Our farmers are world leaders in terms of water productivity. The use of water drives regional economies. The centrality of water to our livelihoods, its finite stock, increasing demands on its use and a challenging climate means there is an immense need to improve how we use water through innovation. Infrastructure and engineering solutions alone will not provide long-term outcomes of producing more from water's finite status.

Water, climate, energy, labour and soil are widely agreed as interrelated priorities with plenty of short-term research challenges. However, it’s time to tackle some long-term holy grails that would lead to the next wave of water efficiency and productivity gains. For example: evaporation from farm dams during summer is the major water loss pathway of the farm water balance and is an international problem requiring new innovations for solutions. Could we harness more water from the atmosphere or more cheaply from the oceans? Can we develop new sensors that measure soil water changes in robust environmental conditions at paddock scale down the soil profile – a geo-spatial moisture sensor?

Seizing water research opportunities - a necessary grand challenge

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Image: An experimental electromagnetic induction soil moisture profile sensor, Narrabri NSW.
Water is the major limiting factor to regional Australia’s productivity, yet we do not have a long-term strategic research and development investment for it. It’s time for a decade of water innovation to springboard Australia to the forefront. This will require venture capital that targets solutions with commercial outcomes, as well as philanthropic and government investments given the centrality of water to livelihoods in both developed and undeveloped nations. It’s a necessary grand challenge.

Introduction

Farmers have extensively utilised research to aid the development of our innovative rural industries. Farming is the biggest user of water on the planet. Globally, irrigated agriculture accounts for about 40% of global food production. More than 80% of all fresh fruit and vegetables are produced using irrigation and in many regional areas irrigated production is the most significant and profitable land use. Our farmers are world leaders in terms of productivity and water use efficiency. For example, water-use productivity by Australian cotton growers has improved by 40% which was achieved by both yield increases and more efficient water-management systems (Roth et al., 2013). Australian rice growers have improved their water efficiency over the past 20 years to use 50% less water per kilogram of rice than the global average (DAWR, 2018).

The impressive, continued increase in productivity of irrigated production would not be possible without improvements resulting from research, innovation and application. Uncertainty related to water is the major limiting factor to much of Australia’s agricultural productivity. Water scarcity, water logging, droughts and floods will continue to cause turmoil for agriculture and rural communities. Infrastructure and engineering solutions will be deployed to improve current management practices. Many of the commonly used water innovations on farms such as poly pipe, soil moisture sensors or biomass indices were actually invented 50 years ago.

The rising cost of energy for pumping and irrigation system pressurisation is leading irrigators to rethink which systems are best in terms of overall farm profit. Energy costs have become a major driver of irrigation water use practice. For example, sugarcane farmers in north Queensland are not applying water to their crops because of excessive energy costs.

There is growing interest in the development of precision and smart irrigation and farming systems which are energy efficient, offer labour savings and maximise input efficiency and profitability. The modernisation of irrigation supply networks has opened new options in the types of irrigations systems now feasible, while many irrigators can now order water on demand. Advances in on-farm irrigation technology and the spread of telecommunications have supported new options in measurement, scheduling and automation. Evaporation from farm dams is the major loss pathway of farm water balance and is an international problem requiring innovation for solutions.

Soil, water, climate, energy, labour, are widely agreed as interrelated priorities with plenty of short-term research opportunities. There is significant potential to improve water use productivity through demonstration of what we currently know as best practice and by fostering developments in sensor technology. However, we must be bold enough to tackle some of the holy grails, that will take 10 years or more of sustained investigation, but if successful would really lead to the next wave of water efficiency and productivity gains. Here are a few thoughts to stimulate discussions on the necessary grand challenge of water use innovation.

Water research opportunities

Research opportunities and priorities will continue to evolve with the circumstances of time and geography. Nevertheless Table 1 (over page) shows a few examples of where research could make a difference to improve water use productivity.
Table 1: Examples of where research could make a difference to improve water use productivity.

