A Pulse Study on the State of Water Research and Development in South Africa

Report to the
Water Research Commission

by

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Abbreviations

CSIR – Council for Scientific and Industrial Research

DHEW – Department of Health, Education and Welfare

EC – European Commission

EUROSTAT – European Statistics

FCCSET – Federal Coordinating Council for Science, Engineering and Technology

GBAOARD – Government Budget Appropriations or Outlays for R&D

GDP – Gross Domestic Products

HRST – Human Resources for Science and Technology

ICT – Information and Communication Technologies

IEA – International Energy Agency

IPRs – Intellectual Property Rights

ISI – Institute for Science Information

JPO – Japanese Patent Office

NIH – National Institutes of Health

NRF – National Research Foundation

NSB – National Science Board

NSF – National Science Foundation

OECD – Organisation of Economic Cooperation and Development

OST – Office of Science and Technology

OTA – Office of Technology Assessment

R&D – Research and Development

RaDiUS – R&D in the United States

RD&D – Research, Development and Demonstration

S&T – Science and Technology

S,T&I – Science, Technology and Innovation

SA – South Africa

SCI – Science Citation Index

SIS – Science Indicators System

STA – Science and Technology Agency

TBP – Technology Balance of Payments

TTL – Title

UCT – University of Cape Town

UNESCO – United Nations Educational, Scientific and Cultural Organization

USA – United States of America

USPCS – US Patent Classification System

USPTO – US Patent

WRC – Water Research Commission

Executive Summary

This document has been prepared on the request of the Water Research Commission (WRC) in order to inform "The *Pulse Study on the State of Water R&D* in South Africa". This study will be one of the first attempts to obtain a quantitative account of key R&D trends in the sector.

The section "Science Indicators Systems: Rational and Review" elaborates on the uses of systems of indicators (mainly for policy assistance) and their characteristics. It is suggested that indicators should reflect their purpose and the ways of intended usage and they should be useful for inter-temporal analysis and compatible with similar indicators abroad. The latter two prerequisites assure trend analysis and international benchmarking.

The following chapter "OECD Recommended S,T&I Indicators" provides information related to the OECD recommendations about the development of indicators. Furthermore, the chapter refers to the OECD manuals which are used internationally for the development of monitoring and assessment indicators. Reference is also made to "IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics" (2011) by the International Energy Agency. The latter is of interest as it is a manual providing definitions and guidelines for the collection of R&D expenditure data in another multidisciplinary research field, the field of energy.

The chapter "Indicators for Water Research Monitoring and Assessment" elaborates in more detail about the indicators which can be used as the basis for a water research system of indicators. Bibliometric indicators are identified as being able to provide valuable inputs in the monitoring of research fields. They can provide information about the evolution of a field over time; comparisons of the performance of a particular discipline in various countries; identify prolific researchers and institutions and so on. Similarly for technological fields, patents can provide useful information. Other indicators of importance are the expenditures on R&D in a particular field and the growth or otherwise in the number of post-graduate students (Masters and PhDs) with focus in the scientific field under investigation.

It is argued that monitoring and assessment of the field of "water research" faces particular challenges arising mainly from the fact that water research is not a coherent, well-defined field of research.

The chapter "Bibliometric Analysis" provides quantitative information related to water research publications in South Africa. The analysis identifies that the field is performing above expectation in comparison with the country's research size (activity index). It is argued that this performance is the result of the existence of a dedicated agency for the support of the field in the country – the Water Research Commission.

South Africa's water research is ranked 19th in the world while the total country is ranked 33rd. It should be noted however, that a number of countries with smaller populations like Canada and

Australia and smaller GDP per capita like India and Brazil produce more relevant knowledge than South Africa.

Identification of the country's producers of research in the field shows that the country's research is distributed to a variety of centres creating subcritical groups.

Environmental sciences are identified as the most important sub-discipline in the field of water resources. Certain disciplines that may be of importance for the field e.g. economics, management, energy, etc. attract little research.

The following chapter "Patent Analysis" identifies the country's performance in terms of patents granted to South African inventors in the field of water by the USPTO. It is identified that South Africa is producing more inventions in the field of water than the comparator countries proportionally (i.e. number of patents in water as a proportion of total patents granted in the country). However, it is emphasized that South Africa is granted a very small number of patents in general from the USPTO.

The final chapter "Discussion and Recommendations" elaborates on the findings and advances the following recommendations:

- The focused support by the WRC is argued to be to a large extent the driving force behind the success of water-related research in South Africa. Government can use the WRC success as an example for implementation and institutionalization of R&D in other areas of national priority.
- The identified distributed character of water research in the country, even though a national characteristic, may adversely affect productivity and economies of scale in the field. It will be important for WRC to examine the issue further and take appropriate action (e.g. establish centers of expertise with critical mass of researchers in focus areas).
- The disciplinary emphasis of the country's institutions indicates that researchers move on their own to specific scientific areas without any particular guidance or cognizance of priorities/diversification. It will be important for WRC to identify research priorities through appropriate approaches (e.g. foresight) and allocate resources accordingly to promising areas. Such an approach will focus resources (human and financial) to areas of importance and has the potential to bring research closer to application.
- Monitoring and evaluating the various facets of the scientific enterprise is a necessary and integral part of science policy. The "Pulse Study" on the State of Water R&D in South Africa is the first attempt to obtain an account of key trends in the sector. Following international best practice it is recommended that the effort should be institutionalized with a relevant report produced every two years. The experience of the National Science Foundation in the USA could be used as a guideline.
- The report identifies two sets of additional indicators that should be developed and be included in the "Pulse study". The first set of indicators, of importance for disciplinary

assessment, is the R&D expenditures. It is emphasised that it will be of importance for the field and the WRC to develop an appropriate methodology based on the GBAOARD approach of the Frascati manual and collect and publish the relevant data regularly. The information has the potential to identify government research priorities in the water sector and guide research inputs to appropriate fields. The second set of data is related to human resources development. It is important to monitor the number and direction of post-graduate students (masters and PhDs) in the field of water research. The WRC should undertake the inclusion of such information in the "Pulse Study".

Introduction

One of the most efficient and objective methods of assessing research and innovation performance is through scientometric indicators. An indicator is defined by the United States Department of Health, Education and Welfare (DHEW, 1970) as "statistics of direct normative interest which facilitates concise, comprehensive and balanced judgments about the condition of major aspects of a society. It is in all cases a direct measure of welfare and is subject to the interpretation that, if it changes in the "right" direction, while other things remain equal, things have gotten better or people better off."

Currently indicators are published routinely to inform the relevant authorities of the state of science, technology and innovation internationally. In the United States of America the National Science Foundation (NSB 2010) uses indicators to monitor the health of American science and technology on a continuous basis; in Europe the European Commission (EC 1997) uses similar approaches in order to monitor the health of the European innovation system; the *Observatoire des Sciences et des Techniques* (OST, 2008) in France produces the biennial report "Science and Technology Indicators" and the Organisation for Economic Cooperation and Development (OECD 2010) uses indicators for monitoring and comparative purposes.

In this report we elaborate on the indicators that will be useful for monitoring and assessing the state of water research in South Africa and we develop bibliometric and patent indicators for water research and invention in the country.

Science Indicators Systems: Rationale and Review

The need to provide the basis for informed policy formulation and analysis has been the main reason for the development and collection of science and technology indicators internationally.

Monitoring and evaluating the various facets of the scientific enterprise is a necessary and integral part of science policy. Rising costs of research and development and competing disciplinary claims for financial resources require intelligent allocation of resources, which presupposes knowledge of the activities and performance of the innovation system. One of the most efficient and objective methods of assessing research and innovation performance is through indicators. Disciplinary and national assessments (Rojo et al. 2005; Dastidar et al. 2005; Schummer 2004; Pouris 2005; Jeenah et al. 2008) based on quantitative indicators are used internationally in support of policy development. There is a growing awareness of the advantages of basing opinions and subsequent choices on criteria that lend themselves more to quantitative evaluation. Science policy reviews would seem inconceivable today without recourse to existing indicators. Disciplinary assessments are used as benchmarks for the identification of effectiveness of policy instruments, for the support and justification of funding to political authorities, for identification of international collaborators, centres of excellence and so on.

There is a multitude of users and uses of indicators.

Public policies whose purpose is to influence innovation, either directly or indirectly, include:

- R&D support programmes;
- corporate tax policy;
- intellectual property rights and antitrust enforcement;
- environmental and health and safety regulation;
- economic development programmes; etc.

Each policy area has its own information requirements for uses ranging from programme impact analysis to the identification of technology trends in particular industries.

Furthermore, information on the chain from R&D to innovation informs government budget decisions regarding the allocation of funds in support of science and technology. To address the basic question of how much the government should spend on R&D and in what fields information is required on the benefits and costs of subsidising R&D and on the market failures that justify government intervention. Private initiatives left to them will not produce socially optimal results.

In addition to meeting public policy information needs, science and technology data contribute to private corporate planning and benchmarking.

This multitude of users and uses of the S&T indicators and the consequent financial trade-offs have led to efforts to develop science indicator systems consisting of prudently organised indicators.

The underlying rationale is that the development of indicators to be included in any SIS should reflect its purpose and the ways of intended usage.

Long term objectives such as comparability of data over time and with other countries have to be balanced with the most pressing local policy issues and current trends. For example, do the indicators offer pronouncements on the increasing cross-national R&D investment, on the collaboration between business and universities, on the growing importance of the service sector R&D and on the emergence of new industries such as biotechnology and nanotechnology?

The Science and Technology Agency (STA 1986) in Japan investigated the issue of SIS in the process of the development of their system. The main findings of that analysis underpin the current theoretical and empirical understanding of SIS and we elaborate on them briefly.

STA argued that a SIS should have the following characteristics:

First, a SIS should be used to grasp the *status quo* of the country's scientific and technological activities or of particular domain.

Second, it should be amenable to be used to set goals which will be attained within a certain time period.

Third, it should be used to formulate and evaluate alternative policies which have been or will be implemented.

