evapotranspirative demands, runoff, baseflow) and engineered components (e.g. reservoirs, groundwater pumping) of water systems. This allows the planner access to a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future use. The result is an effective tool for examining alternative water development and management options.

WEAP operates on the basic principle of a water balance and can be applied to municipal and agricultural systems, a single watershed or complex transboundary river basin systems. Moreover, WEAP can simulate a broad range of natural and engineered components of these systems, including rainfall runoff, baseflow, and groundwater recharge from precipitation; sectoral demand analyses; water conservation; water rights and allocation priorities, reservoir operations; hydropower generation; pollution tracking and water quality; vulnerability assessments; and ecosystem requirements. A financial analysis module also allows the user to investigate cost-benefit comparisons for projects.

The analyst represents the system in terms of its various supply sources (e.g. rivers, creeks, groundwater, reservoirs, and desalination plants); withdrawal, transmission and wastewater treatment facilities; water demands; pollution generation; and ecosystem requirements. The data structure and level of detail can be easily customized to meet the requirements and data availability for a particular system and analysis.

WEAP applications generally include several steps.

Study definition: The time frame, spatial boundaries, system components, and configuration of the problem are established.

Current accounts: A snapshot of actual water demand, pollution loads, resources and supplies for the system are developed. This can be viewed as a calibration step in the development of an application.

Scenarios: A set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, hydrology, and pollution can be explored.

Evaluation: The scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

Scenario analysis is central to WEAP. Scenarios are used to explore the model with an enormous range of "what if" questions, such as:

- What if population growth and economic development patterns change?
- What if reservoir operating rules are altered?
- What if groundwater is more fully exploited?
- What if water conservation is introduced?
- What if ecosystem requirements are tightened?

- What if a conjunctive use program is established to store excess surface water in underground aquifers?
- What if a water recycling program is implemented?
- What if a more efficient irrigation technique is implemented?
- What if the mix of agricultural crops changes?
- What if climate change alters demand and supplies?
- How does pollution upstream affect downstream water quality?
- How will land use changes affect runoff?

An intuitive GIS-based graphical interface provides a simple, yet powerful, means for constructing, viewing, and modifying the configuration. The user designs a schematic of the system using the mouse to "drag and drop" elements to be added to the system. These elements can be overlain on a map built from Arcview and other standard GIS and graphic files. Data for any component can be edited directly by clicking on the desired symbol in the schematic. The user may consult the context-sensitive help feature from anywhere in WEAP. Wizards, prompts, and error messages provide advice throughout the program. With WEAP's highly flexible and comprehensive reporting system, the user may customize reports as graphical, tabular or map-based output and select from a number of formatting options (e.g. metric or English units, years, absolute levels, percent shares, or growth rates). Specific report configurations can be saved as "favorites," which can be combined into "overviews," or summaries, of key system indicators; these overviews can then be retrieved quickly for review.

Features for Integrated water resources planning system include:

- Built-in models for: Rainfall runoff and infiltration, evapotranspiration, crop requirements and yields, surface water/groundwater interaction, and instream water quality;
- GIS-based, graphical "drag and drop" interface;
- Model-building capability with a number of built-in functions;
- User-defined variables and equations;
- Dynamic links to spreadsheets and other models;
- Embedded linear program solves allocation equations;
- Flexible and expandable data structures;
- Powerful reporting system including graphs, tables and maps;
- Context-sensitive help and User Guide;
- Minimal requirements: runs under Windows 2000, XP, Vista, 7 or 8 with 256 MB RAM

WEAP consists of the following main views

- Schematic – GIS tools allow you to easily and quickly configure your system, including "drag and drop" capability to create and position system elements. Add ArcView and other standard GIS vector or raster files as background layers. Quickly access data and results for any element in the system.
- Data – model-building tools help you create variables and relationships, enter assumptions and projections using mathematical expressions, and dynamically link to Excel for data importing and exporting
- Results – detailed and flexible display of all model outputs can be viewed in graphs, tables and on the map. The graph and map formats allow for animated viewing of results through time.