<table>
<thead>
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<th>Evaporation mitigation</th>
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<td>Vast amounts of water are stored in dams in Australia which is a function of our arid and highly variable climate. These dams range from large public storages, on-farm irrigation dams, and stock and domestic farm dams. Depending where you live, evaporation levels can be around 2000 mm or 2 metres per year. On-farm dams are losing around 30–40% of the water stored due to evaporation. Evaporation losses from farm dams and water storages are a major loss pathway for any farm water balance. It is an international problem and we need to find a solution to make some savings.</td>
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Current products are not widely used because of various technical problems and costs. These include floating covers, shade cloth, underground storage and chemicals. Solar panels have even been proposed but for most farms it is going to be easier to install these on land, unless you have a dam full of water 100% of the time. One potential blue sky research option is the use of ultra thin films which is being investigated by The University of Melbourne (Prime et al., 2012). These films, sometimes known as polymers or monolayers offer potential to mitigate evaporation on water storages. There are several technical issues to overcome such as wind stability of the ultra thin film on the water surface, environmental toxicity, and product life in sunlight. However, even a partial solution for one to two summer months of the year or during a period of shortage such as drought would make significant savings on any farm. This is a problem with billion or trillion dollar benefits globally and requires more than one small project to solve this grand challenge.|

Polymers

Perhaps the ‘number one’ water use in agriculture innovation is poly pipe which was invented in the 1950–60s. As stated in the famous movie of that era ‘The Graduate’ starring Dustin Hoffman; “There is a great future in plastics” and there certainly was. There would not be a farm in Australia that doesn’t use poly or PVC pipe for its stock.
and domestic water supply, drip irrigation in vineyards and orchards or even its surface irrigation system. Polymers continue to evolve and most recently there is increasing interest in biodegradable polymer films in broadacre crops where they enable better and earlier seedling emergence. Horticultural industries have been using these technologies for years for weed control and fumigation. Livestock producers also use polymers for bailing twine, fodder wraps, cattle tags, and fence posts. Polymers are currently being examined to help with seed coating to enhance germination and the controlled release of fertiliser. Perhaps they still have a great future for evaporation and seepage mitigation in channels and dams?

Geo-spatial soil moisture monitoring

How much water is stored in your soil? As simple as it may sound, measuring the soil water content has proven scientifically challenging. One of the best, most accurate and robust soil moisture monitoring tools is the neutron probe which was invented in the 1950s. It can measure accurately a decent amount of soil (about the size of a basketball) and can be converted to millimetres of water. Another advantage of this technique is that it can cope with soil cracking and dry soil profile conditions. The main downsides of neutron probes are they cannot be automated, requiring an operator to take the readings, their cost, and the workplace health and safety regulations around their use due to their radioactive source.

More recently, soil capacitance probes, which have a plethora of common trading names have become the most common soil moisture monitoring device. Capacitance probes measure the dielectric content of the soil profile at different depths. These probes can be automated, and data can be read in real time on the farm computer or mobile phone as millimetres of water. Their main downside is they measure only a very small volume of soil, and they must have good contact with the soil, which as the soil profile becomes drier can become precarious. Time Domain Reflectometry (TDR) tools use a different mode of action but have not been widely adopted for similar reasons. Tensiometers and gypsum blocks are the low-cost option and have been around for 50 years or more and these days it is possible to read these probes remotely via telemetry.

All of the commonly used soil moisture sensors are point based systems and are only measuring a sphere of soil between the size of a tennis ball and basketball size to represent
an entire paddock. Therefore, another holy grail and grand challenge is a geo-spatial soil moisture sensor that can measure the entire paddock at several depths to at least 60–80 cm down the soil profile in a cost-effective and timely manner. Electromagnetic Induction or EM meters are one potential solution but are cost prohibitive at this stage. Remotely sensed satellite radar and other frequencies of the electromagnetic spectrum are also currently being explored, but many of these only measure the soil surface. Therefore, a geo-spatial soil moisture profile measurement tool is another grand challenge.