Based on the above purposes of the indicators, STA derived the following typology:

Reporting indicators

The purpose of this type of indicators is to measure the various aspects of the present scientific and technological (S&T) activities as accurately as possible. From the policy maker's viewpoint, this type of SIS can be utilised as an early warning system for S&T activities.

Judgement indicators

The purpose of this type of indicators is to formulate national goals of S&T. Some goals must be decided concerning a country's timetable of S&T activities during a specified time period.

In order to transform the reporting type into the judgement type, the selectively chosen indicators must be organised. These indicators, which are selected to measure the current status of a specific country's S&T activities, should be consistently compared with the time series data of the country and with the corresponding data of other countries.

Through such transformation, policy-makers can utilise SIS as the basis for formulating national goals of S&T activities.

Evaluation indicators

The purpose of this type is to examine the causal relationships among indicators. The system must be further organised so that some statistical analysis could be made on the relationships among the indicators.

STA concluded that almost all existing "science indicators" were of the reporting type, although occasionally some attempts to construct a judgement type of "science indicators" are being made in various countries. However, such attempts have not yet been on a systemic and regular basis.

Nevertheless, this typology shows that reporting type indicators are the basis for the two other types. In other words, the various types and purposes of SIS can be constructed based on the reporting type. Thus, efforts should be centred on the development of a reporting type SIS.

STA has further argued that R&D activities are performed within a more general scientific and technological infrastructure and that the S&T infrastructure is formed on the basis of a more general "societal infrastructure" which supports a country's activities. Consequently SIS should contain indicators reflecting the various infrastructures such as S&T infrastructure (education, economy, culture); R&D infrastructure (e.g. input elements, institutions, etc.). The main categories identified were: S&T infrastructure; R&D infrastructure and R&D results. Additional categories but with fewer indicators included S&T contribution (industrial, international and societal) and societal acceptance.

The Office of Technology Assessment (OTA 1991) in the USA has investigated the adequacy of the US SIS. Table 1 shows the matrix of types of information and their primary users.

The conclusion of the report was that better data on the federal research system are instrumental for the creation and refinement of research policies; that Congress needs agency and budget specific data, while the agencies need data related to the performance of their programmes and their constituent research projects and that depending on data collected by NSF and NIH risks generalising results and trends that might not apply to the system as a whole and vice versa.

Table 1: Desired data and indicators in the USA

			Primary Users			
Category	**Description**	**Method**	**Congress**	**Agencies**	**OMB**	**OSTP**
Agency funding allocation method	Funding within and across fields and agencies	Agency data collection (and FCCSET)	*		*	*
	Cross-agency information on proposal submissions and awards, research costs, and the size and distribution of the research work force supported					
Research expenditures	Research expenditures in academia, federal and industrial laboratories, centres, and university/ industry collaborations	Agency data collection	*	*	*	
	Agency allocations of costs within research projects, by field					
	Megaproject expenditures: their components, evolution over time, and construction and operating costs					
Research work force	Size and how much is federally funded	Lead agency survey	*	*		*
	Size and composition of research groups					
Research process	Time commitments of researchers	Lead agency surveys;		*		
	Patterns of communication among researchers	Onsite studies				
	Equipment needs across fields (including the fate of old equipment)					

			Primary Users			
Category	**Description**	**Method**	**Congress**	**Agencies**	**OMB**	**OSTP**
	Requirements for new hires in research positions					
Outcome measures	Citation impacts for institutions and sets of institutions	Bibliometric surveys of industry and academia	*	*		*
	International collaborations in research areas					
	Research-technology interface, e.g. university/ industry collaboration					
	New production functions and quantitative project selection measures					
	Comparison between ear-marked and peer-reviewed project outcomes					
	Evaluation of research projects/programmes					
Indicators	Proposed success rate, PI success rate, proposal pressure rates, flexibility and continuity of support rates, project award and duration rate, active research community and production unit indices	Agency analysis	*	*		*
Source: Office of Technology Assessment, 1991						

It should be mentioned that the majority of the above indicators are quantitative in nature. Quantitative assessments have a number of advantages over qualitative approaches (e.g. peer review). For example, they are repeatable and verifiable exercises. They are not dependent on the choice of experts and their opinions which may vary as the choice of the participants' changes. Probably their most important advantage is that they allow comparisons among different scientific disciplines and different countries. Both types of comparisons are not possible through peer review approaches as it is almost impossible to find peers with expertise in different scientific fields and knowledge of the research systems in different countries.

OECD Recommended Science, Technology and Innovation Indicators

OECD has been one of the first multilateral organisations to investigate the relevant issues related to indicators even though historians argue that OECD duplicated NSF approaches (Godin 2001). Other important organisations in the field are UNESCO, EUROSTAT and NORDFORSK. In 1963, OECD produced guidelines for the collection of input data to R&D known as the Frascati Manual.

R&D input data has been the predominant policy variables for almost 20 years when the move away from the linear model of innovation brought to the surface the limitations of the R&D input statistics and profoundly articulated the need for additional indicators.

The following are indicators whose development is recommended by OECD currently:

R&D Expenditure Statistics

The collection of R&D expenditure statistics started in the 1960s supported by the rapid growth of the amount of national resources devoted to research and experimental development. The amount of money spent on R&D has been the primary input indicator for decades and has been used as a measure of how much research is being performed. The major advantages of using expenditure data as an indicator are that they are easily understandable, readily available, have been consistently gathered over time and they can measure efforts in different project, disciplines, sector, etc. according to same unit.

The straightforward rationale — the more R&D spending, the more innovative the activity — is the primary advantage to using expenditure data in policy discussions. Its simplicity and close ties to the linear model of innovation allow it to be readily understood by those with little specialised knowledge, making it appealing in policy discussions. These same simplifying characteristics may have led to its use in other areas. In some contexts, countries and companies are categorised according to their technological sophistication on the basis of their R&D spending levels; little attention is given to other factors.

It should be mentioned that the Frascati Manual identifies two different approaches for the collection of data – the researcher-based approach and the Government Budget Appropriations or Outlays for R&D (GBAORD). The two approaches are complementary. The major difference between GBAORD and the data collected by the R&D Surveys is that GBAORD is derived from government budgets while the R&D Surveys are performer-based. GBAORD can identify the amounts that government ministries spend for various objectives (e.g. energy, water et cetera).

The important differences are:

- GBAORD based objectives reflect funders perceptions while R&D survey data reflect performers objectives. As far as objectives are concerned the differences may be substantial.

- GBAORD data also cover payments outside the national territory while R&D survey data cover only R&D activities within the national territory.

- GBAORD data cover the government's fiscal year while R&D survey data may cover different overlapping periods.

Guidelines for the collection of R&D statistics are provided in:

The *Proposed Standard Practice for Surveys of Research and Experimental Development* (Frascati Manual 1993) and *R&D Statistics and Output Measurement in the Higher Education Sector* (Frascati Manual Supplement 1989).

In the above context we should mention the RaDiUS database which monitors financial investments by government. The R&D in the United States (RaDiUS) is a comprehensive database on R&D in the USA funded by the Federal Government. The database offers both a broad overview of R&D, using a range of categories that includes subject, year, geographic location, R&D performer, budget category, and funding mechanism, as well as detailed information on the work being performed both within and outside federal labs.

Specifically, RaDiUS consists of five interconnected levels of increasingly detailed data on federal R&D. The least-detailed level of RaDiUS contains information on the 24 agencies that control and disseminate all R&D dollars spent by the federal government.

The fifth and most-detailed level of RaDiUS tracks these monies to their final destination at the universities, laboratories and centers located throughout the world, both inside and outside the federal government.

The records of these activities are by far the most difficult to obtain, for they are scattered throughout the federal government in a wide variety of forms and formats. In addition, these records represent the core of agencies' missions, so some are reluctant to share such detailed information with other agencies for fear that they might use it to strategic advantage.

Because both detailed substantive descriptions and financial information are available in RaDiUS, scientists, engineers, and managers are able to quickly assemble a comprehensive picture of what's happening nation-wide in any area of federally supported R&D. The database is available to the public for a fee.

Bibliometrics

Bibliometrics is the generic term covering information extracted from publications. Bibliometric analysis uses data on numbers and authors of scientific publications and on articles and the citations therein to measure the “output” of individuals/research teams, institutions, and countries, to identify national and international networks, and to map the development of new fields of science and technology.

Most bibliometric data come from commercial companies or professional societies with main general source the Science Citation Index (SCI) set of databases created by the Institute for Scientific Information (ISI) (now Thomson Reuters) in the United States.

Bibliometrics is currently its own scientific discipline and part of the broader discipline of scientometrics. There are a number of journals covering the field among which are: the international journal of scientometrics and the journal of the American society for information science.

Patent Data

Statistics on patents constitute an important output indicator of the innovation system. The global data concern the number of patents applied for or granted via national, European and other international procedures broken down by country of application and country of residence of the applicant.

The main information that can be drawn from patent documents relates to the type of technology covered by the claim, the name and nationality of the inventor (individual, government agency, private corporation), links between a new patent and knowledge in earlier ones and scientific publications, the economic sector where the invention originated, and the fields and markets covered by the patents.

Patent indicators are used in order to identify technological strengths and weaknesses of corporations, countries etc. and to analyse the rate and direction of technical change.

Guidelines for the collection of R&D statistics are provided in: *Using Patent Data as Science and Technology Indicators* (1994); OECD, Paris, France.

Technology Balance of Payments (TBP) Statistics

The TBP registers the international flow of industrial property and know-how. This type of statistics measure the international diffusion of disembodied technology by reporting all intangible transactions relating to trade in technical knowledge and in services with a technology content between partners in different countries.

Transactions which are covered by these statistics are purchases and sales of patents, licenses for patents, know-how, trademarks, franchising, technical services, models and designs and finance of industrial R&D outside the national territory.

OECD reports currently TBP data according to industry, type of operation and geographical area.

Guidelines for the collection of R&D statistics are provided in:

Proposed Standard Method of Compiling and Interpreting Technology Balance of Payments Data (1990); OECD, Paris, France

Human Resources

The term human resources in science and technology extends to cover everyone who has successfully completed post-secondary education or is working in an associated S&T occupation. It refers to the human resources actually or potentially devoted to the systematic generation, advancement, diffusion and application of scientific and technological knowledge.

