Global experience of automation of irrigation systems

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KEYWORDS  
Canal automation, modernization, water use efficiency, productivity

ABSTRACT  
Delivery of water for irrigation is a complex spatial and temporal problem; especially given the typically long distances irrigation networks traverse, the travel time for water to reach from one point to another, and the changeable dynamics of canal networks. Typically, a large irrigation canal network in India can be up to 75,000Km long and serve service more than a million farmers as well as supplying drinking water to villages and cities.

The first and foremost step in delivering water for irrigation or other consumptive purposes is to know where and when the water is needed, for what duration and in what quantity.

The next step is to transport the water to the appropriate extraction points and deliver the requested flow rate for the duration required. Since historic times, the irrigation sector has followed a supply oriented or top down approach to water delivery which simplifies the distribution process by constraining farmers to growing certain types of crops and only supplying water in accordance with a rigid roster. This approach is followed even in the present day. Such an approach is inefficient on a number of fronts. The first is the economic front; farmers don’t have the flexibility to grow crops to maximise revenue earning potential while minimising risk. Secondly, roster systems mean crops may not get the required water at the optimal time, impacting productivity. Thirdly, it results in an inequitable level of service and lack of social harmony. Farmers nearer the supply source receive a better service, while those further away are starved of water. Finally, mismatched supply and demand results in huge operational losses, meaning the water can’t be productively used by farmers.

The answer to address all the aforementioned problems largely lies in adopting technology to modernise and automate inefficient irrigation delivery systems. Canal conveyance systems need to become dynamic and demand-oriented. They should run autonomously in real time on a continuous 24/7 basis to ensure that the flows at any point in the network on a spatial and temporal basis match demand as per the crop requirements. However, it is not easy. Modernisation is a multidisciplinary activity within the technology realm, and it also requires institutional reforms. The different technologies; electrical, electronic, mechanical, software, control, hydraulics, agronomy, communication and IT should all converge in an optimal manner to realise a robust modernised system that can deliver the required benefits.

Modernised regions of Australia, USA and China have been providing near on-demand water at a consistent flow rates and achieving delivery efficiencies of more than 90% through open canal systems consistently for many years now. Due to the guaranteed on-demand service and consistent flow rates, farmers are motivated to invest in modern on farm infrastructure and increase the crop productivity with less water they have used historically. At the same time automated systems have minimised operational losses significantly making more water available. The benefits are manifold; farmers have been able to expand irrigation into dry land areas and authorities have diverted a percentage of the savings back to river systems to sustain health. The statistics on improvements when applied to the Indian scenario are enticing. However, India has to move swiftly in this direction to address the challenges lying ahead.

1. INTRODUCTION  
Irrigation systems are the backbone of civilization and are the manifestation of human ability to reshape the temporal and spatial distribution of land based fresh water. Its importance has been well recognised for centuries and is well documented in Arthashastra; the ancient treatise authored by Kautilya somewhere between the 2nd century BCE and 3rd century BCE during the Mauryan era. Arthashastra astutely mentions that it is the capability of human societies to grow more than two crops a year that is enabled by irrigation systems that has led to the rise and sustenance of urban society.

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crops and only supplying water in accordance with a rigid roster. This approach is followed even in the present day.

Such an approach is inefficient on a number of fronts. The first is the economic front; farmers don’t have the flexibility to grow crops to maximise revenue earning potential while minimising risk. Secondly, roster systems mean crops may not get the required water at the optimal time, impacting productivity. Thirdly, it results in an inequitable level of service and lack of social harmony. Farmers nearer the supply source receive a better service, while those further away are starved of water. Finally, mismatched supply and demand results in huge operational losses, meaning the water can’t be productively used by farmers. However, in this era when there is competing pressure from growing population and industries for this limited resource, India does not have the luxury to run the irrigation canal systems in a supply oriented basis if it is to grow more food in the future with less water (http://www.fao.org/docrep/006/y4854e/y4854e02.htm). The answer to this lies in modernisation to transform supply-oriented systems into responsive, demand-oriented supply systems.

