Optimal Efficiency in Gravity Water Distribution Systems

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Abstract

New developments in agricultural irrigation technology and management are creating an increased need for on-demand water supplies which can provide water at the precise time and duration needed for optimal efficiency. With most groundwater supplies already being pushed beyond sustainable use, renewable surface water resources must be managed with greater efficiency and timeliness to meet increasingly variable demands.

This paper provides examples of improvement in overall customer service and operating efficiency that have been achieved with modernized canal infrastructure. These examples demonstrate how irrigation control gates and flow meters combined with innovative software and advanced control engineering have improved the management of water in canal distribution systems and on the farm.

With better management and control of surface water supplies in open channel gravity networks, water availability can be improved for all users thereby enabling food and fiber producers to employ the latest advancements in efficient irrigation technology.

Keywords

Water supply network modernization, distribution efficiency, application efficiency, surface water, gravity canal network, automation, flow control, surface irrigation, flood irrigation

INTRODUCTION AND BACKGROUND

New developments in agricultural irrigation technology and management are creating an increased need for on-demand water supplies which can provide water at the precise time and duration needed for optimal efficiency. With most groundwater supplies already being pushed beyond sustainable use, renewable surface water resources must be managed with greater efficiency and timeliness to meet increasingly variable demands.

Recent examples of modernized surface water conveyance networks which provide a near on-demand water supply powered by gravity can be found in Australia. Extensive investments in irrigation modernization have been made incorporating irrigation control gates and flow meters combined with innovative software and advanced control engineering to improve the management of water in canal distribution systems and on farm.

One key Australian modernization project is the Northern Victoria Irrigation Renewal Project (NVIRP) which is modernizing the delivery assets of the Goulburn-Murray Irrigation District. This investment is improving the efficiency of the conveyance and distribution network from 65% to 85% and will ultimately recover 345,000 acre-feet of water every year for further beneficial use.

Irrigation Infrastructure in Australia

The majority of Australia's irrigated agriculture is supplied by gravity surface water conveyance networks. In general, Australia does not have the same deep and contiguous ground water aquifers located beneath key agricultural regions as are available in the United States. Surface water represents 74% of Australia's water supply for irrigated agriculture. Only 23% of irrigation water is sourced from ground water[1].

The bulk of Australia's irrigated agriculture is located in the Murray-Darling Basin, which crosses much of southeast Australia. The basin takes its name from its two major rivers, the Murray and the Darling. It is the country's most important river system.

The key irrigation areas in the Murray-Darling basin are the Goulburn-Murray, Murrumbidgee, Murray, and Coleambally irrigation districts. Each of these districts are implementing the modernization programs outlined in this paper. As shown in Figure 1, these districts span the states of Victoria and New South Wales, which straddle the Murray River. The state of Victoria is approximately equal to Colorado in land area, and the Murray River is approximately as long as the Colorado River and has an equivalent discharge.

Victoria's key agricultural region is known as the Foodbowl. The Foodbowl consumes 70-80% of the water used in Victoria, and produces $10 billion dollars of agricultural production including milk, stone fruits, grapes and tomatoes. Approximately $1.7 billion of this produce is exported annually. The Foodbowl region is supplied by a gravity canal network managed by Goulburn-Murray Water. This region covers 840,000 acres of irrigated land supplied by 3,900 miles of open canals. These canals service 14,000 irrigators through 20,000 turnouts. Goulburn-Murray Water has traditionally managed the canal flows through manual operation of approximately 8,000 drop-board regulating structures.