Users of human resources devoted to science and technology data include policy-makers and analysts in government-related agencies, the private sector and academia. Among the issues facilitated are issues of the brain-drain or gain, skills etc. Availability of skills and planning for the higher education sector are addressed with the use of HRST data.

Human resources devoted to science and technology data are wider and more detailed than the R&D personnel statistics defined in the Frascati Manual.

Guidelines for the collection of human resources devoted to R&D are provided in:

The Measurement of Human Resources Devoted to S&T (Canberra Manual, 1995).

Innovation Data

Innovation data aim to enlarge the picture of the process of innovation provided by the R&D and patent statistics. Innovation data focus on the innovation process other than R&D and in particular on these aspects affecting diffusion rates.

The data collected in different countries differ widely in terms of objectives, methods, definitions and so on. However, they are so conclusively slow that a wide range of data can be produced in the innovation process and assist policy making.

The OECD Oslo Manual provides the basis for international compatible:

a) definitions of innovation and innovative activities;

b) measuring aspects of the innovation process;

c) measuring the cost of innovation;

d) classifications and areas of difficulty for innovation surveys.

Guidelines for the collection of R&D statistics are provided in: *OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data* (Oslo Manual 1997).

A variety of other indicators have been utilised in different projects and different objectives. These include: mobility of human resources; innovative and absorptive capacity of firms; internationalisation of industrial R&D; government support to industrial R&D and innovation (fiscal incentives); information and communication technology and others.

Currently indicators are published routinely to inform the relevant authorities of the state of science, technology and innovation internationally. In the United States of America, the National Science Foundation (NSB 2010) is using educational indicators, bibliometrics, patents, trade in high, medium and low technology products, R&D expenditure analysis and others to monitor the health of American science and technology on a continuous basis; in Europe the European Commission (EC 1997) is using similar approaches in order to monitor the health of the European innovation system; OST in France is producing the biennial report “Science and Technology Indicators” (OST 2008) and the Organisation for Economic Cooperation and Development (OECD 2010) is using the indicators for monitoring and comparative purposes.

A recent effort of particular interest is the production of the manual “IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics” (2011) by the International Energy Agency. The effort is of interest because it is probably the first effort aimed at the development of a manual for a particular discipline/sector (i.e. energy).

The manual is divided into two parts:

Part 1 – Fundamentals: defines how the questionnaire is structured and presents guidelines on which types of budgets/expenditures should be included by national data collectors in the IEA RD&D questionnaire. It covers all energy-related activities.

Part 2 – Definition of terms: provides definitions of all energy-related items that correspond to a specific row in the IEA questionnaire. The questionnaire is split into seven main groups: energy efficiency, fossil fuels, renewable energy sources, nuclear fission and fusion, hydrogen and fuel cells, other power and storage technologies and other cross-cutting technologies or research.

Even though there are certain differences between the Frascati and IEA guidelines the two manuals are to a large extent compatible. The manual also provides a detailed questionnaire that is recommended to be used by national authorities for the collection of relevant statistics.

Indicators for Water Research Monitoring and Assessment

The above-mentioned indicators have been developed in order to describe the performance of science, technology and innovation of countries, and regions. However, disciplinary assessments utilise the same indicators adopted for the particular objectives.

Probably the most often used indicators for disciplinary assessments are those accruing from bibliometrics. In bibliometrics the number of publications in a field is considered as an indicator of research activity. The philosophy underlying the use of bibliometric indicators as performance measures has been summarised in De Solla Price's statement that "for those who are working at the research front, publication is not just an indicator but, in a very strong sense, the end product of their creative effort" (De Solla Price 1975).

The indicators reported in bibliometric assessments include the number of publications of the assessed unit per year; the share in the world publications; citations received by the assessed unit per year; citations in comparison with the average publication in the field; comparisons with other institutions or countries of interest; ranking of institutions, countries and so on and of course there are a number of complex indicators such as activity and impact indicators.

The development of bibliometric indicators requires the identification of an appropriate database. There are a number of specialized databases (e.g. Chemical Abstracts covering physics and chemistry; Compendex covering engineering and technology; Embase covering medical sciences, etc.). The water field is covered by a number of databases, most of them of local character, such as WATERLIT (the Water Research Commission of South Africa's database), the Australian Wetland database and others. However, these databases cannot be used for scientometrics purposes as their coverage is not homogeneous. They include different types of data or no data at all for particular topics and they usually contain monographs, theses, books and articles that are incorporated in the database documents and are not examined for quality. Furthermore not all databases include all authors' addresses, documents from other countries (for comparative purposes) and so on and hence the identification of all contributors to the research is not possible.

The ISI-Thomson-Reuters databases are the most often used databases for the development of science, technology and innovation indicators.

The ISI family includes the following databases;

- *Science Citation Index Expanded*. It is a multidisciplinary index to the journal literature of sciences. It indexes 5 900 major journals across 150 scientific disciplines.

- *Social Sciences Citation Index*. It indexes fully more than 1,725 journals across 50 social science disciplines and it indexes individually selected, relevant items from over 3,300 of the world's leading scientific and technical journals.

- *Arts and Humanities Citation Index*. It covers fully 1,144 of the world's leading arts and humanities journals and it indexes individually selected, relevant items from over 6,800 major science and social science journals.

The combined databases cover comprehensively the most prestigious journals in the world in all fields of research endeavours and constitute a unique information platform for the objectives of this effort. The most important advantage of the ISI journals is that they constitute the most important (in terms of impact) journals in the world. Hence, papers of no or marginal value are not included. All journals indexed by ISI are peer-reviewed. As a group, the ISI indexed set of journals represents an elite body of internationally influential research publications, but it does not represent a comprehensive cataloguing of the entire world's research journals, nor of all peer-reviewed journals.

The use of the ISI databases has a number of advantages. These are:

- The databases are multidisciplinary in nature and hence, they facilitate the monitoring and assessment of all scientific disciplines.
- The structure of the databases facilitates classification according to a large number of scientific disciplines and further focusing to specialities through key word searching.
- The indexing of research in the databases is proceeded by quality control and hence, there is some minimum quality of the articles indexed.
- The databases include all names and corporate addresses of authors hence, articles can be distributed appropriately to relevant institutions and countries. Furthermore, co-authorship can be identified.
- The databases index all citations and hence, impact factors can be developed and be identified.
- The databases are particularly relevant for South Africa as government and universities provide subsidies/incentives for their academics to publish in ISI indexed journals.
- The databases have a long history in existence (since the 1960s) and hence, there is no danger of ceasing to exist.

The databases are used internationally by governments and researchers for indicator development and hence, they are transparent, researched and assessed on a continuous basis.

We suggest that bibliometric indicators constitute the mainstay of research assessment in the WRC efforts.

The same way, in which scientific articles are accepted as a legitimate reflection of scientific research, patents are accepted as a reflection of technological achievements. Griliches (1990) has pointed out that "Patent statistics remain a unique source for the analysis of the process of technical change. Nothing else even comes close in the quantity of available data, accessibility, and potential industrial, organizational, and technological detail."

Patents fulfil two roles. They provide inventors with legal protection for novel products and processes and simultaneously, they ensure that the knowledge of these products and processes becomes available to society. In this way both private and public interests are served. Carr (1995) describes the concept of patent as follows:

"A patent is an exclusionary right granted by a government entity. The concept behind the United States patent system is that the government grants statutory protection to an inventor in the form of exclusionary rights for a period of years in return for a disclosure of the creativity of the grantee. The exclusionary rights granted by the patent are the rights to exclude others from making, using or selling the patented invention throughout the United States and its territories for a period of 17 years. In exchange for these rights, the patent discloses and teaches technical knowledge relating to the invention. During the life of the patent, scientists and other inventors benefit from the disclosure of prior art information by avoiding repeating efforts to discover that which is already known. After the patent expires, the invention belongs to the public and anyone can make, use or sell the invention without permission of the patentee".

Patent analysis possesses a number of strengths that facilitates its universal use as scientometric tools. Patent analysis is highly reliable because they are well defined and unambiguous. They facilitate detailed categorisation and hence make possible the study of scientific and technological fields and sub-fields and finally they make possible international comparisons. OECD provides guidelines for the use of patents in their relevant manual (OECD 1994).

Patent analysis – within the science and technology (S&T) context – is used to measure inventive performance, diffusion of knowledge and internationalisation of innovative activities – across countries, firms, industries and technology areas. Porter et al. (1999) argue that patent indicators are the most appropriate for defining the innovative capacity of countries and that international patenting is strongly correlated with alternative measures of innovative output such as the number of scientific journal articles and also with outcome measures such as a country's market share in high-technology industries.

Although patents facilitate the development of a number of useful indicators they have a number of drawbacks. Patented inventions are not necessarily all the inventions produced in a country or organisation. Many inventions are not patented because there are other barriers to entry (e.g. lack of brand names among the competitors), because inventors may undertake other measures of protection (e.g. the encapsulation of products in epoxy resin to deter imitation) or because inventors consider that the invention will be profitable even if imitators may appear in the foreseeable future. Similarly high costs for application or monitoring infringement as well as the lack of appreciation are additional reasons that may limit the number of patents from a particular country or organisation.

The patents most often utilised internationally for this type of analysis are those awarded by the USPTO. Although most countries in the world have their own patent authorities, the use of the USPTO provides a number of advantages. First in the majority of the patent offices, patents are not examined for originality, usefulness and novelty. Consequently counting and comparing patents awarded by different patent offices in different countries may be misleading because of differences in the criteria used and the easiness of awarding patents, bias towards local patents etc. The obvious solution in order to avoid the above-mentioned shortcomings is to use a common denominator such as an external patent system with an objective approach in its patent awarding approach (i.e. the USPTO). The USPTO examines claims according to a number of criteria. These are (Fordis et al. 1995):

- Subject matter: an invention must fall into one of the categories the patent law divides patentable subject matter into.
- Utility: An invention must fulfil the substantive requirement of "utility". An invention must perform a designed function or achieve some minimum human purpose.
- Novelty: an invention has to be novel.
- Non-obviousness: the knowledge in the technological field at the time of invention must not make the invention obvious to one of ordinary skill in that area.
- Definiteness: one skilled in the art must understand the limits of the invention based on the claim language.