The key objectives of irrigation supply system modernisation projects are most often to facilitate increased agricultural production, use less water, or a combination of both. Modernisation involves redesign, refurbishment and automation. Automation has the potential to provide the improved measurement and control of flows necessary to reduce operational losses and supply water when and where it is required for more efficient on-farm use.

However, it is not easy. Modernisation is a multidisciplinary activity within the technology realm, and it also requires institutional reforms. The different technologies; electrical, electronic, mechanical, software, control, hydraulics, agronomy, communication and IT should all converge in an optimal manner to realise a robust modernised system that can deliver the required benefits.

The motivation to pursue automation and modernise irrigation canal operations in India is huge as it has the potential to secure the maximum amount of water for India’s future needs. It has to be noted that the agriculture sector in India diverts roughly 80% of its available fresh surface water for irrigation (http://www.fao.org/nr/aquastat). Surface irrigation, using gravity, comes with the stigma of poor water efficiency as the operational losses are huge due to the complexity of transporting water to far distances, low frequency of cross regulator operation, lack of accurate water level and flow measurement, and conveyance losses such as seepage and evaporation.

Fig. 1 below depicts the average distribution losses in irrigation supply systems across the world. Note that the gravity fed open canal irrigation network in India operates only at roughly 40% efficiency. India diverts approximately 510Km$^3$ of water per annum for irrigation but only 204Km$^3$ goes for beneficial use. Around 306Km$^3$/annum goes waste. In comparison to these losses, India’s urban and industrial sectors only use 73Km$^3$/annum (http://www.fao.org/nr/aquastat).

Figure 1. Average distribution losses in irrigation supply systems (United Nations, FAO)
networks there is potential to increase the overall delivery efficiency to up to 90%. Automation also provides an equitable, high level of service in the form of near on-demand, consistent flow rates to farms. Water savings generated can be used to increase the area cultivated and divert water to maintain the health of the river systems. As already proven in the modernised regions of Australia, USA and China, automation is the path to pursue if India is to address the competing challenges of increasing food production with significantly less water.

The following sections describe in detail the objectives of automation, the enabling factors needed for successful automation, some case studies and some suggestions on the path the irrigation sector in India should follow.

2. AUTOMATION OBJECTIVES

The key high level objectives of an irrigation modernisation project are:

1. To provide high level of service to all water users by supplying consistent flows at the requested time, rate and duration on a 24/7 basis
2. To provide efficient water conveyance by minimising operational losses and making water available for extending the irrigated area, providing more water to farmers and to sustain the health of the river systems
3. To reduce the operating costs
4. To bring transparency and accountability
5. To create a user friendly and simple platform for water users and irrigation authorities to interface, and
6. To improve occupational health and safety of canal operators

To achieve these objectives, the automation solution implemented must:

1. Have an automated framework that deals with flow order transactions with the water users, and the scheduling
2. Maintain water levels steady at their Full Supply Levels (FSL) in every pool in the canal system. Maintaining water level at FSL will provide the right amount of head and flow for the areas commanded by the canals
3. Eliminate operational spills through escape structures by matching the demand and flow releases at every point in the canal network at any point in time, and
4. Eliminate excess on farm diversions and spills through the end of the farm by enforcing the release of flow exactly as per the crop type, requirement and allocation

3. ENABLING FACTORS FOR AUTOMATION

The key enabling factors for automation are:

1. Intelligent automated gates with integrated flow meters that can operate autonomously in real time on a continuous 24/7 basis either independently or in synchronization with a series of gates in the irrigation system network to achieve a common objective of maintaining water levels within a certain stipulated bound in every pool of the canal network.
2. Communication infrastructure with high availability, high throughput and low latency that enables inter-communication between intelligent automated gates and central control centre, and
3. Irrigation management software that enables irrigation authorities to manage water rights and orders, monitor usage, communicate with customers, generate invoices and analyse performance.

3.1. Intelligent automated gates with integrated flow meters

An automated gate with integrated flow meter ensures that the instrumentation to measure water levels and flows is in the immediate vicinity of the control gate. This is required to ensure that control actions are taken based on the local information which is more representative of the local conditions at the gate
rather than measurements taken at a distance. It also ensure robustness of automation, extends product life and minimize ongoing maintenance. Such a design also minimises the exposure of the gate components to external factors, and thus minimises the chances of vandalism and theft.