**New sources of water**

While the debate will always roll on about water sharing from our river and groundwater systems is it time to explore if we can get more water from other sources which have historically been too costly or inefficient? With most of the water on earth found in oceans, cheaper and more energy efficient desalination processes would be desirable and are becoming possible. These could be small-scale systems supplying a niche industry alongside the coastline. Likewise, atmospheric water capture is gaining renewed technical interest, especially in dry low humidity climates where drought conditions often prevail such as a solar chimney or solar cyclone (Kashiwa et al., 2008). There are small-scale research projects around the globe which prove knowledge advances and quick search of the internet will find several new companies selling new technology for households. Whilst this may be only at the small scale at present and would not suit a large irrigation farm it may suit more intensive agriculture niche industries or the farm homestead. Another five years of physics and chemistry would certainly advance this water challenge for those people in the world without clean drinking water.
Indoor farming or plant factories

Indoor agriculture is on the rise around the world and according to the new Future Foods CRC will be worth $185–395 billion by 2025. Plant factories and growing crops indoors or underground used to seem like a pipedream. However, this is perhaps as not as far off as it once seemed. These systems use LED energy efficient lighting of specific wavelengths, robotics, water capturing technology and climate control (temperature, CO₂) to grow crops under perfect sterile conditions. With modern sensors and specific plant breeding there is no doubt that vertically farmed highly water efficient crops will become more common producing several crops per year. There are currently hundreds of these systems in Asia producing green vegetables with major companies such as Mitsubishi, Panasonic, and Hitachi, while in Iceland barley is being grown.

Automation

Irrigation automatons is perhaps the next disruptive change about to occur across the surface irrigation sector. Potential productivity increases of 15% for cotton and dairy farms and 30% with variable rate technology on dairy farms have been identified through the Smarter Irrigation for Profit project. While water efficiency outcomes are an important motivation to adopt automation the other main driver of change is the saving of labour and time. Developing more robust communication networks for sensing, control and precision and/or variable rate application is required. Real time data technologies coupled with machine learning systems will be possible. The real holy grail though is the data analysis and decision support systems that integrates remote control of irrigation devices, monitors the data of water levels and flows, collates field and crop data and then utilises this information to make an autonomous decision and action.
Alternative partnerships

Water is the major limiting factor to regional Australia’s productivity, yet we do not have a long-term strategic research and development investment for it. It’s time for a decade of water innovation to springboard Australia to the forefront. This will require venture capital that targets solutions with commercial outcomes, as well as philanthropic and government investments given the centrality of water to livelihoods in both developed and undeveloped nations.

Sir David Attenborough recently reflected on his long career in film making and how innovations had given his teams the ability to bring animal behaviour to the screen. Attenborough said:

“All these technical advances had come from the defence industry: to see in the dark, to see from above, to track things, to put electronic tags on things – all this has come from the complicated defence industry.”

Remote sensing and satellite imagery are other examples of defence inventions that were used for spying on other parts of the world, that are now used in agriculture to forecast crop yields and pasture biomass. The current defence research investment program in integrated intelligence, autonomy, advanced materials, space technologies, reconnaissance and unmanned surveillance aircraft should have many synergies for agriculture and regional communities. It would be a worthy grand challenge to explore a possible defence, water and food security partnership for our national prosperity and safety.

Plant breeding

Cropping and horticultural industries will continue to invest in plant breeding programs using fundamentals of genetic diversity, biotechnology and molecular genetics to improve their productivity with spins offs that in turn improve water use productivity. There is no better example than the Australian cotton industry where plant breeding has led to 48% of the increases in crop yields (Liu et al., 2013). Worldwide, the average cotton lint yield is about 800 kg/ha and is increasing at rates of 10–20 kg/ha/year, especially where irrigation is available (Constable & Bange, 2015). Irrigated cotton lint yields in Australia are now commonly 2500–3000 lint kg/ha.
Likewise, there is now increased investment targeting heat stresses and climate adaptation traits. One such example, is at The University of Sydney at Narrabri where genetic variation of wheat and chickpea genotypes is being studied with promising results of genotypes being identified. In a study by Thistlethwaite et al. (2017) trait stability and mechanisms for heat tolerance amongst large numbers of genetically diverse lines were identified across multiple dates of sowing. A subset of genotypes deemed to have superior tolerance to heat were evaluated within field-based artificial heat chambers where a heat shock 4°C above ambient temperature was imposed in climate-controlled greenhouse conditions.