Second, the US represents the most important single market for technological sales and hence, is a key drawing card for technology-based products. Owners of important commercial inventions will make sure that they are protected in the USA market. Third, the costs involved and the complexity of filing foreign patents in the USA tend to screen out trivial patents.

The USPTO classifies the patents to different classes and subclasses. The class breakouts represent major divisions of technology in the US Patent Classification System (USPCS). The USPCS contains currently approximately 460 total classes and 150,000 total subclasses. The classification of the patents to subclasses is done according to information disclosed in the patent. If more than one technology is identified as pertinent to the patent, one subclass is designated as the primary classification and the remainders are designated as cross-reference classifications. Counting patents by primary classification ensures that each patent is counted only once. The residence of the first named inventor listed on the patent grant determines patent origin.

Furthermore, the USPTO classifies patents to utility patents (i.e. patents for invention), reissue patents, plant patents, design patents and statutory invention registrations and defensive publications. In our investigation we utilise only utility patents.

Patents granted by the European Patent office are also of importance. Finally the triadic patents constitute a particular sub-set of patents issued internationally i.e. sub-set of patents all filed together at the EPO, at the Japanese Patent Office (JPO) and granted by the USPTO, protecting the same set of inventions.

In this context we suggest that water related patent indicators from USPTO be utilised by the WRC.

The third set of indicators of importance for disciplinary assessment is R&D expenditures. We have already discussed R&D expenditures and we do not elaborate on the issue again. However, we emphasise that it will be of importance for the field and the WRC to develop an appropriate methodology based on the GABOARD approach of the Frascati manual and collect the relevant data regularly.

Finally it will be important to monitor the number of post-graduate students (masters and PhDs) in the field of water research. The WRC has the option to undertake specialised surveys of the higher education sector or to utilise existing databases. An example of the later is the NRF database NEXUS which can be used for the identification of post-graduate degrees that have been awarded in the water field.

We conclude by emphasising that monitoring and assessment of the field of "water research" faces particular challenges. The challenges arise mainly from the fact that water research is not a coherent, well defined field of research. Furthermore, water research can be classified as interdisciplinary in character. That is, resolution of water challenges require knowledge, approaches and solutions from other scientific domains such as engineering, life and environmental sciences, meteorology, hydrology, economics and other social sciences. The diversity of the scientific disciplines contributing to water research makes the boundaries of the field fuzzy.

The difficulty in defining the field has prevented its inclusion in the list of socio-economic objectives of the Frascati Manual such as defence, control and care of the environment and from the list of special topics such as biotechnology, ICT, health and others.

The above challenge means that water research indicators cannot be extracted from other primary sources but have to be developed from scratch for most of the OECD suggested indicators.

Based on the above we suggest that the first set of indicators should be based on the following:

- Bibliometrics
- Patents
- R&D Expenditures and
- Post-graduate numbers

We have identified that there are no secondary data for R&D expenditures and data for patents and post-graduate students have to be identified through key word searches. The effort of estimating the R&D expenditures is of particular importance for the WRC. The effort could be based on the development of a relevant manual which will include definitions and data collection methodology and on the undertaking of the survey for the collection of the relevant data. It is suggested that a *Government Budget Appropriations or Outlays for R&D (*GBOARD) based methodology (according to the Frascati Manual) will be appropriate for this objective.

Similarly for the identification of the number of postgraduate students the WRC should consider the undertaking of a relevant survey of universities or the utilisation of the NRF NEXUS database. In the latter case the limitations of the database have to be accepted.

Next we develop bibliometric and patent indicators based on the ISI-Thomson Reuters databases for the former and the USPTO for the latter.

Bibliometric Analysis

Bibliometric analysis, the quantitative study of the research system, is based mainly on publication indicators. In bibliometrics the number of publications in a field is considered as an indicator of research activity, and the citations as indicators of impact.

Bibliometric assessments have a number of advantages. For example, they are repeatable and verifiable exercises and they are not dependent on the choice of experts and their opinions, which may vary as the choice of the participants change in peer reviews. Probably their most important advantage is that they allow comparisons among different scientific disciplines and different countries. Both types of comparisons are not possible through peer review approaches as it is almost impossible to find peers with expertise in different scientific fields and knowledge of the research systems in different countries. Hence, bibliometrics provide a unique way to identify "revealed" research priorities in a country or regions as well.

The Institute for Scientific Information (ISI) – Thomson Reuters Scientific – databases (Science Citation Index Expanded, Social Sciences Citation Index and Arts and Humanities Citation Index) are the most often used for these types of investigations and are utilised for the objectives of this investigation.

As already discussed the most important advantage of the ISI journals is that they constitute the most important (in terms of impact) journals in the world.

In South Africa the Department of Education has identified the ISI indexed journals for subsidy purposes (universities receive approximately R120 000 (US$13 000) for each article they produce) and universities give incentives to their researchers to publish in ISI indexed journals. Consequently, it is expected that the databases will cover not only the most important South African water related research but the majority of it as well.

Thomson Reuters produces a number of different databases. The National Science Indicators (NSI) database provides summary statistics that reflect research performance for more than 100 countries in the world.

The ISI database assigns journals indexed to scientific categories. Water related journals are grouped under the title "water resources." The group includes 110 journals (Appendix 1). These 110 journals can be considered as the "core" journals of the field of water research in the Bradfordian sense[1]. Of

[1] Bradford's Law (Bradford 1950) asserts that a relatively small group of journals will account for the large majority of important and influential research in a given field. Bradford's assertion is that an essential core of journals forms the literature basis for all disciplines, and that, most of the important papers are published in relatively few journals. Researchers internationally aim firstly to publish their important research in the core journals of their field and only subsequently consider journals in the periphery. Recent citation analyses have shown that as few as 150 journals account for half of what is cited and one quarter of what is published. It has also been shown that approximately 2,000 journals account for about 85% of published articles and 95% of cited articles (Garfield 1996).

course there may be articles related to water research that are not published in the core journals. However, the most important and highest impact water literature will be that published in the core journals and hence, this analysis aims to identify and analyse South Africa's contribution to the core water research literature. The South African journal Water SA is one of the journals included for investigation.

The indicators reported for the assessment are the country's contribution in terms of the number of publications in the international literature, the country's share in the world literature, the activity index and the relative citation index. The activity index is defined as the ratio of the country's share of the world publication output in a given field in relation to the country's share of the world publication output in all science fields. An activity index of one indicates that the country's research output in the given field corresponds to the world average; an indicator larger than one reflects a higher than average emphasis in the field and vice versa. Similarly, a relative citation index above one indicates that the country's publications in the particular field attract more than average citations and an index of less than one indicates that the field attracts fewer citations.

Figure 1 shows the number of water research publications with at least one author with South African address for the period 1981-2010 (data are presented in Appendix 2). It is apparent that South African researchers were producing approximately 60 publications per year in the beginning of the period. During the 2000s the number increased to around 100 publications per year and during 2009 the number jumped to just below 180 publications.

Figure 2 shows the South African share of water research publications in the field. The share appears to have declined from above 3% of the world publications in the beginning of the period to 1.69% during 2010. It can be speculated that the South African decline is the result of the increase in coverage of water related research of the ISI Thomson Reuters database and the increase in the number of publications in other countries.

