Food Production to Meet the Global Needs of 2050 – The Challenges for Land and Water Resources: An Overview

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Key words: Water resource management; water use efficiency; desalination; precision agriculture

INTRODUCTION

The Paper provides an overview of the demands on the land and water resource to meet global food production needs in 2050 as a consequence of the estimated growth in population and perceived changes in societal behaviour over the next 35 years. It provides an introduction to the principal issues which require to be addressed and some of the innovative, technological and management solutions which seek to achieve sustainable outcomes. The Paper is the first in the series of papers on this Theme within FIG's Commission 8.2 Work Plan 2015-2018.

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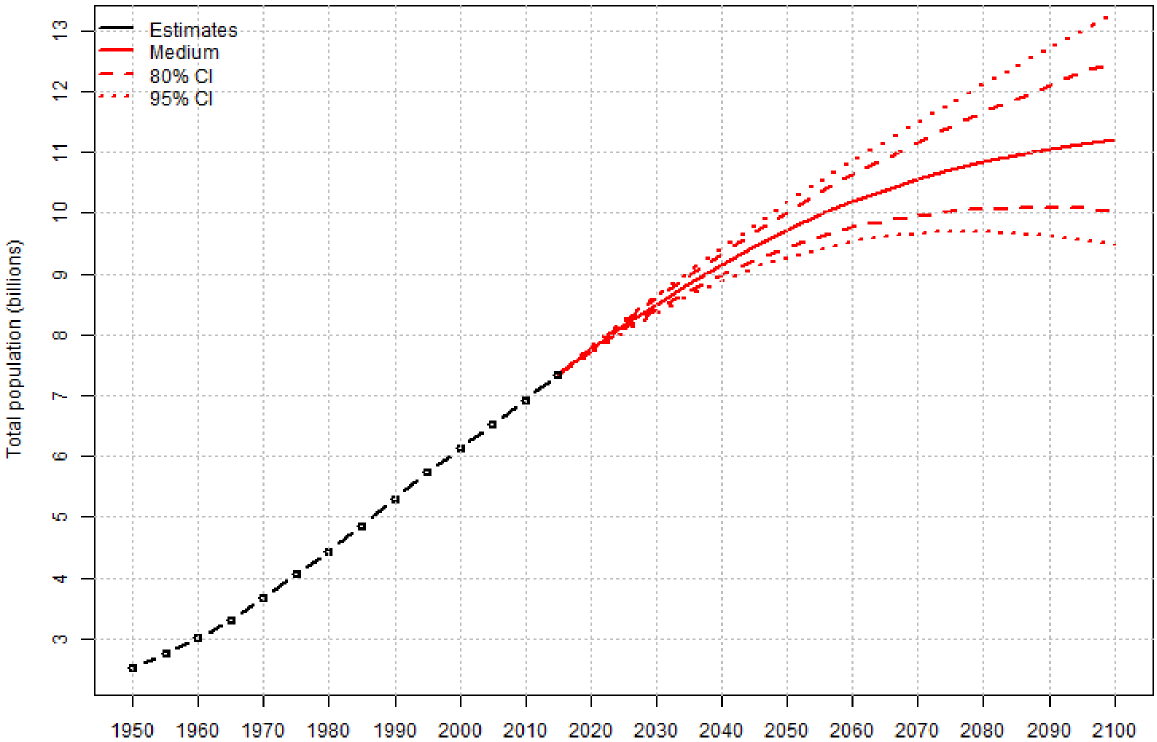
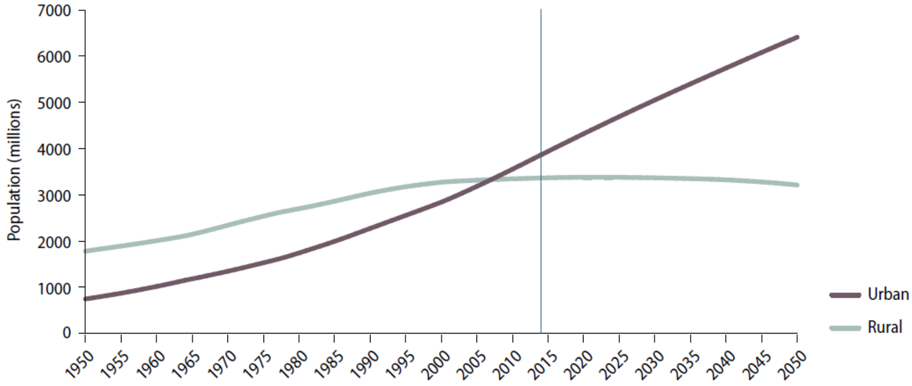
1. THE GLOBAL PROGNOSIS

When I started primary school in 1960, the world population was approximately 3bn. Today it is estimated at 7.3bn and is expected to increase to 9.725bn by 2050. That is equivalent to an increase of 33.2% over the period of this Paper.



