# WATER RESEARCH DEVELOPMENT AND INNOVATION (RDI) ROADMAP SKILLS MAPPING STUDY

## VOLUME 1: UPDATED RDI ROADMAP CAPABILITY MAP

*M Carstens, CD Swartz, NM Elema, E Lekala and MJ Jackson*


WATER RESEARCH COMMISSION

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# WATER RESEARCH DEVELOPMENT AND INNOVATION (RDI) ROADMAP SKILLS MAPPING STUDY

## VOLUME 1: UPDATED RDI ROADMAP CAPABILITY MAP

Report to the
**Water Research Commission**

by

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The outputs of this research project are presented in four separate publications:

Volume I: Updated RDI Roadmap Capability Map **(This report)**
Volume II: Water Sector Postgraduate Training Map **(WRC Report No. TT 865/2/21)**
Volume III: Short Course Skills Mapping Study **(WRC Report No. TT 865/3/21)**
Volume IV: A Water Sector Skills Demand Report **(WRC Report No. TT 865/4/21)**



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# EXECUTIVE SUMMARY


The goal of South Africa's Water Research, Development and Innovation (RDI) Roadmap (2015-2025) is to provide a high-level planning tool to facilitate and guide the refocusing of research, reprioritisation of funds, synergising of existing initiatives and ring-fencing of new resources to address the challenges in the water innovation system. Seven thematic clusters form the focus of the Roadmap, developed during 2014 and 2015. An important aspect of this Roadmap development process was a national Water RDI capability mapping exercise.

The objective of the capability mapping in the current study is to provide insight into where the different water-related RDI disciplinary skills sets lie around the country. The strength of the capability mapping is that it gives information on the different competencies, based on the clusters and Research Focus Areas (RFAs) in the Roadmap, which allows for a more focused consideration on how to best support and structure the RDI capability optimally.

A meeting was held with the WRC research manager who oversaw the previous capability mapping research in order to understand the approach followed. Two online questionnaires were used; the first assessed individual research capability in terms of the Roadmap's RFAs. Data collected from the second questionnaire, focusing on institutional capability, served as a control measure to confirm and verify data collected from individual respondents. The individual questionnaire was distributed to a sample size of 1081 water-related researchers. A response rate of 25.34% of the questionnaires was received for analysis.

The institutional capability survey questionnaire was sent to 177 participants from 43 institutions and organisations involved in research, development and innovation in the water sector. Twenty-eight responses were recorded for the institutional questionnaire, resulting in a 16% response rate.

The highest percentage of individual respondents, according to the recorded results, indicated that their water-related RDI activities are linked to Cluster 1 "Increase ability to make use of more sources of water" at 45%. However, a few clusters reflected low RDI activities, including Cluster 3 "Adequacy and performance of supply infrastructure and operational Performance (Built infrastructure)" (14%), Cluster 5 "Running the water as a smart business" (12%) and Cluster 4 "Adequacy and performance of supply infrastructure and operational performance (Ecological infrastructure/ecosystems)" (23%).

More than 15% of individual respondents indicated that their water-related RDI activities are linked to the following RFAs: environment (RFA 30); environmental pollution (RFA 33); environmental water quality (RFA 35); hydrology and water resources (RFA 48); sustainability (RFA 77); wastewater treatment (RFA 85); water and wastewater treatment (RFA 87); water quality and water resources (RFA 90) and water resource management (RFA 94). No RDI activities were linked to six RFAs and a further 32 RFAs had a very low percentage of respondents (≤2%) linking their RDI activities to these research areas.

In order to measure RDI capability, the individual questionnaire data sets were aggregated into each of the seven Roadmap clusters in terms of the representative organisation of employment, RFA and capability. Capability was based on a composite score calculated from the data collected from the individual survey based on the number of people in the research unit as well as the years of experience and the highest qualification of the respondent.

Bibliometric data was collected as an exploratory piece of work to assist in the discussion of the capability mapping and to highlight the uses of the capability maps. As the data of the capability mapping exercise

reflected self-reported research strength, based on the questionnaire, the bibliometric data was also incorporated into the study to provide a level of sense checking. It is important to note that bibliometric analysis can be used to indicate the water-related research strength of an institution or organisation as an entity but it is not the case with the capability mapping. As stated earlier the capability maps provide information on the research strength of water-related RDI disciplinary skills sets based on RDI activity, reflected as RFAs, within institutions and organisations and can provide insight for each entity into the research strength of their different water-related RDI disciplinary skills sets.

Relevant stakeholders in the water research community, as well as in the higher education environment, can use the information in the capability maps to inform opportunities and thinking relating to knowledge generation, human capital development and research chairs.

The complex nature of the capability mapping exercise produced a magnitude of information which can be used by stakeholders. The report contains seven capability maps, one for each cluster. In every capability map each of the 100 RFAs is mapped against each of the respective institutions and organisations, with the lowest number of institutions mapped 14 and the highest number of institutions mapped 38. However, the drawback and limitation is that it is difficult to make general conclusions and recommendations, due to the more than 16 000 data points, and the information in this report should be used by the relevant stakeholder by a case by case basis. The capability maps provide a visual tool for stakeholders to extract the information for their purpose.

Below are a few guidelines which stakeholders can use to extract the relevant information for their specific goal.

1. The capability maps can be used by relevant stakeholders interested in the research strength of water-related RDI activities within a specific Higher Education Institution (HEI), such as Deans, to:
    a. Identify clusters where the specific HEI is conducting water-related RDI;
    b. Identify RFAs, and their research strength, within each cluster where water-related RDI is conducted; and
    c. Identify interventions or opportunities for the specific HEI based on the research strengths of the specific RFAs.
2. The capability maps can be used by investors and water RDI ecosystem coordinators (government and private funding vehicles) to:
    a. Identify clusters where there are a limited amount of RDI activities;
    b. Identify RFAs, and their research strength, within each cluster; and
    c. Identify investment opportunities and other interventions based on the research strength of the specific RFAs.

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# GLOSSARY OF TERMS

**Centres of Excellence (CoE):** The Department Science and Technology (DSI)- National Research Foundation (NRF) defines research centres of excellence (CoE) as physical or virtual centres where the key focus is the consolidation of resources and accompanied capacity towards research excellence and long-term competitiveness both domestically and internationally. For the purpose of this study, the focus will be both on CoEs as defined and recognised by the DSI-NRF, as well as transdisciplinary research institutes and centres with demonstrated research excellence.

**Cluster:** Cluster is associated with Water RDI Roadmap RDI initiatives in support of water sector objective and targeted RDD outcomes for 2025.

**Knowledge Diffusion (KD):** The extent to which knowledge about a specified topic has diffused from research into practice. The degree of KD is estimated on a scale of 0 (initial research, no implementation), through field testing and pockets of implementation, to 5 (research translated into full adoption).

**Research Capacity**: Research Groups, whether at a particular location or in the form of a distributed network, including masters and doctoral students that are associated with, and needs supervision by this Research Capacity.

**Research, development and deployment (RDD Objective)**: RDD objective is a summary of high-level needs and interventions related to Water RDI Roadmap programs and accompanied activities.

**Research Development and Innovation Capability Mapping:** Capability of South African researchers are mapped in terms of their relevant areas of expertise (defined by the underlying research focus area) and their research strength/maturity.

**Research Focus Area (RFA):** In terms of area of expertise cognisance is taken both of the area of the underlying discipline and in addition, further specialisation into the area of interest or focus.

**Research Strength / Maturity:** Research Strength/maturity was based on a composite score calculated based on the number of people in the research unit as well as the years of experience and the highest qualification of the respondent. Research Strength is gauged on a scale of 0 to 1.

**Sector Objective:** It is the targeted objective of the sector.

**Transdisciplinary:** Transdisciplinary research is defined as research efforts conducted by investigators from different disciplines working jointly to create new conceptual, theoretical, methodological and translational innovations that integrate and move beyond discipline-specific approaches to address a common problem. A critical defining characteristic of transdisciplinary research is the inclusion of stakeholders in defining research objectives and strategies.

# ABBREVIATIONS

| | |
|---|---|
| ARC | Agricultural Research Council |
| AUDA | African Union Development Agency |
| CoE | Centre of Excellence |
| CSIR | Council for Scientific and Industrial Research |
| DoH | Department of Health |
| DSI | Department of Science and Innovation |
| DST | Department of Science and Technology |
| DTI | Department of Trade and Industry |
| DWS | Department of Water and Sanitation |
| HEI | Higher Education Institutions/Institutes |
| IP | Intellectual Property |
| NEPAD | New Partnership for Africa's Development |
| NMISA | National Metrology Institute of South Africa |
| NRF | National Research Foundation |
| NSI | National System of Innovation |
| NWRS2 | National Water Resource Strategy II |
| R&D | Research and Development |
| RDD | Research Development and Deployment |
| RDI | Research Development and Innovation |
| RFA | Research Focus Area |
| SAEON | South African Environmental Observation Network |
| SEDA | Small Enterprise Development Agency |
| SPII | Support Program for Industrial Innovation |
| SU | Stellenbosch University |
| UCT | University of Cape Town |
| UJ | University of Johannesburg |
| UKZN | University of KwaZulu-Natal |
| UNISA | University of South Africa |
| UP | University of Pretoria |
| UWC | University of the Western Cape |
| WISA | Water Institute of Southern Africa |
| WITS | University of the Witwatersrand |
| WRC | Water Research Commission |

# CHAPTER 1: INTRODUCTION AND CONTEXT

Water scarcity remains one of the challenges the World currently faces. For the period of 2016 to 2020 the World Economic Forum identified the water crisis as one of the top five global risks. The World Economic Forum defines water crisis as "*a significant decline in the available quality and quantity of fresh water, resulting in harmful effects on human health and/or economic activity*" (World Economic Forum, 2020). Water scarcity already has a negative impact on a quarter of the world's population (World Resources Institute, 2019).

The situation in South Africa is also dire with the country facing a projected 17% water deficit by 2030. Challenges the water sector face include recurrent droughts, insufficient water infrastructure maintenance and investment, inequalities in access to water, a decline in water quality and a lack of skilled water engineers (DWS, 2018). This reality requires the implementation and management of innovative solutions, technologies and processes carried out by highly skilled individuals.

This has led to the development of South Africa's Water Research, Development and Innovation (RDI) Roadmap (2015 - 2025) during a partnership by the Department of Science and Innovation (DSI) and the Water Research Commission (WRC). The DWS endorses the venture as the implementation plan for the National Water Resource Strategy II (NWRS2), in particular the chapter regarding Research and Innovation (Chapter 14) and Water Sector Skills and Capacity (Chapter 15) (WRC, 2015). There are also linkages between the Roadmap and the Industrial Policy Action Plan 2017-2021 (WRC, 2018).

The goal of the Water RDI Roadmap is to provide a high-level planning tool to facilitate and guide the refocusing of research, reprioritisation of funds, synergising of existing initiatives and ring-fencing of new resources to address the challenges in the water innovation system. Seven thematic clusters form the focus of the Roadmap and were developed during 2014 and 2015. In brief, the water community was divided into four sectors: Agriculture, Industry, Public Sector and Environmental Protection. In the first set of workshops participants identified a list of needs in the respective water sectors. The list of needs was reviewed, and interventions were identified during a second set of workshops. Lastly participants grouped the reviewed list of needs and interventions into seven clusters which formed the basis of the programme of work in the Water RDI Roadmap.

The thematic clusters of the Water RDI Roadmap categorised as supply side needs and interventions are as follows:

1. Increase ability to make use of more sources of water, including alternatives;
2. Improve governance, planning and management of supply and delivery;
3. Improve adequacy and performance of supply infrastructure and
4. Run water as a financially sustainable "business" by improving operational performance.

The thematic clusters categorised as demand side needs and interventions are as follows:

5. Improve governance, planning, and management of demand and use;
6. Reduce losses and increase efficiency of productive use and
7. Improve performance of pricing, monitoring, billing, metering and collection (WRC, 2015).

An important aspect of the Water RDI development process was a national Water RDI capability mapping exercise that took place. The goal of the capability map is to provide the relevant stakeholders in the water community with insight into the location and strength of different disciplinary skills, relevant to water-related RDI, in South Africa. The WRC published South Africa's Water RDI Roadmap in 2015 (WRC, 2015).

The WRC Roadmap Implementation Unit introduced the finalised RDI roadmap to relevant stakeholders in the water sector, including universities, utilities, municipalities, government organisations, entities and companies, during 2016 and 2017 through a series of national roadshows and workshops. During these sectoral engagements a set of human capacity and development needs and opportunities in the water sector emerged (WRC, 2017). One important point was updating the existing RDI Water Roadmap as water experts are highly mobile and changes occur constantly in the sector. This mobility, unless periodically taken into account, limits insight into the distribution, concentration and maturity of different water-relevant disciplinary skill sets in South Africa. This information is essential to enable relevant stakeholders to determine how best to support and structure RDI capability optimally, while identifying new opportunities or current shortfalls in the national water sector. This, and other considerations, prompted the request for proposals by the WRC.

This report focuses on updating the Water RDI Capability Roadmap by mapping the current capability and location of South African based water researchers and their associated research institutions. Relevant stakeholders in the water research community, as well as in the higher education environment, can use the information in the capability maps to inform opportunities and thinking relating to knowledge generation, human capital development and research chairs. The capability maps provide a visual tool for stakeholders to extract the information for their purpose.

# CHAPTER 2: METHODOLOGY

## 2.1 DATABASE COLLECTION

### 2.1.1 Individual database collection

The database which served as the basis for the current study was developed by contacting the project leaders and their collaborators of accepted and rejected proposals submitted to the WRC for the 2014/2015 to the 2018/2019 cycles. Where the info, was not already available through the WRC, the individual's contact details were obtained through internet searches and where necessary, telephone calls. Project leaders and their collaborators submitting proposals to the WRC were used to form the basis of the database since the WRC is the leading funder of water-related research in South Africa. The WRC is currently funding 65% of all water-related research in South Africa (WRC, 2016).

### 2.1.2 Institutional database collection

A comprehensive database was established for the institutional capability mapping which includes entities involved in water-related RDI activities such as: private companies (e.g. engineering consulting firms), networks (e.g. AUDA/NEPAD), councils (e.g. Council for Geoscience), government research and science development agencies (National Research Foundation) and Higher Education Institutions (HEIs). The database includes the contact details of Deans, Directors, Programme Heads, and Heads of Departments (HODs) of higher education institutions as well as Chief Executive Officers, advisors and managers of councils, networks and other relevant agencies.

## 2.2 TAXONOMY OF RFAs

The Research Focus Areas (RFAs), defined as areas of research expertise in water, were developed as part of the development of the National Water RDI Roadmap (WRC, 2015). The underlying discipline and sub-disciplines were used for defining each RFA or area of interest. Soil fertility was, for example, described by the following disciplines: Agricultural sciences (Discipline level 1), Soil Science (Discipline level 2) and Soil Fertility (Discipline level 3). The WRC managers mapped the 106 unique RFAs onto the clusters of the Roadmap to have a high level view of the key disciplines and research specialisations which are driving research in the different thematic clusters.

In the current study, the first raw data file of taxonomy of RFAs that was used in the 2015 study was provided by the WRC. This raw data file was further correlated with the taxonomy of RFAs used in the 2015 RDI Roadmap Capability studies. Minor modifications were made particularly where duplication occurred, before it was finally included in the survey questionnaires. The RFAs are listed in Appendix A.

## 2.3 INDIVIDUAL AND INSTITUTIONAL QUESTIONNAIRES

A meeting was held with the research manager that undertook the previous capability mapping study in order to understand the methodology and approach followed.

Two online questionnaires used by the Water RDI Roadmap team in the previous 2015 – Water RDI Roadmap study were reviewed and updated. The first questionnaire assessed the individual research capability in terms of RFAs, whereas the second questionnaire focused on the institutional capability. The data collected from the individual questionnaire formed the basis of the study while data collected from the institutional questionnaire were incorporated as a control measure to confirm the first set of data. Both questionnaires were approved by the Social, Behavioural and Educational Research ethics committee of Stellenbosch University (REC-2019-9608).

The investment model of the Water RDI Roadmap (WRC, 2015) is focused on delivering socio-economic impacts benefiting water scarcity, economics, public health, society and natural and built environment. To achieve these socio-economic impacts technology development, knowledge generation and human capital development must be supported. Key performance indicators (KPIs) included in this study measure RDI related outputs linked to technology development, knowledge generation, and human capital development and will be discussed in more detail in the following sections (WRC, 2015).

The Stellenbosch University (SU) SUNsurvey online platform was used to construct both survey questionnaires and to distribute the individual and institutional databases. The Water RDI Roadmap Manager facilitated formal communication with potential survey participants. To obtain participants' consent to be included in the respective questionnaire distribution database, an opt-out clause was inserted into the email communication. The individual and institutional databases for the questionnaires were confirmed by excluding those participants that indicated that they did not wish to be part of the survey. In June 2019 the individual questionnaire was distributed online to a sample size of 1081 water-related project leaders and collaborators. The online link to the questionnaire remained active for 25 days. The distribution of the second questionnaire took place in July 2019. The questionnaire was sent to 177 participants from 43 institutions. The online link to the questionnaire remained active for 17 days. A limited number of individual respondents were contacted by email and telephonic interviews to verify data for qualification purposes.

The results of the questionnaires were consolidated into a visual format (referred to as heat maps) and a summary report to provide a comprehensive overview of South Africa's research capability map

### 2.3.1 Water-related sectors, clusters, research disciplines, sub-disciplines and RFAs

To establish the spread and coverage of research disciplines within South Africa's water sector, individual respondents were requested to identify their areas of expertise by selecting the research discipline (e.g. engineering), research sub-disciplines (e.g. coastal engineering), specialisation fields (e.g. ecohydrology), RFAs (e.g. flood defence) and cluster linked to their RDI activities. The thematic water clusters were established as part of 2015 studies during workshopping. The water community was divided into sectors and each sector identified interventions accompanied by a list of actions to satisfy each need (WRC, 2015).

In the current study slight changes were made to the clusters in the current study as reflected in the table below:

**Table 1: Names of the clusters of the 2015 and 2019 survey**

| No | Clusters used in the 2015 survey | Clusters used in the current survey |
|---|---|---|
| 1 | Increase ability to make use of more sources of water, including alternatives | Increase ability to make use of more sources of water |
| 2 | Improve governance, planning and management of supply and delivery | Governance, planning, and management of supply and demand |
| 3 | Improve adequacy and performance of supply infrastructure | Adequacy and performance of supply infrastructure and operational performance (Built infrastructure). |
| | | Adequacy and performance of supply infrastructure and operational performance (Ecological infrastructure / ecosystems) |
| 4 | Run water as a financially sustainable "business" by improving operational performance | Running the water sector as a smart business |
| 5 | Improve governance, planning, and management of demand and use | |
| 6 | Reduce losses and increase efficiency of productive use | Efficiency use of water (Agriculture, industry, and consumers) |
| 7 | Improve performance of pricing, monitoring, billing, metering and collection | Monitoring and metering |

Respondents from the individual questionnaire were also requested to list the maximum number of years of experience in their RFAs. The options that were provided in the questionnaire are listed in Appendices A (RFAs), B (research disciplines), C (research sub-disciplines) and D (specialisation fields). Questionnaire respondents could also add any RFAs relevant to their water-related RDI activities that were not listed in Appendix A.