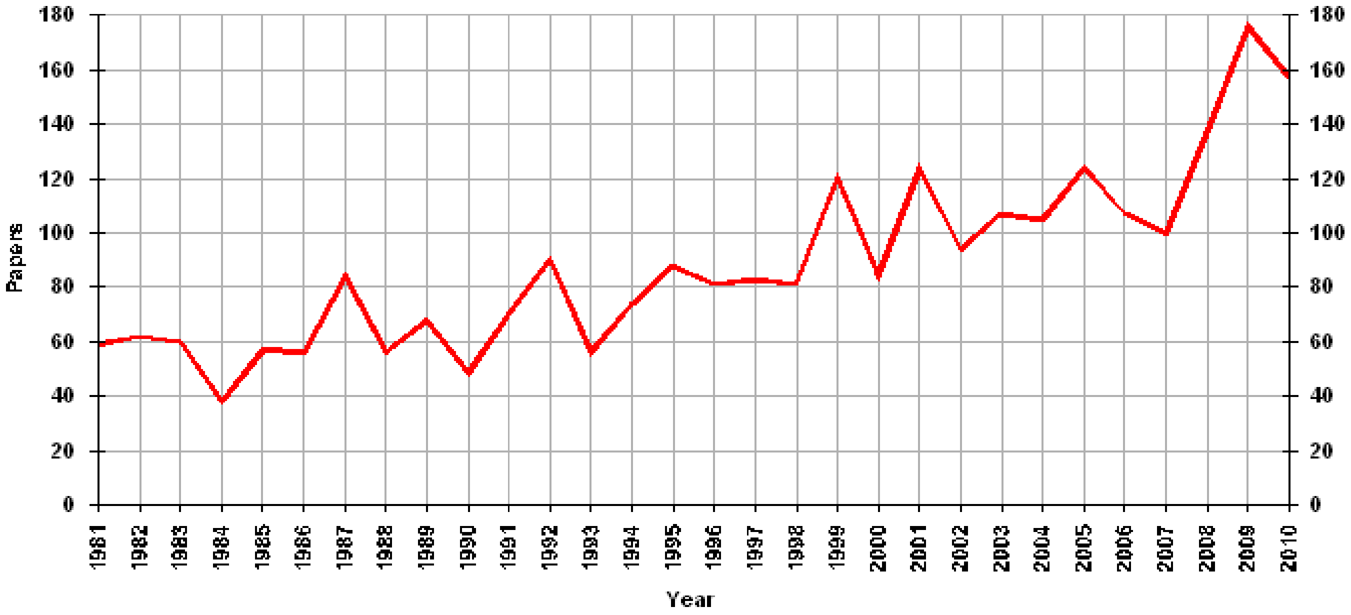

Figure 1: Number of SA water research publications 1981-2010

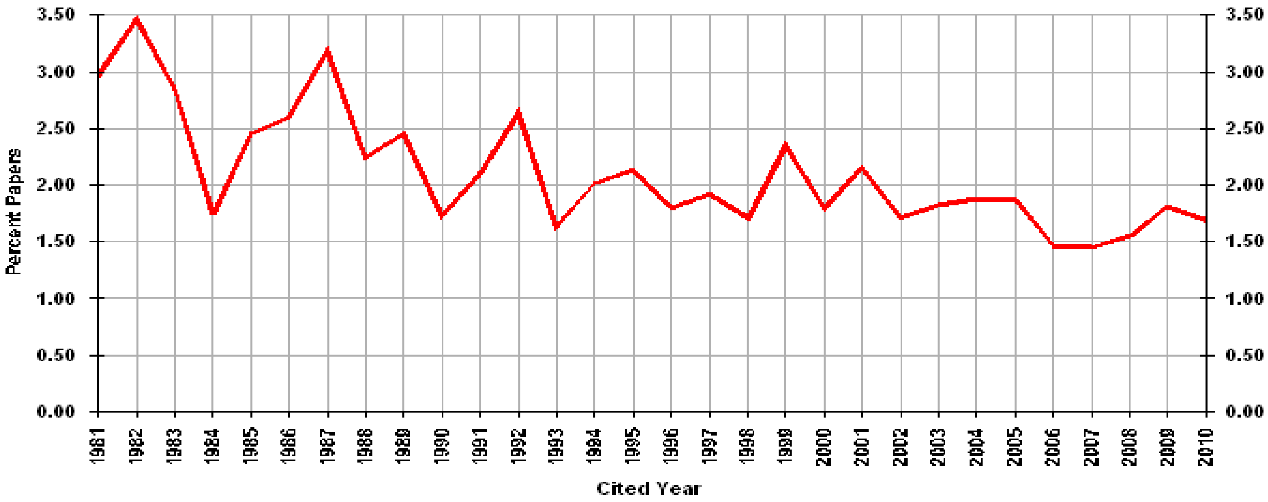

Figure 2: World share of SA water research publications 1981-2010

Figure 3 shows the impact of water publications in comparison to the impact of international articles in the field. The impact is around 0.60 during most years in the period, indicating that the country's publications do not receive the same number of citations as the average world publications in the field. During 2010, there was an increase of the impact to 1.40. Annual variations are usually the effect of high number of citations of individual articles.

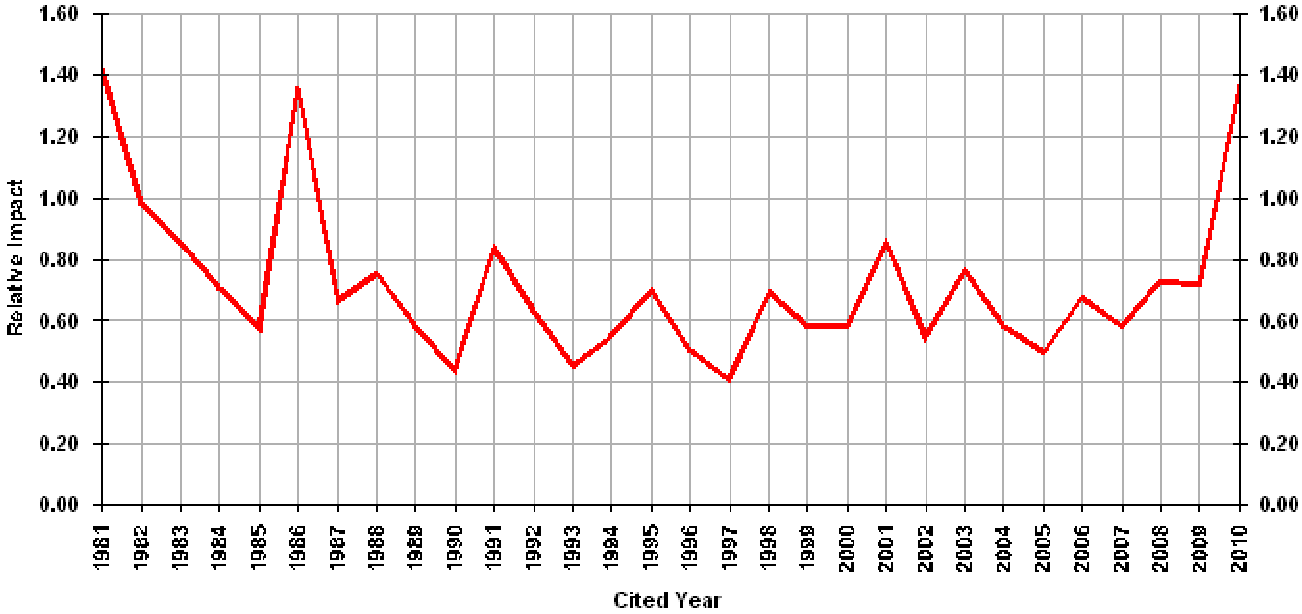

Figure 3: Relative impact of SA water research publications 1981-2010

Table 2: World share of selected disciplines: South Africa 2006-10

Discipline	**Percentage papers in field**	**Activity Index**
Religion	5.44	9.22
Area studies	4.46	7.56
Mining and mineral processing	3.99	6.76
Literature	3.80	6.44
Ornithology	3.76	6.37
Biodiversity Conservation	2.83	4.76
Archaeology	2.74	4.64
Mineralogy	2.68	4.54
Language and linguistics	2.48	4.20
Entomology	2.22	3.76
Ecology	2.17	3.67
Tropical medicine	2,17	3.67
Virology	1.98	3.35
Geology	1.91	3.23
Zoology	1.89	3.20
Plant sciences	1.67	2.83
Water resources	1.61	2.72
Marine and freshwater biology	1.52	2.57

Discipline	Percentage papers in field	Activity Index
Astronomy and astrophysics	1.00	1.69
Biotechnology and applied microbiology	0.82	1.39
Meteorology and atmospheric sciences	0.74	1.25
Energy and fuels	0.60	1.01

Table 2 shows the contribution that South Africa makes in selected scientific fields and in water resources. In water resources, the contribution is 1.61%. There are a number of disciplines in which South Africa makes a bigger contribution than in water resources. Examples include mining, mineralogy, ornithology, biodiversity and others. It has been argued that South African research has been influenced and still is influenced, by the availability of natural resources and the variety of flora and fauna. Examples include the disciplines of mining and mineral processing, ecology, plant sciences, zoology and others. The activity indices show that South Africa is producing more than nine times as much research in religion than what is expected from its relative size (as it is manifested in the total number of publications produced by the country), just below seven times more from the expected in mining and so on. In the field of water resources South Africa is producing 2.72 times more than the expected from the country's gross research outputs.

Table 3 shows that South Africa produced 2323 publications in the field of water research during the period 1999-2012. The table further, indicates the character of those publications. A large number of these publications were related to environmental sciences and environmental engineering. Certain disciplines that may be of importance for the field e.g. soil science; economics, management, energy, etc. attracted little research.

Table 3: Water research SA Science Categories 1999-2010

Water Research SA – Science Categories	
Categories	**Record Count**
Water Resources	2 323
Environmental Sciences	581
Engineering Environmental	419
Geosciences Multidisciplinary	316
Meteorology Atmospheric Sciences	187
Engineering Civil	148
Engineering Chemical	76
Marine Freshwater Biology	49
Agronomy	42
Soil Science	27
Ecology	20

Water Research SA – Science Categories	
Categories	**Record Count**
Limnology	20
Oceanography	18
Engineering Mechanical	17
Chemistry Applied	12
Economics	12
Management	12
Public Environmental Occupational Health	10
Toxicology	10

Identification of the collaborative patterns in the field show that South African researchers collaborate with researchers in England (3.2% of publications); USA (3.1%); Australia (2.7%); Netherlands (1.5%); Zimbabwe (1.5%); France (1.3%); and Germany (1.2%).

Table 4 shows the country's most prolific institutions in the field of water research. The University of Pretoria appears on top of the list with 287 publications during the period. The University of Cape Town and CSIR follow with 239 and 183 publications respectively.

Table 4: Water Research SA – Prolific Institutions 1999-2010

Institutions	Record Count
Univ. Pretoria	287
Univ. Cape Town	239
CSIR	183
Univ. KwaZulu-Natal	180
Rhodes Univ.	159
Univ. Witwatersrand	148
Univ. Natal	136
Univ. Stellenbosch	133
Univ. Johannesburg	94
Univ. Orange Free State	91
Rand Afrikaans Univ.	72
Univ. Western Cape	54
Dept Water Affairs & Forestry	51
Tshwane University of Technology	39
Univ. Zululand	39
Water Res Commission	38
Potchefstroom Univ.	35

Institutions	Record Count
Univ. FT Hare	35
Univ. Free State	33
Univ. Venda	32
Umgeni Water	31

Figure 4 shows the time series of the most prolific producers of water research publications in South Africa. During 2010, the University of Pretoria (24) produced the most number of publications followed by Rhodes University (17). It should be noted that all institutions produce less than 25 publications per year indicating a dispersion of expertise and lack of concentration and creation of critical mass. It has been argued (Pouris 2011) that political equity consideration in the country spill-over in the research domain as well. For example, research funders may tend to spread their resources thinly in order to support as many researchers as possible and avoid complaints. The policy question then is: can a country leap-frog its science and innovation system to catch up with the rest of the world and compete internationally through a ''distributed'' approach or should it concentrate its limited scientific expertise to a limited, focused number of research centers?

The table also reveals that the majority of research is undertaken in the country's universities. The research councils sector is represented in the list by CSIR with 183 publications during the period. It should be noted that the Department of Water Affairs appears in the list with 51 publications and Umgeni Water, a state-owned entity, involved in water management, with 31 publications. In South Africa, government departments and parastatals rarely undertake publishable research.