Rural water use extension programs

During the last 20 years or more there have been waves of investments by State Departments of Agriculture and industry in irrigation extension and adoption programs. These programs typically had similar names as they were reinvented every three years; for example, ‘Water use on the farm’, ‘More crop per drop’, ‘Water for profit’, ‘Waterwise’, or ‘Rural Water Use Efficiency’. Generally, the independent evaluations of these programs show they were very successful with high participation rates, improved levels of knowledge by farmers and advisers, and could demonstrate 10–30% improvements in water use efficiency on case study farms and savings around 5% per year across an entire commodity industry. If there is any downside of these successful programs it is that many farmers see the ‘honest broker’ as an important part of the public extension role but lament the high turnover of extension staff that makes it difficult for them to build relationships.

Research has highlighted that in relation to water management most farmers are: ‘change ready’; are active seekers of information; actively share knowledge; and willing to experiment and continuously learn (Callan et al., 2004; Christiansen et al., 2004). This research also identified that farmers, and other sectors of agriculture, are highly experiential learners who have many different mechanisms by which they prefer to learn and seek information. Their own experience was clearly the dominant influence on decision-making with particular focus on economic and practical implications of the information. This research also found that experience is developed through application on-farm, observations and discussion with peers, field days, forums, participation in research trials, benchmarking and personal networks. Grower learning groups also play a role in the knowledge systems for many farmers and advisers.

The ‘Smarter Irrigation for Profit’ project 2015–18 applied the experiential learning group model by partnering researchers, farmers and advisers with equipment suppliers to undertake collaborative trials.
## Smarter Irrigation for Profit

The project aimed to improve the profit of cotton, dairy, rice and sugar irrigators with the support of 16 research and development partners and 19 farmer irrigation technology learning sites during 2015–18. Grower-led irrigation research and extension aimed to collect commercially relevant comparative data on different irrigation systems and technologies.

The project consisted of three components:

1. Practical, reliable irrigation scheduling technologies.
2. Precise, low cost automated control systems for a range of irrigation systems.
3. A network of 19 farmer-managed learning sites located around Australia.

The flagship strategy of the project was use of the key learning sites. These 19 sites were located all around Australia and were mostly on commercial farms. They all involved farmers, advisers, scientists and agribusiness. Thousands of people inspected or visited one of these sites. Some were more ‘research’ focused; testing a hypothesis with robust scientific methods. Others were ‘demonstration’ focused involving monitoring current actions and making changes as experience and confidence grew. One of the strengths of the project was having both approaches.

The project had key learning sites; in Queensland: Ayr, Emerald, Warwick, Dalby, Toowoomba, St George; NSW: Moree, Narrabri, Wee Waa, Tamworth, Aberdeen, Whitton, Jerilderie; Victoria: Numurkah, Shepparton, Macalister, Goulburn Murray Irrigation District; Tasmania: Rocky Creek, Sisters Creek, South Riana, Montana, Cressy; South Australia: Allendale, Eight Mile Creek, Mt Schank; Western Australia: Harvey.

## Key findings

### Irrigation system selection

There is no universal best type of irrigation system – even within a region and a production system. It is a matter of selecting the system that offers the best fit for purpose. Considerations include topography and soil types, the nature and security of the water supply, and the style of management. Establishment (or conversion) costs and payback periods, along with productivity, water use, and operating, labour and energy costs affect the attractiveness of options.