Respondents were also requested to indicate in which sub sector within the water sector their primary research activities are located. These include agriculture, public sector, industry and environmental protection; with an option for "other" in the event that the list provided did not accommodate their choice.

### 2.3.2 Research group staff profile

KPIs of Research and Development (R&D) in South Africa's National System of Innovation (NIS) surveys include the total number of research and development personnel and the total number of researchers in an institution (Manzini, 2015). It is included as a KPI as the size of the research group is commonly used to measure the R&D efforts of an institution (Kleinknecht et al., 2002). The questions included in this section also measure human capital development as it investigates the research capacity and the number of students involved in a water-related RDI unit (WRC, 2015).

Respondents from the individual questionnaire were therefore requested to indicate the number of people involved in RDI activities that are research chairs, research/institute directors, professors, associate professors, senior lectures, lecturers, researchers, postdoctoral fellows, PhD students, Masters students, Honours students, laboratory assistants, chief scientists, innovation officers, business designers and innovation analysts. Respondents from the institutional questionnaire were requested to indicate the number of employees that conduct water-related RDI activities who are postdoctoral fellows, who have a PhD (excluding postdoctoral researchers) and who have a Masters and Honours degree, respectively. The results of these questions are incorporated into the capability maps (Section 2.3 – Capability of the clusters).

### 2.3.3 Collaborations

Cooperation for innovation activities is used as a KPI of innovation in South Africa's NIS surveys (Manzini, 2015). Respondents from the individual and institutional questionnaires were therefore requested to indicate internal and external collaborations. Furthermore, respondents had to link the collaborations with RFAs.

### 2.3.4 Funding

Gross domestic expenditure on R&D and financial support for innovation activities are used as KPIs of R&D, and innovation, respectively, in South Africa's NSI surveys (Manzini, 2015). It is included as a key indicator as expenditure on R&D, as with the number of people involved with R&D, is commonly used to measure the R&D efforts of an institution (Kleinknecht et al., 2002).
Respondents from the individual and institutional questionnaires were therefore requested to indicate sources from which funding was received for water-related RDI activities in the last five years. This could potentially shed light on whether innovation funding vehicles are utilised to their optimal levels in as far as water RDI are concerned.

### 2.3.5 External factors' significance on institutional research capabilities

Factors hampering innovation activities are used as a KPI of innovation in South Africa's NSI surveys (Manzini, 2015). Respondents from the institutional questionnaire were therefore requested to indicate whether any of the factors listed in the questionnaire negatively impact the organisation's overall research output. The list of factors included limited infrastructure, lack of funding or limited funding, lack of sector coordination, lack of monitoring and evaluation and lack of sector responsiveness. Respondents could also list any other factors not included in the list.

### 2.3.6 Outputs

A measurable RDI related output linked to technology development includes prototypes while registered patents, patent applications and publications are RDI related outputs linked to knowledge generation (WRC, 2015). Respondents from the individual questionnaire were therefore requested to indicate which outputs their water-related RDI activities achieved within the last five years. The list included publication/conference paper, Intellectual Property (IP) registration, patent registration, prototyping, trials, post-trial production, business registration and options for other and none of the above.

Bibliometric data was collected as an exploratory piece of work to assist in the discussion of the capability maps to highlight the uses of the capability maps and how it differs from bibliometric analysis. A bibliometric search was completed using the keywords "water" for 27 South African HEIs and research units using the search engine Web of Science. The search was from 2014 to 2018 for the total number of outputs, articles, proceeding papers, reviews, book chapters as well as the average number of citations and the total number of citations for the outputs.

## 2.4 CAPABILITY OF CLUSTERS

In order to measure RDI capability, the individual questionnaire data sets were aggregated into each of the seven Roadmap clusters in terms of the representative organisation of employment, RFA and capability. Capability was based on a composite score calculated from the data collected from the individual survey based on the number of people in research unit as well as the years of experience and the highest qualification of the respondent. Data was combined in the instances where more than one person per organisation completed the questionnaire.

The data from responses were populated into “heatmaps” that reflect: the organisation on the horizontal x-axis, RFAs on the vertical y-axis, research strength/maturity of RDI capability in terms of the number of research related employees, qualification and years of experience in water research (intensity of the colour representing the heat map).

The research strength/maturity of RDI capability, based on the composite score was identified at four levels, namely Emerging (0-0.2), Building (0.2-0.4), Established (0.4-0.6) and Mature (above 0.6 - 1).

# CHAPTER 3: RESULTS

This section presents the results and the discussion of the Water RDI Roadmap Capability Map study. Where applicable the results of the individual and institutional questionnaires were combined as the data collected from the institutional questionnaire served as a control measure to confirm the data collected from individual respondents.

## 3.1 PARTICIPATION

The individual questionnaire was distributed to a sample size of 1081 water-related researchers. A response rate of 25.34% of the questionnaires was received for analysis. It should be noted that the response rate is similar to the response rate of 26.7% obtained in the South Africa Innovation Survey of 2008 (HSRC, 2011).

The institutional questionnaire was sent to 177 participants from 43 institutions. Twenty-eight responses were recorded from the 177 participants, resulting in a 16% response rate.

### 3.2.1 Water-related sectors, clusters, research disciplines, sub-disciplines and RFAs

Researchers in the individual questionnaire had to indicate in which sector their water-related RDI activities are located (Figure 1). The results show that the majority of RDI activities within the water research community are located in the Environmental Protection sector at 49%, followed by the respondents indicating that their RDI activities do not fall into a sector specified in the questionnaire (Other) at 24%, the Agricultural sector at 20%, Public sector at 19% and the Industry sector at 15% (Figure 1). Respondents specified sectors (Others) not included in the questionnaire, according to their knowledge, as water resources, engineering, education, mine water research, systems, security studies, water law, groundwater supply, health and biotechnology, etc.

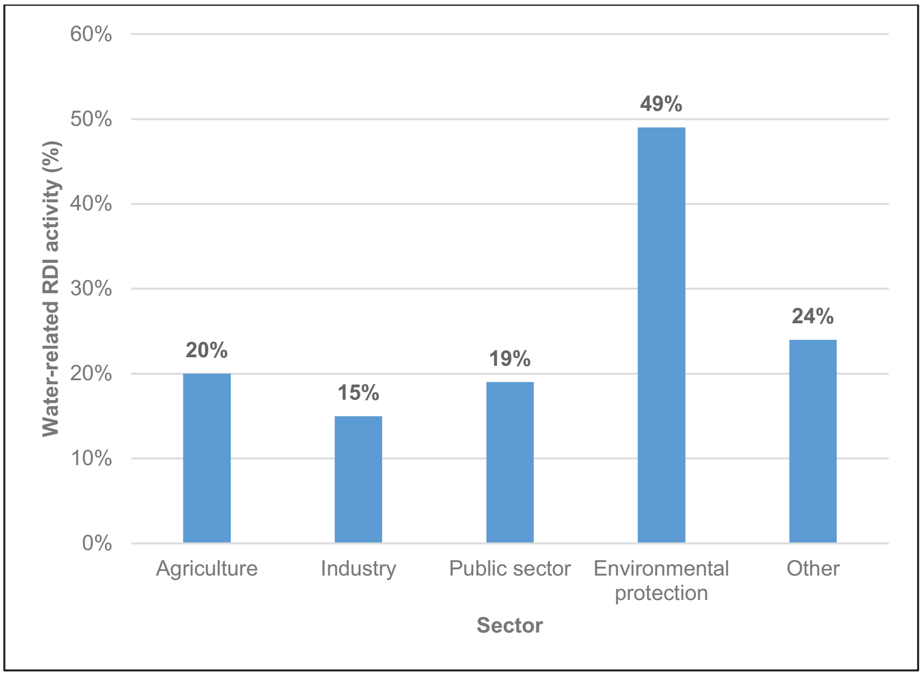



**Figure 1: Percentage water-related RDI activity reported per sector (Individual questionnaire) (n = 220)**

Researchers had to indicate in which of the seven thematic cluster(s) their water-related RDI activities are located (Figure 2). The results show that the majority of reported water-related RDI activities take place within the cluster “Increase ability to make use of more sources of water” at 45%. The clusters with the least amount of water-related RDI activities reported were the clusters “Adequacy and performance of supply infrastructure and operational performance (Built infrastructure)” and “Running the water sector as a smart business” at 14 and 12%, respectively.

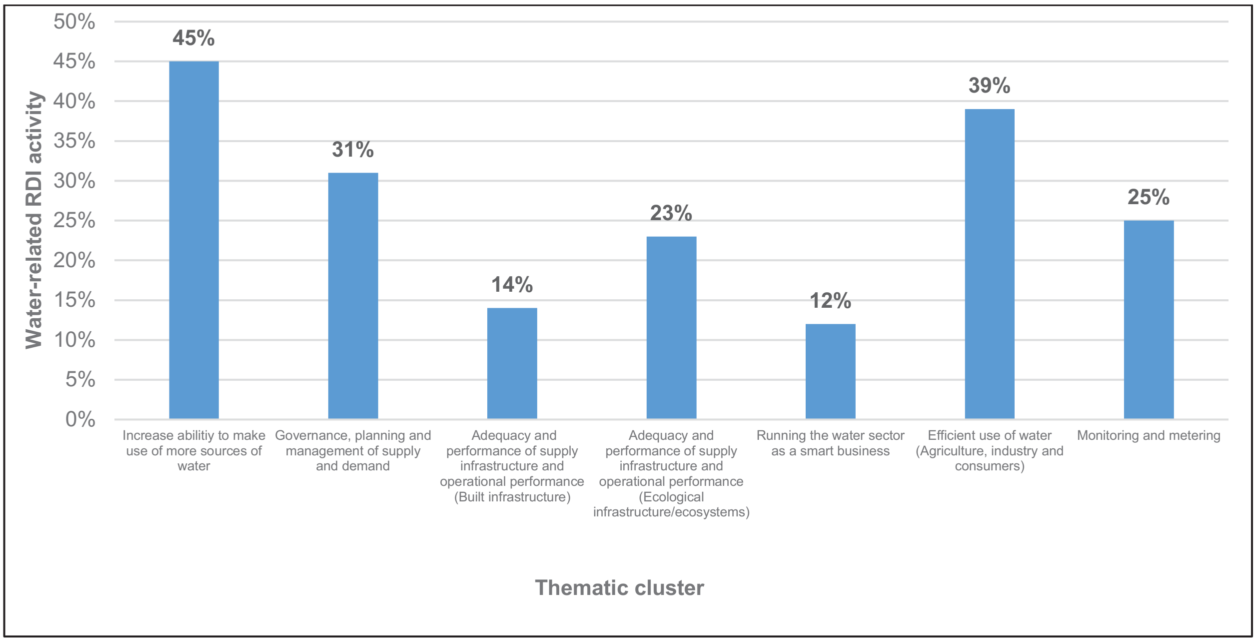



**Figure 2: Percentage water-related RDI activity reported per thematic cluster (individual questionnaire) (n = 220)**

Researchers indicated the discipline(s) in which their water-related RDI activities are located (Figure 3). The results show that the majority of water-related RDI activities take place within the following disciplines: Water quality and water resources (37%), environmental pollution (31%), environmental sciences (29%) and hydrology and water resources (27%). None of the respondents that completed the questionnaire are conducting water-related RDI activities in clinical medicine, linings and covers for potable water, immunology and ocean wave power.

The results of the percentage water-related RDI activities reported per sub-discipline, RFA and specialisation field are shown in Appendices E to G, respectively. More than 15% of individual respondents indicated the their water-related RDI activities are linked to the following RFAs: environment (RFA 30); environmental pollution (RFA 33); environmental water quality (RFA 35); hydrology and water resources (RFA 48); sustainability (RFA 77); wastewater treatment (RFA 85); water and wastewater treatment (RFA 87); water quality and water resources (RFA 90) and water resource management (RFA 94) (Appendix F). According to the results of the study, a number of RFAs with no water-related RDI activities were reported and are the following bioethics (RFA 10), geomembrane linings and covers for potable water storage (RFA 39), non-Newtonian fluid mechanics (RFA 61), ocean wave power (RFA 62), plant life extension technologies (RFA 64) and unsaturated zone (RFA 81) (Appendix F).

Respondents specified RFAs not included in the questionnaire, according to their knowledge, as the following: agricultural economics; agricultural sustainability; agroforestry, food security and conservation agriculture; agrometeorology; climate-smart agriculture; complex social-ecological systems; dam safety; ecological infrastructure and services; ecotoxicology; effects of land use on water quality; energy storage; environmental and ecological economics; environmental history; extraction metallurgy; financing water; geochemistry;

groundwater hydraulics; hydropower; integrated water utilisation; machine learning, data mining, Artificial Intelligence; microbial biotechnology; nanoecotoxicology; nanotechnology; pipeline leakage detection; political ecology; radar and satellite rainfall modelling; rainwater and greywater harvesting; river basin research and management; rural development; sanitation and human settlement; surface water and groundwater interactions; sustainable tourism; utilisation of water pollution microbes; water infrastructure development and maintenance; water-energy-food climate change nexus; watershed management and compliance regulation and watershed modelling. Although these RFAs were noted by researchers as areas of activities, there will be a need for a sector recognition and validation process, before the areas of research can be included in the WRC Taxonomy of Research Focus Areas.

### 3.2.2 Collaborations

Respondents from the individual and institutional questionnaires were requested to indicate internal and external collaborations linked to their water-related RDI activities. Furthermore, respondents had to link the collaborations with RFAs.

Appendices H and I show the results for internal and external collaboration linked to water-related RDI activities, respectively, of respondents of the individual and institutional questionnaires. In general, respondents from the institutional questionnaire reported higher percentages of internal and external collaboration when compared to the results of the respondents of the individual questionnaire.

The three RFAs with the highest reported internal collaboration from the institutional questionnaire were RFA 35 (Environmental water quality) at 39%, RFA 90 (Water quality and water resources) at 32% and both RFA 91 (Water quality monitoring, ecosystems functioning, environmental water quality and animal health) and RFA 48 (Hydrology and water resources) at 29%. Results from the individual questionnaire show that RFA 94 (Water resource management) had the highest percentage of reported internal collaboration at 15% followed by RFAs 30 (Environment) and 35 (Environmental water quality) both at 12% (Appendix H).

The three RFAs with the highest reported external collaboration from the institutional questionnaire were RFA 34 (Environmental protection and pollution control) at 39%, RFA 46 (Hydrologic engineering) at 36% and RFA 8 (Beneficial agricultural use of municipal sludge) at 32%. Results from the individual questionnaire shows that RFAs 35 (Environmental water quality) and 94 (Water resource management) had the highest percentage of reported external collaboration both at 13% followed by RFA 48 (Hydrology and water resources) and RFA 7 (Aquatic ecosystems) both at 12% (Appendix I).

Results from the individual questionnaire show no internal collaboration reported in 10 RFAs and no external collaboration reported in 9 RFAs. Results from the institutional questionnaire show no internal collaboration in 17 RFAs and no external collaboration in 12 RFAs (Appendices H and I).

### 3.2.3 Funding

Respondents from the individual and institutional questionnaires were requested to indicate sources from which funding were received for water-related RDI activities in the last five years. Results from the individual questionnaire show that the WRC leads funding activities with 53% of the respondents reporting having received funding from the WRC from 2014 to 2018 (Figure 4). In the institutional questionnaire the WRC was reported to be the second biggest funder of water-related RDI activities at 50% (Figure 4).

The National Research Foundation (NRF) is, according to this study, another important source of funding. Results from the individual and institutional questionnaire show that the NRF supports 32% and 86%, respectively, of individuals involved in water-related RDI activities from 2014 to 2018 (Figure 4).

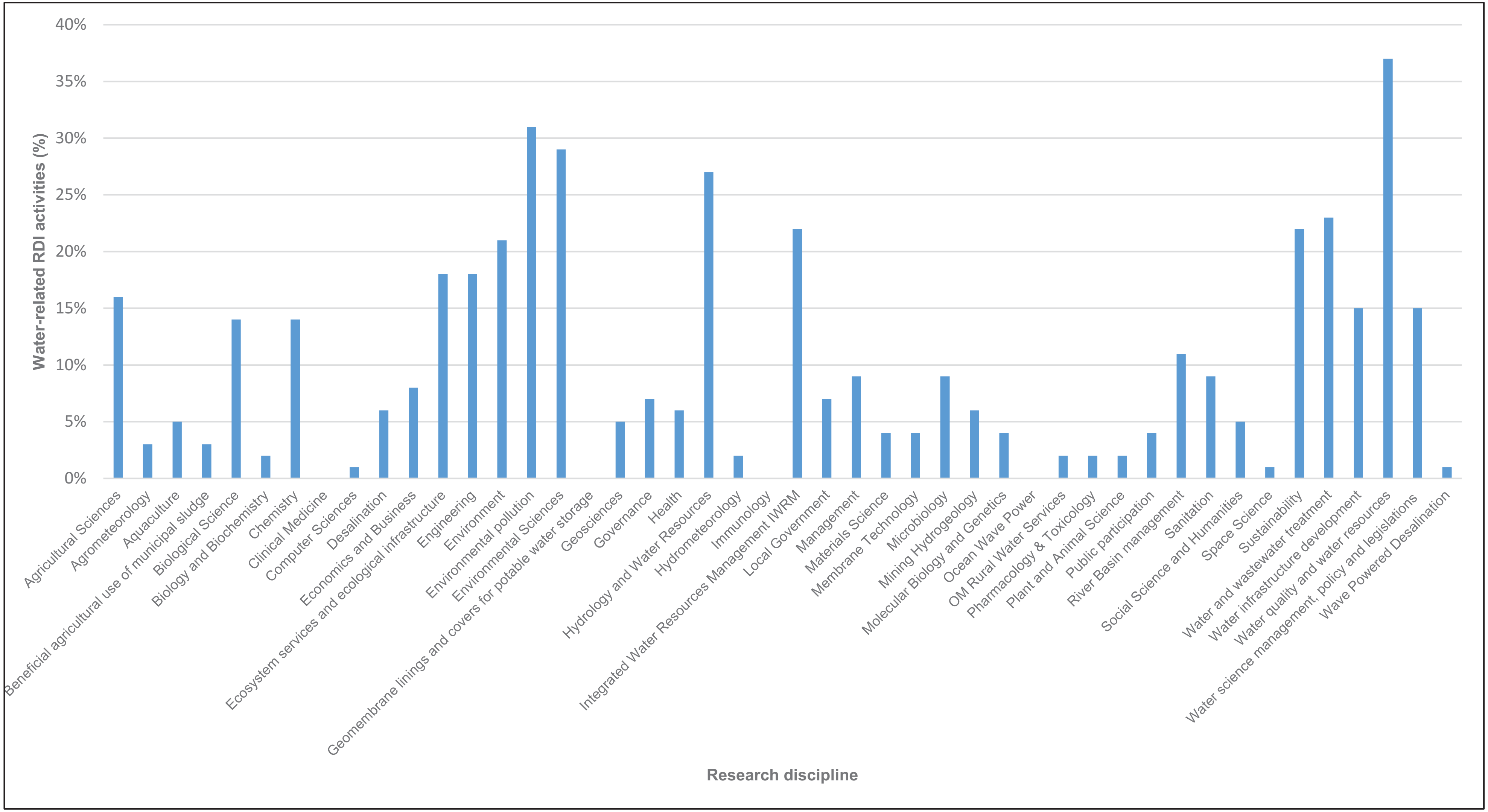



**Figure 3: Percentage water-related RDI activity reported per research discipline (individual questionnaire) (n = 220)**

Twenty-three percent of respondents from the individual questionnaire indicated receiving funding from South African companies (i.e. local private sector) in the time-period of 2014-2018 while 10% indicated receiving funding from international companies (i.e. international private sector). Similar results were obtained from the institutional survey. Twenty-nine percent of respondents from the institutional questionnaire indicated receiving funding from South African companies (i.e. local private sector) in the time-period of 2014-2018 while 11% indicated having received funding from international companies (i.e. international private sector).