Table 5 shows the research emphasis of various institutions. Environmental sciences appear on top of the list of four of the six institutions in the table. Geosciences and multidisciplinary research is emphasised in UKZN and Wits.

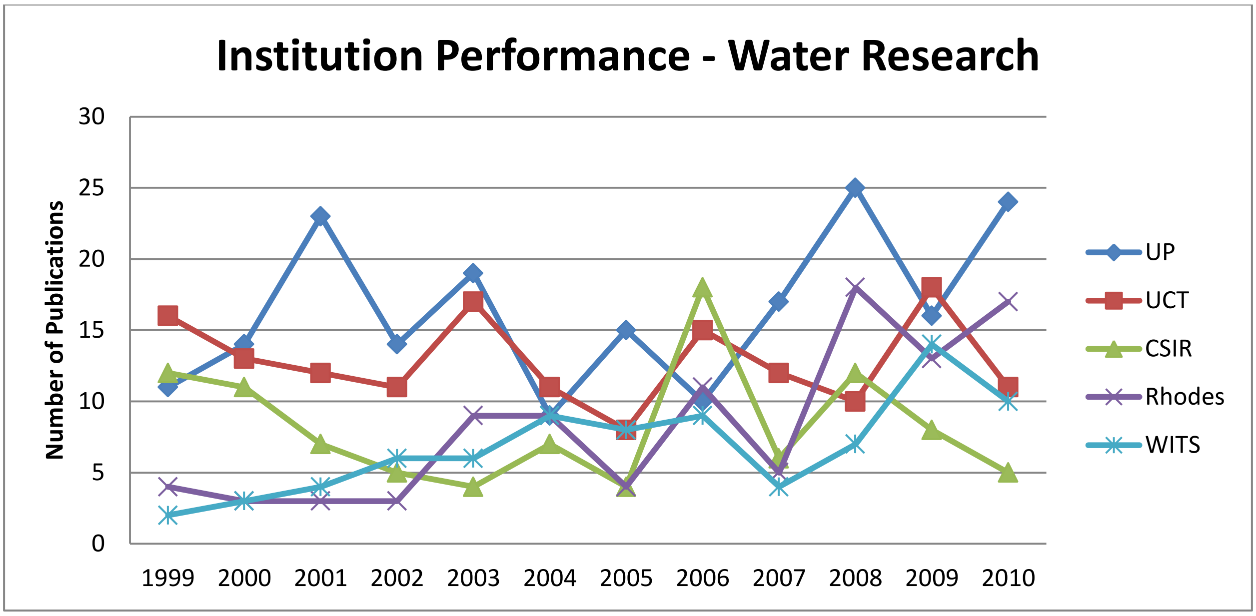

Figure 4: Prolific producers of Water research: SA 1999-2010

Table 5: Institutional emphasis: water resources publications

Institutional Emphasis					
Science Categories	**%**	**Science Categories**	**%**	**Science Categories**	**%**
UP		**UCT**		**CSIR**	
Environmental Sciences	33.79%	Environmental Sciences	33.89%	Environmental Sciences	46.44%
Engineering Environmental	28.92%	Engineering Environmental	28.03%	Engineering Environmental	38.25%
Engineering Chemical	6.27%	Geosciences Multidisciplinary	7.53%	Geosciences Multidisciplinary	9.29%
Geosciences Multidisciplinary	6.27%	Engineering Civil	4.18%	Marine Freshwater Biology	7.65%
Agronomy	4.18%	Marine Freshwater Biology	3.34%	Ecology	6.01%

UKZN		RU		WITS	
Geosciences Multidisciplinary	29.44%	Environmental Sciences	17.61%	Geosciences Multidisciplinary	23.64%
Meteorology Atmospheric Sciences	15.00%	Geosciences Multidisciplinary	16.35%	Engineering Civil	16.21%
Environmental Sciences	12.22%	Engineering Civil	8.17%	Meteorology Atmospheric Sciences	14.18%
Engineering Civil	10.55%	Engineering Environmental	8.17%	Environmental Sciences	13.51%
Engineering Environmental	6.11%	Meteorology Atmospheric Sciences	5.66%	Engineering Environmental	6.08%

Table 6: Prolific authors in water resources: 1999-2010

Author	Number publications	Institutional Address
Ekama G.A.	96	UCT
Wentzel M.C.	84	UCT
Buckley C.A.	47	KZN
Hughes D.A.	47	Rhodes Univ.
Cloete T.E.	43	UP
Haarhoff J.	39	Univ. Johannesburg
Mamba B.B.	29	Univ. Johannesburg
Grobow W.O.K.	28	UP
Venter S.N.	25	UP
Bux F.	23	DUT
Kfir R.	23	WRC
Pegram G.G.S.	22	KZN
James C.S.	21	Wits Univ.

Additionally, table 6 shows the most prolific authors in the field of water resources in South Africa. The UCT has the two most prolific authors: Ekama and Wentzel. The other authors follow with less number of publications. It should be emphasised that researchers that do not publish in the core water journals do not appear in the list. Similarly the institutional address may vary as researchers move to different institutions.

We have also interrogated the database in order to identify the funders of research as they appear in the publications (acknowledgements). The name of NRF was on top of the list with 114 citations. The name of the Water Research Commission follows with 90 citations. A number of articles mentioned various universities as the primary source of funding. It should be emphasised that a large number of articles do not mention their funders.

Table 7 shows the number of water resources publications produced by various countries during the five-year period 2006-10 (Appendix 2 shows data for the 1981-85 period). The USA appears on top of the list with 10530 publications. China and the UK follow. It should be noted that countries with small populations like Canada and Australia and countries with relatively small GDP per capita (e.g. India and Brazil) produce more research in the field than South Africa. However, it should be noted that South Africa ranks 19th in the world in the field while the overall country (according to total number of publications in all fields) was ranked 33rd in the world (Pouris 2012).

Table 7: Water resources articles: South Africa and selected countries 2006-10

Rank	Country	Number of Publications
1	USA	10 530
2	China mainland	3 619
3	UK	2 779
4	Germany	2 754
5	Canada	2 486
6	France	2 348
7	Spain	2 097
8	Australia	2 027
9	Italy	2 024
10	India	1 796
11	Japan	1 655
12	Netherlands	1 340
13	South Korea	1 286
14	Taiwan	979
15	Switzerland	914
16	Brazil	751
17	Iran	726
18	Greece	707
19	South Africa	677
20	Belgium	650
21	Sweden	598

Patents Analysis

Intellectual property rights (IPRs) refer to rights conferred by governments for the creations of the mind, both artistic and commercial.

Artistic creations are covered by copyright laws, which protect works such as books, movies, music, paintings, photographs, and software; and give the copyright holder exclusive right to control reproduction or adaptation of such works for a certain period of time.

Commercial or industrial intellectual property includes inventions, designs; trade- and service-marks, commercial names and designations. Industrial intellectual property rights are protected by patents, registered trademarks, registered industrial designs and integrated circuits and geographical indications (‘appellations’).

Whilst copyright rights do not prevent the same (or similar) piece of work being created independently by two or more creators, industrial property rights make such a distinction.

Among the protective mechanisms, patents occupy a pre-eminent position. The complexity in their modus operandi and the high stakes surrounding their ownership in knowledge intensive economies make them the primary vehicle of attention and debate internationally.

Patents play an increasingly important role in innovation and economic performance. Between 1992 and 2002, the number of patent applications filed in the main innovation centers (i.e. Europe, Japan and the United States) increased by more than 40%. Although nearly all technology fields experienced growth in patenting over the 1990s, two fields – biotechnology and ICT – contributed disproportionately to the overall surge in patenting (OECD, 2004).

The increasing importance of patents is accompanied by an increase in their use as indicators of inventive activity. Currently there is an increasing trend among policy makers, researchers, innovation analysts and technocrats to rely on patent statistics as indicators of inventive activity.

Patent analysis possesses a number of strengths that facilitates their universal use as scientometric tools. They are highly reliable because they are well defined and unambiguous. They facilitate detailed categorisation and hence make possible the study of scientific and technological fields and sub-fields. And finally they make possible international comparisons. OECD provides guidelines for the use of patents in their relevant manual (OECD, 1994).

Among factors that contribute to the strength of patent counts, the following two are probably among the most important. Firstly, since patents (excluding utility and design patents) are granted for inventions that pass the patentability threshold (novelty, utility/industrial application, non-obviousness/inventive step), they are considered as safe in the avoidance of double-counting of inventions. Secondly, their easy availability and fair authenticity presupposes strength in counts, since all patent offices keep the official records for patents filed/granted, including their aggregates.

Probably the most important characteristic of patents that make them valid indicators is the fact that they go through assessment – proper validation that the content is a contribution to knowledge. While a number of analysts utilise patent applications as indicators of innovation progress, it is the award of patents that make them valuable.

Griliches (1990) has pointed out that “Patent statistics remain a unique source for the analysis of the process of technical change. Nothing else even comes close in the quantity of available data, accessibility, and potential industrial, organizational, and technological detail.”

Porter et al. (1999) argued that patent indicators are the most appropriate for defining the innovative capacity of countries and that international patenting is strongly correlated with alternative measures of innovative output such as the number of scientific journal articles and also with outcome measures such as a country’s market share in high-technology industries.

The patents most often utilised internationally for this type of analysis are those granted by the USPTO. Although most countries in the world have their own patent authorities, the use of the USPTO provides a number of advantages. First in the majority of the patent offices, patents are not examined for originality, usefulness and novelty. This is also the case in South Africa (Pouris et al. 2011). Consequently counting and comparing patents awarded by different patent offices in different countries may be misleading because of differences in the criteria used and the easiness of awarding patents, bias towards local patents etc. The obvious solution in order to avoid the above-mentioned shortcomings is to use a common denominator such as an external patent system with an objective approach to awarding patents (i.e. the USPTO).