- Scenario Explorer – design a group of summary graphs to highlight key system indicators for quick review. Explore how changes in data can affect results.

5.5 USA: California State

A review by the National Research Council (2010) of the biological opinions that govern operations of the Central Valley Project and the State Water Project pointed out that scientific support for water management in the Delta is weak, poorly organized, and lacking integration. The Little Hoover Commission (2005, 2010) offered similar observations, as has the Delta Vision Blue Ribbon Task Force (2008). Yet the Delta has perhaps the state's most organized and best-funded science programs to support decision making. National Research Council reviews of science for Klamath Basin management have had similar findings. It is not enough to simply state that insufficient resources have been invested in science for improving water management. Beyond an almost entirely nontechnical California Water Plan Update developed by the Department of Water Resources every five years or so, there is little to no statewide organization, prioritization, and synthesis of technical and scientific activity applied to water problems. This gap stems partly from the highly decentralized management of water. The tensions between water districts – stemming from perceived competition for resources – and institutional barriers between federal, state, and local agencies have balkanized water science and engineering in California.

5.5.1 CALSIM

The Water Resource Integrated Modeling System (WRIMS model engine or WRIMS) (formally named CALSIM) is a generalized water resources modeling system for evaluating operational alternatives of large, complex river basins (Close et al., 2003). WRIMS integrates a simulation language for flexible operational criteria specification, a linear programming solver for efficient water allocation decisions, and graphics capabilities for ease of use. These combined capabilities provide a comprehensive and powerful modeling tool for water resource systems simulation. CalSim is the model used to simulate California State Water Project (SWP)/Central Valley Project (CVP) operations.

Together, WRIMS and CalSim replaced the Department of Water Resources' planning model of the State Water Project/Central Valley Project system, DWRSIM. Unlike DWRSIM, in which the engine and model were tightly coupled, the entire system and related operational criteria in CalSim, are specified as input to WRIMS and may be modified or replaced without requiring changes in WRIMS. WRIMS and CalSim are products of joint development between DWR and Bureau of Reclamation.

The simulation of large, complex water resource systems for planning studies requires a flexible and efficient modeling tool to assist in the evaluation of rapidly changing alternatives. The California Department of Water Resources has developed a general purpose water resources simulation model, CALSIM, that enables users to quickly develop system representations and specify operational criteria. CALSIM represents a fundamental change in the modeling approach used to simulate the operation of California's water resource systems, particularly the coordinated operation of the Federal Central Valley Project (CVP) and the California State Water Project (SWP). Model users now specify the system objectives and constraints as input to the model, rather than embedding the simulation goals and logic in thousands of lines of procedural code as is common in traditional simulation models. While CALSIM is not a prescriptive optimization model, it utilizes optimization techniques to efficiently route water through a network given user-defined priority weights. A linear programming (LP)/mixed integer linear programming (MILP) solver determines an optimal set of decisions for each time period given a set of weights and system constraints.

The physical description of the system is expressed through a user-interface with tables outlining the system characteristics. The priority weights and basic constraints are also entered in the system tables. A new modeling language, Water Resources Engineering Simulation Language (WRESL), has been developed to serve as an interface between the user and the LP/MILP solver, time-series database, and relational database. Specialized operating criteria are expressed in WRESL. The WRESL expressions can be compartmentalized to provide for a highly organized arrangement of logical units and to serve as self-documenting modules.

Once the WRESL statements have been converted to Fortran90 code, relational and timeseries data are read from separate databases. CALSIM utilizes the HEC-DSS time-series data storage system developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center in Davis, California. Hydrologic data spanning a 73-year period are currently stored in this database. Relational data such as index-dependent flow standards and monthly flood control diagrams are stored in simple, text-based, relational tables. WRESL statements, using SQL-type syntax, allow access to the relational and time-series data. Once the relational and time-series data are read from the databases, the entire problem is assembled into the proper format and passed to the solver. The MILP solver performs the necessary solution algorithms and returns the decision variable results to the time-series database. Diagnostic information from the solver is passed to the controlling user-interface and individual output files. The process involving the generated code, data access, and solver is repeated for each time period until the simulation is complete.