According to the individual survey questionnaire, no respondents received funding from the National Innovation System (NIS), Academy of Science of South Africa (ASSAF), Support Program for Industrial Innovation (SPII), the Innovation Fund and Godisa Supplier Development Fund. Similar results were obtained from the institutional survey questionnaire with respondents indicating that no funds were received for water-related RDI activities from NIS and ASSAF while the Department of Technology and Innovation (DTI), Godisa Supplier Development Fund, the Innovation Fund, Support Program for Industrial Innovation (SEDA) and SPII each supported only 4% of water-related RDI activities (Figure 4).

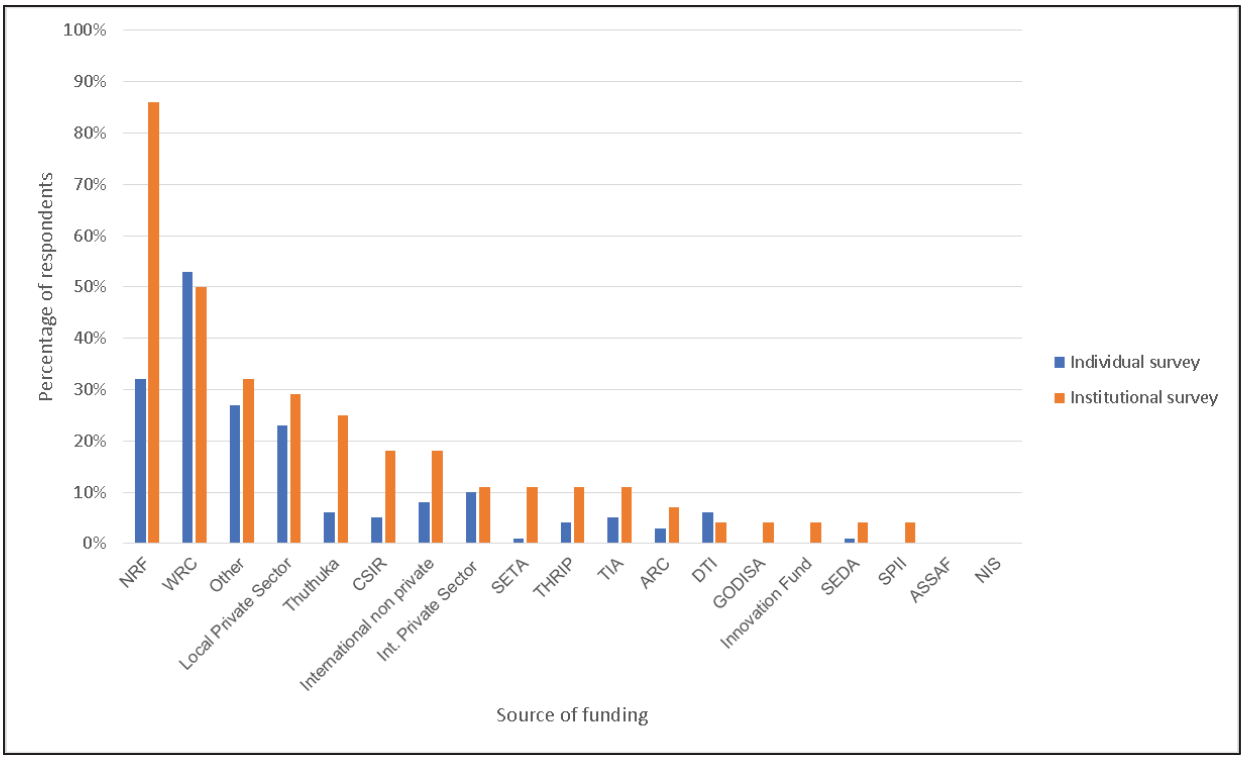



**Figure 4: Percentage of respondents indicating source/s of funding (n = 220 for individual questionnaire and n = 28 for institutional questionnaire)**

### 3.2.4 External factors' significance on institutional research capabilities

Respondents from the institutional questionnaire indicated, from a list of options, external factors hampering the research capabilities of the respective institute. Most respondents (93%) indicated a lack of funding or limited funding and a lack of monitoring and evaluation as factors that negatively impact their organisation's overall research output. Many respondents also indicated that limited research infrastructure (89%), lack of sector coordination (89%) and lack of sector responsiveness (86%) are also barriers to the respective institution's research outputs (Figure 5).

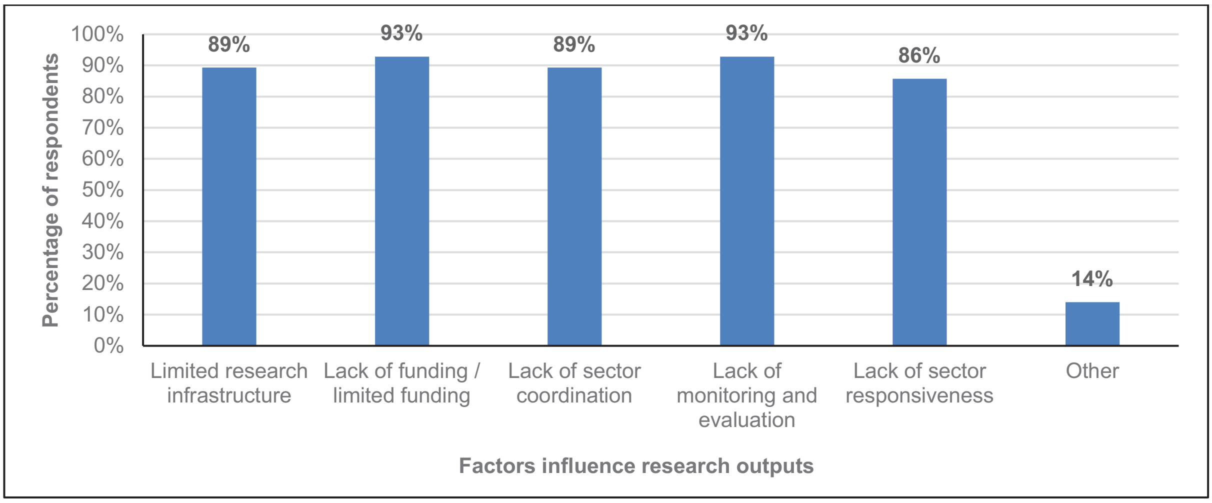



**Figure 5: Percentage of respondents indicating factors negatively influencing institutions research outputs (n = 28)**

### 3.2.5 Outputs

Respondents from the individual questionnaire were requested to indicate which research outputs, from a list of options, their water-related RDI activities achieved within the last five years (2014 - 2018). Results show that the majority of respondents indicated publication(s) and/or conference paper(s) (76%) as research outputs linked to their water-related RDI activities. This was followed by 13% of respondents indicating that they have delivered a research output not included in the questionnaire, 5% for patent registration and 4% for both post-trial production and business registration (Table 2).

Nine percent of the respondents selected the "*None of the above*" option in the questionnaire. This indicates that there was no research outputs linked to their water-related RDI activities during the time period of 2014 to 2018.

**Table 2: Research outputs of individual respondents (n = 220)**

| Research outputs | Percentage (%) |
|---|---|
| Publication/Conference Paper | 76 |
| Other | 13 |
| Prototyping | 10 |
| Trials | 9 |
| None Of The Above | 9 |
| IP Registration | 6 |
| Patent Registration | 5 |
| Post-trial production | 4 |
| Business Registration | 4 |

As 76% of outputs of water-related RDI activities of individuals were linked to publications and conference papers a bibliometric search was completed for South Africa HEIs using the keywords "water" from 2014 to 2018. The results show all the affiliations linked to each publication. It should therefore be noted that the NRF forms part of the data since the bibliometric search recorded the NRF for publications linked to researchers with NRF Resarch Chairs. In these publications the NRF was registered as an affiliate of the researcher. National Metrology Insitute of South Africa (NMISA), Walter Sisulu University, Mintek, South African Environmental Observation Network (SAEON), Mangosuthu University of Technology (MUT) and Central University of Technology (CUT) [referred to as Central University of Free State (UFS) in the previous capacity study conducted in 2015] produced less than 50 outputs during the timespan (Figure 6). Amongst the South

African HEIs the University of Pretoria (UP), University of Cape Town (UCT) and University of KwaZulu-Natal (UKZN) produced the highest number of research publications from 2014 to 2018, with over 800 each (Figure 6).

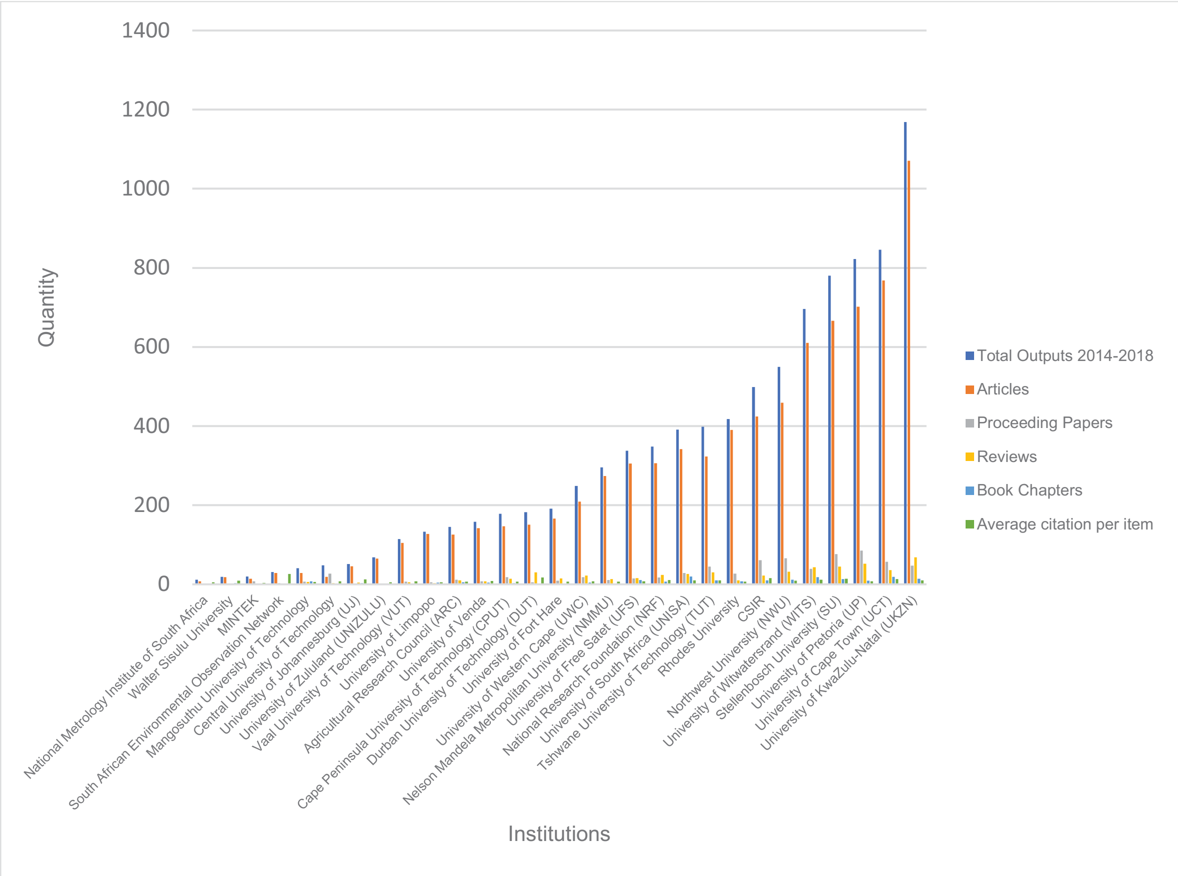



**Figure 6: Bibliometric results (total number of different outputs as well as average number of citations per item) for South African HEIs conducting a search using the key words "water"**

## 3.3 CAPABILITY OF CLUSTERS

The research strength/maturity of RDI capability, based on the composite score was identified at four levels, namely emerging (0-0.2), building (0.2-0.4), established (0.4-0.6) and mature (0.6 - 1). For each cluster the objective and targeted research, development and deployment (RDD) outcome for 2025, as described in South Africa's Water RDI Roadmap (2015-2025), will be given. A RFA with mature research strength will have a high number of researchers in the RDI team and the lead researcher will have numerous years of experience as well as a high qualification. A RFA with emerging research strength will have a low number of researchers in the RDI team and the lead researcher will not have many years of experience and will not be highly qualified. The capability maps are based on a composite score of three variables which include number of researchers in the RDI team, the highest qualification of the lead researchers and number of years of experience.

In the appendices the results of the current capability maps are compared to the results of the capability maps in South Africa's Water RDI Roadmap (2015-2025). The aim of the analysis is not to determine the water-related RDI research strength of the institutions or organisation in its entirety but to use the presence of absence of emerging and mature RFAs as indicators when comparing the capability maps of the current study to the capacity maps of the 2015 study. It is important to take note that the comparison does not take into account the number of the different RFAs at the different levels of research strength (emerging, building, established and mature) as well as the spread of the RFAs across the seven clusters. To make the comparison feasible the results of the different capability maps in the 2015 study were combined for each cluster. For example Cluster 1 in the 2015 study contains three initiatives namely need, potential and enablers. Mapping of capacity in this cluster was undertaken for each of the three initiatives. To identify the institutions with mature research strength: any institutes listed, at least once, in any three of the maps were included in the analysis. To identify the institutes with emerging or no research strength, as well as for the RFAs with no activity, the respective RFA or institute must be present in all three capability maps to be included in the analysis.

### 3.3.1 Cluster 1: "Increase ability to make use of more sources of water"'

The objective of this cluster is to increase ability to make use of more sources of water, including alternatives. South Africa's Water RDI Roadmap (2015-2025) states that the targeted RDD outcome for 2025 is "Technology development for utilisation of diverse water sources at catchment level, with source localisation and exploitation driven by fitness for use is a key point of excellence in South African practices" (WRC, 2015).

Thirty-eight institutions were included in the capability mapping in Cluster 1, including HEIs and institutions from the private sector. According to the recorded results six institutions have one or more RFAs with research strength at mature level. These institutions, all HEIs, are North-West University, University of Pretoria, Durban University of Technology, Vaal University of Technology, University of South Africa and University of the Witwatersrand (Table 3). The University of the Free State was the only institution with RFAs identified at a mature research strength in the capability mapping in the 2015 study (Appendix J). In the current capability mapping, the University of the Free State, according to the recorded results, have RFAs with established research strength.

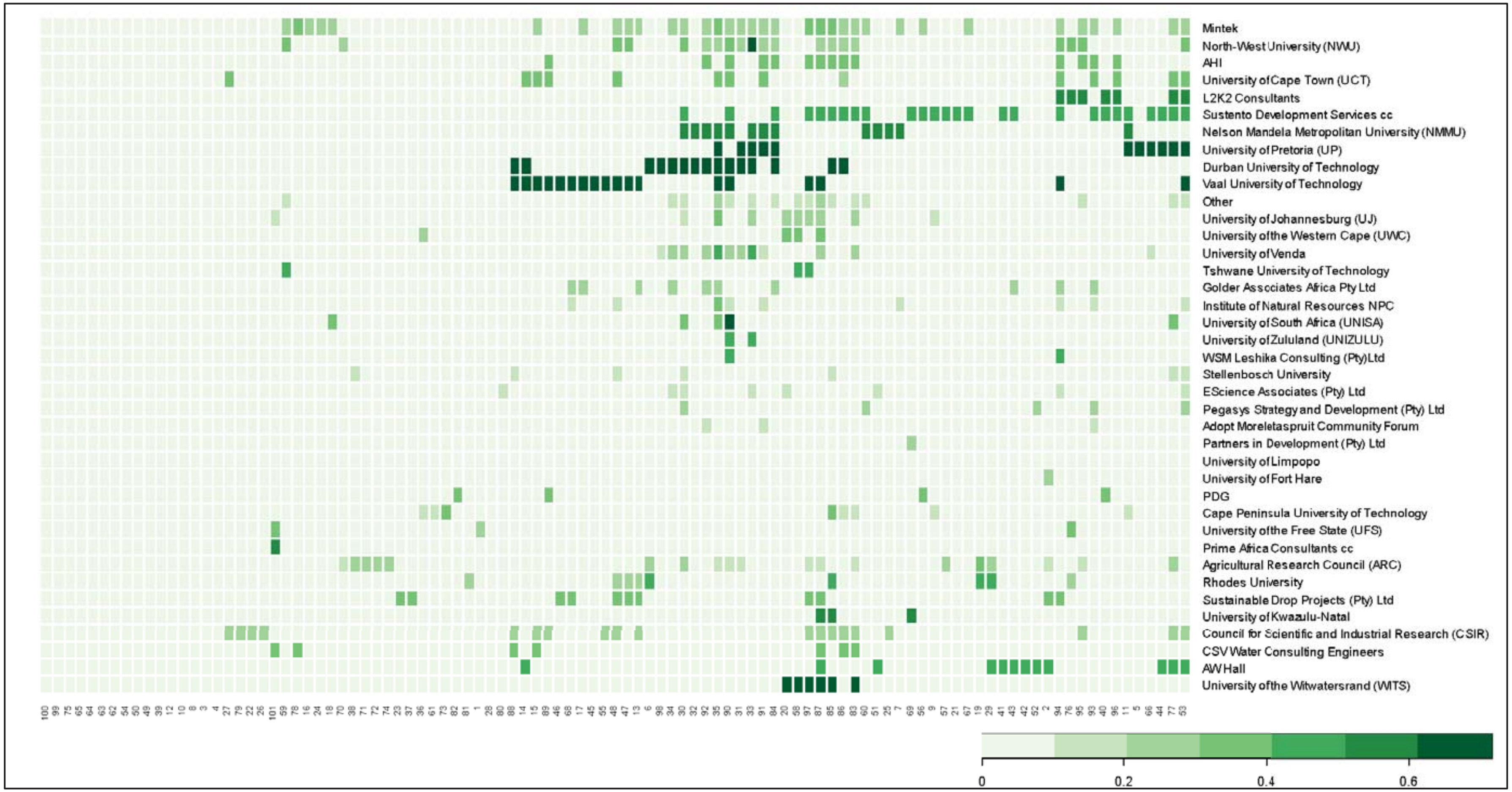
According to the questionnaire the University of Limpopo does not have any RFAs with a recorded research strength. Stellenbosch University and Escience Associates (Pty) Ltd have been identified as institutions with RFAs with research strengths at emerging level (Table 3). The University of Limpopo was also identified as an institution with RFAs with emerging level in the capability mapping in the 2015 study (Appendix J). The RFAs in Cluster 1 with no recorded research strength, according to the individual questionnaire, are listed in Appendix K.