Smarter Irrigation for Profit compared different systems and showed their various strengths and weaknesses, and how they varied in different seasons – enabling irrigators to make more informed choices. A key message for farmers evaluating irrigation system comparisons is to look for long-term data over several irrigation seasons (wet, dry, hot, cool).

### Irrigation system design and drainage

Surface irrigation (be it by furrow or in bays) is the most common form of irrigation due to its low capital cost and low energy requirements. Well-designed and well-managed surface irrigation can achieve application efficiencies of 95% – showing that efficiency comes from design and management and is not an inherent characteristic of the system itself. Trials showed that application efficiencies for surface irrigation can often be improved by better design and scheduling – reducing losses through deep drainage and run-off. Key measure; measure to manage.

### Irrigation system efficiency

Smarter Irrigation for Profit included on-farm audits of energy efficiency and irrigation uniformity (checking that irrigation systems are performing...
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They exposed considerable variation in efficiencies – even with recently installed irrigation systems. The audits showed that many farmers could save money and improve productivity by running periodic checks or audits and giving attention to maintenance. Irrigators should also ensure suppliers provided a commissioning test before hand-over, to ensure equipment is operating within specification.

Irrigation monitoring practice

Scheduling irrigations to provide plants with the right amount of water, at the right time, depends on knowing what is happening in the soil and to the plant. Models or ‘rules of thumb’ can contribute, but monitoring is a mainstay for accurate scheduling. Monitoring options range from high-tech to low-tech and encompass soil-water, plant condition, and weather conditions influencing evapotranspiration. Sites explored innovative options for plant sensing, including infrared canopy sensors to detect stress, remotely sensed data and the use of smartphone cameras mounted on irrigators. It also used drones equipped with a thermal-infrared camera to provide real-time information on the advance of surface irrigation to enable smarter scheduling and demonstrated the value of a network of autonomous rain-gauges to improve water budgets and irrigation scheduling.

Irrigation scheduling practice

Irrigation scheduling is determining when to irrigate, at what rate, and for how long. It’s about getting the timing, volume and rate right for optimum crop growth or yield. Scheduling uniform applications (e.g. to maintain a water balance) is a first step toward efficient irrigation. Adding elements of precision – varying application rates in response to variations in soil type or crop requirements – is another step. Increasing the degree of precision even further (e.g. with a wide array of real-time sensors or sophisticated scheduling software), is another. Evidence in the project found progressions like improved scheduling can produce step-changes in irrigation operations. A report was compiled summarising the pros and cons of the many tools in the market place.

Precision irrigation

Poor irrigation uniformity results in areas of over and under-watering on uniform paddocks, but more precision is needed if all parts of a variable paddock are to be irrigated optimally. Precision irrigation relies on being able to monitor variations in the water needs of plants and to variously apply water to meet them. Sophisticated irrigation scheduling is used to link the monitoring with more precise irrigation. Variable rate irrigation systems, improved scheduling for more precision in furrow irrigation, and sophisticated scheduling tools with the potential to control fully autonomous variable rate irrigation systems were demonstrated.

Irrigation automation

The flow of irrigation water can now be controlled automatically from source to within a field. It relies on sensors and telecommunication to control automated equipment, permitting the remote control of irrigation through a computer or smartphone interface. Coupling automation with precision scheduling packages ensures the resultant irrigation is optimal, not just the remote control of automated, poor practice. Significant benefits to irrigators through convenience and time saving, as well as improved irrigation practice were found. The work showed that highly automated, if not autonomous (self-controlling), systems are feasible, and they have potential for continued development and wider application. Automation can be phased into a farm beginning with simple monitoring.
Learning and capacity development

Grower-led, field-scale trials were widely used to show the practical implications of incorporating new technologies. The network of ‘optimised farms’ enabled exploration of the issues behind farm-scale performance that are otherwise left to early adopters to sort out. It also provided a ready platform for farmers to share directly with other farmers through field days, videos and podcasts – and it helped researchers see issues from irrigators’ perspectives.

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