Source: United Nations, Department of Economic and Social Affairs, Population Division (2015). *World Population Prospects: The 2015 Revision*. New York: United Nations. (http:esa.un.org/unpd/WPP/Publications/Files/Key Findings WPP 2015.pdf)
One-third of the global population increase will be in China and India.

Urbanisation is the major feature of population concentrations and is forecast to continue at an increasing pace. Whereas in 1900 there were 6.7 rural dwellers to each urban dweller, by 2025 it is estimated there will be 3 urban dwellers to 2 rural dwellers.



Source: UN Department of Economic and Social Affairs Report on World Urbanization Prospects (2014): Urban and Rural Population of the World 1950 -2050

12% of the world's population now live in 28 megacities.

Another feature of increasing urbanisation is the expectation of an improvement in living standards; the OECD predict that global Gross Domestic Product will nearly triple over the next 40 years – with the largest growth in India and Africa. This also impacts on dietary preferences, with meat consumption per capita rising significantly. The UN FAO estimates that by 2050 some 4.7bn people (52%) will live in countries with national averages of over 3,000kcal per person per day, compared to 28% currently.

2. THE DEMAND FOR FOOD

The UN FAO's estimate is that food production will need to increase by 60% by 2050.

The 60% increase would mean:

- An increase of 15% in per capita production;
- Agricultural production could more than double in South Asia and nearly triple in sub-Saharan Africa;
- Nearly 90% of the increase in annual production will occur in developing countries, with a particular emphasis on livestock production.
- Globally, 90% of the growth in crop production to 2050 will come from intensification - both from high yields and the more intensive use of land.

This increase in production equates to an additional 1bn tonnes of cereals and 200m tonnes of livestock products per annum.

3. THE CHALLENGE OF LAND

The UN's Global Agro-Ecological Zone studies show that there are still ample land resources available for the potential additional crop production. Globally, the extent of arable crop production, currently around 11% of the land surface, is expected to increase by 70m ha (<5%) by 2050, but this masks that 120m ha will be in developing countries and is offset by a reduction in croppable area of about 50m ha in developed countries. Most of the potential lies in Latin America and sub-Saharan Africa.

Many countries with growing populations are extremely land scarce, and much of the potential land is capable of growing only a few crops, and not necessarily those for which the demand is highest.

There are often obstacles to production – most notably chemical contamination, physical constraints, endemic diseases and a lack of infrastructure.

Desertification accounts for land losses of 12m ha per annum globally. If the land was properly maintained, with a reliable supply of water, this area could produce 20m tonnes of grain per annum.

Case Study: Desertification – soil turning to sand in Senegal.

The lack of, and unpredictability of, rainfall and consequential soil erosion and lack of boreholes has destroyed the harvest (peanuts) and changed the once fertile land into desert. This has threatened livelihoods and it is estimated that between 50 and 60 million people will migrate from the desert areas of sub-Saharan Africa by 2020.