### 3.3.2 Cluster 2: "Governance, planning and management of supply and demand"

The objective of this cluster is to improve governance, planning and management of supply and demand. Cluster 2 "Improve governance, planning and management of supply and delivery" and Cluster 5 "Improve governance, planning and management of demand and use" in South Africa's Water RDI Roadmap (2015-2025) was grouped and renamed as Cluster 2 "Governance, planning and management of supply and demand" in the current capability study. South Africa's Water RDI Roadmap (2015-2025) states that the targeted RDD outcome for 2025 is "The new DWA water allocations map (2016) is implemented by nine functional Catchment Management Agencies. The map includes groundwater, seawater and wastewater. There is equitable and transparent access to water supplies that are managed at catchment level co-operatively with DoH, DAFF, DHS, and DEA" (WRC, 2015).

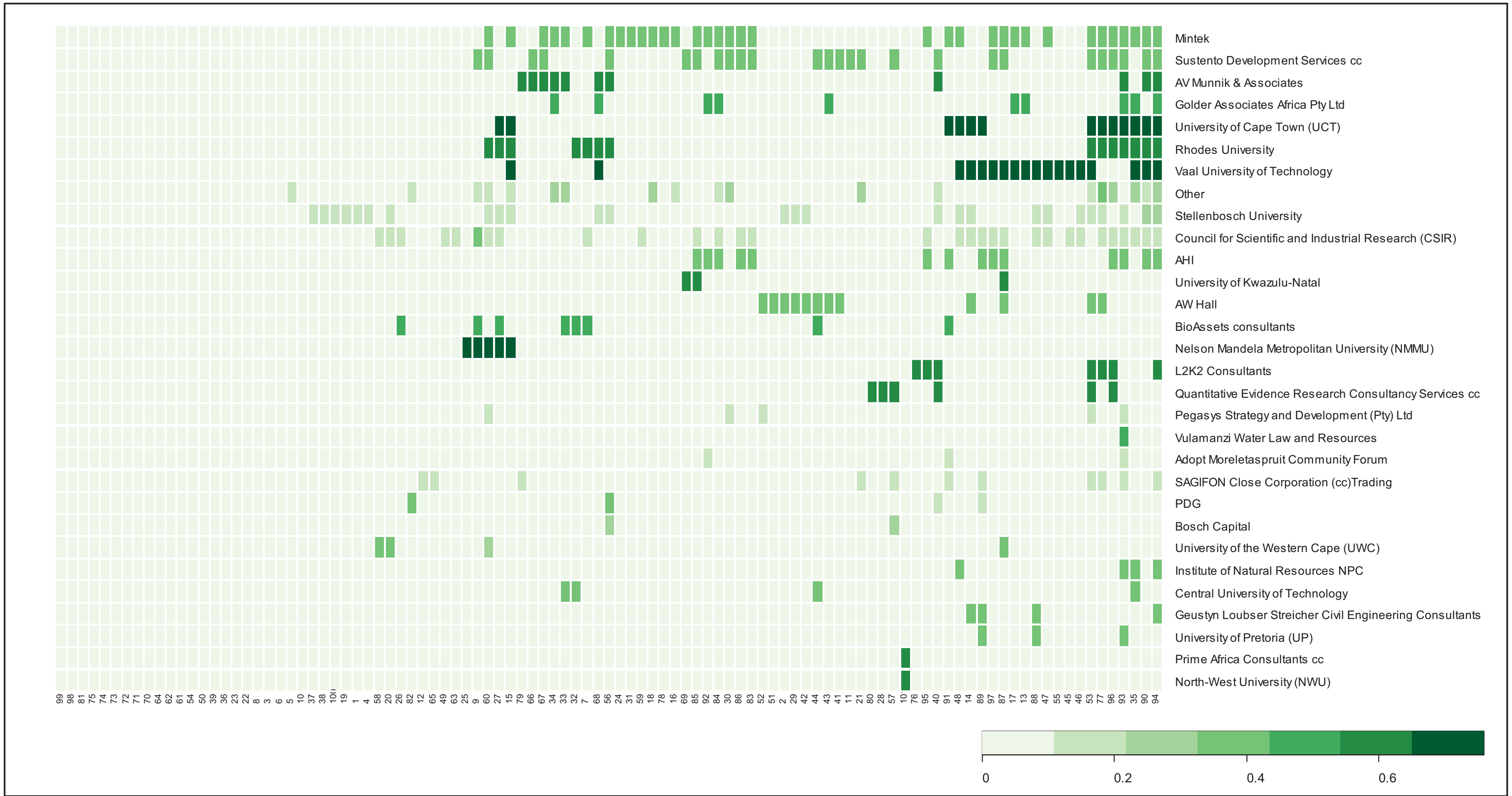
Twenty-nine institutions were included in the capability mapping in Cluster 2, including HEIs and institutions from the private sector. According to the recorded results three institutions have one or more RFAs with research strength at a mature level. These institutions, all HEIs, are University of Cape Town, Vaal University of Technology and Nelson Mandela Metropolitan University (Table 4).

**Table 3: Mapping of capability in underlying science (RFA) in Cluster 1: Increase ability to make use of more sources of water (n = 220)**




The key bar at the bottom of the table indicates the strength of the respective RFAs. The more mature the RFAs, the darker the green shading [emerging (0-0.2), building (0.2-0.4), established (0.4-0.6) and mature (0.6-1).

**Table 4: Mapping of capability in underlying science (RFA) in Cluster 2: "Governance, planning and management of supply and demand" (n = 220)**




The key bar at the bottom of the table indicates the strength of the respective RFAs. The more mature the RFAs, the darker the green shading [emerging (0-0.2), building (0.2-0.4), established (0.4-0.6) and mature (0.6-1].

Pegasus Strategy and Development (Pty) Ltd, Adopt Moreletaspruit Community Forum and Sagifon Close Corporation (cc) Trading are the three institutions with one or more RFAs recorded with research strength at an emerging level. No similarities could be detected between the capability mapping conducted in 2015 and the current capability mapping when comparing the institutions with RFAs at a mature and emerging research strength (Appendix J). The RFAs in Cluster 2 with no recorded research strength, according to the individual questionnaire, are listed in Appendix K.

#### 3.3.3 Cluster 3: "Adequacy and performance of supply infrastructure and operational performance (Built infrastructure)"

The objective of this cluster is to improve adequacy of performance of built infrastructure. Cluster 3 (Improve adequacy and performance of supply infrastructure) in South Africa's Water RDI Roadmap (2015-2025) has two research initiatives namely ecological infrastructure and built infrastructure. In the current capability mapping study this cluster is divided into each of the research initiatives namely a cluster for built infrastructure and another cluster for ecological infrastructure. South Africa's Water RDI Roadmap (2015-2025) states that the targeted RDD outcome for 2025 is "Increased volume and adaptability of storage capacity for raw water and treated effluent is available" (WRC, 2015).

Fourteen institutions were included in the capability mapping in Cluster 3, including HEIs and institutions from the private sector. According to the recorded results four institutions have one of more RFA with research strength at mature level. These institutions, all HEIs, are University of South Africa, University of Cape Town, Vaal University of Technology and Durban University of Technology (Table 5).

No similarities could be detected between the capability mapping conducted in 2015 and the current capability mapping when comparing the institutions with RFAs at mature and emerging research strength (Appendix J). The RFAs in Cluster 3 with no recorded research strength, according to the individual questionnaire, are listed in Appendix K.

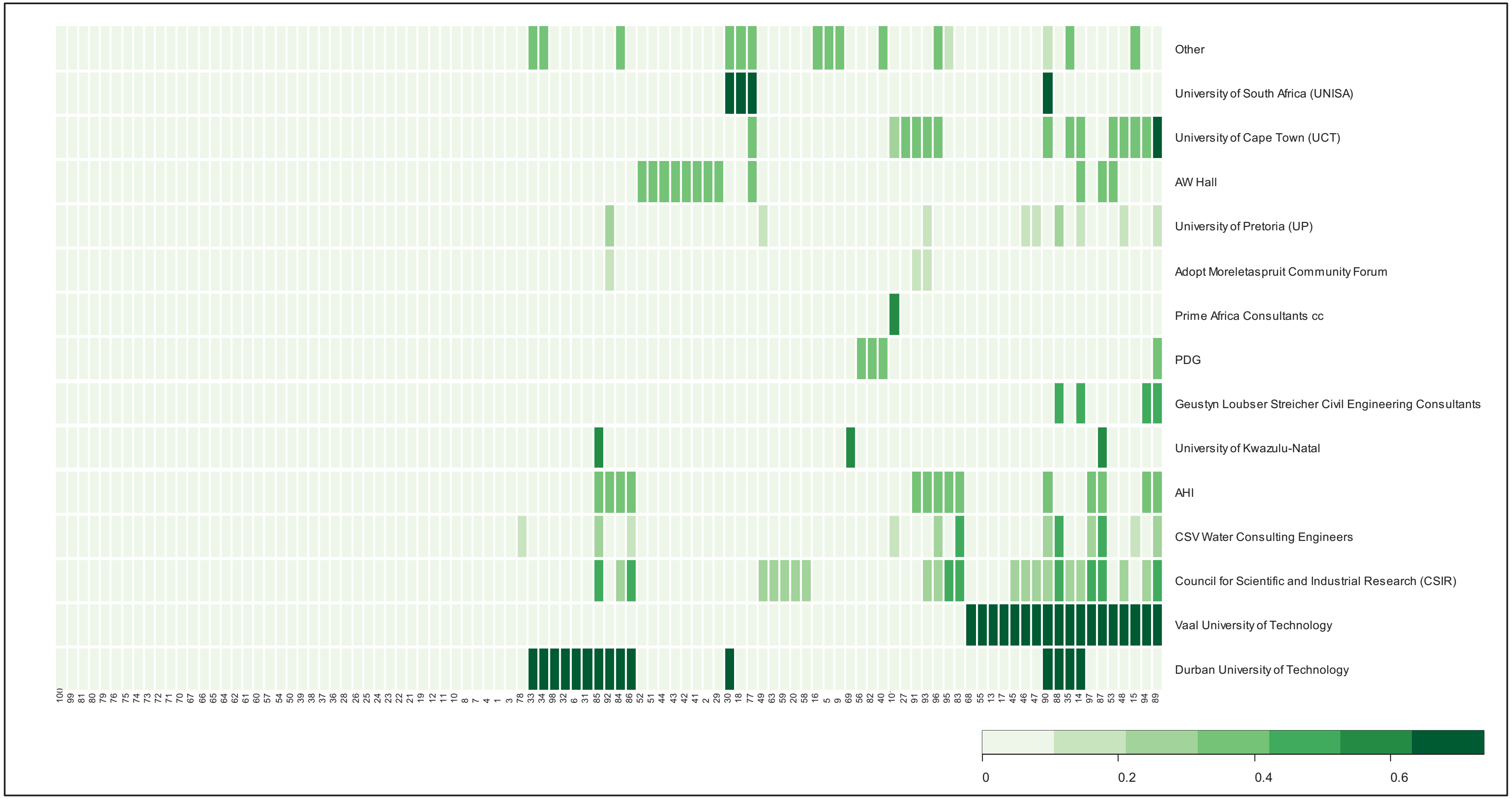
#### 3.3.4 Cluster 4: "Adequacy and performance of supply infrastructure and operational performance (Ecological infrastructure/ecosystems)"

The objective of this cluster is to improve performance of ecological infrastructure. As stated previously Cluster 3 (Improve adequacy and performance of supply infrastructure) in South Africa's Water RDI Roadmap (2015-2025) has two research initiatives namely ecological infrastructure and built infrastructure. In the current capability mapping study this cluster is divided into each of the research initiatives namely a cluster for built infrastructure and another cluster for ecological infrastructure. South Africa's Water RDI Roadmap (2015-2025) states that the targeted RDD outcome for 2025 is "Increased volume and adaptability of storage capacity for raw water and treated effluent is available" (WRC, 2015).

Twenty institutions were included in the capability mapping in Cluster 4, including HEIs and institutions from the private sector. According to the recorded results four organisations have one or more RFAs with research strength at a mature level. According to the results, HEIs reported with one or more RFAs with mature research strength, are Stellenbosch University, University of South Africa, Nelson Mandela Metropolitan University and University of Cape Town (Table 6).

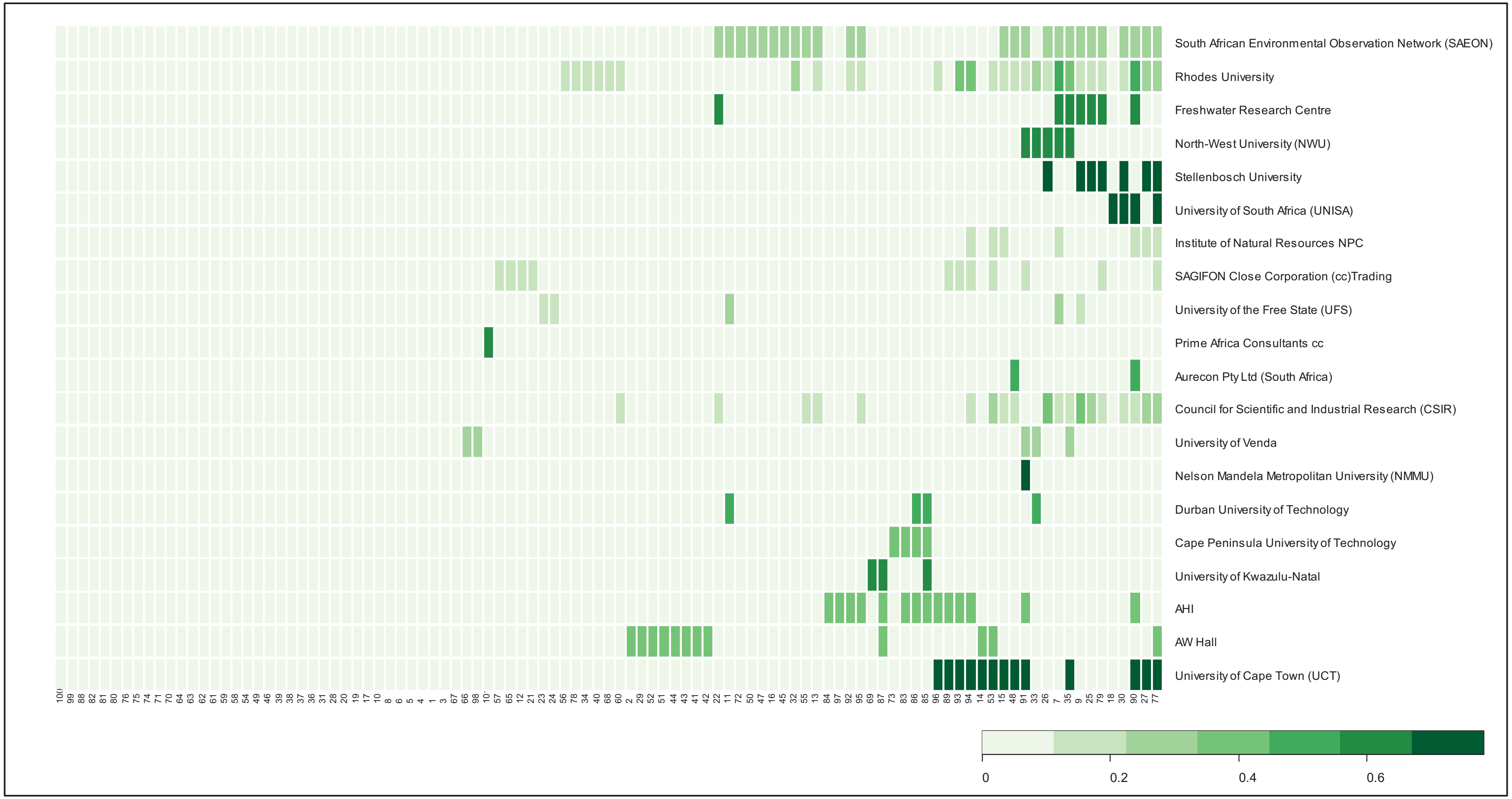
Two institutions, the Institute of National Resources and Sagifon Close Corporation (cc) Trading, have been identified, according to the results, with one or more RFA with a research strength at an emerging level (Table 6). In this cluster no similarities between the capability mapping in the current study and the capability

**Table 5: Mapping of capability in underlying science (RFA) in Cluster 3: "Adequacy and performance of supply infrastructure and operational performance (Built infrastructure)" (n = 220)**




The key bar at the bottom of the table indicates the strength of the respective RFAs. The more mature the RFAs, the darker the green shading [emerging (0-0.2), building (0.2-0.4), established (0.4-0.6) and mature (0.6-1].

**Table 6: Mapping of capability in underlying science (RFA) in Cluster 4: "Adequacy and performance of supply infrastructure and operational performance (Ecological infrastructure/ecosystems)" (n = 220)**




The key bar at the bottom of the table indicates the strength of the respective RFAs. The more mature the RFAs, the darker the green shading [emerging (0-0.2), building (0.2-0.4), established (0.4-0.6) and mature (0.6-1].

mapping in the 2015 study could be detected (Appendix J). The RFAs in Cluster 4 with no recorded research strength, according to the individual questionnaire, are listed in Appendix K.

### 3.3.5 Cluster 5: "Running water as a smart business'

The objective of this cluster is to improve governance and its implementation in the management of demand and use. South Africa's Water RDI Roadmap (2015-2025) states that the targeted RDD outcome for 2025 is "The financial sustainability of the water services system is secured." Cluster 5 contains one initiative namely policy, technology and capacity and therefore contains one map as in the current study (WRC, 2015).

Fourteen institutions were included in the capability mapping in Cluster 5, including HEIs and institutions from the private sector. According to the recorded results only one organisation, University of South Africa has one or more RFAs with research strength at a mature level. No institutions have been identified, according to the results, with one or more RFA with research strength at an emerging level (Table 7). In this cluster no similarities between the capability mapping in the current study and the capability mapping in the 2015 study could be detected (Appendix J). The RFAs in Cluster 5 with no recorded research strength, according to the individual questionnaire, are listed in Appendix K.

### 3.3.6 Cluster 6: "Efficient use of water (Agriculture, industry and consumers)"

The objective of this cluster is to reduce losses and increase efficiency of productive use. South Africa's Water RDI Roadmap (2015-2025) states that the targeted RDD outcome for 2025 is to "reduce unintended losses and increase efficiency of productive use" (WRC, 2015).