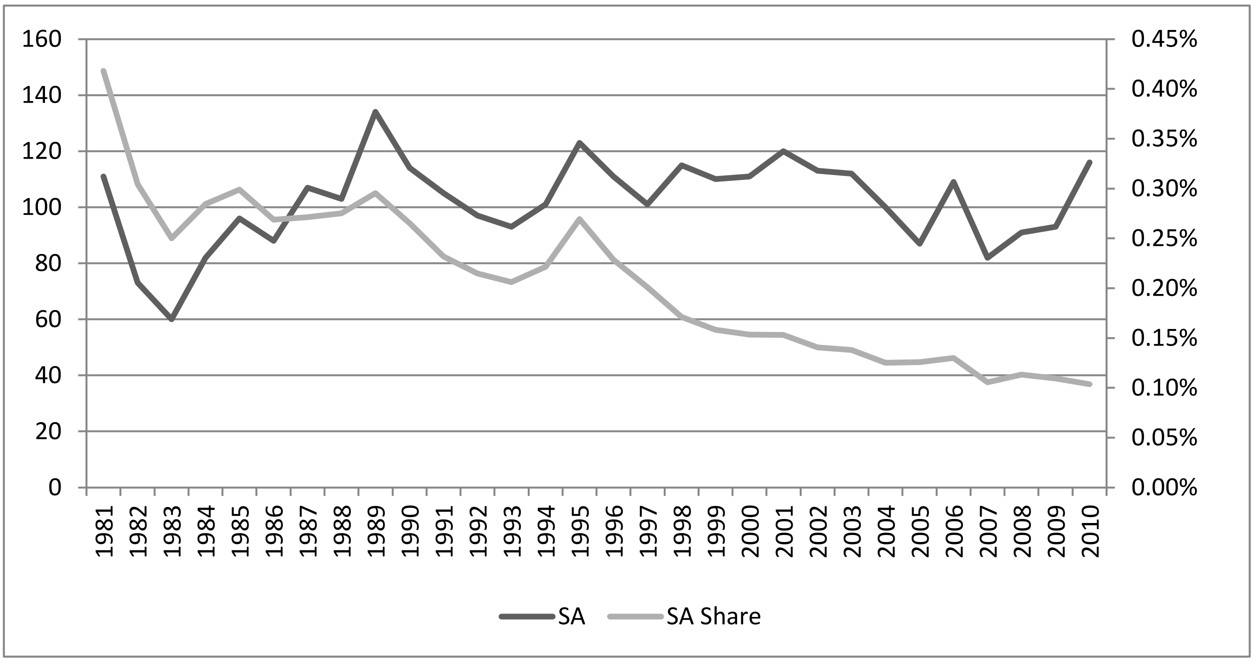

Figure 5: Patents granted to SA inventors and SA share: USPTO 1981-2010

Figure 5 shows the number of patents awarded to South Africans by the USPTO. It also shows the South African share in foreign patents (non-USA) awarded by the USPTO. The most recent two years exhibit an increase in the number of patents awarded to South Africa and it appears that the long-term decline in the South African share has been stabilised. Of course it is too early to derive any conclusions about trends from the most recent two years. It is noticeable however, that South Africa in general gets very few patents in the USPTO. Companies like IBM are granted more than 3000 patents a year.

In order to identify water-related patents granted to South African inventors by the USPTO we utilised a search strategy identifying key words in the titles of patents. The search strategy was as follows:

TTL (Water OR Desalination OR Dewatering OR Filtration OR (reverse AND osmosis) OR sludge OR purification OR catchment OR river OR sewage OR irrigate OR estuary OR wetland OR rainfall OR effluent).

Simultaneously we limited the search to South African inventors and to patents granted between 2000 and 2010.

We have also searched for assignees from South Africa with the word "water" in the name.

The search identified 48 South African patents during the period. Visual inspection identified six false positives (i.e. patents that they are not necessarily related to water inventions such as swimming pool equipment, water vehicles, etc.).

Figure 6 shows the number of patents awarded to South African inventors during the 2000-2010 period. South African inventors received just above four patents per year on average.

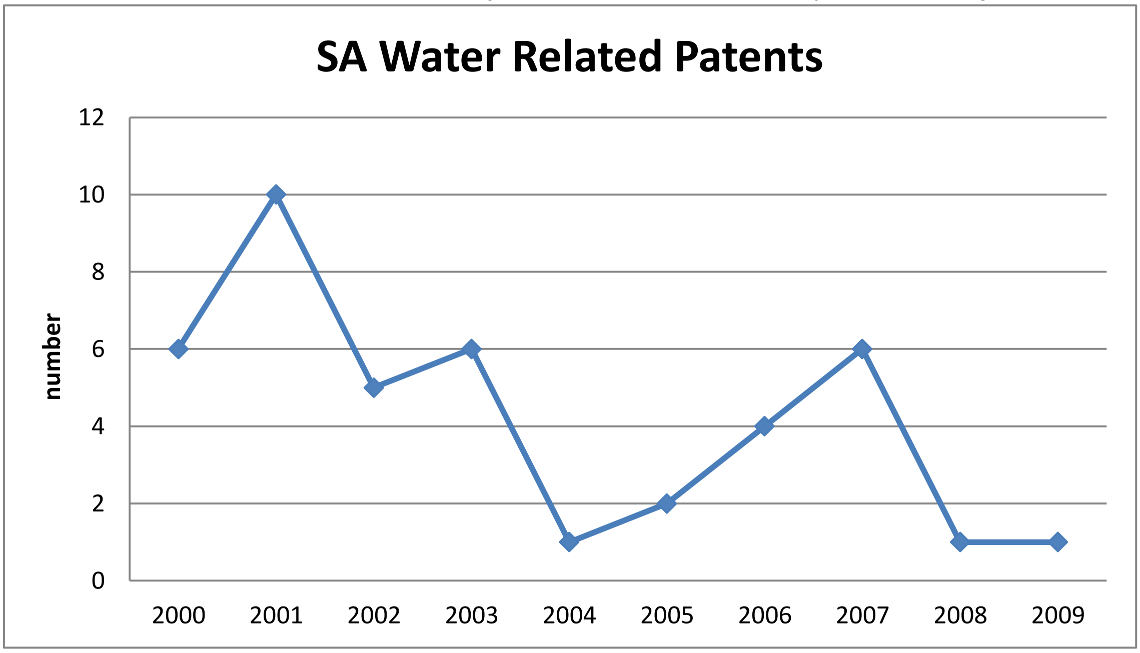

Figure 6: SA water related patents: 2000-2010 USPTO

We have also identified the assignees of the South African patents. The assignees with the most patents are the Water Research Commission and Sasol Technology (Pty) Ltd with seven patents each. CSIR follows with four patents during the period.

We undertook a key word density analysis in order to identify the frequency of appearance of key words. Apart from the word “water” the most frequent words were: “treatment” (6.5%); “method” (4.2%); purifying (2.8%); Fisher Tropsch (2.7%); filtration (2.3%) and sulphate (1.4%).

Table 8 shows the number of patents awarded to South Africa and a number of selected countries during the 2000-2010 period.

Table 8: USPTO water related patents: 2000-10 South Africa and selected countries

Country	Patents granted
Japan	2 469
Canada	573
UK	397
Australia	180
China	112
India	66
Finland	61
Russia	56
South Africa	42
Brazil	28

South Africa appears to perform better than Brazil and just below Russia in terms of absolute number of patents.

Table 9: Water patents as % of total granted patents: 2000-2010

Countries	Water Patents	Total Patents	Ratio
Japan	2469	384738	0.64
Canada	573	38941	1.47
UK	397	29097	1.36
Australia	180	12055	1.49
China	112	8675	1.29
India	66	5085	1.30
Finland	61	9293	0.66
Russia	56	2141	2.62
South Africa	42	1134	3.70
Brazil	28	1207	2.32

Table 9 shows that South Africa owns more water related patents as a percentage of the total patents granted than the other countries in the table.

Discussion and Recommendations

This report identifies the performance of water resources research in South Africa through bibliometric and patent analysis. The bibliometric analysis identifies that the field is performing above expectation in comparison with the country's research size (activity index). It can be argued that this performance is the result of the existence of a dedicated agency for the support of the field in the country – the Water Research Commission.

South Africa's water research is ranked 19th in the world while the total country is ranked 33th. It should be noted however, that a number of countries with smaller populations like Canada and Australia, or a smaller GDP per capita like India and Brazil, produce more relevant knowledge than South Africa.

Identification of the country's producers of research in the field shows that the country's research is distributed to a variety of centres creating subcritical groups.

The policy question then is: can a country leap-frog its science and innovation system to catch up with the rest of the world and compete internationally through a ‘‘distributed'' approach or should it concentrate its limited scientific expertise to a limited number of focused research centers?

Environmental sciences are identified as the most important sub-discipline in the field of water resources. Certain disciplines that may be of importance for the field e.g. economics, management, energy, etc. attract little research.

The patent analysis also identifies that South Africa produces more inventions in the field of water than the comparator countries proportionally. However, it should be noted that South Africa is granted a very small number of patents in general from the USPTO.

The above findings lead to a number of conclusions: Water research appears to perform above the average scientific discipline in South Africa. Although a matter for speculation, it can be argued that the focus support by the WRC is to a large extent the driving force behind that success. Government can use the WRC success as an example for implementation and institutionalisation in other areas of national priority.

The identified distributed presence of water research in the country, even though a national characteristic, may adversely affect productivity and economies of scale in the field. It will be important for the WRC to examine the issue further and take appropriate action (e.g. establish centers of expertise with critical mass of researchers in focus areas).

The disciplinary emphasis of the country's institutions indicates that researchers move on their own to specific areas without any particular guidance or cognizance of priorities/ diversification. It will be important for WRC to identify research priorities through appropriate approaches (e.g. foresight) and allocate resources accordingly to promising areas. Such an approach will focus resources (human and financial) to areas of importance and has the potential to bring research closer to application.