Intelligent automated gates must have the following critical capabilities for them to successfully operate within an automated canal environment:

1. Ability to take high duty cycle to operate on a continuous 24/7 basis
2. Inbuilt intelligent controller that must be able to control the gate autonomously in real time under different control regimes such as position control, flow control, and upstream and downstream control
3. Precise and accurate gate positioning ability to achieve system stability
4. Measure flow accurately to within ±2.5% (under standard testing condition) for accounting, local stability and network stability
5. Measure flow at high frequency to track the dynamic variations of flow
6. Operate using solar power for use in remote locations
7. Integrated water level and flow meters that are factory precalibrated
8. Low head loss to ensure that the gate and meter does not create obstruction to the flow
9. Self-diagnostics to alert operators of any faults
10. Redundancy and fault tolerant design
11. In built communication infrastructure to transact with peer gates and a central control centre

3.2 Irrigation management software

Irrigation management software is a key component of automation. It consists of a core database and a collection of tools that automate and/or streamline a part of an irrigation district’s business and performs automatic regulation of the control gates. The collection of software tools can be broadly classified under:

1. Remote device monitoring and operations tool popularly known as SCADA for remote supervision and intervention
2. Customer communications interface such as web and interactive voice response to enable water users to communicate directly with irrigation authorities
3. Tools for management of water rights and compliance to manage water allocation rights, ensuring compliance with those rights and with government regulations
4. Tools for management of orders, rotations and scheduling to collect, manage and schedule water deliveries to utilise the available capacity of a canal system, and then schedule farm outlets to automatically open and close at the planned time, day or night
5. Tools for management of tariffs, rates and invoicing tool to streamline the management of revenue data
6. Network visualisation software to view the schematic representation of the irrigation network
7. Network control software to supervise and coordinate a sequence of intelligent automated gates along the length of a canal to optimise the whole network operation in response to water user requirements

3.3 Difference between remote device monitoring and operations (SCADA) and autonomous control

In the context of automation, it is important to note that SCADA is completely different from autonomous control. SCADA is a system that enables humans to remotely monitor and operate devices. It provides human operators with data which they can then act upon. The basic requirement to improve efficiencies and improve service levels in an irrigation canal system requires frequent action to be taken in response to water level and flow data at cross regulators and farm outlets as per changing water user requirements.

However, the scale and complexity of an irrigation district mean that human operators are not capable of making the many thousands of adjustments required. For example, a typical large scale irrigation system in India may span across 75,000Km and have thousands of cross regulators and more than a million farmer outlets, making acting on the large amount of data at very short intervals a complex task that cannot be performed manually.
With autonomous control, software and hardware automatically act upon the data at very minute intervals to ensure that the high level control objectives are met, without any human intervention. For example, a single gate operating under autonomous control may make several hundred flow adjustments per day.

An example of autonomously controlled canal is shown in Fig. 2 below. The lines at the top section of the figure are water levels at three consecutive gates along the length of a canal system in Goulburn Murray Water in northern Victoria in Australia. The lines at the bottom section of the figure are the cumulative demand and the flow rates at the respective gate sites. The canal system had intelligent automated gates for the period shown in the figure. However, autonomous control was not turned on initially and the operators ran the canal system the way it was run historically. Notice the large water level deviations on the left side of the figure, when the canal system was operated though SCADA.

Roughly around 1st of Nov 2008, automatic control was activated. This means that the control system at the intelligent gates and the central server autonomously regulated the canal. It can be seen that the water level in all the three stretches are steady at their Full Supply Level (FSL), even though the demand is changing dynamically as per the farmer needs. The steadiness of the water level ensures that all the farmers along these stretches get an equitable and high level of service.

While in the past, the farmers at the bottom stretch would be impacted the most as can be seen by the large deviations in the water level in the bottom pool (third line from the top) when operated through SCADA.

![Figure 2. Difference between SCADA and autonomous control – water level control and flows (courtesy – Goulburn Murray Water, Australia)](image)

It is also worthy of noting that the flow rates in all the three pools matches the demand changes quite closely implying that only the right amount of water is released in to the conveyance system thereby minimising operational losses.