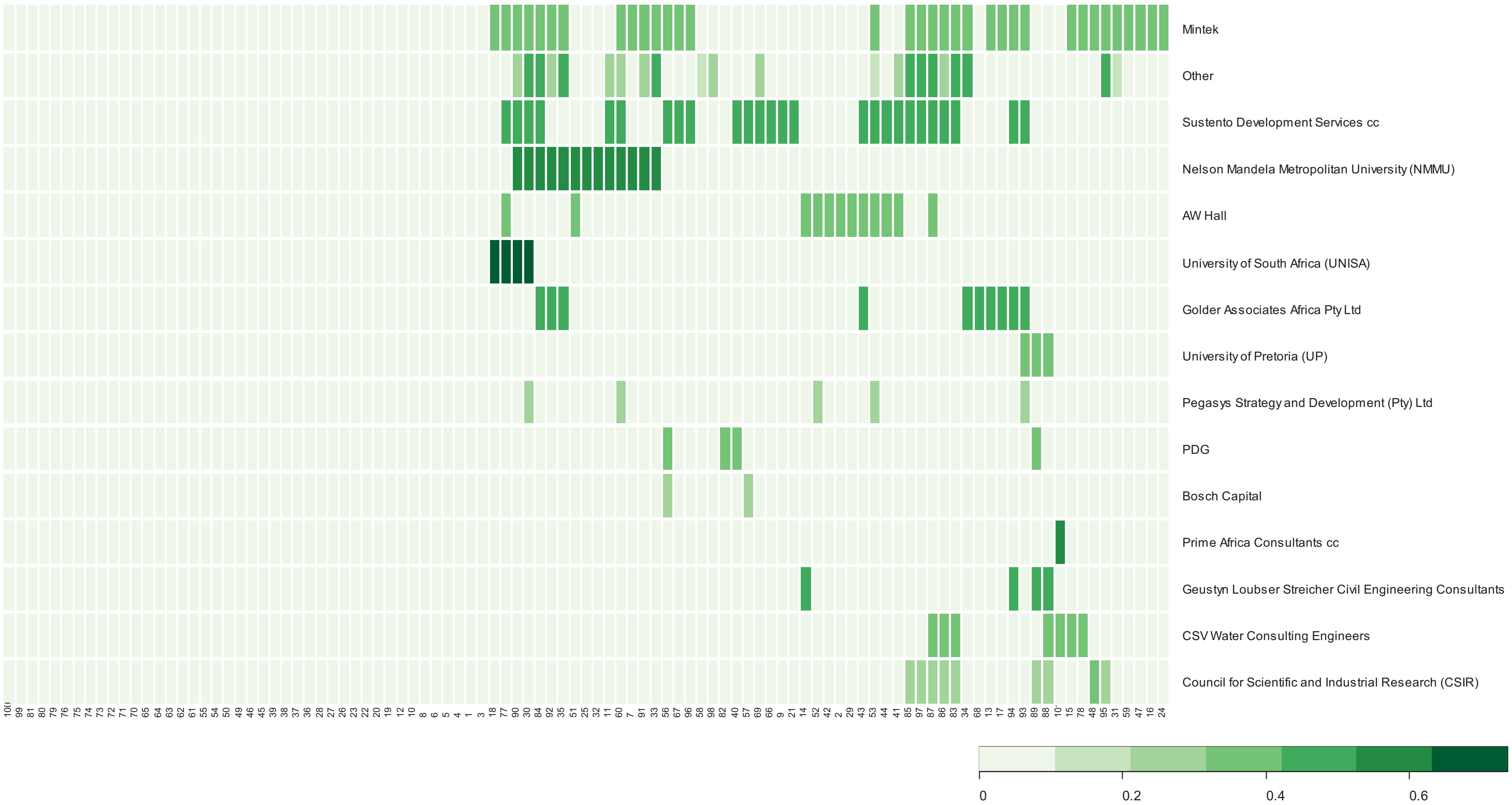
Twenty-seven institutions were included in the capability mapping in Cluster 6, including HEIs and institutions from the private sector. According to the recorded results two organisations, University of South Africa and North-West University, have one or more RFAs with research strength at a mature level (Table 8). The University of Limpopo has, according to the results, no RFAs with any research strength. EScience Associates (Pty) Ltd, has been identified, according to the results, with one or more RFA with a research strength at emerging level (Table 8). However, the University of Limpopo was identified as an institution with RFAs with emerging research strength in the capability mapping in the 2015 study (Appendix J). The RFAs in Cluster 6 with no recorded research strength, according to the individual questionnaire, are listed in Appendix K.

### 3.3.7 Cluster 7: "Monitoring and metering"

The objective of this cluster is to improve performance of pricing, monitoring and collection. South Africa's Water RDI Roadmap (2015-2025) states that the targeted RDD outcome for 2025 is "improved performance of pricing, monitoring, billing, metering and collection" (WRC, 2015).

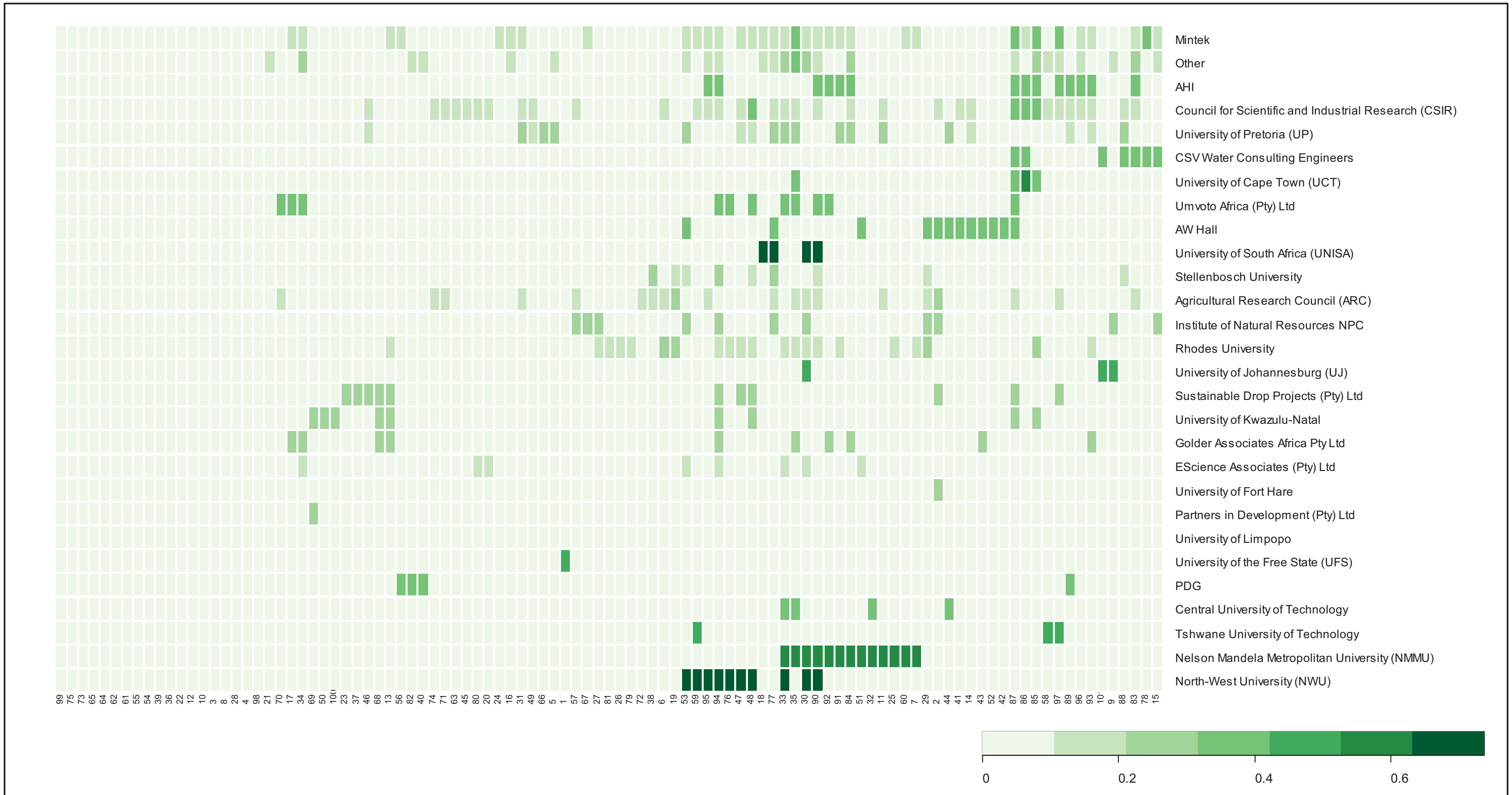
Nineteen institutions were included in the capability mapping in Cluster 7, including HEIs and institutions from the private sector. According to the recorded results two organisations, University of South Africa and North-West University, have one of more RFAs with research strength at a mature level (Table 9). Stellenbosch University and Safigon Close Corporation (cc) Trading, have been identified, according to the results, with one or more RFAs with a research strength at an emerging level (Table 9). Stellenbosch University was also identified as an institution with RFAs with emerging research strength in the capability mapping in the 2015 study (Appendix J).The RFAs in Cluster 7 with no recorded research strength, according to the individual questionnaire, are listed in Appendix K.

**Table 7: Mapping of capability in underlying science (RFA) in Cluster 5: "Running water as a smart business' (n = 220). The key bar at the bottom of the table indicates the strength of the respective RFAs**



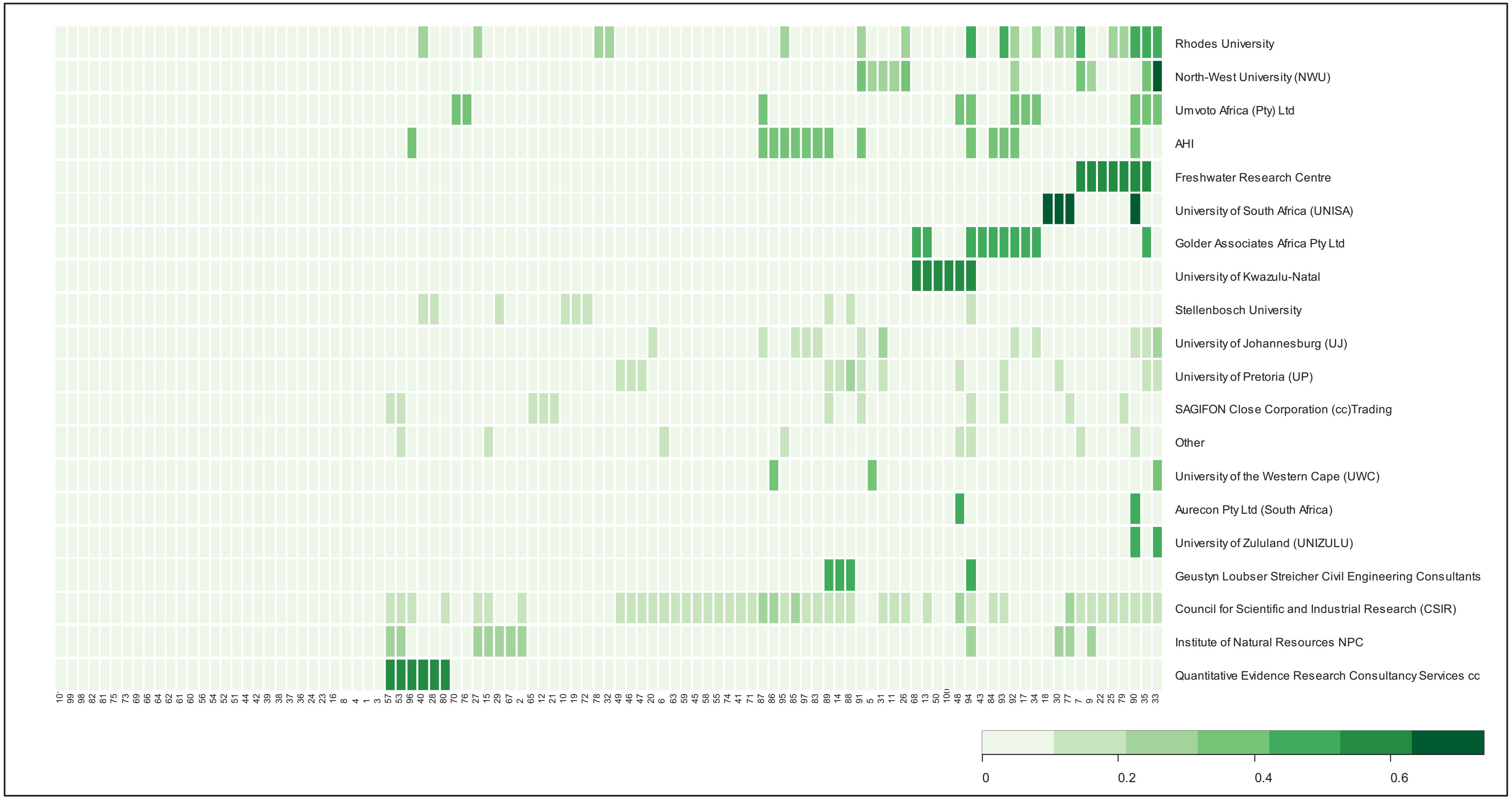

The more mature the RFAs, the darker the green shading [emerging (0-0.2), building (0.2-0.4), established (0.4-0.6) and mature (0.6-1].

**Table 8: Mapping of capability in underlying science (RFA) in Cluster 6: "Efficient use of water (Agriculture, industry and consumers)" (n = 220)**




The key bar at the bottom of the table indicates the strength of the respective RFAs. The more mature the RFAs, the darker the green shading [emerging (0-0.2), building (0.2-0.4), established (0.4-0.6) and mature (0.6-1].

**Table 9: Mapping of capability in underlying science (RFA) in Cluster 7: 'Monitoring and metering' (n = 220)**




The key bar at the bottom of the table indicates the strength of the respective RFAs. The more mature the RFAs, the darker the green shading [emerging (0-0.2), building (0.2-0.4), established (0.4-0.6) and mature (0.6-1].

# CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

## 4.1 CLUSTERS

The highest percentage of individual respondents, according to the recorded results, indicated that their water-related RDI activities are linked to Cluster 1 "Increase ability to make use of more sources of water" at 45% (Figure 2). The capability map of Cluster 1 also has the highest number of institutions mapped (38) and the highest number of institutions (six) with RFAs at mature research strength identified (Table 3). According to the WRC RDI Roadmap (2015 - 2025), the highest percentage (38%) of the total investment budget should be allocated to the cluster "Sources". Therefore the highest percentage of water-related activities linked to this cluster coincides with the fact that the highest percentage of the total budget should be allocated to this cluster, as indicated by the Investment Requirements chapter of the WRC RDI Roadmap (2015 - 2025).

Cluster 6 "Efficient use of water (Agriculture, industry, and consumers") and 2 "Governance, planning and management of supply and demand" also had high percentages of respondents linking their water-related RDI activities to these clusters, at 39% and 31%, respectively. Twenty-seven and 29 institutions were mapped onto the capability map of Cluster 6 (Table 8) and 2 (Table 4), respectively.

According to the WRC RDI Roadmap (2015 - 2025), the second highest percentage of the budget (23%) should be allocated to the cluster "Productive use" ("Reduce losses and increase efficiency of productive use"). Therefore the second highest percentage of water-related activities (39%) linked to this cluster coincides with the fact that the second highest percentage of the total budget (23%) should be allocated to this cluster, as indicated by the Investment Requirements chapter of the WRC RDI Roadmap (2015 - 2025).

According to the WRC Roadmap (2015 - 2025), 8% should be allocated to "Governance, planning and management of demand" and 6% to "Governance, planning and management of supply". In the current study these two clusters were grouped under the title "Governance and management of supply and demand". Therefore if the required total investment of the demand and supply side of Governance, planning and management are added the total that should be allocated to this cluster must be 14%. Although the third highest percentage of the total investment required for "Government, planning and management of supply and demand" coincides with the third highest percentage of reported water related RDI-activities in this cluster it should be noted that approximately thirty percent of the reported activities are linked to the cluster compared to 12% of the total investment that should be allocated towards it.

The lowest percentage of individual respondents, according to the recorded results, indicated that their water-related RDI activities are linked to Cluster 5 "Running the water sector as a smart business") at 12% (Figure 2). The capability map of Cluster 5 also has the lowest number of institutions mapped (14) and the lowest number of mature institutions (one) identified (Table 6). According to the WRC RDI Roadmap (2015 - 2025) 10% of the total investment required should be allocated to the cluster "Operational Performance" ("Run water as a financially sustainable "business" by improving operational performance").

In certain cases, there seems to be an alignment between the total investment required in the WRC RDI Roadmap (2015 - 2025) and the reported water-related RDI activities in the majority of the clusters in the current study. It should however be noted that the figures regarding the investment requirements are based on forecasts. The percentages of the WRC budget spend per cluster are only available in the public domain for the 2015 (Pouris, 2018) and 2016/2017 financial year (WRC, 2017). The Water RDI Roadmap is a ten-year plan which is still in progress until 2025. Therefore, care should be taken when using the investment requirements as stated in the Water RDI Roadmap as an indicator.

The research conducted for the Water RDI Roadmap took place from 2014 to 2015. The water-related RDI landscape in South Africa could have changed during the last few years and is an area for future research. Cluster 5 “Running the water sector as a smart business” is just one example, as stated previously it had the lowest percentage of reported water-related RDI activities. However recent research has shown there are water boards (Ngobeni and Breitenbach, 2020) and water service authorities (Nkabane and Nzimakwe, 2018; Dikgang et al. 2020) that can be operated more efficiently by reducing costs and improving revenue generation. In future the need for RDI activities linked to this cluster could increase and needs to be further investigation.

Researchers can use the information in the report to determine opportunities for projects in certain clusters. Investors can also use the information in the report to investigate the research strength of clusters to determine the current funding needs in the RDI ecosystem of the water sector and also use it as a starting point to determine how it may change in future.

It should however be taken into consideration that the response rate of the individual questionnaire was 25.3%. A higher response rate would have provided a more accurate profile of the research strength of the different clusters.

## 4.2 RESEARCH FOCUS AREAS

More than 15% of individual respondents indicated that their water-related RDI activities are linked to the following RFAs: environment (RFA 30); environmental pollution (RFA 33); environmental water quality (RFA 35); hydrology and water resources (RFA 48); sustainability (RFA 77); wastewater treatment (RFA 85); water and wastewater treatment (RFA 87); water quality and water resources (RFA 90) and water resource management (RFA 94) (Appendix F). In all seven clusters, capability in all of the above RFAs was indicated by one or more institutions (Table 3 - 9).

Of the above mentioned RFAs only environmental water quality (named RFA 22) and wastewater treatment (further characterised and named RFA 17, 21 and 87) was included in the previous RDI Roadmap capability mapping in 2015. The other RFAs were not included in the questionnaire as their naming was not selected as unique (WRC, 2015). This is a possible shortcoming in the current study since the RFAs with the broader names could explain the high percentage of respondents indicating water-related RDI activities linked to these areas.

Overall, a considerable number of Postgraduate courses were also linked to these RFAs. Forty-one postgraduate courses were linked to environment (RFA 30), 9 courses were linked to environmental pollution (RFA 33), 7 courses were linked hydrology and water resources (RFA 48), 46 courses were linked to sustainability (RFA 77), 15 courses were linked to wastewater treatment (RFA 85), 10 courses were linked water and wastewater treatment (RFA 87), 17 courses were linked water quality and water resources (RFA 90) and 56 courses were linked to water resources management (Volume 2).