The CALSIM model represents water resource systems, consisting of reservoirs and channels (natural and artificial), as a network of nodes and arcs. Nodes in the network may represent reservoirs, groundwater basins, junction points of two or more flows, or simply a point of interest on a channel. Arcs represent water flows between nodes, or out of the system, and may be inflows, channel flows, return flows, or diversions. An example network is shown in Figure 7.

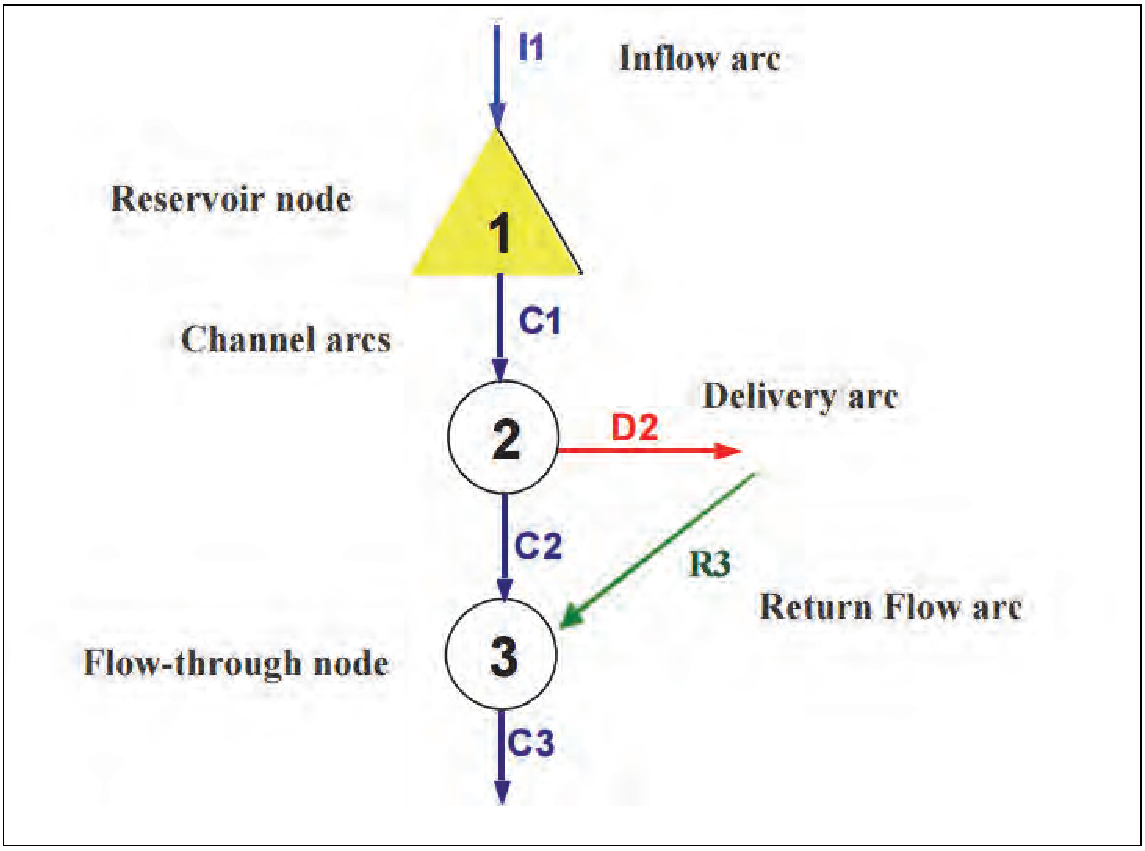

Figure 7: Example of CALSIM network

The mathematical formulation used in the CALSIM model consists of a linear objective function and a set of linear constraints. The objective function describes the priority in which water should be routed through the network and the constraint set describes the physical and operational limitations toward achieving the objective. CALSIM maximizes the objective function in each time period to obtain an optimal solution that satisfies all constraints. Priority weights assigned to variables (flow or storage) in the objective function describe the relative importance of that particular variable in the system operation.