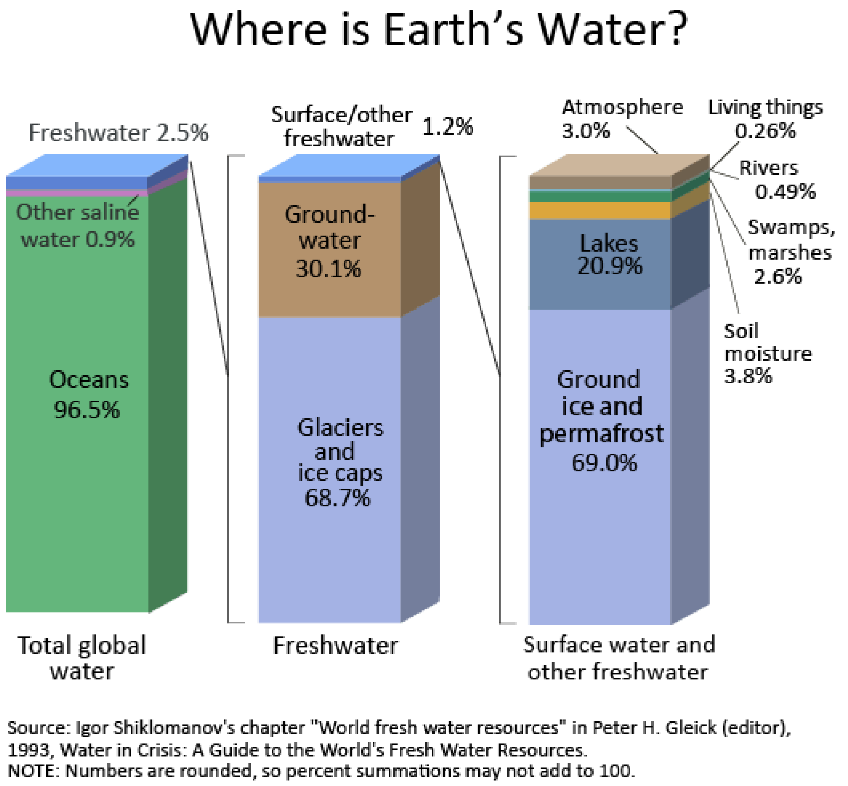
Part of the solution in Senegal is the creation of the Great Green Wall –a vegetation belt aimed at providing minimum living conditions. It is a section of the Pan –African Regeneration Project, some 15 km wide and 7,100 km long, being planted to halt the spread of the Sahara Desert. But it will take 10 – 15 years to deliver results.

The other threat to productive land use is that of the possible consequences of **sea level rise, mainly due to climate change.** The USGCRP National Climate Assessment predicts that the sea level will rise between 300mm and 1,200mm by 2100, compared to a baseline of the 2014 level. Obviously, low –lying coastal areas and deltas, often very rich agriculturally, will be most vulnerable to a rise in sea level and inundation. It has been predicted that a 1 metre rise in sea level could result in productive land loss of 12-15% in Egypt; 16% in Bangladesh and many tens of thousands of hectares in China. And there are other threats from climate change –some physical such as soil erosion, more severe weather patterns with implications of flooding and drought and, of course, temperature variation and seasonality.

However, despite the threats, some of them perhaps becoming acute during the period of study, there is hope. Historically, the world's cultivated area has grown by 12% over the last 50 years. The irrigated-equipped area has doubled and continues to expand by 0.6% per annum.

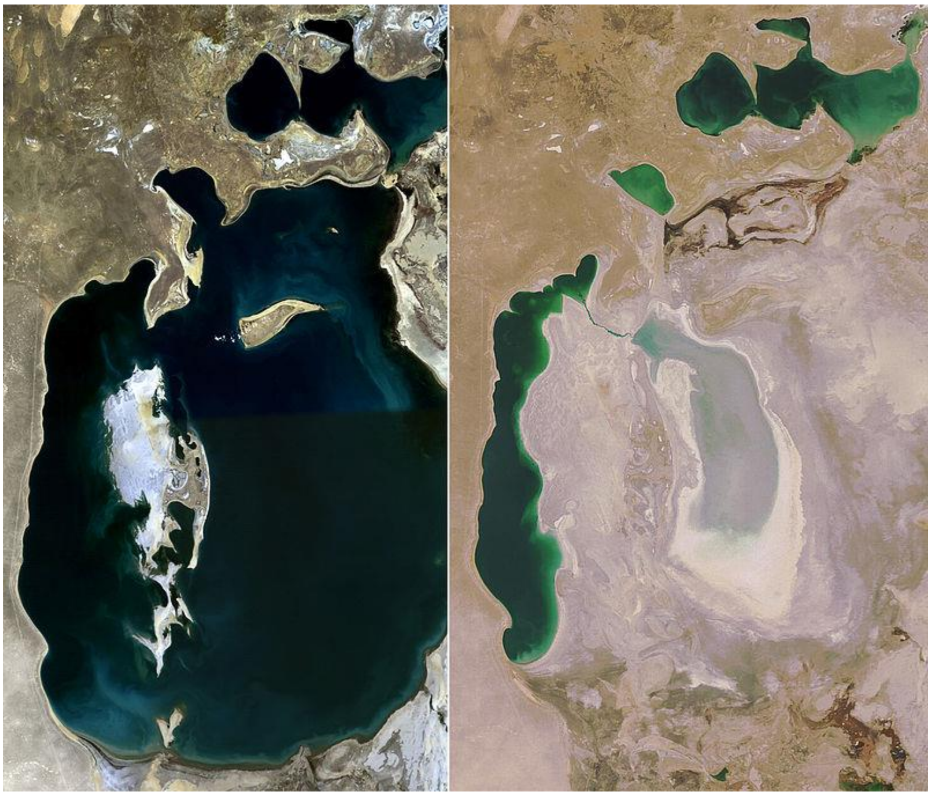
4. THE CHALLENGE OF WATER

Without water, Earth would not be a living entity. Ironically the planet we call Earth is also termed the Blue Planet –water covers 71% of its surface, yet only 2.5% is a freshwater resource.