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[1] Source: Australian Bureau of Statistics

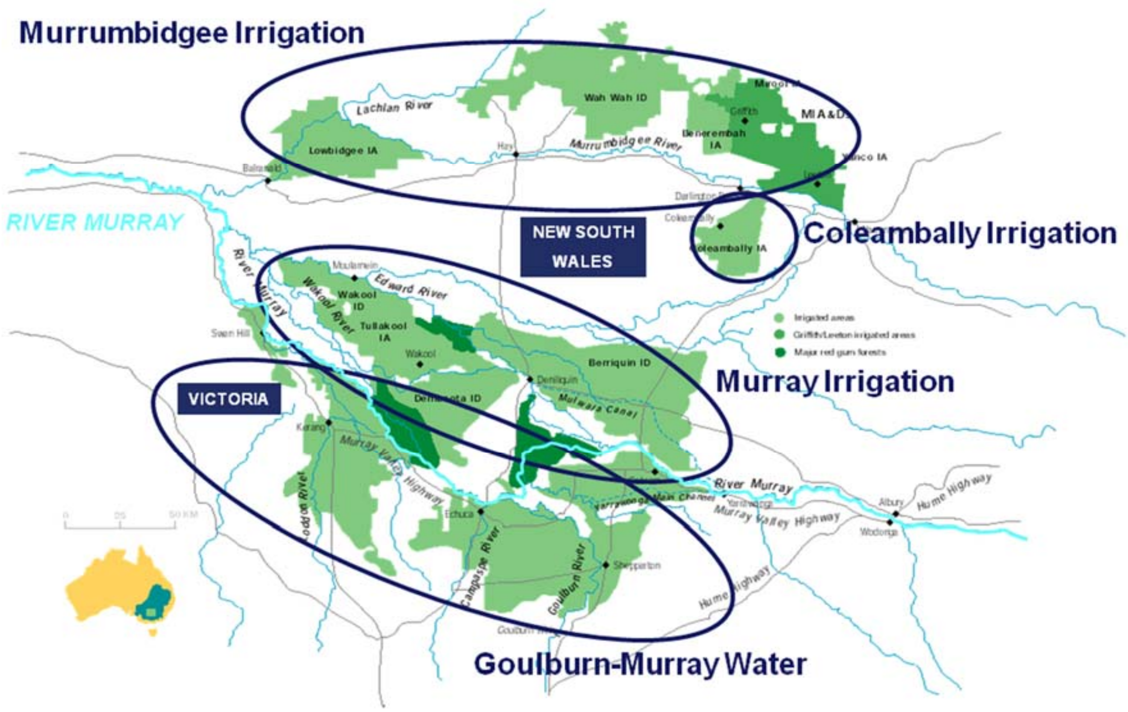

Figure 1 – Modernized Irrigation Districts in the Murray Darling Basin

The farmers that receive this water have historically employed surface irrigation. Surface irrigation (also known as flood irrigation) is used to water approximately 62% of all irrigated farmland in Australia. The land on which the farms have been developed is generally flat and surface irrigation provides an economic means of applying water with no reticulated power and no exposure to energy costs. Approximately 28% of Australia's agriculture is watered by sprinkler irrigation and the remaining 10% is watered by micro irrigation. Due to the widespread use of surface irrigation, many of the on-farm efficiency improvements since the 1980s have focused on constructing sloping borders to achieve more efficient border check irrigation outcomes. Laser grading has been applied in Australia to create field slopes generally of 1:500 to 1:2000. This work was supported by government funded Land and Water Management plans. Sloping borders are the common configuration for surface irrigation in Australia, the use of level basins is not widespread.

Pre-Modernization Surface Water Distribution Efficiency in the Murray-Darling Basin

Pre-modernized Australian irrigation districts have been very well managed, considering the difficulties of matching supply to demand in gravity canal networks combined with traditional flood irrigation practices. These difficulties resulted in less than half of the water diverted for agriculture productively consumed by crops.

Due to the difficulties of matching supply to demand in gravity canal networks, irrigation customers generally received water with four-day lead times and often received inconsistent flows, with inequitable supply between farmers and inaccurate measurement onto farms.

Manual system operations limited the achievable efficiencies in these networks. The largest losses were during transportation of water and the largest of these losses were due to outfalls (spills). Even with a highly skilled and trained workforce, efficient manual operation of canals was a big challenge. Inefficiencies in water supply networks were caused by antiquated infrastructure and customer desire for improved service which placed priority on maintaining stable pool supply levels ahead of minimizing operational spills.

Approximately 30% of the water that entered Australia's pre-modernized open canal irrigation systems was unaccounted for or lost before it reached the farm. Some of these losses returned as recoverable fractions to the water system, but most of this water was no longer available for beneficial use.