CALSIM II represents a state-of-the-art modeling system that is similar in general concept, while differing in specific details, to other data-driven river basin modeling systems such as ARSP, MODSIM, OASIS, REALM, RiverWare and WEAP.

CALSIM II currently consists of a combination of software modules developed in several languages, including FORTRAN, Java and C. Several of the modules require proprietary software packages in order to run CALSIM II (Lahey FORTRAN and XA Solver). DWR and USBR staff have said that these components are being replaced by public domain software that can be obtained free of charge. Very good public domain software packages of optimization, visualization, file management, and data base support are currently available, and new ones will continually be produced. Periodic updates should be anticipated as part of the business of maintaining the modeling system. Significant thought should be given to the sustainability of the CALSIM II software. How will future programmers be able to maintain this software? How will future software developments be incorporated into the system? Will the solver currently being developed by LBNL be adequate in terms of accuracy and computation speed? Will other solvers need to be tested? Can the system accommodate these future developments without major modifications? What reasonable modifications could be made now in anticipate of future developments?

Some of these strengths include:

- Consensus model. CALSIM II is the official joint modeling environment of the State DWR and USBR. This includes a common schematic, hydrologic representation of the system, common set of facility capacities, and common representation of system operating policies. This helps all parties improve representations, rather than compete over representations.
- Common effort. The joint development of CALSIM II by USBR and DWR has provided more focused and effective use of resources and expertise than previous development of agency-specific models. CALSIM II development has also involved other agencies and consulting expertise more than previous models of this system.
- Data-driven model. CALSIM II is a rather data-driven simulation model with an optimization engine. This modeling approach provides greater flexibility than its predecessors and traditional water resources simulation approaches and a promising framework for improving transparency, data, and model documentation, compared to other approaches.
- Public domain. The model and data are substantially in the public domain, facilitating transparency and adaptability for California's decentralized water system.
- Steady improvements. Data improvements have been steadily pursued following the adoption of CALSIM II, although deficiencies remain.
- Improved Delta water quality representation. Although problems appear to remain, the model developers have made substantial gains in representing Delta water quality operating criteria and performance.
- Better groundwater representation. Efforts to better include groundwater and non CVP-SWP project operations merit continuation and expansion.
- Benchmark Studies. The development of documented benchmark studies have resulted in significant model improvements and aided in the development of comparative model applications. Such exercises should be continued and improved.
- Long-term vision. The vision of a more transparent and publicly available model that can be employed by those outside the major agencies is excellent. This is a major change in direction, and achieving this vision will require adjustments over time. Often, these adjustments will be externally driven. Externally-driven improvements are a price of success and evidence of success for an open, public, modeling policy.

As its strengths are many, so are its weaknesses. It seems worth saying, however, that no model can perfectly (meaning efficiently and effectively) serve all interests in a system as complex as the CVP-SWP. Tradeoffs need to be made. This can result in what some would call weaknesses. Such weaknesses are often accepted to gain strengths in another ways. Some say the CALSIM II model is too complex. Some believe that it does not handle particular components of the system with sufficient detail. And such is the dilemma of any complex model, such as CALSIM II. The model is clearly too complex, and not complex enough. The root of this difficulty is that when such a model is constructed, it is not clear what level of detail is needed, so the model must be made sufficiently complex to ensure it is complex enough. And the complexity needed to address some issues will remain in the model when it is used to address other less complex issues, or the same issues at less complex locations. One approach to addressing this issue is to develop different linkable modules of CALSIM II having different complexities. In this way the level of detail can be varied to be consistent the application or study at hand, and level of sophistication and resources available to the user. Other weaknesses model users would like addressed include:

- The model provides limited and inadequate coverage of non CVP or SWP water and of the California water system south of the Delta.
- The model assumes that facilities, land-use, water supply contracts and regulatory requirements are constant over this period, representing a fixed level of development rather than one that varies in response to hydrologic conditions or changes over time.
- Groundwater has only limited representation in CALSIM II.
- Groundwater resources are assumed infinite, i.e. there is no upper limit to groundwater pumping.
- The linear programming model considers only the current month, and hence CALSIM II operating rules are required to determine annual water allocations, to establish reservoir carryover storage targets, and to trigger transfers from north of Delta to south of Delta storage.
- Better quality control is needed both for the model and its current version and the input data. Procedures for model calibration and verification are also needed. Currently many users are not sure of the accuracy of the results. A sensitivity and uncertainty prediction capability and analysis is needed.
- Need improved ways of altering the model's geographic scope and resolution and its temporal resolution to better meet the needs of various analyses and studies.
- Need to improve the model's comparative as well as absolute (or predictive) capabilities.
- CALSIM II needs better capabilities for analyzing economic, water quality, and groundwater issues.
- Need improved documentation explaining how the model works, its assumptions, its limitations, and its applicability to various planning and management issues.
- DWR and USBR have not provided a centralized source of support for CALSIM II. More training for CALSIM II is needed. There is a need for more people who can run CALSIM II. There is a need for a well-publicized user group. A more extensive users' guide is needed.
- Improved capabilities are needed for real-time operations especially during droughts, gaming involving stakeholders during a simulation run, handling of evapotranspiration and agriculture demand changes over time, water transfers, Delta storage, carryover contract rights, refuge water demands and more up to date representation of Feather River, Stanislaus River, Upper American River, San Joaquin River and Yuba River operations.
- Need an improved graphical user interface to facilitate input of model data, setting of model constraints and weights, operating the model, and displaying and post analysis of model results.
- Need to be able to change the model time period durations for improved accuracy of model results.

6 COMPARISONS

6.1 Overall

Table 3 presents an overall summary of selected data for the countries assessed. When comparing, it becomes evident why Australia and the USA have selected to manage their water resources on a State by State basis due to the large size of the States. South Africa is the driest in terms of mean annual rainfall across the country. Brazil has by far the highest runoff, with New South Wales lower then South Africa's. The literature reviewed showed that England is unique in water management with the concept of the privatisation of water.

Table 3: Summary of information per country

	South Africa	Australia: New South Wales	Brazil	England	USA: California State
Land Area (km^2)	1 221 000	809 444	8 516 000	130 395	423 970
Population (million)	52.98	7.54	200.4	53.01	38.8
Rainfall (mm)	450	554	1739	885	563
Runoff ($x10^9\ m^3$)	50	30	5667	50	86
Runoff (mm)	41	37	665	383	203

6.2 Legislation

The legislative approaches for the five countries that were compared tend to be fairly similar. All use terms such as sustainable, integrated and participatory. South Africa, as with the others assessed, has recognized the need to include many levels of participatory inputs. It is interesting to note that all the countries are using legislation that has been updated or changed since the 1990s. Whilst South Africa's changes may have been originally motivated by the changing political environment, all the countries appeared to see the need to modify their legislation surrounding water in the late 20th century. This was probably due to a worldwide mind shift that recognised the need to protect water resources, focusing especially on the environment. Australia's specific motivation was the apparent poor river health that became evident around that time.

South Africa and Australia's Acts are very similar, with many common threads. Brazil did not completely rewrite their legislation, but rather chose to add to it. One of the significant changes to Brazil's legislation was to recognize the need for equality amongst the different water user sectors. South Africa's legislation also highlights the need for equality, however, this is more related to demographics and the previously disadvantaged than it is amongst user sectors.

The Australian legislation appears to focus quite substantially on water trading and recognizes the economic value of water. This has not yet been addressed in the South African context and requires further investigation.

Both England and Brazil's legislation make mention of the "classification" of water resources and "resource quality objectives". This is something that South Africa is currently focusing on, as it also forms part of the National Water Act's requirements.