Source: usga http://ga.water.usgs.gov/edu/waterdistribution.html

One of the world's largest lakes, the Aral Sea in Russia, used to extend to 68,000m³, but has all but disappeared due to 60 years of feeder rivers being diverted on Soviet irrigation projects. It is considered the largest Man-made loss of water in recorded history. The eastern basin is now renamed the Aralkum Desert.



Source: NASA satellite images – latest, on right hand side, in August 2014

There are other significant constraints on the available freshwater resource.

- Nearly two-thirds of China’s groundwater and a third of its surface water was rated as unfit for human contact in 2014.
- Freshwater is not always where it is most needed. Brazil has 3% of the world’s population and 13% of its land based water; India has 18% of the population but only 3% of the water and China has 20% of the global population, but only 6% of the water.
- Access to water is a basic human right. Water rights are complex and highly variable and subject to local and national regulation. Having a value, it has a cost, but that is irregular and frequently misrepresented.

The global water use is estimated at 7,500 km³ per annum – equivalent to the annual flow of the Amazon, the largest river in the world.

The principal consumers are:

The relative percentage users vary considerably between countries – in developed countries the industrial usage is significantly higher. Freshwater withdrawals have been estimated to have increased threefold in the last 50 years, with demand increasing by 64bn m^3 per year (Source: The Pacific Institute, USA).It is estimated that the annual demand for water will increase by 47% by 2030 to satisfy China's needs and will double in both South America and India. Accelerated growth in the sub-Saharan continent of Africa is estimated will generate a 283% increase in annual demand over the same period.

The crux is that at increases of 2.5% per annum, water consumption is growing faster than the world population.

Water Footprinting

Of more relevance than global statistics is the work by UNESC –IHE, Gleike and Allan on the water resource implications of the goods and services we consume. This is the concept of "virtual water", which captures the total water used, or embedded, in the production of a commodity.

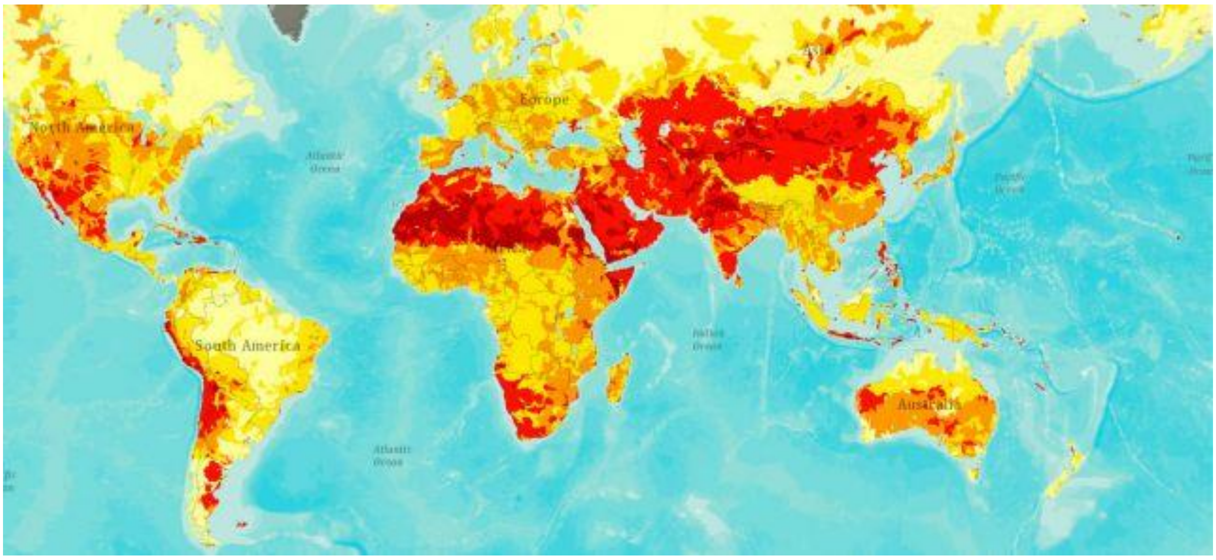
Table 1 Water footprints of crops and livestock production (per kg produced)