According to the results of the study, six RFAs with no RDI activities were reported and are the following bioethics (RFA 10), geomembrane linings and covers for potable water storage (RFA 39), non-Newtonian fluid mechanics (RFA 61), ocean wave power (RFA 62), plant life extension technologies (RFA 64) and unsaturated zone (RFA 81) (Appendix F). No research strength was reported for the RFAs bioethics and unsaturated zone (numbered RFA 99 and 75) in the previous RDI capability mapping (WRC, 2015). Geomembrane linings and covers for potable water storage, non-Newtonian fluid mechanics, ocean wave power and plant life extension technologies were mapped to the seven clusters of needs and interventions in the South Africa's Water RDI Roadmap (WRC, 2015) but was not included in the questionnaire for capability mapping. Therefore no comparison for these RFAs between the two studies could be made. Thirty-two RFAs were also linked to very low numbers of water-related RDI activities with ≤2% of respondents indicating their work falling into these research areas.

During the postgraduate mapping desktop study and accompanied survey no Honours, Masters of PhD courses for geomembrane linings and covers for potable water (RFA 39) and bioethics (RFA 10) were reported. One postgraduate course was linked to non-Newtonian fluid mechanics (RFA 61) and unsaturated zone (RFA 81), two courses were linked to ocean wave power (RFA 62) and four courses were linked to plant life extension technologies (RFA 64).

In the study a list of RFAs not included in the WRC Taxonomy of Research Focus Areas have been specified by respondents. Although these RFAs were noted by researchers as areas of research activities, there will be a need for a sector recognition and validation process, before the areas of research can be included in the WRC Taxonomy of Research Focus Areas.

Researchers seeking collaborators for specific RFAs can use the information in the capability maps to identify the location of water experts for a specific RFA. Furthermore, researchers wanting to start a new project can use the information in this report to determine if there is an "oversupply" of researchers in a specific RFA or if there is a need for more research in that specific area. Likewise investors wanting to fund projects in certain RFAs can use the capability maps to determine the location of water experts for a specific RFA. Investors can also use the information in this report to determine the need for funding for RFAs with low or no reported water-related RDI activities.

It should however be taken into consideration that the response rate of the individual questionnaire was 25.3%. A higher response rate would have provided a more accurate profile of the research strength of the different RFAs.

## 4.3 HIGHER EDUCATION INSTITUTIONS AND RESEARCH COUNCILS

The bibliometric data was collected as an exploratory piece of work to assist in the discussion of the capability mapping to highlight the uses of the capability maps and how it differs from bibliometric analysis. The research strength of the two HEIs and research councils with less than 50 publications and two HEIs and/or research councils with more than 800 publications (from 2014 to 2018), respectively, were analysed using the capability maps of the seven clusters. The results were compared to the capability maps of the previous study conducted in 2015.

Mintek and Central University of Technology (referred to as Central University of Free State in the previous capacity study conducted in 2015) produced less than 50 outputs during the timespan (Figure 6).

When taking a closer look at Mintek, 29 RFAs with emerging research strength and 5 RFAs with building research strength were identified in Cluster 1 "Increase ability to make use of more sources of water". In Cluster 2 "Governance, planning and management of supply and demand" 34 RFAs with building research strength were identified. In Cluster 5 "Running the water sector as a smart business" 34 RFAs with building research strength were identified. In Cluster 6 "Efficient use of water (Agriculture, industry and consumers)" 29 RFAs with emerging research strength and five RFAs with building research strength were identified. Although the RFAs identified were at emerging and building research strength level, these RFAs were numerous and present in the capability maps of four clusters in the current study. This highlights the fact that bibliometric analysis is not the most appropriate tool when analysing the research strength of research councils as the number of prototypes and new technologies, patents and Intellectual Property Licence Agreements are seen as important technical performance and scientific outputs together with oral and poster presentations, journal articles, conference papers and book chapters (Mintek, 2019). In the previous 2015 study RFAs with the same level of research strength, building, were identified for Mintek in the capability maps of six of the clusters (WRC, 2015).

Four RFAs with building research strength were identified in both Cluster 2 “Governance, planning and management of supply and demand” and Cluster 6 “Efficient use of water (Agriculture, industry and consumers)” during the analysis of Central University of Technology in the current capability study. Central University of Technology is referred to as Central University of Free State in the capacity study conducted in 2015. In the capacity study one RFA with building research strength and two RFAs with emerging research strength were identified. In this case the both bibliometric data and the reported data collected in the capability maps suggest that the water-related research capability of Central University of Technology can be improved.

Further focussed needs to be placed on institutions and organisations, especially HEIs, with a limited number of reported RFAs with emerging and building RDI strength, requires possible investment focussing on knowledge generation, human capital development and research chairs. Furthermore, an alignment of focus areas, targeted research programmes, partnerships and resources should take place (WRC 2015).

The number of RFAs with mature and established research strength was further investigated for the University of Pretoria, University of Cape Town and University of KwaZulu-Natal since these HEIs produced the highest number of research publications from 2014 to 2018 (Figure 6). Similar results were obtained by Pouris (2018) which indicates that from 2005 to 2015 University of KwaZulu-Natal, University of Pretoria and University of Cape Town published the highest number of water research articles.

In Cluster 1 “Increase ability to make use of more sources of water” three RFAs with established research strength was identified for the University of KwaZulu-Natal. The same three RFAs were identified for each of the following three clusters: Cluster 2 “Governance, planning and management of supply and demand”; Cluster 3 “Adequacy and performance of supply infrastructure and operational performance (Built infrastructure)” and Cluster 4 “Adequacy and performance of supply infrastructure and operational performance (Ecological infrastructure/ecosystems)”. In Cluster 6 “Efficient use of water (Agriculture, industry and consumers)” four building research strength RFAs were identified while six established research strength RFAs were identified in Cluster 7 “Monitoring and metering”.

When taking a closer look into the research strength of University of Pretoria, 11 RFAs with mature research strength were identified. All the mature research strength RFAs were however detected in one cluster namely Cluster 1 “Increase ability to make use of more sources of water”. No mature or established RFAs were identified in any of the other clusters in the capability mapping. Three building research strength RFAs were identified in both Cluster 2 “Governance, planning and management of supply and demand” and Cluster 5 “Running the water sector as a smart business”. In Cluster 3 “Adequacy and performance of supply infrastructure and operational performance (Built infrastructure)” seven emerging and one building research strength RFAs were, respectively, identified. In Cluster 6 “Efficient use of water (Agriculture, industry and consumers)” seven emerging and 12 building research strength RFAs were, respectively identified while in Cluster 7 “Monitoring and metering” 12 emerging and one building RFAs were, respectively, identified. In 2015, no RFAs with mature and 13 RFAs with established research strength were identified during the capability mapping.

Although University of KwaZulu-Natal had no RFAs with mature research strength when compared to University of Pretoria, numerous RFAs with building and established research strength were identified. The RFAs with building and established research strength for the University of KwaZulu-Natal were detected in six of the seven clusters. In comparison the RFAs with mature research strength for University of Pretoria were only identified in one cluster while the no established RFAs were detected in any of other the clusters. RFAs with emerging and building research strength for University of Pretoria were identified in five of the clusters. This highlights the fact that the information in the capability maps makes direct comparisons of water-related research strength comparisons between institutions not feasible as the objective of the capability maps are to locate water experts within institutions and organisations.

Institutions identified with RFAs with established and matured research strength are producing sufficient research to address market needs (WRC, 2015). Further investigations should take place to determine whether products are diffused into the markets. A study by Pouris (2018) indicated that one to two water-related patents are awarded to South African inventors per year from the period of 2000 to 2015. In the study 6% of respondents reported that their water-related RDI activities were linked to IP registrations and 5% of respondents reported that their water-related activities were linked to patent registrations. According to Pouris the "*issue is not just in the water field concern but a system wide challenge*". These research groups could submit proposals to financing vehicles which supports innovation and technology development such as the SPII, (SEDA), the Innovation Fund, DTI, and GODISA. Proposals for projects which are at demonstration stage could also be submitted to Water Technologies Demonstration Programme (WADER), a partnership between the DSI and the WRC (WRC, 2018). Lastly, although scientists can take a dual approach by publishing in a high impact journal and at a patent office this approach should be taken with care (Peter, 2019).

## 4.4 INSTITUTIONS FROM THE PRIVATE SECTOR

A number of institutions in the private sector were identified with established research strength including Freshwater Research Centre, Aurecon Pty Ltd (South Africa), Quantitative Evidence Research Consultancy Services cc, Sustento Development Services cc, AW Hall, Golder Associates Pty Ltd, Prime Africa Consultants cc, Geustyn Loubser Streicher Civil Engineering Consultants, L2K2 Consultants, AV Munnik & Associates and Bioassests consultants.

According to a WRC study (Amis and Lugogo, 2018); South African HEIs lead water-related innovation activities with few linkages between these institutions and other sectors of the economy. The study further identified building of partnerships between the different sectors in the innovation environment as a possible step to accelerate the development and deployment of water-related innovations in South Africa (Amis and Lugogo, 2018). The capability maps of the different clusters can be used, by the relevant stakeholders, to identify institutions in the private sector that could be approached for possible collaborations.

## 4.5 OTHER KEY OBSERVATIONS

According to the questionnaire results, the NRF and the WRC are the leading sources of funding, as opposed to financing vehicles which support innovation and technology development such as the SPII, (SEDA), the Innovation Fund, DTI, and GODISA. The investigation by Amis and Lugogo (2018) produced similar results with the statement that WRC and NRF are *"championing research and development in the water sector".* Although individual and institutional respondents only indicated their sources of funding and were not requested to specify the funding figures involved, the results reflect the mandate of South Africa's Water RDI Roadmap 2015 - 2025. According to the Roadmap, 4% of the total investment required should be allocated to technology development while 56% should be allocated to research capacity (WRC, 2015).

Publications and conference papers (76%) are the main RDI outputs as compared to IP registration (6%), patent registration (5%), prototyping (10%), trials (9%), post-trial production (4%), and business registration

(4%). South Africa's Water RDI Roadmap 2015-2025 anticipated RDD outputs involved in knowledge generation for the ten-year time span is as follows: 1937 peer reviewed publications, 78 new full registered patents and 224 provisional patent applications (WRC, 2015). Although respondents in this questionnaire were not requested to quantify research outputs linked to their water-related RDI activities, the results indicate knowledge generation through the publication of peer reviewed papers and conference patents. A disquieting fact to take note of is that nine percent of the respondents selected the "*None of the above*" option in the questionnaire. This indicates that there was no research outputs linked to these individual respondents' water-related RDI activities during the time period of 2014 to 2018.

Based on the institutional survey responses, a number of key factors were noted by respondents as barriers to research outputs such as "lack of monitoring and evaluation" and "lack of funding". However, the low response rate is not conclusive in providing insight into knowledge diffusion and uptake of RDI activities.

### 4.6 LIMITATIONS AND STRENGTHS OF THE CAPABILITY MAPS IN THE STUDY

The objective of the capability mapping in the current study is to provide insight into where the different water-related RDI disciplinary skills sets lie around the country. The strength of the capability mapping is therefore that it gives information on the different competencies, based on the clusters and RFAs, which allows a more focused consideration on how to best support and structure the RDI capability optimally.

The bibliometric data was collected as an exploratory piece of work to assist in the discussion of the capability mapping to highlight the uses of the capability maps and how it differs from bibliometric analysis. As the data of the capability mapping exercise were self-reported research strength, based on the questionnaire, the bibliometric data was also incorporated into the study to provide a level of sense checking. It is important to take note that bibliometric analysis can be used to indicate the water-related research strength of an institution or organisation as an entity but it is not the case with the capability mapping. As stated earlier the capability maps provides information on the research strength of water-related RDI disciplinary skills sets, reflected as RFAs, within institutions and organisations and can provide insight for each entity into the research strength of their different water-related RDI disciplinary skills sets.

It should be taken into account that this piece of exploratory bibliometric analysis only took into account the number of publications. Some countries utilises paper counts as an indicator as part of their performance-based research funding systems for their universities. The disadvantage is that it could encourage researchers to publish in lower quality journals to increase their number of published articles (Butler, 2003). Therefore certain countries also incorporates the Thomson-Reuters impact factor in their calculations while other countries incorporates citation information (Hicks, 2012). Wallin (2005) also noted that there is not enough scientific evidence to use quantitative bibliometrics, beyond a doubt, to assess research quality. Other important factors to take into consideration regarding the use of bibliometrics are the fact that it does not capture societal impacts of research programmes (Council for Medical Sciences, 2002) and can only assess, with certainty, the short-term effects of research programmes (Kostoff, 1998).

Limitations in the current study included the low response rate, especially the institutional survey, and the difficulty between comparing the results of the current capability mapping and the capacity mapping that took place in 2015. The response rate of the individual questionnaire, at 25.3%, although similar to the response rate of 26.7% obtained in the South Africa Innovation Survey of 2008 (HSRC, 2011), is still relatively low. A higher response rate would have provided a more accurate profile of the research strength of the different institutions in the different clusters. The South African waste sector survey, conducted in 2012, increased the initial, voluntary participation of 19% to 30% through numerous follow-up telephonic and email reminders by the project team (DST, 2013). The Department of Science and Technology (DST) is now known as the

Department of Science and Innovation (DSI). An email reminder could be sent to all participants in future capability studies a few days before the closing date of the questionnaire.

Capacity was identified and calculated in 2015 using the variables number and seniority of people, budget, publications and products, and technical services. Capability was identified and calculated in the current study using the number of researchers and the highest qualification and years' of experience of the lead researchers in the calculation. This fact needs to be taken into account when comparing the results of the capacity and capability mapping as the formula used to produce the results would not be exactly the same.

Other differences between the two studies, which should be taken into consideration when interrogating the results between the capacity and capability mapping, are the naming of the clusters and the numbering of the RFAs. The reader should refer back to the name keys provided in Appendix A (p.33 in this report) in the current capability study and the taxonomy of RFAs table on page 77 in South Africa's Water RDI Roadmap: 2015-2025 (WRC, 2015).

## 4.7 USE OF THE CAPABILITY MAPS BY THE RELEVANT STAKEHOLDERS

Relevant stakeholders in the water research community, as well as in the higher education environment, can use the information in the capability maps to inform opportunities and thinking relating to knowledge generation, human capital development and research chairs.

The complex nature of the capability mapping exercise produced a magnitude of information which can be used by stakeholders. The report contains seven capability maps, one for each cluster. In every capability map each of the 100 RFAs is mapped against each of the respective institutions and organisations, with the lowest number of institutions mapped 14 and the highest number of institutions mapped 38. However, the drawback is that it is difficult to make general conclusions and recommendations, due to the more than 16 000 data points, and the information in this report should be used by the relevant stakeholder by a case by case basis. The capability maps provide a visual tool for stakeholders to extract the information for their purpose.

1. The capability maps can be used by relevant stakeholders interested in the research strength of water-related RDI activities within a specific HEI, such as Deans, to:
    a. Identify clusters where the specific HEI is conducting water-related RDI.
    b. Identify RFAs, and their research strength, within each cluster where water-related RDI are conducted.
    c. Identify interventions or opportunities for the specific HEI based on the research strengths of the specific RFAs.
2. The capability maps can be used by investors and water RDI Ecosystem coordinators (government and private funding vehicles) to:
    a. Identify clusters where there is a limited amount of RDI activities.
    b. Identify RFAs, and their research strength, within each cluster.
    c. Identify investment opportunities and other interventions based on the research strength of the specific RFAs.

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# APPENDICES

## Appendix A: RFAs keys

| Key | RFA |
|---|---|
| 1 | Agricultural Meteorology |
| 2 | Agriculture Ecosystems and Environment |
| 3 | Agroforestry |
| 4 | Agrometeorology |
| 5 | Animal, human, public, and environmental health |
| 6 | Aquaculture |
| 7 | Aquatic Ecosystems |
| 8 | Beneficial agricultural use of municipal sludge |
| 9 | Biodiversity and Conservation |
| 10 | Bioethics |
| 11 | Biological Science |
| 12 | Business efficiency |
| 13 | Catchment hydrology |
| 14 | Civil engineering aspects of water cycle |
| 15 | Climate dynamics, resilience, adaptation |
| 16 | Climatology |
| 17 | Contaminant hydrology |
| 18 | Corporate social responsibility and environmental management |
| 19 | Crop production |
| 20 | Desalination |
| 21 | Development Economics |
| 22 | Ecohydrology |
| 23 | Ecological informatics and modelling |
| 24 | Ecology Evolution and Systematics |
| 25 | Ecosystem functioning |
| 26 | Ecosystem functioning and health |
| 27 | Ecosystem services and ecological infrastructure |
| 28 | Education |
| 29 | Efficient agriculture |
| 30 | Environment |
| 31 | Environmental and Analytical Chemistry |
| 32 | Environmental health and ecosystem functioning |
| 33 | Environmental pollution |
| 34 | Environmental protection & pollution control |
| 35 | Environmental water quality |
| 36 | Enzymes |
| 37 | Flood defence |
| 38 | Food security and business efficiency |
| 39 | Geomembrane linings and covers for potable water storage |

| Key | RFA |
|---|---|
| 40 | Governance |
| 41 | Health |
| 42 | Horticulture |
| 43 | Human health |
| 44 | Human, public, and environmental health |
| 45 | Hydrodynamics |
| 46 | Hydrologic engineering |
| 47 | Hydrology |
| 48 | Hydrology and Water Resources |
| 49 | Hydromechanics |
| 50 | Hydrometeorology |
| 51 | Improved food production |
| 52 | Improved food security |
| 53 | Integrated Water Resources Management IWRM |
| 54 | Irrigation and Drainage |
| 55 | Land surface hydrology |
| 56 | Local Government |
| 57 | Management |
| 58 | Membrane Technology |
| 59 | Mining Hydrogeology |
| 60 | Natural resource management |
| 61 | non-Newtonian fluid mechanics |
| 62 | Ocean Wave Power |
| 63 | OM Rural Water Services |
| 64 | Plant life extension Technologies |
| 65 | Process automation and control - potable and wastewater treatment |
| 66 | Public health |
| 67 | Public participation |
| 68 | River Basin management |
| 69 | Sanitation |
| 70 | Soil Chemistry |
| 71 | Soil Fertility |
| 72 | Soil Management |
| 73 | Soil microbiology and biochemistry |
| 74 | Soil morphology and genesis |
| 75 | Soil Physics |
| 76 | Subsurface hydrology |
| 77 | Sustainability |
| 78 | Sustainability in mining |
| 79 | Systems Ecology |
| 80 | Technoeconomic |
| 81 | Unsaturated zone |
| 82 | Urban Economics |
| 83 | Wastewater and potable treatment |

| Key | RFA |
|---|---|
| 84 | Wastewater and potable treatment, ecosystem functioning, environmental water quality, animal, human, public, and environmental health |
| 85 | Wastewater treatment |
| 86 | Water and Wastewater Microbiology |
| 87 | Water and wastewater treatment |
| 88 | Water Engineering |
| 89 | Water infrastructure development |
| 90 | Water quality and water resources |
| 91 | Water quality monitoring, ecosystem functioning, environmental water quality, animal health |
| 92 | Water quality monitoring, ecosystem functioning, environmental water quality, animal, human, public, and environmental health |
| 93 | Water resource governance and management |
| 94 | Water Resources Management |
| 95 | Water Science |
| 96 | Water science management, policy and legislations |
| 97 | Water treatment |
| 98 | Waterborne Pathogen characterisation |
| 99 | Wave Powered Desalination |
| 100 | Weather and Forecasting |
| 101 | Other |