An interesting aspect to the California legislation is that they view urban uses as the highest priority with irrigation second. They maintain that irrigation is directly liked to food production, and, as a result, should be allocated a high priority. In South Africa, irrigation has traditionally been one of the lower priority users due to the large inefficiencies in the sector and the concept that farmers can withstand longer periods of drought than other more strategic users. It would be interesting to elaborate on this assumption in the context of food production during drought periods and whether the notion still stands that irrigators waste a significant amount of water due to inefficient systems.

The English legislation appears slightly different due to the focus on competition amongst companies as a result of privatisation of the sector.

Despite the long time period between the promulgation of the Acts in South Africa and Australia, both countries are struggling to implement all the requirements. It was noted that some of the requirements that originally appeared simple (such as setting up Catchment Management Agencies and compulsory licensing) have been problematic to implement and are taking longer than originally anticipated, with Australia moving away from Catchment Management Agencies in favour of Local Land Services.

Australia has had to put a physical cap on the Murray-Darling water resources due to the over allocation and use of water there. South Africa can learn from this approach, especially in some of the northern areas where large deficits in the available and required water balance exist.

6.3 Typical studies and Documentation

As with the legislation, many similarities exist between the countries in terms of the typical studies undertaken and documentation required to be produced to manage their water resources. The overall feeling is that South Africa is on a par in the documentation requirements, and appears ahead when it comes to studies and approaches to manage the water resources on an annual basis. However, the delay with setting up of Catchment Management Agencies has resulted in some areas not having adequate strategies to manage their water resources as yet, and this is an area of concern.

In Australia the Water Resource Assessment Studies are similar to South Africa's WRC Water Resources Studies which are carried out on an ongoing basis. Brazil also does this with the National Water Resources Information System. All see the need for and promote the concept of a central storage of water resources information, which should be continued in South Africa.

Australia's required Water Resource Plans are similar to South Africa's Catchment Management Strategies, though South Africa lags behind in producing these due to the delay in establishing the Catchment Management Agencies. The interim Reconciliation Strategies for the selected larger areas are acting as a substitute in the meantime. Australia's rules to meet Resource Quality Objectives are set out in the Water Resource Plans, and similarly should be included in South Africa's Catchment Management Strategies when undertaken.

South Africa's planning horizon of 25 years (up till 2040) appears in line with the others, with England using 25 years, California 20 years and Australia 10 years.

The Australian approach of carrying out an annual water assessment appears similar to South Africa's Annual Operating Analyses. Broad comparisons, however, show that the Australian approach does not seem as sophisticated nor efficient with a very conservative initial result which can improve as the year goes on. South Africa's approach of carrying out the analyses once at the start of the operating year and the result being implemented throughout the year appears more effective, as users will obtain a better indication of what they are likely to receive for the entire year initially. It is unclear how the Australian system affects farmers who would need to know prior to planting what they are likely to receive.

The English approach to preparation of plans stresses the need for consultation with stakeholders. It appears that, in England, the task of ensuring the availability of future water resources also falls with the water service providers. It also appears that the concept of a wider basin planning approach and the need for coordination of water companies sharing water resources within a basin is relatively new. South Africa has been using this catchment wide management concept for many years now.

In California there is a need for urban water suppliers to do long term planning. It appears there is a strong guidance and support basis to develop the required plans. This should be learned from in South Africa, where closer communication and support as well as uptake of responsibility is required between DWS and Municipalities. Perhaps the establishment of the CMAs will address this.

6.4 Institutions

While it appears necessary to manage the countries on a State level due to their large sizes, New South Wales in Australia, California in the USA and Brazil all struggle with management relating to State versus Federal governments. The States are usually given the mandate to manage, however, they still need to adhere to federal rules. In addition, there appears to be a major issue of governing boundaries not being the same as catchment boundaries. In South Africa the approach to manage per Water Management Area is sound as it eliminates this issue. The other countries are forming other organizations represented by various States (e.g. The Murray-Darling Basin Authority) to overcome the problem.

