Confronting the Global Water Crisis Through Research

Globally and across disciplines, water resources research expands as countries invest to solve growing problems

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Introduction

Earth, the water planet, is beset by water problems. Although two-thirds of our world's surface is covered by water, about 97% of it is salty. Of the approximately 3% that is not salty, 70% is frozen, which leaves only 0.75% available for the survival of all living creatures outside of the sea.

Human global population growth – 83 million more people each year – leads to concomitant growth in water demand by agriculture, consumers and industry, which in turn leads to water resources crises throughout the world. The best example is the growing demand for agricultural products – nearly 70% of worldwide water use is for irrigation. Expanding population and consumerism have led to increasing demand for food and consumer goods, which in turn fuels the demand for water. For example, it takes 1,857 gallons of water to produce a pound of beef, 2,900 gallons for a pair of cotton blue jeans, and 766 gallons to produce one T-shirt.[i]

Growing industrialization also increases water demand. Approximately 22% of fresh water use is industrial, including hydroelectric plants, water for cooling in data centers, and in processes in manufacturing and refineries. Only 8% is used for household purposes – cooking, bathing and washing. However, water use varies widely. Average water use per person per day is 575 liters per day in the United States and 4 liters per day in Mozambique.[ii]

Human uses of water are dramatically outstripping the resupply of water sources. Over pumping of groundwater, polluted runoff and erosion are problems facing agriculture and cities throughout the world. Unsustainable groundwater use occurs throughout the world, in high- and low-income nations. In Europe, 60% of cities over 100,000 people are using groundwater faster than it can be replenished.[iii] Critical aquifers are being drained: Mexico City, Bangkok, Beijing, Shanghai, Madras and Manila have all seen their drinking water aquifers drop between 10 to 50 meters.[iv] Within 15 years, 1.8 billion people will live in regions with severe water scarcity.[i]

A well-known problem is that the warming of the planet has led to shrinking icecaps and glaciers – the planet's principal reservoir of fresh water – whose fresh water supply is draining away into the salty sea. Water resource crises also threaten national security when water scarcity creates instability by thwarting economic development, threatening public health and heightening regional conflicts.[v]

Yet, many of our planet's water resources problems can be resolved. A 2006 United Nations report, entitled "Water, A shared responsibility," states this fact emphatically: "There is enough water for everyone."

The report concluded:

> "Water insufficiency is often due to mismanagement, corruption, lack of appropriate institutions, bureaucratic inertia and a shortage of investment in both human capacity and physical infrastructure." [vi]

Such conclusions underscore the critical importance of water resources research and explain its rapid global expanse. Countries are increasingly turning to water resources research to solve local, regional and global water problems. With this analysis we examine the literature on water resources over five years up to 2008.

Methodology

The analysis was split in to two phases: phase I looked at the water resources literature landscape and phase II, which took a look at a number of nations doing significant water resources research and some institutions that are main contributors to the field.

Phase I – To construct the initial data pool, the keywords "water resources*" were used to search titles, abstracts, and keywords of original articles, reviews, and proceedings papers published in the SciVerse Scopus™ database[1] (http://www.info.sciverse.com) from Elsevier between January 1, 2004 and Dec 31, 2008. The resulting pool of research papers related to water resources was then analyzed. The data pool was used to generate a list of subject categories, institutions, and nations ranked in three ways: according to the total number of papers, total cites, and total cites/ paper.

Phase II – SciVal® Spotlight[2] (http://www.info.scival.com/) was used to gain deeper insights into the core strengths of these top nations and the institutions that are contributing to these national strengths.

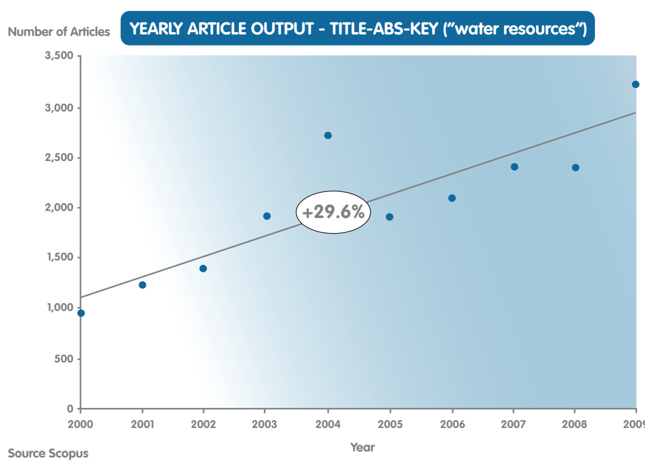
PHASE I – The Water Resources Research Landscape

The 2010 evaluation of the status of the global water resources research by Elsevier revealed a steady yearly growth of nearly 30% from 2000 to 2009, 27% greater than the average annual growth rate of published articles. It also showed that the field was becoming increasingly international, and that many new subject areas are starting to be incorporated into the research literature, making it increasingly multidisciplinary in nature.