## Appendix B: Research discipline keys

| Key | Research Discipline |
|---|---|
| 1 | Agricultural Sciences |
| 2 | Agrometeorology |
| 3 | Aquaculture |
| 4 | Beneficial agricultural use of municipal sludge |
| 5 | Biological Science |
| 6 | Biology and Biochemistry |
| 7 | Chemistry |
| 8 | Clinical Medicine |
| 9 | Computer Sciences |
| 10 | Desalination |
| 11 | Economics and Business |
| 12 | Ecosystem services and ecological infrastructure |
| 13 | Engineering |
| 14 | Environment |
| 15 | Environmental pollution |
| 16 | Environmental Sciences |
| 17 | Geomembrane linings and covers for potable water storage |
| 18 | Geosciences |
| 19 | Governance |
| 20 | Health |
| 21 | Hydrology and Water Resources |
| 22 | Hydrometeorology |
| 23 | Immunology |
| 24 | Integrated Water Resources Management IWRM |
| 25 | Local Government |
| 26 | Management |
| 27 | Materials Science |
| 28 | Membrane Technology |
| 29 | Microbiology |
| 30 | Mining Hydrogeology |
| 31 | Molecular Biology and Genetics |
| 32 | Ocean Wave Power |
| 33 | OM Rural Water Services |
| 34 | Pharmacology & Toxicology |
| 35 | Plant and Animal Science |
| 36 | Public participation |
| 37 | River Basin management |
| 38 | Sanitation |
| 39 | Social Science and Humanities |
| 40 | Space Science |
| 41 | Sustainability |
| 42 | Water and wastewater treatment |
| 43 | Water infrastructure development |

| Key | Research Discipline |
|---|---|
| 44 | Water quality and water resources |
| 45 | Water science management, policy and legislations |
| 46 | Wave Powered Desalination |

## Appendix C: Research sub-disciplines keys

| Key | Research sub-discipline |
|---|---|
| 1 | Agribusiness |
| 2 | Agricultural and Resource Economics |
| 3 | Agroforestry |
| 4 | Agronomy |
| 5 | Analytical Sciences |
| 6 | Analytics and Visualisation |
| 7 | Anthropology |
| 8 | Applied Economics |
| 9 | Applied Engineering in Agriculture |
| 10 | Aquaculture and Ichthyology |
| 11 | Aquatic biology |
| 12 | Atmospheric Sciences |
| 13 | Behavioural Finance |
| 14 | Biomolecular engineering |
| 15 | Botany |
| 16 | Business and Economic Statistics |
| 17 | Chemical |
| 18 | Chemicals in potable water |
| 19 | Civil |
| 20 | Coastal Engineering |
| 21 | Communications |
| 22 | Computational Economics |
| 23 | Corporate social responsibility and environmental management |
| 24 | Crop Science |
| 25 | Decision Sciences |
| 26 | Desalination and Water Treatment |
| 27 | Development Economics |
| 28 | Development Studies |
| 29 | Earth Observation |
| 30 | Earth Sciences |
| 31 | Ecology |
| 32 | Econometrics |
| 33 | Economic Modelling |
| 34 | Education |
| 35 | Entomology |
| 36 | Entrepreneurship and Management |
| 37 | Environmental / Resources Management |
| 38 | Environmental Economics |
| 39 | Environmental Systems |
| 40 | Forecasting and Game Theory |
| 41 | Gender Studies |
| 42 | Genetics |
| 43 | Geography |

| Key | Research sub-discipline |
|---|---|
| 44 | Health-related microbiology |
| 45 | Herpetology |
| 46 | History |
| 47 | Hydrology |
| 48 | Hydrology and hydrogeology |
| 49 | Industrial |
| 50 | Inorganic Chemistry |
| 51 | Insurance Mathematics and Economics |
| 52 | Irrigation and Drainage |
| 53 | Irrigation and Drainage Science Engineering |
| 54 | Land observation and remote sensing |
| 55 | Law |
| 56 | Library and information science |
| 57 | Limnology |
| 58 | Living resources |
| 59 | Macroeconomics |
| 60 | Mammalian biology |
| 61 | Marine science |
| 62 | Marine |
| 63 | Materials safety |
| 64 | Metagenomics |
| 65 | Microbial ecology |
| 66 | Microeconomics |
| 67 | Modelling and Simulation |
| 68 | Molecular biology |
| 69 | Nanoscience and Nanotechnology |
| 70 | Ocean and Coastal Management |
| 71 | Oceanography |
| 72 | Organic Chemistry |
| 73 | Philosophy |
| 74 | Physiology and endocrinology |
| 75 | Political Science |
| 76 | Presentation and User Interaction |
| 77 | Public Health |
| 78 | Remote Sensing |
| 79 | Scientific Programming |
| 80 | Sociology |
| 81 | Soil Science |
| 82 | Toxicology |
| 83 | Wastewater treatment |
| 84 | Water Management / Engineering |
| 85 | Water treatment |
| 86 | Waterway Port, Coastal and Ocean Engineering |
| 87 | Other |

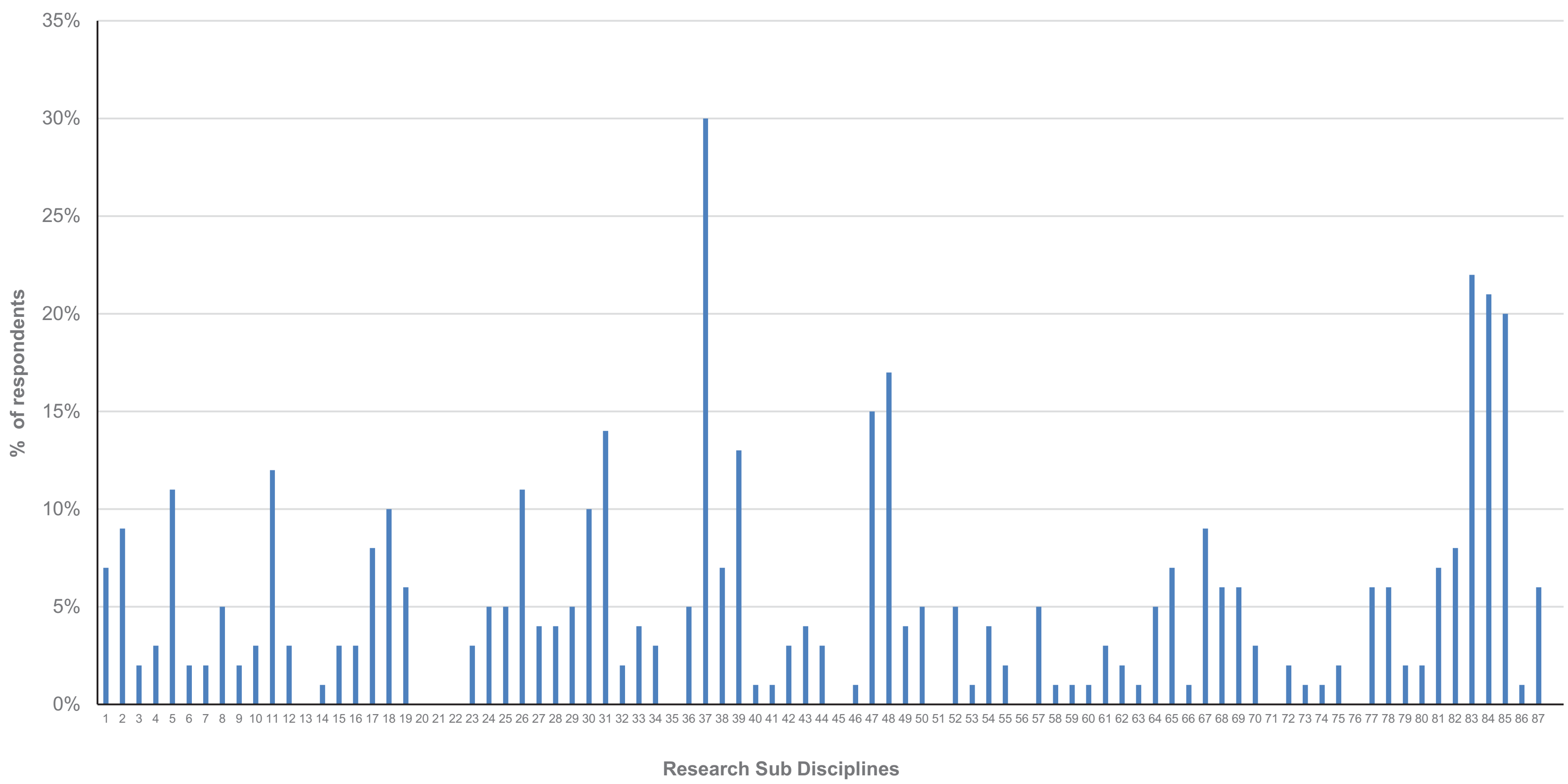
## Appendix D: Specialisation field keys

| Key | Specialisation field |
|---|---|
| 1 | Advanced biological processes |
| 2 | Agrichemicals |
| 3 | Agriculture |
| 4 | Agriculture Ecosystems and Environment |
| 5 | Agroforestry |
| 6 | Applied Entomology |
| 7 | Applied Herpetology |
| 8 | Aquaculture Research |
| 9 | Aquatic Biology |
| 10 | Aquatic Botany |
| 11 | Aquatic Ecosystems |
| 12 | Aquatic Insects |
| 13 | Aquatic Living Resources |
| 14 | Aquatic Mammals |
| 15 | Aquatic Microbial Ecology |
| 16 | Aquatic Toxicology |
| 17 | Bacteriology |
| 18 | Beneficial microbes |
| 19 | Biodiversity and Conservation |
| 20 | Bioinformatics |
| 21 | Biological processes |
| 22 | Chemicals and materials safety |
| 23 | Climatology |
| 24 | Computational Geosciences |
| 25 | Corporate social responsibility and environmental management |
| 26 | Crop production |
| 27 | Crop Production and Physiology |
| 28 | Degradation of priority pollutants |
| 29 | Digital records management and archival studies |
| 30 | Distribution |
| 31 | Dynamic systems |
| 32 | Earth Science Informatics |
| 33 | Ecohydrology |
| 34 | Ecological informatics and modelling |
| 35 | Ecology Evolution and Systematics |
| 36 | Ecosystem functioning |
| 37 | Emerging engineered nanomaterials |
| 38 | Emerging pathogens |
| 39 | Endocrinology |
| 40 | Environmental Law |
| 41 | Fate and behaviour of metals in the environment |
| 42 | Fate and behaviour of pollutants |
| 43 | Fluoridosis |

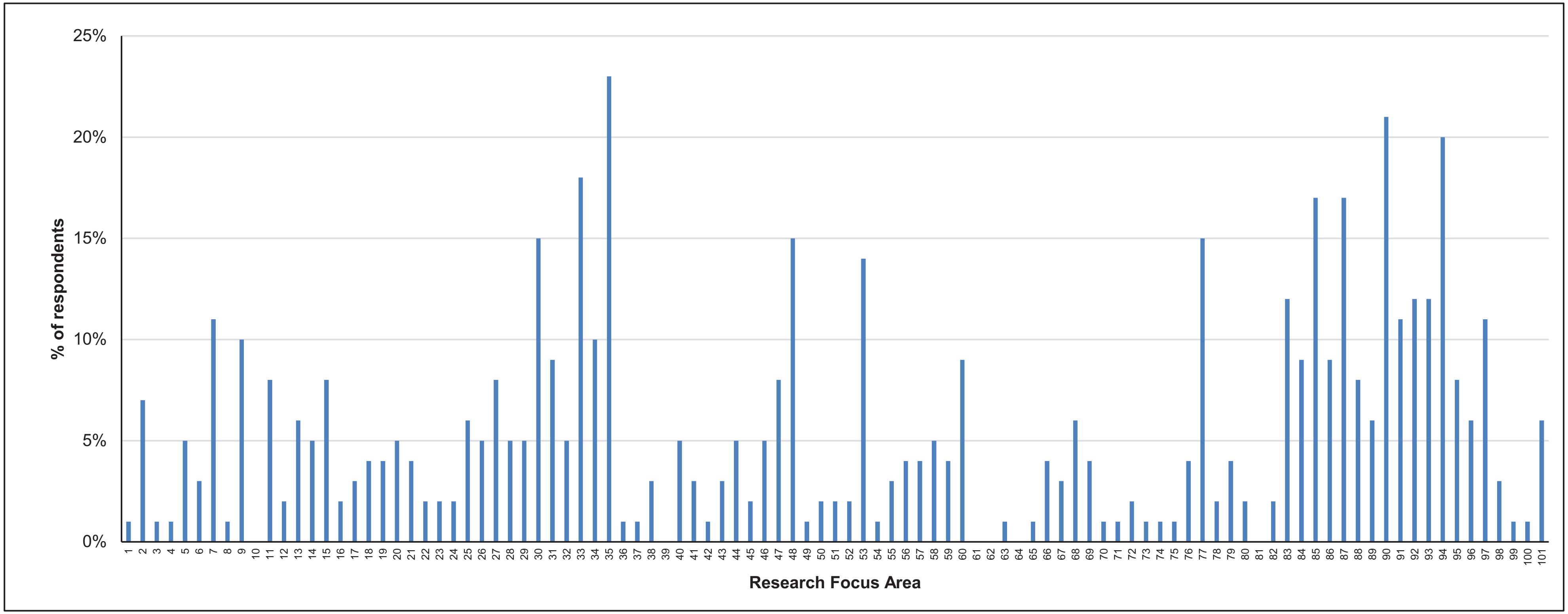
| Key | Specialisation field |
|---|---|
| 44 | Genetics and Plant Breeding |
| 45 | Geology |
| 46 | Geomorphology |
| 47 | Health Planning |
| 48 | Horticulture |
| 49 | Hydrodynamics |
| 50 | Hydrologic engineering |
| 51 | Hydromechanics |
| 52 | Ichthyology |
| 53 | International Relations |
| 54 | Irrigation and Drainage Science Engineering |
| 55 | Land use |
| 56 | Machinery |
| 57 | Marketing |
| 58 | Metals: toxicity and micronutrient value |
| 59 | Meteorology |
| 60 | Microbial ecology |
| 61 | Mineralogy |
| 62 | Mycology |
| 63 | Nutrient cycling |
| 64 | Oxidation and disinfection |
| 65 | Pathogens and parasites |
| 66 | Pattern recognition |
| 67 | Pollution detection and control |
| 68 | Population Health Management |
| 69 | Potable water safety |
| 70 | Precision agriculture |
| 71 | Processing |
| 72 | Protection |
| 73 | Public Administration |
| 74 | Public Policy |
| 75 | Remote sensing and GIS |
| 76 | Safety |
| 77 | Sales |
| 78 | Science Communication |
| 79 | Science Education |
| 80 | Security Studies |
| 81 | Seed supply |
| 82 | Soil Chemistry |
| 83 | Soil Fertility |
| 84 | Soil Management |
| 85 | Soil microbiology and biochemistry |
| 86 | Soil morphology and genesis |
| 87 | Soil Physics |

| Key | Specialisation field |
|---|---|
| 88 | Structural and Materials |
| 89 | Subsurface hydrology |
| 90 | Surface hydrology |
| 91 | Systems Ecology |
| 92 | Toxicity of engineered materials |
| 93 | Virology |
| 94 | Water Resources |
| 95 | WRC - Water at work |
| 96 | Other |

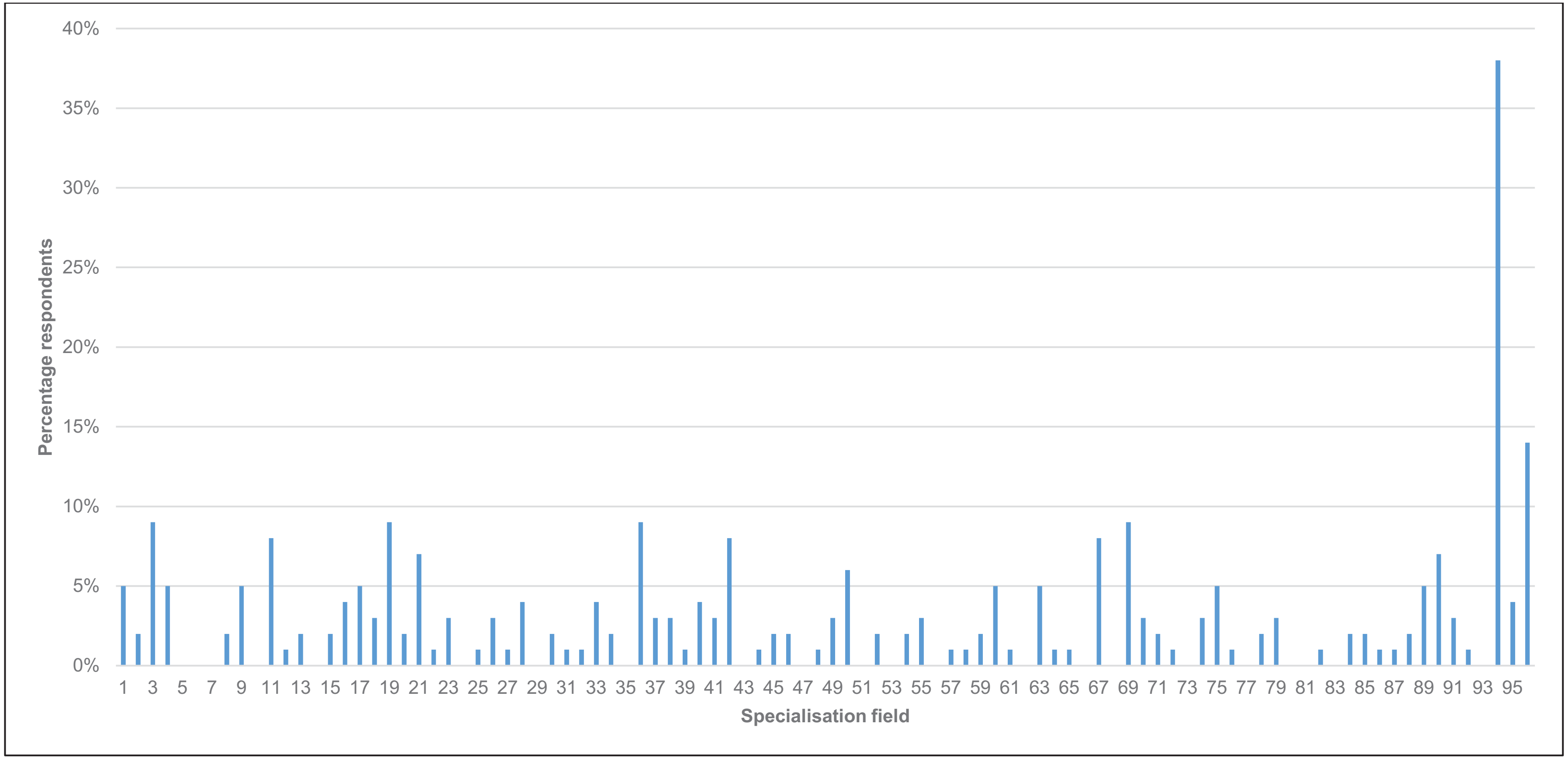
**Appendix E: Percentage water-related RDI activity reported per research sub-discipline (individual questionnaire) (n = 220). Appendix C lists sub-disciplines.**