Figure 2 illustrates the key loss components in Australia's pre-modernized agricultural water supply systems. It can be seen in this figure that less than half of the water diverted from storage was productively used by crops. This figure is typical of pre-modernized irrigation system performance globally. Given the proportion of freshwater used by agriculture, recovery of these losses presented an opportunity to reclaim around one third of Australia's freshwater for further beneficial use.

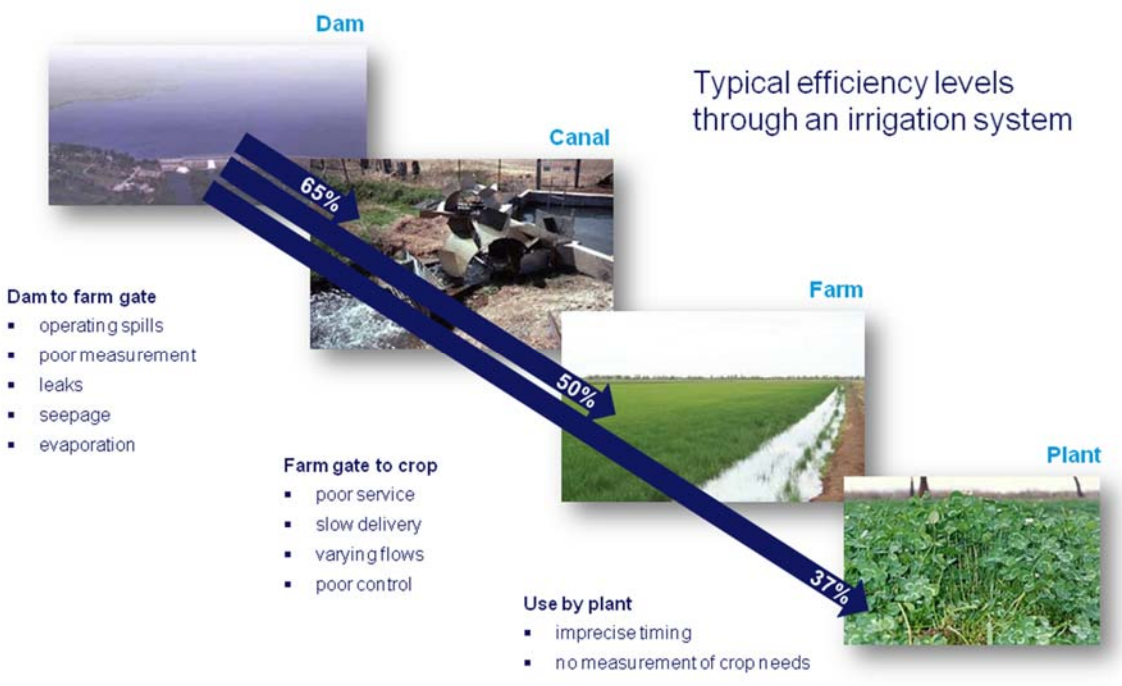

Figure 2 – Typical Efficiency Levels In Pre-Modernized Australian Irrigation Systems

The Millennium Drought – A Catalyst for Change

Annual precipitation has proven to be highly variable in Australia. It was common throughout the last century for Australia's large surface storage reservoirs to be drawn down over prolonged dry periods. Long-term water availability is governed by the volume of precipitation which is captured and stored. In periods of extended dry, the precise management of stored water for maximum beneficial use becomes a very high priority.

The start of this century witnessed the worst drought in Australia's recorded history. This unprecedented crisis triggered a major overhaul of Australian water law which was underpinned by an investment in one of the world's most advanced modernized irrigation canal networks.

During the Millennium Drought water issues became a top government priority. In response to crisis, new water laws were drafted as part of the National Plan for Water Security, and a new statutory agency – the Murray-Darling Basin Authority- was created to manage the Murray-Darling Basin in an integrated and sustainable manner. The Authority released a major document entitled Guide to the Proposed Murray-Darling Basin Plan, outlining a plan to secure the long-term ecological health of the Murray-Darling Basin. The plan proposed the investment of $10 billion to save the ecology of the Murray-Darling Basin. The specifics included $3.1 billion to buy back water allocations from willing sellers and $5.8 billion for infrastructure investment.