The analysis revealed the emergence of China as a center for water resources research that is growing at the fastest rate. While the United States produces the most and the widest variety water resources research, it is rising less sharply compared to China.

Investment in water resources research is growing as governments recognize that solutions for local, regional and global threats to fresh water supply must be found at research universities and institutions. Drawing an accurate picture of how nations and their institutions contribute to the subject of water resources research can help them gauge where to invest more of their research funds in the future.

Fig. 1
Graph showing steady article growth in water resources literature (2000-2009)



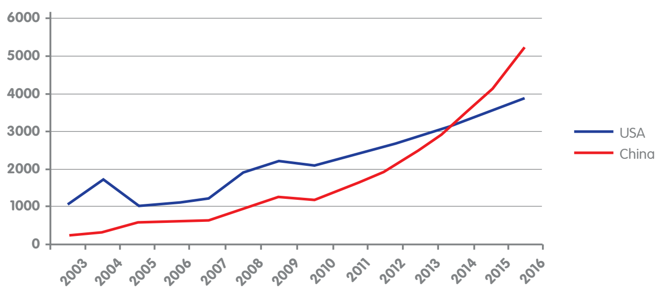
[1] SciVerse Scopus is the world's largest multidisciplinary abstract and citation database, and includes peer-reviewed research literature, quality web sources and patents. It covers more than 18,000 titles from over 5,000 global publishers.

[2] SciVal Spotlight is a customized web-based tool that enables institutions and nations to evaluate their research performance in order to make informed strategic decisions. Learn more about how SciVal Spotlight addresses the challenges of today's research executives in the following video (http://www.info.scival.com/scival-spotlight-video).

Emergence of China

From 2003-2010, the number of articles published by China grew from with an average annual growth rate of 28%. During the same period, the number of publications of articles from USA institutions on water resources research had an annual increase of 11%. Moreover, if a straight-line growth trend is assumed, China will surpass the United States in this field of research in 2014, see Figure 2 – *Overall article growth for USA and China assuming linear growth from 2010 onwards (2003-2016).*

Fig. 2
Overall article growth for USA and China assuming linear growth from 2010 onwards (2003-2016)



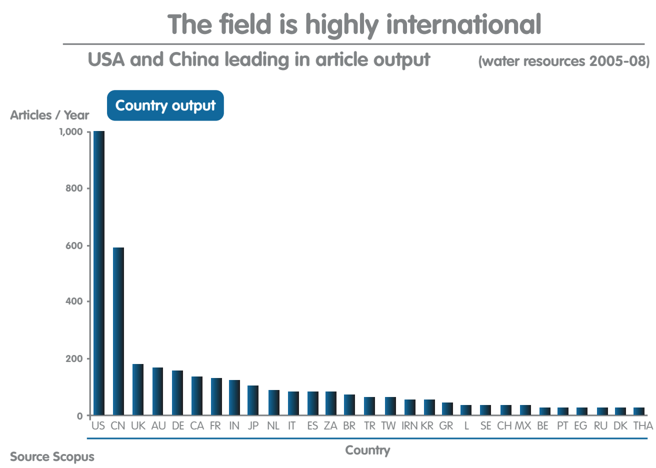
However, there is a significant difference in the type of research being conducted in these two nations, as a closer look at the actual articles reveals. China's research is more focused on local issues related to water resources like the treatment of water and waste water management, not surprising given the country's significant problems with water pollution. In contrast, the USA covers a greater number of issues that can be applied in a broader context and are therefore globally more relevant.

A review of China's water resources research in SciVal Spotlight shows that their strengths lie in looking at water resources within a mathematical, engineering, agricultural and earth sciences context. While the USA also covers these disciplines, it has a wider subject spread. In addition to the subject areas covered by China, the research strengths in the USA also lay within the context of Medicine, and Social Sciences, such as Environmental Policy/ Management and Economics.

International growth

As the problem of water scarcity is relevant to many countries across the globe, it is not surprising that the rapid growth of water resources research is increasing significantly in some countries, including some where until recently there was very little such research at all. These are countries where rising industrialization and growing prosperity have created unsustainable water resource practices that countries are now employing science to confront.

Fig. 3
Article output per country (2004-2008)

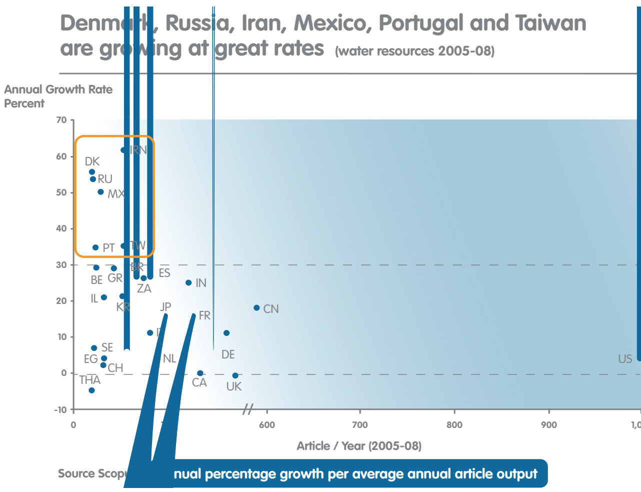


Iran and Mexico are good examples of such countries, where growing industrialization and population growth has produced unsustainable water resource practices – and consequently an understandable growth in water resources research. Iran, for example, has experienced a dramatic population increased in the latter part of the 20th century, reaching an estimated 75 million in 2009 from less than 20 million in 1955. In the past decade, its gross domestic product has risen significantly – and so has its consumption of energy and water. Iranians use more than double the amount of water used by Europeans and their energy consumption is 6.5 times that of global average.[vii]