Fig. 3 shows the recordings of the cumulative spill volume through the escape site of the canal system of interest here. It can be seen that when the canal system was operated by the SCADA operators, the cumulative spills increased steadily. This is because the operators tend to bias the service towards farmers by sending more water than required to account for the uncertainties such as conveyance losses, transportation delays and different manifestations of non-compliance by the water users. It can be seen that as soon as autonomous control implementation was completed, the operational losses ceased to climb and completely stopped. At the same time the control system ensured steady water
levels in all the three pools as shown in Fig. 2.

Hence autonomous control can provide high level of equitable on-demand service and at the same time completely eliminate operational spills, which are the single highest loss component in an open canal delivery system.

![Figure 3](image.png)

**Figure 3.** Difference between SCADA and autonomous control – elimination of operational spills (courtesy – Goulburn Murray Water)

4. CASE STUDIES

The irrigation sector around the world has been very late in adopting technology in automating its operations. Australia has been at the forefront of this revolution that was largely forced due to a drought known as the Millennium Drought that hit the south east food bowl region of Australia between 1996 and 2010. During this period the river flows presented 44% less than the average flow period 1891-1997.

Countries like the USA, China, NZ, the European nations, Mexico and Chile have recently started following the footsteps of Australia in modernising their irrigation delivery systems.

This section provides three short case studies of irrigation automation, one each from Australia, USA and China. Rubicon’s Total Channel Control® (TCC®) suite of technology is used at all these places.

4.1 Shepparton irrigation district, Australia

The Shepparton Irrigation Area is one of six gravity districts managed by Goulburn-Murray Water in Victoria, Australia. It has over 700 Km of channels and 40 Km of pipeline servicing 2,500 customers.

Typical of many irrigation districts, Shepparton lost 30% of the water it diverted during transmission. It also provided a poor service to irrigators, which resulted in inefficient on-farm water use.

Automatic water ordering, demand scheduling and a demand oriented automatic control was implemented throughout the majority of the district’s canal network. In addition, there was rationalisation of underutilised assets, some canal remediation and some pipelining. The solution implemented included:

1. Automatic network control canal regulation
2. Automatic water ordering, entitlement checking, delivery scheduling and usage accrual
3. Replacing manually operated cross regulators with intelligent automated FlumeGates
4. Replacing manually operated farm outlets with automated FlumeGates and SlipGates

The two-year modernisation project was completed in late 2009 and has resulted in major operational improvements. Delivery efficiency improved from 70% in the 2007/08 season to 90% in the 2010/11 season. Farmers now benefit from a reliable system with delivery almost on-demand, which means they can now maximise the productive output of every litre of water used.

The 20% increase in delivery efficiency has resulted in the annual recovery of 39 Gigalitres (GL) of water. Of this, 29 GL is used for environmental use. This water is retained in storage and is periodically released into the river system in a controlled manner to maximise environmental benefit to downstream wetlands and lakes.

The various sources of recovered water is shown in Fig. 4 below.

![Sources of water savings in Shepparton Irrigation District, Victoria, Australia (Cardno)](image)

**Figure 4.** Sources of water savings in the Shepparton Irrigation District, Victoria, Australia (Cardno)

Fig. 5 below shows the photo of a cross regulator on Shepparton’s main water carrier Eastern Goulburn Main canal.

![Cross regulator on Shepparton’s main water carrier Eastern Goulburn Main canal](image)

**Figure 5.** Shepparton’s Eastern Goulburn Main canal in Victoria, Australia

### 4.2 RD 108, USA

RD108 is one of the largest agricultural water providers on California’s Sacramento River, delivering water to nearly 19,000 hectares of farmland primarily growing rice.

RD108 implemented network control to automatically manage pumps that supply the district’s canals
with water from the river, plus an after bay and primary channels. Fig. 6 shows the aerial photo of RD 108's pumping station and after bays.

The key task of automatic control is to ensure that the requested flow rates at the offtakes are met, while still maintaining the desired water levels in the primary canals. The solution automatically coordinates and controls actions FlumeGates regulating the primary canals and also controls the pumps so that they supply the exact amount of water needed by the downstream network.