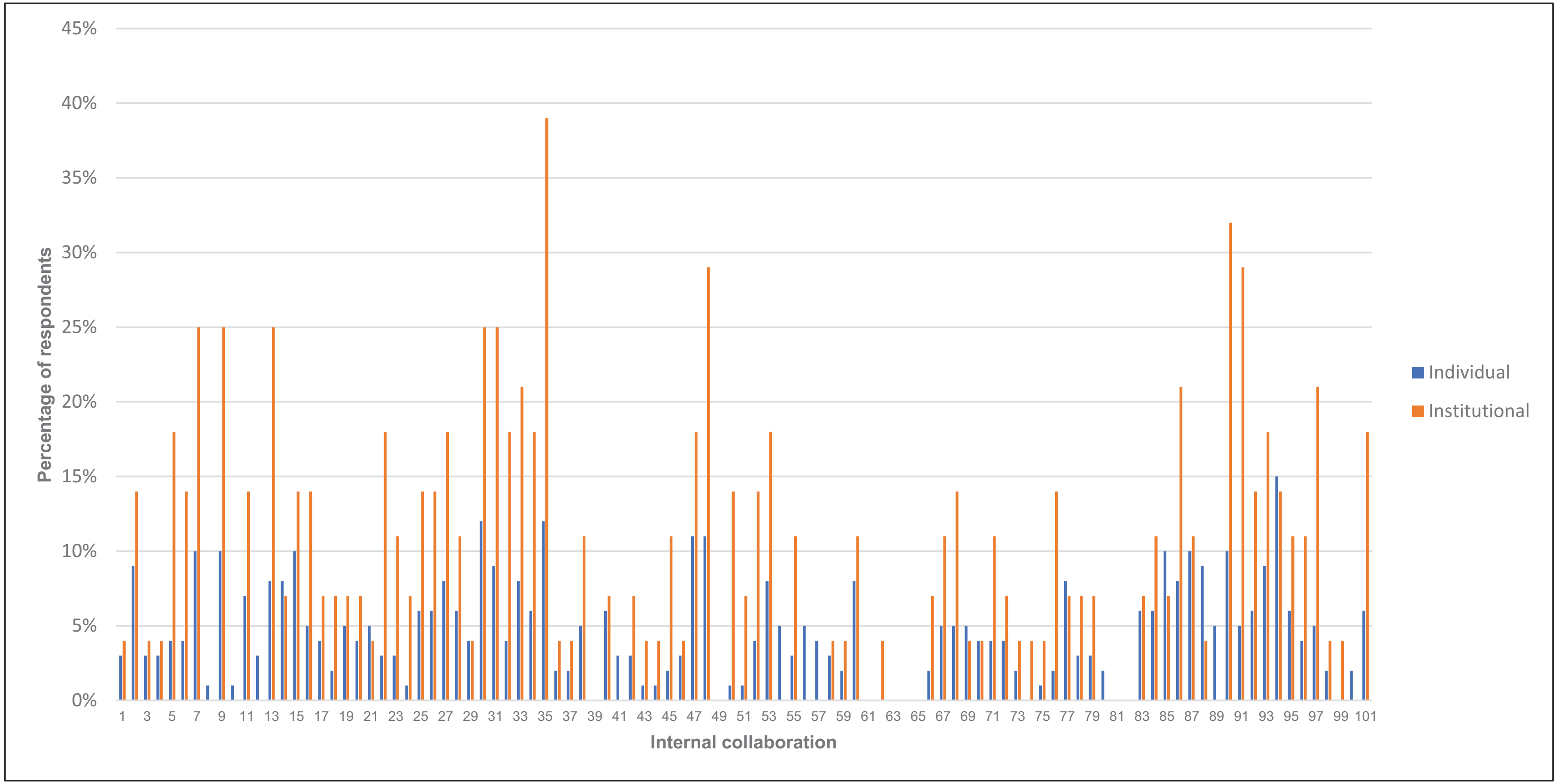
**Appendix F: Percentage water-related RDI activity reported per RFAs (individual questionnaire) (n = 220). Appendix B lists RFAs.**



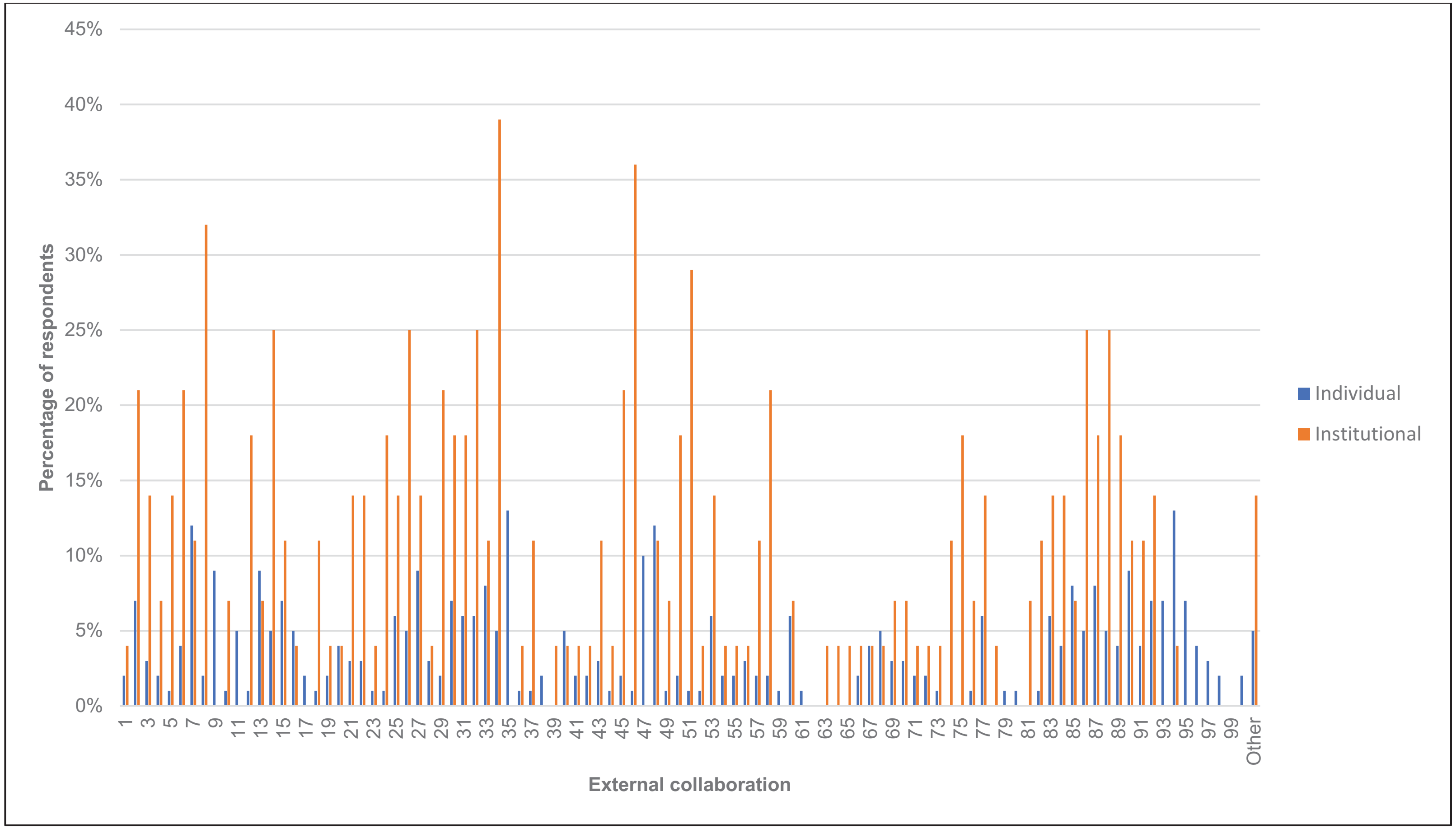
**Appendix G: Percentage water-related RDI activity reported per research specialisation field (individual questionnaire) (n = 220). Appendix D lists fields.**



**Appendix H: Percentage internal collaboration reported per RFA.**



**Appendix I: Percentage external collaboration reported per RFA.**



**Appendix J: A comparison between institutions recorded with mature and no/emerging research strength identified in the capability maps (2019) and the capability maps (2015).***

| | Presence of RFAs | Capability mapping (2019) | Capability mapping (2015) |
|---|---|---|---|
| Cluster 1[1] | Mature | North-West University, University of Pretoria, Durban University of Technology, Vaal University of Technology, University of South Africa and University of the Witwatersrand. | University of Free State |
| | No or emerging | University of Limpopo, Adopt Moreletaspruit Community Forum, Escience Associates (Pty) Ltd, Stellenbosch University | Central University of Free State, Durban University of Technology, NRF, South African Environmental Observation Network, South African Weather Service, University of Limpopo, University of Venda, Wildlife and Environmental Society of South Africa |
| Cluster 2[2] | Mature | University of Cape Town, Vaal University of Technology and Nelson Mandela Metropolitan University | University of Free State |
| | No or emerging | Pegasys Strategy and Development (Pty) Ltd, Adopt Moreletaspruit Community Forum and Sagifon Close Corporation (cc) Trading | Albany Museum, Central University of Free State, Durban University of Technology, NRF, South African Environmental Observation Network, University of Limpopo, University of Venda, Vulamanzi Water Law, Wildlife and Environment Society of South Africa |
| Cluster 3[3] | Mature | University of South Africa, University of Cape Town, Vaal University of Technology, Durban University of Technology | None |
| | No or emerging | Adopt Moreletaspruit Community Forum | Durban University of Technology, National Metrology Institute of South Africa, NRF, South African Environmental Observation Network, University of Limpopo, University of Venda, Wildlife and Environment Society of South Africa |
| Cluster 4[4] | Mature | Stellenbosch University, University of South Africa, Nelson Mandela Metropolitan University and University of Cape Town | None |
| | No or emerging | Institute of natural resources, Sagifon Close Corporation (cc) Trading | Central University of Free State, Durban University of Technology, Rhodes University, University of Fort Hare, University of Limpopo, University of Venda, Vaal University of Technology, NRF, SAEON, Wildlife and Environment Society of South Africa |
| Cluster 5[5] | Mature | University of South Africa | None |
| | No or emerging | None (all the institutions had RFAs at research strength building and higher) | ARC, Cape Peninsula University of Technology, Environmental Engineering Services, National Metrology Institute of South Africa, SASRI, Stellenbosch University, University of Johannesburg, University of Limpopo, University of Free State, University of Venda |
| Cluster 6[6] | Mature | University of South Africa, North-West University | University of Free State |
| | No or emerging | University of Limpopo, Escience Associates (Pty) Ltd | Central University of Free State, Durban University of Technology, NRF, South African Environmental Observation Network, Stellenbosch University, University of Johannesburg, University of Limpopo, |
| Cluster 7[7] | Mature | North-West University and University of South Africa | University of Pretoria, University of Witwatersrand |
| | No or emerging | Stellenbosch University and Safigon Close Corporation (cc) Trading | ARC, AU/NEPAD SA Network for Water COEs, Durban University of Technology, Rhodes University, SASRI, Stellenbosch University, University of South Africa, University of Free State, South African Sugar Association |

* In the Mature rows institutions and organisations with the at least one RFA at mature level are stated and in the No or emerging rows institutions and organisations with the highest RFA at emerging level or RFAs with no research strength were indicated.

The aim of the analysis is not to determine the water-related RDI research strength of the institutions or organisation in its entirety but to use the presence of absence of emerging and mature RFAs as indicators when comparing the capability maps of the current study to the capacity maps of the 2015 study. It is important to take note that the comparison does not take into account the number of the different RFAs at the different levels of research strength (emerging, building, established and mature) as well as the spread of the RFAs across the seven clusters.

[1]Combined results for Cluster 1 Alternative sources - “needs”, “potential” and “enablers” maps

[2]Combined results for Cluster 2 “Governance” (supply), “Planning and Management” (supply), and Cluster 5 “Governance” (demand), “Planning” (demand) and Management (demand) maps

[3]Results for Cluster 3 Supply infrastructure “Built Infrastructure” map

[4]Results for Cluster 3: Supply infrastructure results for “Ecological Infrastructure” map

[5]Results for Cluster 4: Business efficiency “Operational performance” map

[6]Combined results for Cluster 6: Efficiency “technical loss” and “deliberate demand” maps

[7]Results for Cluster 7: Monitoring and metering “cost” and “volume” maps

**Appendix K: The Research Focus Areas (RFAs) with no recorded research activity in the capability map of each cluster.**

| Cluster | RFA(s) with no recorded research strength |
|---|---|
| 1 | Agroforestry (RFA 3), agrometereology (RFA 4), beneficial agricultural use of municipal sludge (RFA 8), bioethics (RFA 10), business efficiency (RFA 12), geomembrane linings and covers for potable water storage (RFA 39), hydromechanics (RFA 49), hydrometerology (RFA 50), irrigation and drainage (RFA 54), ocean wave power (RFA 62), OM rural water services (RFA 63), plant life extension technologies (RFA 64), process automation and control – potable and wastewater treatment, soil physics (RFA 75), wave powered desalination (RFA 99) and weather and forecasting (RFA 100). |
| 2 | Agroforestry (RFA 3), beneficial agricultural use of municipal sludge (RFA 8), ecohydrology (RFA 22), ecological informatics and modelling (RFA 23), enzymes (RFA 36), food security and business efficiency (RFA 38), hydrometereology (RFA 50), irrigation and drainage (RFA 54), non-Newtonian fluid dynamics (RFA 61), ocean wave power (RFA 62), plant life extension technologies (RFA 64), soil chemistry (RFA 70), soil fertility (RFA 71), soil management (RFA 72), soil microbiology and biochemistry (RFA 73), soil morphology and genesis (RFA 74), soil physics (RFA 75), unsaturated zone (RFA 81), waterborne pathogen characterisation (RFA 98) and wave powered desalination (RFA 99). |
| 3 | Agricultural meteorology (RFA 1), agroforestry (RFA 3), agrometeorology (RFA 4), aquatic ecosystems (RFA 7), beneficial agricultural use of municipal sludge (RFA 8), bioethics (RFA 10), biological science (RFA 11), business efficiency, crop production (RFA 19), development economic (RFA 21), ecohydrology (RFA 22), ecological informatics and modelling (RFA 23), ecology evolution and systematics (RFA 24), ecosystem functioning (RFA 25), ecosystem functioning and health (RFA 26), education (RFA 28), enzymes (RFA 36), flood defence (RFA 37), food security and business efficiency (RFA 38), geomembrane linings and covers for potable water storage (RFA 39), hydrometeorology (RFA 50), irrigation and drainage (RFA 54), management (RFA 57), natural resource management (RFA 60), non-Newtonian fluid mechanics (RFA 61), ocean wave power (RFA 62), plant life extension technologies (RFA 64), process automation and control – potable and wastewater treatment (RFA 65), public health (RFA 66), public participation (RFA 67), soil chemistry (RFA 70), soil fertility (RFA 71), soil management (RFA 72), soil microbiology and biochemistry (RFA 73), soil morphology and genesis (RFA 74), soil physics (RFA 75), subsurface hydrology (RFA 76), systems ecology (RFA 79), technoeconomics (RFA 80), unsaturated zone (RFA 81), wave powered desalination (RFA 99), weather and forecasting (RFA 100). |
| 4 | Agricultural meteorology (RFA 1), agroforestry (RFA 3), agrometeorology (RFA 4), animal, human, public and environmental health (RFA 5), aquaculture (RFA 6), beneficial agricultural use of municipal sludge (RFA 8), bioethics (RFA 10), contaminant hydrology (RFA 17), crop production (RFA 19), desalination (RFA 20), education (RFA 28), environmental and analytical chemistry (RFA 31), enzymes (RFA 36), flood defence (RFA 37), food security and business efficiency (RFA 38), geomembrane linings and covers for potable water storage (RFA 39), hydrologic engineering (RFA 46), hydromechanics (RFA 49), irrigation and drainage (RFA 54), membrane technology (RFA 58), mining hydrology (RFA 59), non-Newtonian fluid mechanics (RFA 61), ocean wave power (RFA 62), OM rural water services (RFA 63), plant life extension technologies (RFA 64), soil chemistry (RFA 70), soil fertility (RFA 71), soil morphology and genesis (RFA 74), soil physics (RFA 75), subsurface hydrology (RFA 76), technoeconomics (RFA 80), unsaturated zone (RFA 81), urban economics (RFA 82), water engineering (RFA 88), wave powered desalination (RFA 99), weather and forecasting (RFA 100). |
| 5 | Agricultural meteorology (1), agroforestry (3), agrometeorology (4), animal, human, public and environmental health (5), aquaculture (6), beneficial agricultural use of municipal sludge (8), bioethics (10), business efficiency (12), crop production (19), desalination (20), ecohydrology (22), ecological informatics and modelling (23), ecosystem functioning and health (26), ecosystem services and ecological infrastructure (27), education (28), enzymes (36), flood defence (37), food security and business efficiency (38), geomembrane linings and covers for potable water storage (39), hydrodynamics (45), hydrologic engineering (46), hydromechanics (49), hydrometeorology (50), irrigation and drainage (54), land surface hydrology (55), non-Newtonian fluid mechanics (61), ocean wave power (62), OM rural water services (63), plant life extension technologies (64), process automation and control – potable and wastewater treatment (65), soil chemistry (70), soil fertility (71), soil management (72), soil microbiology and biochemistry (73), soil morphology and genesis (74), soil physics (75), subsurface hydrology (76), systems ecology (79), technoeconomics (80), unsaturated zone (81), wave powered desalination (99), other (101). |
| 6 | Agroforestry (3), agrometeorology (4), beneficial agricultural use of municipal sludge (8), bioethics (10), business efficiency (12), ecohydrology (22), education (28), enzymes (36), geomembrane linings and covers for potable water storage (39), irrigation and drainage (54), land surface hydrology (55), non-Newtonian fluid mechanics (61), ocean wave power (62), plant life extension technologies (64), process automation and control – potable and wastewater treatment (65), soil microbiology and biochemistry (73), soil physics (75), waterborne pathogen characterisation (98), wave powered desalination (99). |
| 7 | Agricultural meteorology (RFA 1), agroforestry (RFA 3), agrometeorology (RFA 4), beneficial agricultural use of municipal sludge (RFA 8), climatology (RFA 16), ecological informatics and modelling (RFA 23), ecology evolution and systematics (RFA 24), enzymes (RFA 36), flood defence (RFA 37), food security and business efficiency (RFA 38), geomembrane linings and covers for potable water storage (RFA 39), horticulture (RFA 42), human, public, and environmental health (RFA 44), improved food production (RFA 51), improved food security (RFA 52), irrigation and drainage (RFA 54), local government (RFA 56), natural resource management (RFA 60), non-Newtonian fluid mechanics (RFA 61), ocean wave power (RFA 62), plant life extension |

| Cluster | RFA(s) with no recorded research strength |
|---|---|
| | technologies (RFA 64), public health (RFA 66), sanitation (RFA 69), soil microbiology and biochemistry (RFA 73), soil physics (RFA 75), unsaturated zone (RFA 81), urban economics (RFA 82), waterborne pathogen characterisation (RFA 98), wave powered desalination (RFA 99) and other (RFA 101). |