The Australian movement from CMAs to Local Land Services has resulted in the amalgamation of water management with the Agricultural Department and this has come with problems. These include the functions of staff in these offices. New South Wales has a total of eleven Local Land Services for an area of 809 444 km^2, whereas South Africa will have nine CMAs for its size of 1 221 037 km^2. The long time in establishing these CMAs (currently only two operate) is a growing concern.

Brazil is attempting to decentralize and get management levels closer to the users. Again, the English management system appears significantly different due to the privatisation of water supply. As mentioned previously, they have only recently seen the need for an additional tier of management to cross catchment boundary levels.

6.5 Models

Literature on water resources modelling in Australia makes mention of a Modelling Community and places a strong emphasis on the requirement to exchange issues, ideas and suggestions for users. South Africa is considered weak in this regard, and, while it was previously set up and maintained, this has all but stagnated to date. The ad hoc exchange of ideas does take place, however, there is a need to build on this and allow for more users to participate and share information. California mentioned the backup support for the use of their main model CALSIM also lacks and should be improved. They state that there is a need for a well-publicized user group.

Another aspect to learn from in the Australian context is the significant funding they put behind the development, maintenance and improvement of their water resources models. It is evident that they understand the importance of the models. One project quoted a sponsorship totaling $60 million over a seven-year period (that's approximately R1 million per year for seven years), in which the country is dedicated to building an Integrated Catchment Modelling Toolkit for use by the natural resources management sector. Another report mentioned that the "Parliamentary Secretary for Sustainability and Urban Water, Senator Don Farrell, today announced that the Gillard Government would provide almost $4 million to support the adoption of the eWater 'Source' platform to aid water planning and management across Australia to better model water distribution in Australia".

In contrast, in South Africa funds appear to be limited. While significant funding has gone into the development of the modelling techniques to date, these funds appear to have decreased significantly, with very little model improvement and maintenance budgets being provided. The model developers appear to be doing what they can on an ad hoc basis, however, no formal improvement and maintenance funds are forthcoming.

An obvious strength in the South African water resources sector is the many years of using one standard approach. This was not the case in the other countries, and all made mention of the problems arising with different States and organisations using different modelling approaches across catchment boundaries. These countries are now on a path to attempt to standardize and to select one modelling tool across the board. Certain users in South Africa are promoting models that differ to the standard approach, however, the comparison shows the strength in the concept of one approach. Continuity in time and across catchments is maintained if the same approach is used, and this has been recognized by the international countries.

The Brazilian water resources modelling sector appears to have moved into using GIS systems linked with modelling tools to improve model communications and Stakeholder understanding. The standard South African water resources models are lagging behind in this functionality, again a result of the lack of funding and further development in recent years. There was previously an attempt to move the stand alone model versions over to more understandable user friendly interfaces, however, the development of these has also been slow and many users have moved back to the original, less user friendly approach. Links to GIS are all but nonexistent, and graphical capabilities cumbersome.

Brazil has many rainfall-runoff models which all appear to do a similar task and are based on a similar approach. South Africa can learn from this and rather streamline efforts to maintain a few, widely used models then to spread the resources too thinly for a wide variety. A careful assessment should be carried out as to which models are used in practice, and the resources should be targeted at these. There seems to be a clear divide in South Africa between models developed and used for research purposes by academic institutions and those used by practitioners. In Brazil, it appears that the Universities work alongside with practitioners, all developing models for a common cause.

The literature reviewed was not clear on the most appropriate time step for water resources management modelling, with some countries preferring daily, even hourly, models, and others (such as South Africa) stating monthly modelling is sufficient. It was evident for some of the studies utilizing daily time steps the major effort in configuring the models, and the required focus on the set up as opposed to the model results.