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Appendix 1: Water Resources Journals

- ACTA HYDROCHIMICA ET HYDROBIOLOGICA
- ADVANCES IN HYDROSCIENCE
- ADVANCES IN WATER RESOURCES
- AFRICAN JOURNAL OF AQUATIC SCIENCE
- AGRICULTURAL WATER MANAGEMENT
- ANNALES D HYDROBIOLOGIE
- AQUATIC CONSERVATION-MARINE AND FRESHWATER ECOSYSTEMS
- CAHIERS ORSTOM HYDROBIOLOGIE
- CANADIAN WATER RESOURCES JOURNAL
- CATENA
- CHINA OCEAN ENGINEERING
- CLAYS AND CLAY MINERALS
- CLEAN-SOIL AIR WATER
- DESALINATION
- DESALINATION AND WATER TREATMENT
- DISASTER ADVANCES
- EAU DU QUEBEC
- ENGENHARIA SANITARIA E AMBIENTAL
- ENVIRONMENTAL EARTH SCIENCES
- ENVIRONMENTAL FLUID MECHANICS
- ENVIRONMENTAL GEOCHEMISTRY AND HEALTH
- ENVIRONMENTAL GEOLOGY
- ENVIRONMENTAL GEOLOGY AND WATER SCIENCES
- ENVIRONMENTAL TOXICOLOGY
- ENVIRONMENTAL TOXICOLOGY AND WATER QUALITY
- GROUND WATER
- GROUND WATER AGE
- GROUND WATER MONITORING AND REMEDIATION
- GRUNDWASSER
- HOUILLE BLANCHE-REVUE INTERNATIONALE DE L EAU
- HYDROGEOLOGY JOURNAL
- HYDROLOGICAL PROCESSES
- HYDROLOGICAL SCIENCES BULLETIN-BULLETIN DES SCIENCES HYDROLOGIQUES
- HYDROLOGICAL SCIENCES JOURNAL-JOURNAL DES SCIENCES HYDROLOGIQUES
- HYDROLOGIE UND WASSERBEWIRTSCHAFTUNG
- HYDROLOGY AND EARTH SYSTEM SCIENCES

- HYDROLOGY RESEARCH
- ICID JOURNAL
- INGENIERIA HIDRAULICA EN MEXICO
- INTERNATIONAL HYDROGRAPHIC REVIEW
- INTERNATIONAL JOURNAL OF SEDIMENT RESEARCH
- INTERNATIONAL JOURNAL OF WATER RESOURCES DEVELOPMENT
- IRRIGATION AND DRAINAGE
- IRRIGATION SCIENCE
- JOURNAL AMERICAN WATER WORKS ASSOCIATION
- JOURNAL OF CONTAMINANT HYDROLOGY
- JOURNAL OF FLOOD RISK MANAGEMENT
- JOURNAL OF HYDRAULIC ENGINEERING-ASCE
- JOURNAL OF HYDRAULIC RESEARCH
- JOURNAL OF HYDRO-ENVIRONMENT RESEARCH
- JOURNAL OF HYDROINFORMATICS
- JOURNAL OF HYDROLOGIC ENGINEERING
- JOURNAL OF HYDROLOGY
- JOURNAL OF HYDROLOGY AND HYDROMECHANICS
- JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING-ASCE
- JOURNAL OF SOIL AND WATER CONSERVATION
- JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
- JOURNAL OF THE CHARTERED INSTITUTION OF WATER AND ENVIRONMENTAL MANAGEMENT
- JOURNAL OF THE INSTITUTION OF WATER AND ENVIRONMENTAL MANAGEMENT
- JOURNAL OF THE IRRIGATION AND DRAINAGE DIVISION-ASCE
- JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT-ASCE
- JOURNAL OF WATER SUPPLY RESEARCH AND TECHNOLOGY-AQUA
- JOURNAL OF WATERWAY PORT COASTAL AND OCEAN ENGINEERING-ASCE
- LAKE AND RESERVOIR MANAGEMENT
- MINE WATER AND THE ENVIRONMENT
- NATURAL HAZARDS
- NATURAL HAZARDS AND EARTH SYSTEM SCIENCES
- NATURE & RESOURCES
- NORDIC HYDROLOGY
- OCEAN & COASTAL MANAGEMENT
- OCEAN ENGINEERING
- PHYSICS AND CHEMISTRY OF THE EARTH
- PHYSICS AND CHEMISTRY OF THE EARTH PART B-HYDROLOGY OCEANS AND ATMOSPHERE

- PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS-MARITIME ENGINEERING
- PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS-WATER AND MARITIME ENGINEERING
- PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS-WATER MANAGEMENT
- PROGRESS IN WATER TECHNOLOGY
- REGULATED RIVERS-RESEARCH & MANAGEMENT
- RESEARCH JOURNAL OF THE WATER POLLUTION CONTROL FEDERATION
- RIVER RESEARCH AND APPLICATIONS
- SCHWEIZERISCHE ZEITSCHRIFT FUR HYDROLOGIE-SWISS JOURNAL OF HYDROLOGY
- SCIENCES ET TECHNIQUES DE L EAU
- SOIL TECHNOLOGY
- STOCHASTIC ENVIRONMENTAL RESEARCH AND RISK ASSESSMENT
- STOCHASTIC HYDROLOGY AND HYDRAULICS
- STYGOLOGIA
- TECNOLOGIA Y CIENCIAS DEL AGUA
- URBAN WATER JOURNAL
- VADOSE ZONE JOURNAL
- WASSERWIRTSCHAFT
- WATER AIR AND SOIL POLLUTION
- WATER AND ENVIRONMENT JOURNAL
- WATER ENVIRONMENT RESEARCH
- WATER INTERNATIONAL
- WATER POLICY
- WATER QUALITY RESEARCH JOURNAL OF CANADA
- WATER RESEARCH
- WATER RESOURCES
- WATER RESOURCES BULLETIN
- WATER RESOURCES MANAGEMENT
- WATER RESOURCES RESEARCH
- WATER SA
- WATER SCIENCE AND TECHNOLOGY
- WATER SUPPLY & MANAGEMENT
- WATER-ENGINEERING & MANAGEMENT
- WEM-WATER ENGINEERING & MANAGEMENT
- WETLANDS ECOLOGY AND MANAGEMENT
- ZEITSCHRIFT FUR WASSER UND ABWASSER FORSCHUNG-JOURNAL FOR WATER AND WASTEWATER
- RESEARCH

- ZEITSCHRIFT FUR WASSER- UND ABWASSER-FORSCHUNG-JOURNAL FOR WATER AND WASTEWATER
- RESEARCH-ACTA HYDROCHIMICA ET HYDROBIOLOGICA

Appendix 2: Water Research Data

Table 10: Number of SA water research publications 1981-2010

Year	Water Papers
1981	59
1982	62
1983	60
1984	38
1985	57
1986	56
1987	84
1988	56
1989	68
1990	48
1991	70
1992	90
1993	56
1994	74
1995	88

Year	Water Papers
1996	81
1997	83
1998	81
1999	120
2000	84
2001	124
2002	94
2003	107
2004	105
2005	124
2006	107
2007	100
2008	137
2009	176
2010	157

Table 11: World share of SA water research publications 1981-2010

Year	% Papers
1981	2.97
1982	3.47
1983	2.84
1984	1.74
1985	2.46
1986	2.6
1987	3.19
1988	2.24
1989	2.45
1990	1.73
1991	2.1
1992	2.64

Year	% Papers
1996	1.8
1997	1.92
1998	1.71
1999	2.35
2000	1.8
2001	2.15
2002	1.71
2003	1.82
2004	1.88
2005	1.87
2006	1.46
2007	1.45

Year	% Papers
1993	1.63
1994	2.02
1995	2.13

Year	% Papers
2008	1.55
2009	1.81
2010	1.69

Table 12: Relative impact of SA water research publications 1981-2010

Year	Relative Impact
1981	1.42
1982	0.99
1983	0.86
1984	0.71
1985	0.58
1986	1.36
1987	0.67
1988	0.76
1989	0.59
1990	0.44
1991	0.83
1992	0.63
1993	0.45
1994	0.55
1995	0.7

Year	Relative Impact
1996	0.5
1997	0.41
1998	0.69
1999	0.58
2000	0.59
2001	0.86
2002	0.55
2003	0.76
2004	0.58
2005	0.5
2006	0.68
2007	0.58
2008	0.73
2009	0.72
2010	1.36

Table 13: Prolific producers of Water research: SA 1999-2010

Year	UP	UCT	CSIR	Rhodes	WITS
1999	11	16	12	4	2
2000	14	13	11	3	3
2001	23	12	7	3	4
2002	14	11	5	3	6
2003	19	17	4	9	6
2004	9	11	7	9	9
2005	15	8	4	4	8

Year	UP	UCT	CSIR	Rhodes	WITS
2006	10	15	18	11	9
2007	17	12	6	5	4
2008	25	10	12	18	7
2009	16	18	8	13	14
2010	24	11	5	17	10

Table 14: Patents granted to SA inventors and SA share: USPTO 1981-2010

Year	SA	SA Share
1981	111	0.42%
1982	73	0.30%
1983	60	0.25%
1984	82	0.28%
1985	96	0.30%
1986	88	0.27%
1987	107	0.27%
1988	103	0.28%
1989	134	0.30%
1990	114	0.27%
1991	105	0.23%
1992	97	0.21%
1993	93	0.21%
1994	101	0.22%
1995	123	0.27%

Year	SA	SA Share
1996	111	0.23%
1997	101	0.20%
1998	115	0.17%
1999	110	0.16%
2000	111	0.15%
2001	120	0.15%
2002	113	0.14%
2003	112	0.14%
2004	100	0.12%
2005	87	0.13%
2006	109	0.13%
2007	82	0.11%
2008	91	0.11%
2009	93	0.11%
2010	116	0.10%

Table 15: Number of water publications South Africa and selected countries 1981-1985

Country	Number of water publications 1981-85
Australia	344
China	55
France	255
Germany	670
India	347
Italy	156
South Africa	276
Spain	32
UK	749
USA	4 900
Belgium	83
Brazil	29
Greece	53
Iran	156
Japan	284
Netherlands	306
South Korea	8
Sweden	153
Switzerland	159
Taiwan	10