As water problems mount, water resources research has come into more prominence. Only 12 papers on water resources research were produced by Iran in 30 years, from 1970 to 2000. But in 2009, Iran produced 96 papers, and from 2005 to 2008 the country produced more than 60 per year.

Fig. 4

Annual%age growth per average annual article output



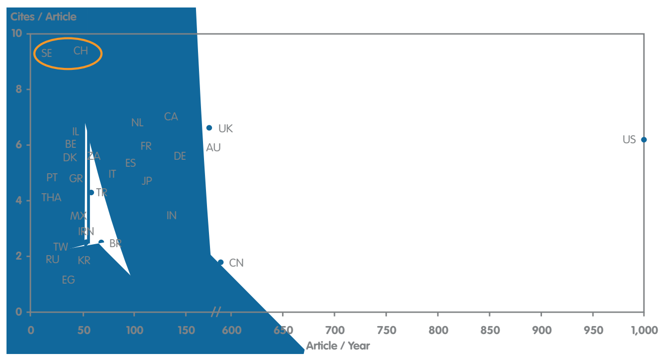
Like many countries, Iran is over-drafting its groundwater supply at unsustainable rates, while rapid population growth and urbanization have put strains on safe drinking water supplies in cities. Water pollution from industrialization, lack of wastewater treatment capacity and myriad water quality problems in the village economy are other problems the country faces,[viii] likely driving increased investments in water resources research by government and institutions.

The high annual growth rates of water resources research in countries where recent economic expansion has created water problems or where decades of industrialization are now taking their toll, and there is a dawning realization globally that fresh water supply is finite and that water management in all regions and countries has been inadequate or ignored altogether. The countries where increases in water resources research has been most dynamic include high-population industrialized nations such as India, South Africa, Brazil and Mexico where rapid increases of industrialization and urbanization are creating severe water problems. Others include South Korea, Taiwan, Denmark, Portugal and Spain, where the problems resulting from decades of industrialization and urbanization, coupled with the growing sophistication of research institutions, have led to increased output of water resources research.

Overall, the United States continues to be the leader in the field. A review of article output from 2005-2008 shows the United States produced approximately 1,000 articles per year and China approximately 600, although trends show China's output is accelerating compared to the USA. Other nations, such as Britain, Canada, Netherlands and Germany, have shown a steady output of 100-200 articles per year, while France and Japan have slightly smaller outputs but slightly higher growth rates.

Fig. 5

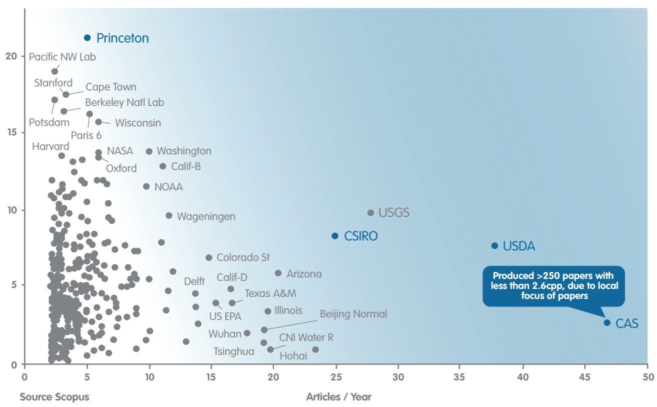
Countries in accordance to annual output and citations



From Figure 5 – *Countries in accordance to annual output and citations per article*, it can be seen that when a threshold of 80 articles or more, and over 5 citations per article the following countries remain: USA, Australia, UK, Canada, Germany, France, and the Netherlands. Suggesting that the relevance of the research conducted in these countries is higher than other nations, like China.

Figure 6 – *Institutes in accordance to annual output and citations per article*, shows that when a threshold of 7 citations/ article and a production of over 10 articles per annum are introduced, we are left with the following high achieving institutes: USDA, USGS, CSIRO, Colorado St, and Wageningen University.

Fig. 6
Institutes in accordance to annual output and citations per article



For this report we selected the three countries and institutes for the second phase of the study utilizing SciVal Spotlight, namely: the USA and the USDA, Australia and CSIRO, and the Netherlands and Wageningen.