Modernization Solutions

Prior to 2003 not much had changed in Australian canal management practices in 100 years. As shown in Figure 4, inefficiencies in water supply networks were being caused by antiquated infrastructure and coarse and infrequent regulation adjustments made manually by adjusting traditional drop boards.

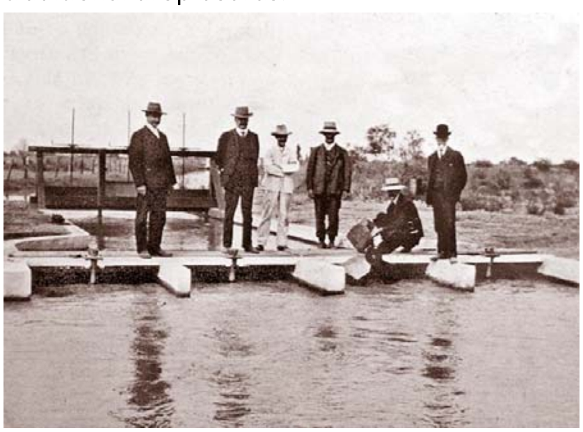

Figure 4 – Australian irrigation canal management before modernization – comparison of system operations in 1903 and 2003

An investment in infrastructure modernization was recognized as an opportunity to generate shared benefits. The investment would generate both water savings and improved levels of service to farmers which would accelerate on-farm investment and result in improved irrigation. This system investment would enable improved water use, more agricultural production and less runoff which would in turn result in catchment benefits such as reduced nutrients and salinity.

The cost-performance ratings for various supply modernization options were considered. Water conservation investment decisions were driven by capital costs, operating costs, distribution efficiency and customer service outcomes.

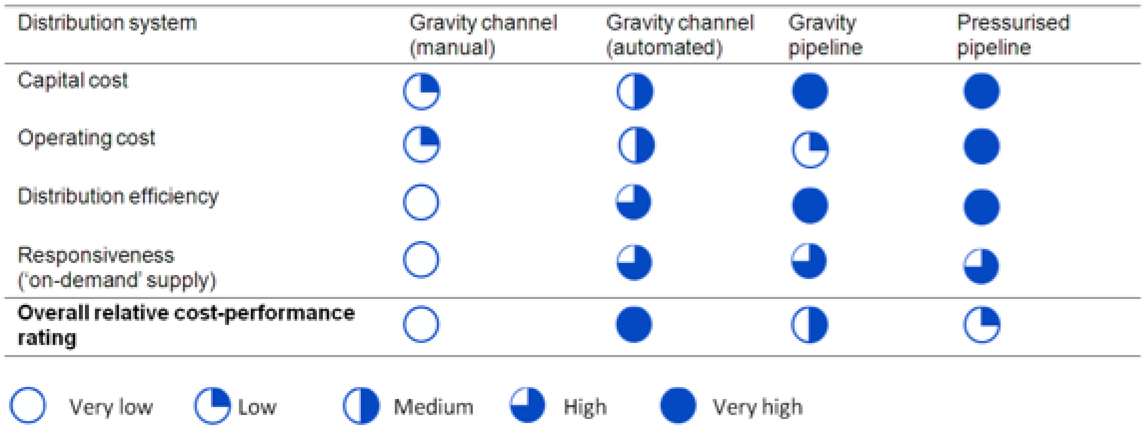

Figure 5 – Evaluation of Canal Modernization Alternatives

As shown in Figure 5, automated gravity canals were found to provide the best combination of capital costs, operating costs, distribution efficiency and customer service outcomes. Pilot studies of modernized gravity canal systems in the Coleambally Irrigation District and Goulburn-Murray Irrigation District had demonstrated that automated gravity canals could provide distribution efficiencies approaching those of pipelines.