It was interesting to note the approach by Australia to move the custodianship of the models to eWater, a similar institute to South Africa's WRC. It appeared that the institute is more efficient and effective in carrying out the modelling enhancement and support than the governmental institutions. The advantages of this should be further investigated in South Africa where a lack of control by the current custodian (DWS) has resulted in many model versions being used and ad hoc changes being made throughout the sector.

The modelling focus on climate change appears significantly stronger internationally, with limited practical studies being carried out in South Africa in this regard.

The South African standard models appear to be lacking in the graphics and results presentation capabilities. Most other models reviewed often quoted the graphical capabilities as key features. The DWS user interface was developed to address this, however, slow progress in development has resulted in users having to produce their own ad hoc solutions to present results.

A similarity amongst many of the models assessed is that they use linear programming and arcs with penalties to drive flow and decisions. This is exactly as the South African models do. Many appear to be taking existing models and building additional functionality into the framework for ease of use. Most say there is an advantage in the ability to adjust operating rules that are not hard coded into the model. It appears that there is a new drive to explore further use of free software in the model development, and South Africa should definitely consider investigating this option.

The standard international approach appears to be to consolidate many models together, and this would significantly assist in the South African context. The current approach is cumbersome, with the three main models all requiring similar data in different formats. Configuring one set of data which can be used by the Pitman, WRYM and WRPM models would greatly add value to the modelling sector by eliminating the time required for individual configurations. It is strongly advised to investigate the potential to use a combined interface for all three models. In addition, the English appear to be harnessing other tools such as Visual Basic to improve their models. It does appear, however, that the typical models used there are of a more simplified nature to what is used in South Africa. In addition, literature indicated that the English system should move towards a "risk based water resources planning approach", a methodology that has been used in South Africa for many years.

The South African models have many similarities to CALSIM used in California. Overall, in terms of the models used, it is evident that South Africa is up to standard in terms of the model capabilities, however, appears to now lag in the graphics capabilities and GIS functionality. Improvements can be made to the maintenance and enhancement approach, and utilizing the benefits of open source software should be investigated.

7 CONCLUSIONS AND RECOMMENDATIONS

A literature review summarizing the water resources management approaches used in South Africa and four international countries has been carried out. The countries selected were Australia (the State of New South Wales), Brazil, England and the State of California in the USA. The areas focused on have included Water Resources Management legislation, typical documentation and studies carried out, Institutional arrangements and Modelling capabilities. Key differences have been highlighted, and where possible, recommendations for improvements to the South African approach have been made based on the international approaches.

As a result of today's internet capabilities, a significant amount of literature is available on line. It became evident during the study that the topics covered were possibly too wide, and selected areas should have been focused on to gain more insight on a specific issue. It is believed that this literature review, however, does include a broad basis from which further investigations into more specific areas could be carried out if required.

The general conclusion is that South Africa, though for many still considered a developing country, currently maintains a very high standard in managing its water resources, and is comparable to some of the most developed countries in the world. It appears that, when comparing management approaches, South Africa was, for many years, leading the group. However, it appears that in recent years, a stagnation of further maintenance and development of the techniques used has allowed others to catch up and possibly even move past. It is believed that South Africa can learn from the other countries when it comes to model development, though the actual modelling approach and methodology (risked based) used are still very highly rated.

It is recommended that:

- The legislative requirements for managing the South Africa's water resources be adhered to, and that the establishment of all Catchment Management Agencies take place without further delays.
- Mechanisms be put in place to further transfer knowledge and support from the National Department of Water and Sanitation to the Municipalities who have the responsibility of managing their own water resources.
- South Africa continues to use the standard modelling tools and methodologies that have been used in the past, as the continuity and consistency of modelling techniques has been seen to be a strength, and the models compare very well with what is used internationally.
- South Africa build further on the existing tools to include GIS technology and explore the option of open source software.
- South Africa continues to provide funding for the enhancement and maintenance of the modelling tools.
- A strong support group for the users of the water resources management tools is established in order to share ideas and assist one another.
- South Africa implements a toolkit where all models are centrally stored and can be accessed, and where the need to duplicate model configuration is eliminated.

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