Crop	**Total water requirement (litres)**
Wheat/Alfalfa	900-2,000
Sorghum/corn/maize	1,000-1,800
Rice	1,900-5,000
Soybeans	1,000-2,000
Livestock	
Sheep	6,000
Pig	4,800
Beef	15,500
Chicken	3,500-5,700
Eggs	3,300 (120-200 l per egg)

Source: Extract from World Water 2008/09 and Water Footprint (http://www.waterfootprint.org)

The availability of water internationally: Water Risk

The challenge of water centres around how much? where? and when? The World Resources Institute (WRI) has developed an Aqueduct Overall Risk Map showing geographical areas where significant problems occur as a consequence of a shortage of water, being available in the right place, and at the right time.



Source: WRI Aqueduct Overall Risk Management Map

The UN define water stress where the annual supplies are <1,700m³ per capita. There are no shortages in Scotland, but there are serious shortages in India, Pakistan, Yemen, parts of Africa (Ethiopia), and parts of USA (California). In Sao Paulo, the world's 12th largest city, the figure is 200m³, or "absolute scarcity". Water 2030 predicts that by 2030 demand will have exceeded supply by 40% and half of us will live in "water stressed areas".

5. The UN's analysis of irrigated agriculture and the potential for expansion

Currently, irrigated agriculture covers 16% of arable land in use, but accounts for 44% of all crop production. For developing countries the figures increase to 21% of arable land, accounting for 49% of production. The figure for cereals is 60%. The world expansion of arable area over the next 35 years is critically dependent on the ability of the non-temperate countries to maintain, improve and expand irrigated agriculture.

The projection is that the area equipped for irrigation could expand by 20 million ha (6.6%) by 2050. Nearly all of this increase will be in developing countries. By 2050, nearly 60% of all land with irrigation potential (estimated at 417million ha), will be in use. Taking account of new irrigated areas lost to degradation, water shortages, etc, the remaining areas in developing countries suitable for irrigation (ie beyond 2050) but not yet in use, will be severely restricted in extent.

The regions where the expansion of new irrigation schemes will be most prevalent are likely to be those where more intensive cultivation is problematic, such as East Asia, South Asia and the Near East/ North Africa. Further expansion will, of course, become increasingly more difficult as water scarcity increases and competition for water from households and industry continues to reduce the share available to agriculture.

6. RESPONDING TO THE CHALLENGES

Historically, the appliance of science and technology has contributed very significantly to increased agricultural production and will be the key to unlocking the potential for further increases. This is not a Malthusian Trap – the "We're doomed" outlook on future prospects. Rather, it is an excellent illustration of the Boserup Theory in practice. Boserup can be paraphrased as "Necessity is the Mother of Invention", a pro-active approach which I continue to promote as the solution.

As a sector, Agriculture can be immensely proud of its track record on innovation. Past achievements through research and development, and sheer practical expertise and experience, have brought huge advances in the appliance of science and engineering: crop and livestock genetics, soil fertility, mechanisation, and precision farming. To use just one example –the UK population has increased by a factor of 5 since 1800, but the productivity of rainfed wheat has increased tenfold. The 2015 harvest in Northumbria set new world records for cereal yields.

7. THE BASIC OPTIONS

There are three basic precepts to sound resource use and management:

- How can we use less of it?
- How can we use the same resource more effectively?
- How can we create more resource?

All of the above are properly constrained by the objective that in using this resource, we do not inadvertently damage or destroy another one – the principle of sustainable development. The solutions to achieving successful water resource management need to include global, regional and local perspectives –including the water catchment and farm level.

8. HOW CAN WE USE LESS OF IT?

There are eight generic "majors" before we focus on the specifics.

- Population control: Obviously the largest variable in the equation on the feeding the world's population is the population. Leaving aside the abhorrence of war and disease, it is worth dwelling on China's "one-child policy". Even although this policy was changed in 2015, it did deliver population "savings" of 300 million, which equates to an approximately 20% decrease in water usage.