Northern Victoria Irrigation Renewal Project

One of the centerpieces of the infrastructure investment committed during the Millennium Drought was the Northern Victoria Irrigation Renewal Project (NVIRP). The objectives of this project were to modernize the delivery assets of the Goulburn-Murray Irrigation District. The investment was designed to improve the efficiency of the conveyance network from 65% to 85% and thereby recover 345,000 acre-feet of water every year for further beneficial use. At the same time service levels to irrigators were improved significantly, allowing the full potential of on-farm water savings investments to be realized.

Nearly 12,000 automated gates and meters were installed to automate 1,875 miles of primary canals. The largest agricultural SCADA system in the world was deployed, spanning more than 7,445 RTUs over thousands of miles. A Demand-Integrated Network Control solution was deployed throughout the district to optimize the delivery of water, eliminate spills, provide remote management and data collection and improve farmer service. Works also included the installation of accurate flow meters, and targeted lining of old earthen canals.

Sophisticated management software managed both demand and supply in the entire system to deliver water exactly when and where required. Images of the works undertaken in the project are shown in Figure 6.

In addition to tranforming the canal network from a supply-driven system to a real-time demand-driven system and thereby eliminating operational spills, the modernization project also included the installation of automated flow metering turnouts. These automated flow control turnouts provide accurate and constant flows independent of fluctuations in canal supply levels. Among the many benefits provided by these fully automated flow control turnouts, farmers are now able to easily irrigate at night to reduce their evaporative losses and crop scorching. The new automated turnouts were sized to deliver larger flows than the previous turnouts had delivered, and these higher flow rates were a key part of improving the efficiency of surface irrigation as will be detailed below.