Automatic control ensures the right amount of water is pumped from the river, water level fluctuations are minimised and the required flow rates at the offtakes are met. Water levels are now maintained within ±3 inches of their designated level 97% of the time. With stable water levels and reliable flow rates, canal operators can provide a better service to customers downstream.

4.3 Fen River, China

The Fen River Irrigation District in China's Shanxi province consists of two reservoirs and three weirs diverting water from the Fen River into five main canals for irrigation and industrial uses.

In recent years the province has faced serious water shortages resulting from drought and growing demand from domestic and industrial water users.

Built in 1950, the district's infrastructure mainly consists of manual control gates and almost no flow measurement. The distribution efficiency of the system, which includes farm channels, is estimated to be around 45%, meaning most water is lost before it reaches farmers' fields.

The key task of automation was to replace the old control infrastructure with new intelligent automated gates with flowmeters and automatically coordinate and control the gates to optimise the delivery of water and eliminate spills and provide remote management and data collection. Fig. 7 shows a FlumeGate cross regulator in the Fen River canal.

Impressed with the performance of the pilot installation, Fen River authorised the China Irrigation and Drainage Development Centre (CIDDC) to assess the pilot project and compare the costs and benefits of implementing network control throughout the district with the alternative of lining all channels and replacing existing gates with new manual gates.

The CIDDC report found that automatic network control;

1. Provides farmers with an equitable, reliable and flexible water supply
2. Improves efficiency by up to 20%
3. Could be implemented at 25% of the cost of channel lining and would enable the easy identification of high-loss areas of channel for targeted lining
4. Could be deployed much more quickly than traditional channel lining and gate replacement
5. Should be used by other large irrigation districts to enable them to meet their modernisation objectives

![Figure 7. FlumeGate cross regulator at Fen River canal in Shan Xi province in China](image)


As shown through these case studies, the experience globally is that automation has successfully proven to achieve all the benefits on achieving equitable high level of service to farmers, a near on-demand delivery of water and water savings consistently for a long period now.

**6. ON-FARM BENEFITS**

Guaranteed delivery of water to farmers at on-demand basis gives them confidence to invest in modernised on-farm practises and equipment to improve water application efficiency to the crops. An autonomously controlled irrigation system can provide consistent and higher flow rates to the farms precisely as per the crop requirements compared to what was achievable through manual operations.

Precise high flow rate application of surface water to crops has many benefits:

1. It results in high water application efficiencies and reduces infiltration below the root zone
2. Prevents water logging and rise of water table at the top end of the farm
3. Prevents water run off at the end of the farm
4. Can reduce the duration of irrigation by half, hence the farmers can use the time saved for more productive purposes

On-farm water application efficiencies of more than 90% has been achieved in Australia through precision high flow surface irrigation ([https://www.usq.edu.au/news-events/news/2015/10/studies-show-overwatering-cuts-dairy-pasture-growth-by-up-to-20-percent](https://www.usq.edu.au/news-events/news/2015/10/studies-show-overwatering-cuts-dairy-pasture-growth-by-up-to-20-percent)). The efficiency achieved is comparable to localised irrigation techniques such as drip and sprinkler irrigation but comes with zero energy and maintenance costs as gravity does all the hard work, and is sustainable.

**7. CONCLUSION**

Automation experience around the world has been shown to improve the efficiency of surface water delivery systems to up to 90% consistently for many years now (Annual report Coleambally Irrigation, Annual report Goulburn Murray Water). The benefits are manifold; increased productivity, more revenue for the farmers, better lifestyle, equitable service, better occupational health and safety, reduced cost of
operation, more water to irrigate more land, more water for urban sector and the industries, more water for the river systems to improve its ecosystem.

To achieve these benefits an irrigation canal system requires frequent action to be taken in response to water level and flow data at cross regulators and farm outlets as per changing water user requirements.

Experience from around the world, has shown that autonomous control is required to achieve the full benefits.

There is a real need and desire for change in India. For India the change has to start at a policy level. Legislation to introduce the concept of farm water entitlements and legislation on metering of flow for irrigation is a start. India also needs to bring metering standards for non-urban sector.

The statistics on improvements when applied to the Indian scenario are enticing. However, India has to move swiftly in this direction to address the challenges lying ahead.

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