- Dietary changes: The water footprint work referred to earlier holds the key to how “we could eat ourselves out the problem” (Tony Allan). Shifting from a preponderance of meat to a vegetarian diet could reduce per capita water consumption in the industrial countries by up to 40%.
- It isn’t cricket is it? In Canada a farmer is rearing insects for human food consumption. Containing twice the protein per gram as beef, the farming of insects could yield significant savings in both land and water compared to traditional crop and livestock production. A family of four eating insect-derived food for one day per week could, it is estimated, save 1 million litres of water over conventional farming methods. Food for thought?
- Stop wasting food: The UN FAO estimate that 32% (by weight) of all food produced globally is lost or wasted. This is equivalent to 1.4bn ha of superfluous cropland and is tantamount to throwing away water!
- Use the right water for the correct purpose: Whilst the World Health Organisation estimates that there are over a billion people who lack access to safe drinking water, industrialised nations use water of potable quality not only to drink, but also to wash the car, water the garden and flush the toilet.
- Treat and Recycle “greywater”: Greywater is all wastewater generated in domestic and commercial operations without faecal contamination. With minimal treatment it can be re-used on site for toilet flushing, landscape and crop irrigation purposes.
- Reduce water wastage: A running sore (literally) is the amount of treated water which is lost in the distribution system. 8.6 trillion gallons are lost to leakage globally each year – enough to supply Niagara Falls for four months.

Source: Deborah M Keith (August 2015)

- Turning sewage into drinking water (the toilet to tap solution): This is the big ask! Using polymer membranes no thicker than a human hair, in Orange County in California, the plant sited next door to the district's waste water treatment facility, pumps out 100 million gallons of drinking water each day, sufficient to supply 850,000 local residents. This is the largest "toilet to tap" facility on the planet, but by 2040 it is predicted that recycled wastewater will be the major source of California's water supply.

What can Agriculture do to meet the challenge of reducing water needs?

- Develop drought-resistant crops/varieties that require less water

The International Maize and Wheat Improvement Centre (CIMMYT) is developing new crop and resource management initiatives, including practices which reduce the use of inputs, especially Water and Nitrogen. These include a drought-tolerant maize for Africa seed scaling.

- Plant crops that are less thirsty than staple feedstuff crops

Grain Sorghum is the third most important cereal grown in the USA and ranks fifth in the world. Sorghum has a very fibrous root system which can extend to a depth of 1.2m and the crop develops its seed heads over longer periods of time than maize. Therefore short periods of water stress do not usually have the ability to prevent kernel development. With a waxy coating on its leaves and stems, it holds water in its foliage better than maize. It can, therefore, be grown in low rainfall areas and is popular in drought-prone regions. While the older varieties with high tannin content are more limited in their use as feedingstuffs, the newer non-tannin varieties can be used without limitation, and the energy value is broadly comparable with maize. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is making significant efforts to improve sorghum farming. A new variety in India produces 7 tonnes per ha and there are now 194 improved cultivars worldwide.

Paradoxically, given its drought –resistant physiology, sorghum is also more tolerant of wet soils and flooding than most grain crops.

- Reduce the reliance on feed crops as a protein source by using substitutes as an alternative

As a stable source of protein and fatty acids, cultivating fly larvae or maggots from insects as a substitute protein source in animal feeds could release a significant area of land, globally, for other food crops. The Food and Environment Research Agency's PROteINSECT project is working to provide outcomes which will advance opportunities for scaling this as a recognised technique in the sustainable food chain.

- Genetic Modification of crops and livestock

Seeking varieties of crops or breeds of livestock which use water more efficiently e.g. where a decrease in the water to feed ratio and improvements in the feed conversion ratio can be achieved through effective breeding schemes. Water quality is also key to maximising production – it affects the gut and therefore the ability to absorb feed effectively.

- Reduce water usage/wastage in buildings

In intensive livestock buildings the farmer is seeking to ensure the animal gets sufficient water on which to thrive, whilst avoiding wasting water through spillage, with resultant contamination consequences. In chick rearing units, for example, the use of an inverted nipple contained within a spill cup provides a clean, easily controlled and zero-spillage option.

Source: www.roxell.com

- Reduce water losses in the field through improved management practice

Changes in crop rotations to include crops that are less exposed and/or less sensitive to water deficits or droughts may achieve water use efficiencies overtime. Similarly, changing the sowing date to benefit from longer growing seasons and reduce the probability of the crop being exposed to a drought period may offer some wins on the challenge of water, but these are very dependent on the accuracy of seasonal weather forecasts. In the field, practical measures, such as operating irrigation sprinklers by application near the surface of the crop/soil will reduce losses due to evaporation or spray drift.

9. HOW DO WE USE THE SAME RESOURCE MORE EFFICIENTLY?

The UN's Sustainable Development Goals (SDGs) were launched in 2015. SDG 6 clearly sets out the imperative of achieving water efficiency in the use, management and development of water resources across all sectors.