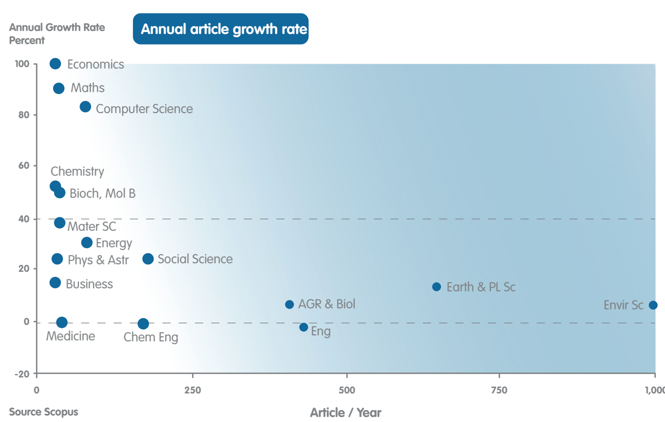
Multidisciplinary growth

Over the five year period it is evident that water resources research is becoming increasingly multidisciplinary in nature. Environmental science, earth sciences, engineering and agricultural/ biological sciences continue to dominate water resources research, reflecting the importance of issues related to water pollution, water supply and agricultural irrigation.

But trends are toward the increasing role of other related disciplines, for example, social sciences – particularly economics and policy development – have grown in importance, as have computer sciences, mathematics, and economics. Regarding the latter, government funders are increasingly seeking information on the economic impact of water resource problems and often require researches to cover these topics in their research to be eligible for a grant. At the same time, we can assume that forecasting and computer modeling have become integral components in the search for solutions.

The annual growth rate in economics articles within water resources research was 100% from 2005 to 2008, while the growth in math and computer science was above 80%. Chemistry, biochemistry and molecular biology articles have been growing at an annual rate of over 50%. These fast-growing disciplines reflect the changing interests of governments and grant-making institutions as they turn to science to help solve an increasing variety of problems within water resources.

The field is becoming more and more multi-disciplinary
(water resources 2005-08)



PHASE II – Country and institute strengths in water resources research

It is evident that the water research landscape is changing and becoming multidisciplinary in nature, as we see a sharp rise in the involvement of, mathematics, economics and computer sciences. To solve today's scientific challenges increasingly requires a multidisciplinary approach.

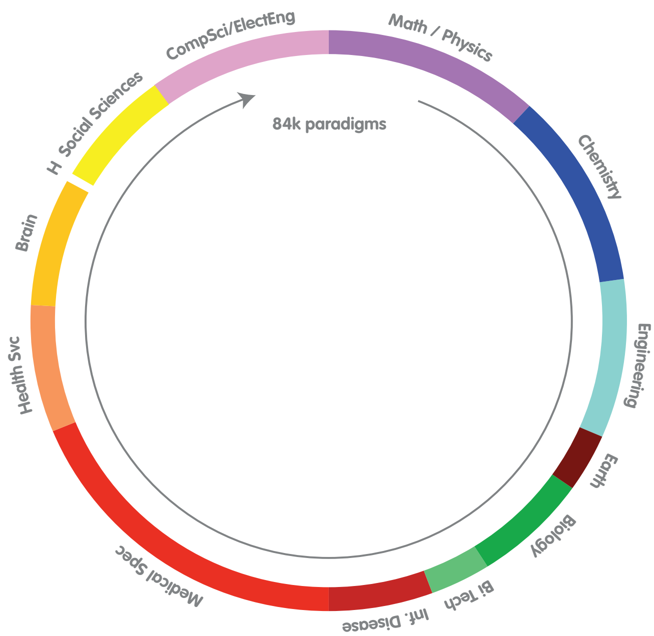
As a consequence the second phase of the research utilized Elsevier's SciVal Spotlight, a performance measurement tool based on a more detailed model of the current structure of science, to take a closer look at the research landscape at a country and institute level. The model is based on Scopus data, and includes 5.6 million separate research papers published between 2004 and 2008. Co-citation analysis is used to identify 84,000 paradigms within the content, see Figure 7 – *The Circle of Science – along which the paradigms are ordered around the perimeter for visualization purposes.*

The model can also be used to identify areas where countries or institutes tend to focus their work within a unique set of related paradigms. For any given country or institution, these paradigms form natural clusters that are based on the networks within the institute. These clusters formulate the unique core competencies or "*distinctive competency*[3] *(DCs)*" of the country or institute.

For water resources research each country has a number of DCs and ECs.