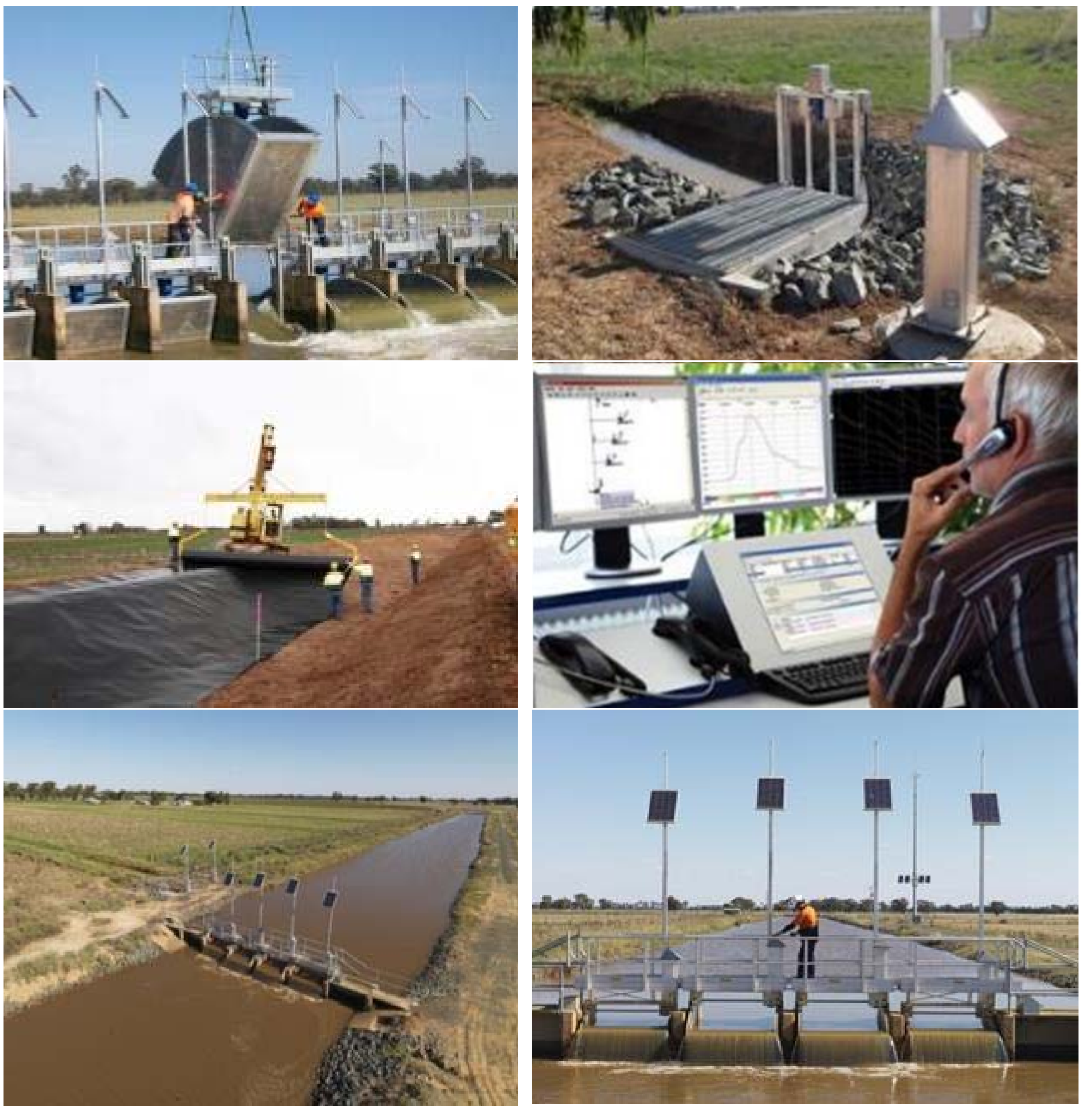

Figure 6 – Modernized Canals in Victoria's NVIRP Project

A farmer survey conducted by Victoria's Department of Sustainability and Environment documented the system benefits shown in Figure 7[2]:

[2]Source: Random survey of 25 farmers, Goulburn-Murray Irrigation District 2008 Irrigation Modernisation Works Post Implementation Review, DSE

Question	Yes	No
Do you get a more constant flow onto your farm with your new meter outlet compared with the old one?	100%	0%
Is having a constant flow onto your farm during irrigation an important factor?	90%	10%
Was reducing your irrigation order notice time any benefit to your business?	92%	8%
Was the ability to commence or change your irrigation during non-daylight hours any benefit to your business?	100%	0%
Was option of upgrading to a remote operating meter outlet any benefit to your business?	100%	0%
Was option of upgrading to a higher flow rate meter outlet any benefit to your business?	60%	40%
Is the ability to confirm you requested order instantly via waterline any benefit to you business?	100%	0%
Overall, how would you describe your support for the modernization projects	Average score: 4 out of 5	

Figure 7 – Government Survey of Benefits of Automated Canal Systems

On-Farm Modernization

In parallel with the investments in conveyance networks, significant investment has also been made in improving on-farm water use efficiencies.

A large proportion of on-farm modernization in Australia is designed to leverage off the significant investments in laser grading of sloping borders made over the last decades, and also to leverage off the in-system canal improvements that have been described above.

Well designed and managed gravity-fed surface irrigation systems have been proven to have the potential to deliver on-farm application efficiencies in excess of 85% and up to 95% on the right soils. Figure 10 below summarizes research by the University of Southern Queensland highlighting the relationship between application efficiency and energy use. Near equivalent water savings can be achieved by high-performance surface irrigation without the increase in energy required by pressurized systems.

Investments in high-performance surface irrigation represent a large proportion of the on-farm water efficiency investments being made in Australia.

The application efficiency of sloping border irrigation is commonly limited through runoff (or tailwater) at the end of the plot or by water infiltrating into the soil below the plant's roots. By applying water at high flow rates, application uniformity can be increased, and both deep percolation and surface runoff can be reduced.

System	Application efficiency	Water applied (ML/ha)	Water savings (ML/ha)	Energy use (MJ/ha)	Increase in energy use (MJ/ha)
Traditional surface	55%	7.3	-	9700	-
Sprinkler	90%	4.4	2.9	17000	7300
Micro	95%	4.2	3.1	16000	6300
High-performance surface	85%	4.7	2.6	9700	0

Figure 10 – The Application Efficiencies and Energy use of Various Application Techniques[3]

To irrigate sloping borders using high-performance surface irrigation, water must be supplied onto farms at high flow rates. This is the reason that the turnout flow capacities were significantly increased in the in-system modernization projects such as NVIRP. Secondly, on-farm application systems need to be capable of applying water at high flow rates, which means large bay gates or valves. Thirdly, on-farm systems need to be automated so that gates and valves can be programmed to open and close at a pre-determined time to optimize application efficiency.