- Improve irrigation techniques – modelling and remote sensing.

"Produce more crop per drop" is a useful way of looking at the significant advances which have been derived from the evolution and development of Precision Agriculture. Precision agriculture is the fusion of information and engineering technology. By bringing sensitivity to the timing and accuracy of input applications, it directly contributes to improvements in the Natural Resource Productivity, strengthened further by biotechnological advances.

The appliance of Precision Agriculture in seeking to improve water use efficiency is the subject of the following two papers this afternoon. I shall therefore leave the detail to our speakers to cover; however, I would emphasise the encouraging progress which has been made in this area deserves adequate research and development funding and attention to practical, cost-effective applications, to reap the maximum benefits.

- Ensure most effective use of physical irrigation application techniques

Rather than broadcast water across a wide area, as is the traditional practice,–where the spray can evaporate and much of the water fails to reach where it is needed on the crop, the use of variable rate irrigation provides the crop with water where and when it is required. On the farm, the use of pivotal and lateral irrigation systems are capable of variable rate irrigation using individual nozzle control with time pulsing. Again, there is more detail on this subject from Craige Mackenzie.

- Improve traditional management practices

Even in traditional agricultural systems there is scope to adopt more efficient methods of irrigation. Furrow surge irrigation -one where on and off surges of stream water are delivered at the head of the furrows, can save between 20 and 30% of irrigation water and reduce run-off by a further 10%. The use of automatic valves, in more sophisticated arrangements incorporating water meters, provide the opportunity to achieve high levels of control and yield economic results.

- Make more of the soil resource

We use only a fraction of the capacity of the soil, yet it is a key medium for crop growth. Look to improve drainage, soil structure, cover cropping, enhanced organic matter, strip tillage, rotations and other husbandry techniques as a means of improving water use efficiency.

- Collect "spare" water

Consider rainwater harvesting as an option for capturing and using "spare" water – for cleaning purposes, or with minimal treatment, as a source of drinking water, noting the water quality prerogative. Also note the use of permeable materials in construction and yard areas where rainfall can be absorbed – note the concept of a “sponge “ city has been developed in cities such as Beijing where the devastating flood waters are captured to bolster, somewhat ironically, their chronic water shortage.

- On –farm storage

Develop on –farm or cooperatively owned reservoirs where water sharing or water trading agreements between neighbouring farms can work to everyone’s benefit.

- Recycle on –farm water

In Australia, “trickle water” is used as a temperature control to chill the air as it enters intensive poultry houses. The water continuously trickles down 150mm corrugated cooling pads on huge tunnel fans/inlets. The condensation moisture produced from evaporative cooling is captured and recycled within the ventilation/cooling system. In hot climates like Australia where water is extremely scarce, this is an excellent example of how the water is used and re-used to maximum effect.

- Use of on-farm wastewaters

The use of recycled farm waste water on crops as a water resource has the added value of a fertiliser component. Guidance is widely available on water quality and health protection measures e.g. UN Land and Water Division: Safe Use of Wastewater in Agriculture. The use of reed-bed filtration is often a relatively easy way of treating waste waters and also offers an opportunity to create a wildlife habitat on the farm.

- Re-use “public” wastewater for irrigation

Modern urban waste water treatment systems are significantly more reliable in removing contaminants, heavy metals etc. from waste water than their predecessors. Clearly full laboratory analysis of both the “cleaned” waste water and the receiving soil is a pre-requisite to ensure compliance with physical, chemical and micro-biological parameters. There are some useful examples where the safeguards have been rigorously applied, which demonstrate this re-use is an accepted agricultural practice. Israel sets the benchmark high – it reclaims and recycles almost 100% of its wastewater for non-potable uses, with a significant proportion going to irrigation. In Italy and Spain, over 4,000 ha of various crops are irrigated using recycled water.

- Promote Best Practice through Education and Incentive

As farming and the wider community understands the issue of water resource scarcity, momentum will gather pace on new initiatives. These might include an extension advisory service on integrating water use and water use efficiencies into a whole farm plan approach. Capital grants for investment in infrastructure and associated equipment to farmers, or capital allowances under the taxation system, both tied to the requirement for asset maintenance and environmental objectives, offer alternative policy initiatives.

On the community education front, food labelling tells us much about the ingredients and the supply chain, but one major fact it fails to mention is the cost of the water, measured, perhaps, in water footprint terms.