Fig. 7

The Circle of Science – along which the paradigms are ordered around the perimeter for visualization purposes



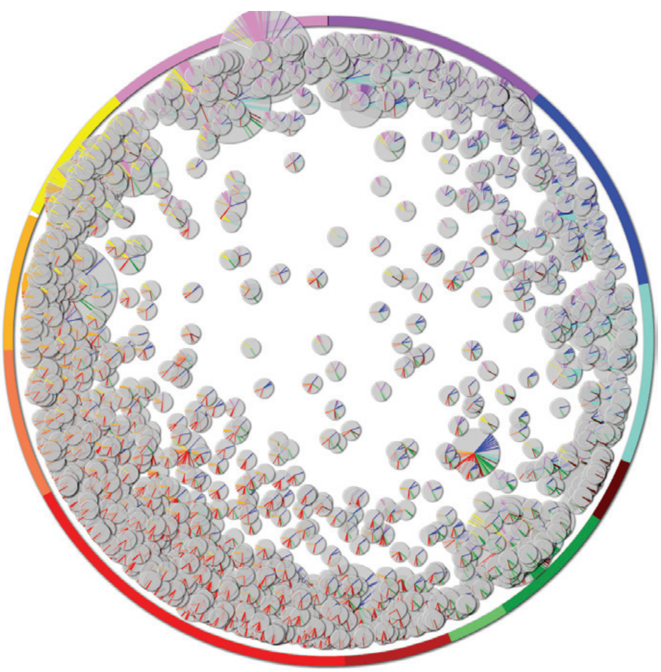
[3] Distinctive Competency (DC) A Competency is considered a distinctive competency if it is large and meets at least one of three leadership criteria. A sliding scale is used to determine if a competency is considered large – for larger institutions (>3,000 articles per year) the threshold is 500 articles, while for smaller institutions (<1,200 articles per year) the threshold is 200 articles. For medium sized institutions, the threshold size ranges linearly between 200 and 500 articles based on overall publication output. The three leadership criteria are:

- Publication leadership – A relative measure of the volume or quantity of publications an institution (or author) has produced in the past 5 years, compared to other institutions (or authors) within a particular competency. The institution is ranked #1 in a number of publications in the publication window (i.e., the institution has the greatest number of publications; therefore the Relative Article Share of the institution in the competency is greater than 1.0)
- Reference leadership – A relative measure of the volume or quantity of highly cited reference articles an institution (or author) has produced compared to other institutions (or authors) within a particular competency. The institution is ranked #1 in a number of reference papers (i.e., the institute has the greatest number of references in the article clusters; therefore, the Relative Reference Share of the institution in the Competency is greater than 1.0)
- State-of-the-art leadership – SotA is a measure indicating the recentness of articles cited by the institution's articles within a competency. The calculation is done by taking the median reference year for each individual article within a competency and comparing the average value of an institution to the average of the whole of the competency. The state-of-the-art measure varies around zero. Positive values indicate that the institution is citing more recent work within the competency than the world as a whole; while negative values indicate that the institution is citing older work than the world as a whole. The institution has a Relative Article Share > 0.8, and the State-of-the-Art value is greater than the corresponding value for largest institution in the Competency.

Table 1
Number of DCs and ECs for each country related to water resources research

Country	Distinctive Competencies (DC)	Emerging Competencies (EC)
USA	42	0
Australia	0	7
Netherlands	1	6
China	10	0

Figure 8
The 2008 circle of science for the USA



USA

The United States has long been the largest producer of water resources research, with a production of approximately 1,000 articles per year from 2003 onwards, because of high funding levels and numerous scientific institutions that dedicate significant intellectual resources to this critical area of applied science. A trend that can be seen from a closer look at the data is the increase in conference papers within the field, rising from around 150 papers annually to around 700 papers over the last three years from 2008-2010.

What is clear is that the United States also has many critical water problems, including unsustainable use of groundwater; water pollution from urbanization, industrialization and agriculture; high demand from agriculture, industry and consumers; water use impacts on land environment; impacts on coastal marine environment, and salt water intrusion of fresh water in coastal areas. At the same time, the United States is undertaking a wide range of water solutions, including constructed wetlands, desalination of sea water, purification of wastewater, conservation, and many others. Water resources research for local, national and global solutions remain an important investment.

A United States national map created through SciVal Spotlight shows a total of 1,635 research competencies, of which 42 are related to some extent to water resources, a far wider variety of disciplines within water resources research than any other country.

USDA – United States Department of Agriculture

The USDA is a large public agency within the Executive Branch of the United States Government established more than 150 years ago. The department is charged with developing and executing USA federal government policy on farming, agriculture, and food. It supports farmers and ranchers, promotes agricultural trade and production, assures food safety, protects natural resources, and seeks to end hunger worldwide. From the USDA's SciVal Spotlight map it can be seen that their strengths congregate around the subjects of Agriculture, Earth Sciences, and Biological sciences, as one would expect from a focused organization.

USDA has two main arms to support its public research mission – the Agricultural Research Service (ARS) and the Economic Research Service (ERS). Both support internal and external water resources research, but ARS is by far the larger of the two services. ARS includes 1,200 research projects, 2,100 scientists, 100 research locations including in other countries and a $1.1 billion fiscal year 2009 budget. ARS coordinates 1,000 research programs ranging from animal and crop production to sustainable systems and water quality. ERS, with 350 employees, is a social science agency, where highly-trained economists and social scientists conduct research, analyze food and commodity markets, produce policy studies, and develop economic and statistical indicators. The agency's research program is aimed at supporting information development and public policy development for government, trade association, public interests groups, the media and the general public.