With high flow rates, stopping an irrigation even a little late will mean that large volumes of water are lost to surface runoff in a matter of minutes, as well as causing excessive waterlogging, quickly eliminating any efficiency gains up to that point and reducing crop growth. Irrigation duration (or run-time) becomes critical to reaching higher application efficiencies: with high flow rates, the optimal run-time is much shorter and the accuracy and precision required to manage it increases (see Figure 11 below).

The logistics of manually opening and closing gates with short irrigation duration has led to automation of the irrigation to ensure gates or valves close precisely at the right cut-off points and an alert message is sent if they fail to close. The importance of managing irrigation duration (or run-time) is compounded by the fact that the optimal cut-off point in a given bay changes with each irrigation event because conditions such as crop density and soil moisture deficit change. Traditionally, cut-off points have been determined by rules of thumb based on years of experience or by physically visiting a bay to see the progress of the water and then making an assessment. More recently, decision-making is being aided by simple field sensors located halfway along the length of a bay to remotely indicate the progress of the water front.

[3] Kanya L Khatri and Rod Smith (2011), Surface irrigation for energy and water use efficiency, Irrigation Australia Conference.

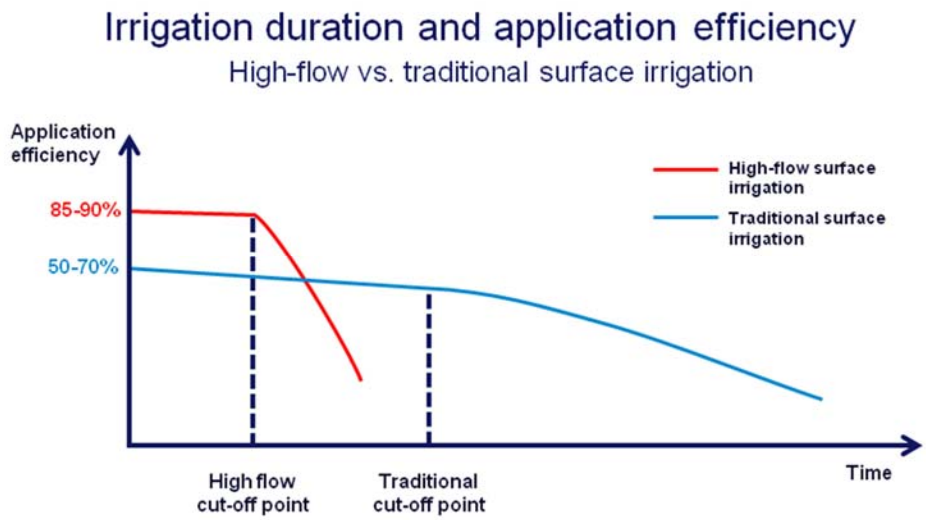

Figure 11 – Increased efficiency and decreased duration of high-flow surface irrigation

Figure 12 – Automated High Flow Surface Irrigation Systems

This technology is achieving application efficiencies similar to sprinkler and drip irrigation, making high-performance surface irrigation a cost-effective on-farm modernization alternative.

Conclusion

As a result of innovative systems installed within the Murray-Darling Basin's major irrigation districts, canal distribution efficiencies have improved from around 65% to 90%. Farmers can now irrigate more productively with high, consistent flows and near on-demand service. These irrigation districts are now more resilient in the face of reduced rainfall.

An independent review of drought policies endorses the improvements made in the Murray-Darling Basin. A paper released by the Committee for Economic Development of Australia (CEDA) in 2011 states: "The value of these benefits in the Southern Murray-Darling Basin ran into the hundreds of millions of dollars per annum during the drought and represents a major success in water policy. Demands for water will increase as Australia's population grows. The NVIRP and associated water management systems demonstrate how improved efficiencies can ensure this precious resource is managed to meet growing demands and needs now and into the future.