10. HOW DO WE CREATE MORE WATER RESOURCE?

- Develop cost effective methods of desalination

The fact that 97.5% of the world's water resource is saltwater, or at best, brackish, has meant that it has until recently been "off-limits". Simple agronomy tells us that plants do not like salt. Indeed irrigation processes tend to leave salt minerals behind leading to soil contamination issues with irrigated farmland –some 21% of total irrigated land is subject to salt damage. Access to desalination can reduce dependence on precipitation cycles and enable the use of traditionally unusable water, but it dramatically increases costs and the water supply's reliance on energy. Developments in the last decade, however, mean that desalination may offer, if not a panacea for all ills, at least some solace in our quest for freshwater.

The two significant advances which have made desalination a viable option are:

a) Advances in the reverse osmosis process, including membrane development and forward osmosis processes; and
b) The reduction in energy costs with the use of renewable energy.

The forward osmosis process actually combines improved membrane performance and reduces the energy requirement for irrigation water by up to 80%. Developed by the Centre for Technology in Water and Wastewater (CTWW) at the University of Technology in Sydney, the Fertiliser Drawn Forward Osmosis system draws water from saline via osmosis by employing high-concentration soluble fertilisers (typically ammonium hydrogen phosphates) on the opposite side of the membrane filter. As Australia uses 60% of its water supply for irrigation, this could be a major innovation.

Today's desalination plants use renewable energy sources, in particular solar power, and consume only 3kWh/m^3 of energy compared to the 10kWh/m^3 in the 1970s.

What else might a farmer get out of his use of desalinated water? Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) have experimented with conditioning the desalinated water with minerals and nutrients at the point of treatment. Adding nutrients to improve crop quality and production may help make the water product more cost-effective.

Some 70% of world capacity in desalination is currently in the Middle East, principally in Saudi Arabia, Kuwait, United Arab Emirates and Qatar. A further 6% is in Libya and Algeria. However the drought in California, now in its fifth year, has prompted investment activity on desalination plants – with the Carlsbad plant near Los Angeles becoming operational in 2016. The market analysts, Frost & Sullivan forecast that global desalination will double in the number of facilities by 2019.

- Grow salt tolerant crops

Research by Zilt Proefbedrijf in The Netherlands has grown potatoes, and some other crops, successfully in salinized soil conditions. At the International Center for Biosaline Agriculture (ICBA) in Dubai, experiments are undertaken on crops which can flourish on least water, and, in particular, those which can thrive on saline soil. One crop which may have potential as a pseudocereal or as animal feed is quinoa –best known in the UK as a nutrient rich health food served by up-market chefs. It is drought –tolerant and has a low water requirement. However, it is also tolerant of salt water and thrives on the salt beds of Bolivia and northern Chile.

- The Rainmakers - the science of cloud seeding or "weather modification"

A report by the US National Academy of Sciences has stated that "searching for ways to enhance precipitation…. is one of the most important challenges that can be tackled by science". It has developed as a practical science since the 1940s, but today the United Arab Emirates lead the development of this innovative solution to drought –the National Center of Meteorology & Seismology launched an ambitious 3 year research programme, worth US$5m, in January 2016. The applications of technology are likely to include the production of new seeding materials, remote sensing as well as in-situ observation and technologies applied to rainfall enhancement. Cost will be the key –however, early indications are that the cost is approximately US$0.01/m³ of water which compares extremely favourably with the US$ 0.60/m³ cost of traditional desalination processes.

11. CONCLUSION AND RECOMMENDATIONS

The Paper concludes, therefore, that there are sufficient land and water resources available to produce food for the anticipated global population in 2050. The appliance of science and technology will bear fruit. Necessity truly is the Mother of Invention.

There are two important caveats to this winning streak, however:

- The continued success in increases in both land capability and yields requires that the investments required to develop these resources are made and that the neglect of recent decades in the agricultural research and development effort, particularly in terms of funding, is reversed; and
- The achievements in food production have often been associated with management practices which have resulted in the degradation of the land and water resources and the deterioration of related eco-systems, e.g. reduction in environmental river flows; changes in downstream access to water and reduction in the extent of wetlands with important ecological functions of biodiversity, nutrient retention and flood control.

The solutions must therefore:

- Adopt sustainable land management practices; and
- Adopt practices which use the irrigation water more efficiently through enhanced flexibility, reliability and timing of irrigation water delivery.

The ensuing papers in the Working Group's Theme will look at a range of the innovative measures which are in development. The initial two papers, presented at the New Zealand Working Week in 2016, examine the development and practice of precision agriculture, with particular reference to improving water use efficiency in agriculture.

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BIOGRAPHICAL NOTES

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