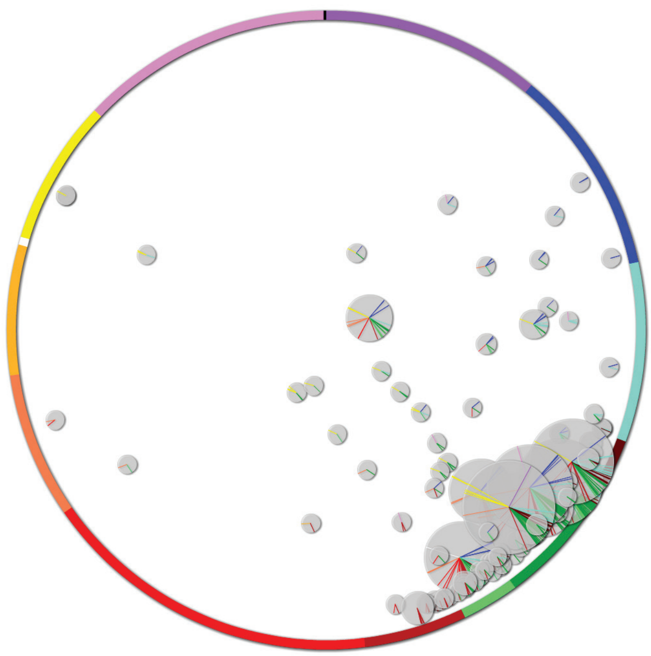
The analysis shows the USDA to have four distinctive and two emerging competencies in the area of water resources. Three of its competencies are first class, i.e. where the organization is ranked above all other institutes worldwide in this selected area of expertise.

Compared to the other institutes examined for the study, the USDA shows a very the strongest targeted strengths among institutions measured by SciVal Spotlight but little variety of research in water resources research. The map shows extreme depth and distinctive competencies in engineering, earth sciences, biology and biotechnology, including very large areas of water resources research in specific areas such as crop production, soil moisture, weed control, grain yield, forest management and health impacts. These areas correlate to USDA's principal missions, for example, multiple research projects on pine trees as part of its stewardship of the country's forests, and on Escherichia coli, better known as e. coli, a very dangerous, food-borne pathogen. Other areas of specific distinctive competencies linked to water resources research include freshwater biology, agricultural engineering, hydraulic conductivity, porous media, sediment yield, ecological modeling, soil erosion, ground water and soil science.

While USDA does not produce the variety of multidisciplinary research as other agencies, there are a few very large areas in water resources research, including a very large multidisciplinary competency that includes biology, biotechnology, engineering, chemistry and social sciences.

Emerging competencies at USDA in water resources research include remote sensing, fish biology and water waste.

Figure 9
The 2008 circle of science for the USDA



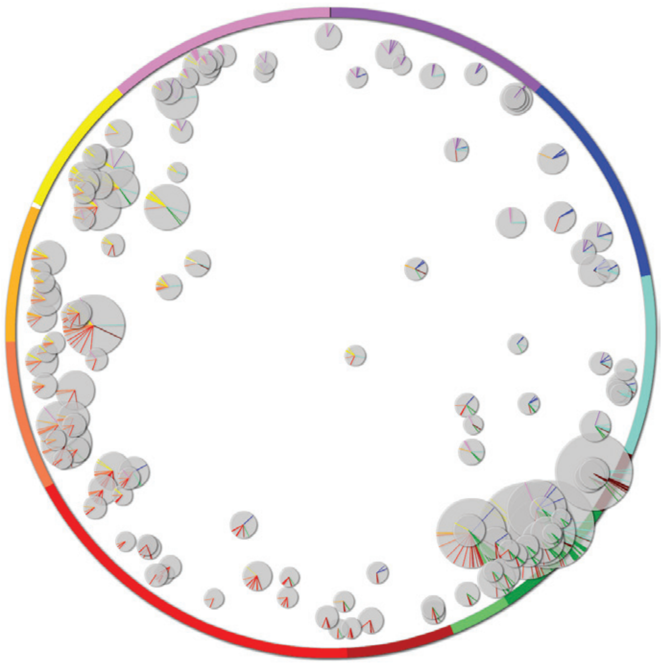
Australia

Australia is the world's driest continent, increasingly vulnerable to droughts which in recent years have struck urban areas, agriculture and the environment. Strict water conservation and rationing have been imposed in both cities and farms in recent years. Australia also is considered a flashpoint for climate change impacts, which are expected to cause extreme rains in some part of the continent, continued drought in others and heightened evaporation rates of lakes, rivers and wetlands.[ix] Coastal water ecosystems surrounding Australia, including the famous Great Barrier Reef, are under threat from climate change, loss of coastal habitat due to development and polluted water runoff.[x]

Australia has the fourth highest article output in water resources research, after the United States, China and Britain, with approximately 180 articles per year. It had a moderate article growth rate of about 10% per year, equal to many European countries with competencies in water resources research. Australia has evenly developed multidisciplinary competencies in water resources research, with particular strengths in earth sciences and biology, including and also in health sciences and social sciences. Because of the dynamism of its institutions, and proportional size of its investment in science, Australia features emerging competencies in many strategic areas of water resources research. For example, social sciences is an emerging research competency in Australia that includes water consumption and conservation, applied economics, agricultural economics, political science and human rights, all of which support policy planning and development. Another important area of emerging competency in water resources research in Australia includes the impact of El Nino and La Nina weather systems on coral reefs and fish species. This multidisciplinary area of research includes marine biology, fish research, fish biology, oceanography and climatology.

Figure 10

The 2008 circle of science for Australia



CSIRO

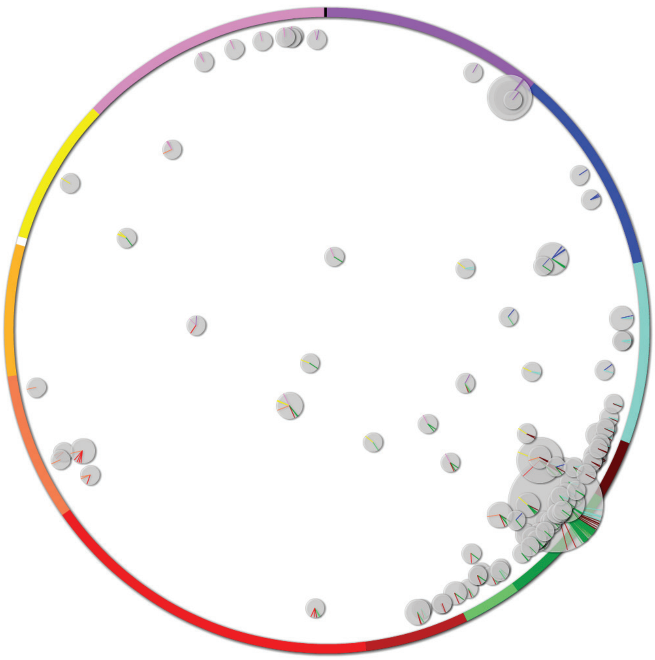
First formed in 1926, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), is Australia's national science agency, and one of the largest and most diverse research institutions in the world. CSIRO's research activities are divided into National Research Flagships, which are described as large-scale, long-term, multidisciplinary science to address Australia's major national challenges and opportunities. Many of these flagships, such as Wealth from Oceans, Sustainable Agriculture and Food Futures, include water resources research, and there also is a Flagship entitled Water for a Healthy County.

CSIRO's competencies in water resources research are clustered around biology, earth sciences and biotechnology. With other noted competencies in chemistry, math and physics, reflecting computer science research for analyzing and mapping, a noted CSIRO strength. For example, CSIRO's profile includes distinctive competencies in the impact of El Nina and La Nina climatic systems on rainfall and in biodiversity conservation. Other distinctive competencies include fish biology, oceanography, atmospheric science, and water waste. Such competencies reflect CSIRO's position as one of the world's top oceanography and climatology institutes and also Australia's growing continental need for answers to water supply and quality problems caused by drought and floods. CSIRO conducts principal research in biology, earth sciences and biotechnology for a better understanding of these phenomena, but also invests heavily in computer science for water resources research for analyzing and mapping these phenomena.

CSIRO's emerging competencies linked to water resources research are in the agricultural realm, including soil water content, gully erosion, remote sensing, hydrology and soil science.

Figure 11

The 2008 circle of science for CSIRO

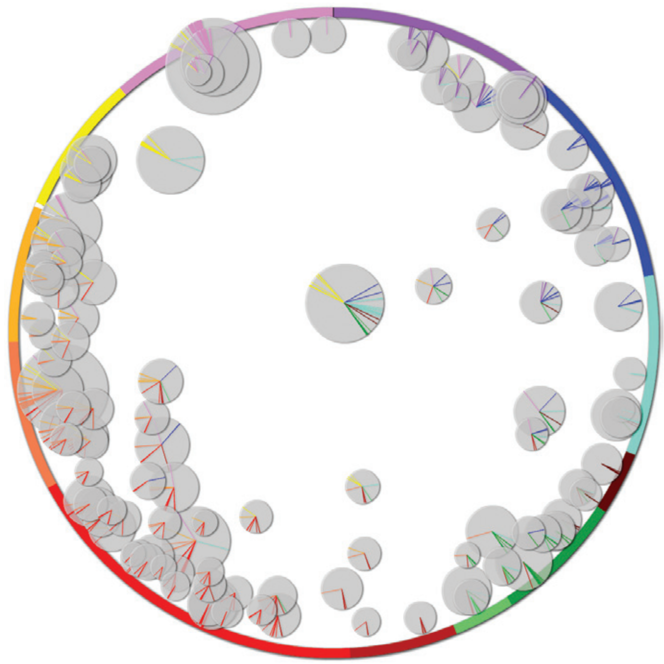


Netherlands

Water resources problems have defined modern Netherlands. It is a geographically low-lying country with about 20% of its area and 21% of its population located below sea level,[xi] and with 50% of its land lying less than one meter above sea level[xii]. Large swaths of Netherlands have been reclaimed from the sea and then preserved through an elaborate system of polders and dikes. The estuaries of three important European rivers – the Rhine, Meuse and Scheldt – make up an important part of Netherlands. Because so much of its landmass is low-lying, Netherlands is one of the countries that may suffer most from rising sea levels caused by global climate change[xiii]. Changing weather patterns also may cause future problems in river estuaries.

Figure 12

The 2008 circle of Science for the Netherlands



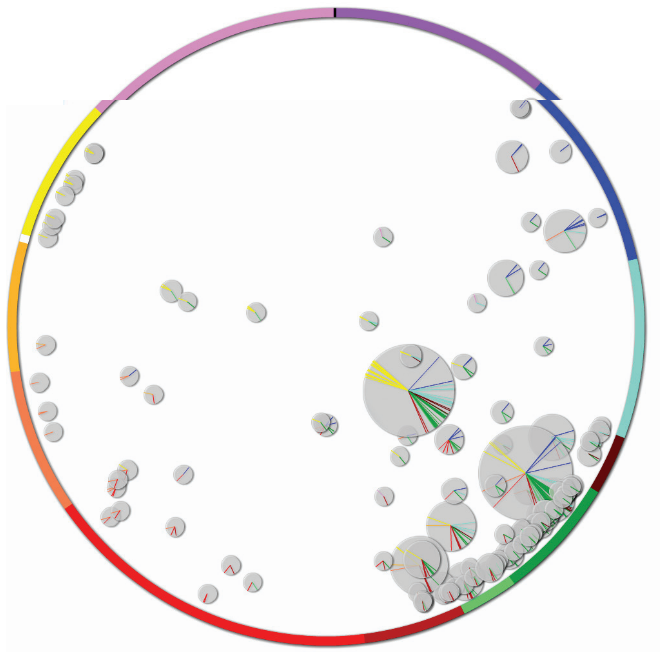
Wagening University

A major research institution in the city of Wageningen, this university specializes in research about life sciences and natural resources. In water resources research, Wageningen shows strengths in emerging competencies in a variety of disciplines as well as multidisciplinary work. In many areas of agricultural research, Wageningen is considered one of the top universities in the world. That expertise includes many areas of water resources research, because water resources are critical to agriculture. For example, Wageningen has distinctive competencies and projects in water resources research linked to soil organic matter, soil fertility, soil science and poultry science, which match its status as a leading agricultural institution. Wageningen also has distinctive competencies in water resources research linked to ecological modeling, biological conservation, and atmospheric science.

Some of Wageningen's emerging research competencies in water resources research reflect Netherlands' national struggle against the sea, including research in virtual water, which refers to the volume of water used to produce goods and services; river basins and water supply; soil water content; soil erosion; and ecosystem services. Wageningen also leads Netherlands in emerging research competencies in water research related to environmental and water policy, renewable energy, water waste, soil science and remote sensing. Wageningen is the second biggest contributor in Netherlands in ecological modeling, mass spectrometry, surfactants, bacteriology and plant disease within the field of water resources research.

Figure 13

The 2008 circle of science for Wageningen



One of Wageningen's research strengths is in its multidisciplinary work, particularly as it relates to agricultural and water resources research. For example, in its distinctive competency within agricultural fields of soil fertility and organic soil matter, some of the top disciplines include social science, political geography and geomorphology. One large area of multidisciplinary work includes a large component of social sciences and engineering. Wageningen does not have a strong component in the math and physics or computer science fields that are used for mapping and modeling or in engineering. Wageningen also does not rank in the top ten in Netherlands in other areas of water sources research, including emerging competencies of research policy, technology management and regional studies.

However, Wageningen's strength in interdisciplinary research provides opportunities to strengthen its research in many emerging competencies in water resources and other research.

Conclusion

Water resources research is expanding worldwide as countries and funding agencies turn to scientists to help solve problems of dwindling fresh water supply and oceanic changes that impact every continent.

Many countries which ten years ago undertook very little water resources research, are today ramping up their research capacity. These often are countries where rapid industrialization and population growth has created unsustainable water resources practices. Since the year 2000, the number of published research articles worldwide on water resources has grown at a steady rate of 30% a year.

China has seen a steady annual growth rate of 28%, while the water resources research output from the United States has risen with only 11% a year. Though the United States still leads the world in water resources research, if linear growth is assumed China will surpass the United States in article output by 2014. Another significant change in water resources research has been its increasingly multidisciplinary nature. Although Environmental science, earth sciences, engineering and agricultural/ biological sciences continue to dominate the research landscape, while economics, math, computer science, chemistry, biochemistry and molecular biology are growing quickly. This reflects the complexity of problems within water resources research and the determination of funding agencies and institutions to broaden the search for answers with cross-discipline teams of expertise.

[i] National Geographic, April 2010. Water: Our Thirsty World

[ii] Human Development Report 2006. UN Development Programme. http://hdr.undp.org/hdr2006/

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