Irrigation Water Ordering

– With applications for Thailand and surrounding regions

An Australian Perspective

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About the Authors

RMCG is a 30 year old Australian environmental and agricultural consulting business. It provides policy, planning and technical consulting services to ensure a healthy future for the environment, industry and communities. RMCG's experience is based around a solid understanding of agriculture, water supply, the environment, communities and industry, which comes from working with farming families, community groups, water agencies/local government and individual businesses. RMCG has played an active role in water supply and management changes which have occurred within the Murray-Darling Basin over the last twenty years. RMCG has been engaged to provide technical and policy advice to support water reform initiatives across several Southeast Asian countries including Vietnam, Cambodia and Thailand. RMCG has over 50 consultants and for this project utilised three of its most experienced water specialists – Rob Rendell, George Warne and Matthew Toulmin (with water resources management consultant Dr Hugh Turral also contributing significantly). Rendell and Warne have worked with many different water ordering systems for irrigation supply for over 40 years.

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Managing scarce water to maximise food production is becoming increasingly important in the Asia-Pacific region. In turn, this means that the productivity, efficiency and effectiveness of irrigation needs to be significantly improved. Adopting the right water ordering system is a fundamental contribution to achieving this and enhanced equity.

Australia has a long history of successfully designing and using different water ordering systems for irrigation.

This report:

- summarises why water ordering is important, supported by a series of propositions about the merits and challenges in its adoption;
- elaborates the principles underlying water ordering as it is practised in Australia; and
- presents case studies that illustrate a range of contexts and approaches to managing water ordering to achieve a high level of irrigation service.

Australia has found that water ordering enables the provision of a flexible and efficient irrigation service that is well suited to increasing productivity in irrigated agriculture*. Water ordering enables increased areas of irrigation as peak demand can be reduced, it uses less water as system losses are lower, and can save on infrastructure costs significantly by utilising "right sized" capacity systems.*

Application opportunity in Thailand:

Dr Thanet Somboon, a senior expert in hydrology from the Thai Royal Irrigation Department (RID) visited Australia in early September 2018. A site visit to three irrigation areas in Northern Victoria and Southern NSW was undertaken by Dr Somboon with AWP representatives. The aim of the site visits was to enable Dr Somboon to better understand Australian irrigation water supply systems and the sharing of limited canal capacity utilising water-ordering.

The advent of widely available mobile phone technology in Thailand providing voice, and data transfer to a central canal operator, and then providing advice immediately back to water-users at relatively low cost, combined with a governance regime to encourage compliance, may enable the implementation of water ordering rapidly and effectively within Thai scheme areas where capacity to deliver water as required by growers is constraining irrigated agricultural production.

In particular, the system currently used within Coliban Water (Bendigo, Victoria), with small modification, may provide the basis for a Thai trial, enabling a low-cost and rapid deployment of water-ordering at an irrigation project or district scale, involving multiple irrigation water user groups, or even at a whole Irrigation scheme area (i.e. on a whole of valley-scale).

2 Why water ordering is important?

2.1 The productivity of irrigation water is low and needs improvement

Irrigation managers and farmers are under increasing pressure to improve the productivity and sustainability of water use in the face of increasing scarcity and competition for water. Competition for available water resources arises from a combination of:

- rapid population growth;
- rapid and extensive urbanisation and industrial development;
- recognition of the environmental consequences of previous water development and the need to reserve or return water to natural systems;
- climate changing in many areas, making dry periods even drier.

The need to be more economically and physically efficient is driven by the need to produce more and better-quality food with the same or lower water use. In order to raise productivity, manage scarce resources, and operate irrigation systems efficiently, we need to provide farmers with good access to water.

The *de facto* alternative to carefully managed supply involves the water being captured by those best placed in terms of geography, power, wealth or influence. This is inequitable, economically inefficient and politically divisive.

Raising productivity requires farmers having good access to water.

2.2 Thailand wishes to improve the productivity of its irrigation sector

Irrigation development in Thailand proceeded rapidly in the second half of the 20th century, mainly in the Chao Phraya river basin, where rice is the principal crop. Irrigation is supplemental in the monsoon period and essential in the dry season.

There are significant supply limitations in the dry season, coupled with distribution problems in the canal networks. Many supply systems have difficulty providing good access to water to irrigators, particularly irrigators at the end of the system.

This has resulted in extensive and sometimes costly pumping by farmers to scavenge surface and groundwater. Crop yields remain low compared to potential. Better access to water is one contributing factor to raising yields.

Larger scale and more intensive agriculture are also becoming increasingly important as a consequence of urban migration and industrialisation and the pressure to increase farm size to generate a decent living. Farmers require precise timing and high reliability in irrigation to achieve higher levels of productivity. Increasing precision in water delivery is a key to encouraging growers to move away from paddy rice to more valuable row-crops.

The Royal Irrigation Department of Thailand (RID) is interested in the experience that Australia has gained over 100 years of irrigation development in providing farmers with good access to water based on various approaches to water ordering.

2.3 Water ordering can help individual farmers improve access to water

Farmers who have good access to water can satisfy their crop watering needs at a time and place of their choosing. This allows them the flexibility and security to intensify production, use other inputs (notably fertilisers) and apply higher levels of management to increase yields and profit margins. It also affords them the option to diversify into higher value but more risky enterprises, such as vegetable and fruit production.

Many farmers rely on gravity supply through canals that are provided, financed and managed by government. Gravity irrigation systems have historically been designed to provide an equitable distribution of water, either through continuous flow, or using proportional division or through rotation of larger flows to a fixed schedule. Neither of these approaches is very flexible, or well suited to the variable demands of more intensive agriculture.

Water ordering has the potential to improve farmers' access to water in canal and piped irrigation systems in the following ways:

- providing improved Level of Service (LoS) through access to defined flows over a defined time period;
- enabling increased intensity and diversification in crop production, leading to higher productivity and income;
- reduction in user conflict;
- enabling system operators (at both the basin level and at a local level) to deliver water efficiently; and
- enabling effective rationing and management of scarce water resources when required.

Productivity and farmers' incomes can improve with timely access to sufficient water provided by a good ordering system.

2.4 Other factors may impair or reduce productivity

Good access to water requires more than implementing a water ordering system. Other important factors also affect the provision of a good LoS.

Many existing canals suffer from inappropriate design and inadequate maintenance that results in:

- insufficient water supply;
- insufficient channel capacity;
- insufficient or ineffective water control – i.e. lower water level and smaller discharge.

A lack of funds for Operation, Management and Maintenance (OMM) is often identified as an underlying reason for low levels of service.

Because of these deficiencies, farmers often do not comply with irrigation schedules in administered systems and take more water than "allowed" and take it out of turn. Where the governance structure is poor, it becomes difficult to manage, monitor and enforce the provision of equitable and effective service.

Poor operation of existing irrigation systems can be attributed to:

- poor training;
- low skill levels in operation;
- poor communication;
- high transaction costs due to the large number of users;
- rent seeking/bribery, where users pay for preferential access to water.

The type of water ordering system that can be developed depends on how many other impediments to good service prevail.

2.5 Water ordering is hard, costly, technically demanding and requires good communication, information and governance

Effective water ordering relies on good, clear information flows, based on a sound recording and collation of water deliveries, requests and adjustments. It requires:

- an agreed system of water rights (this defines what farmers "can have");
- good water measurement at the service point (this records what farmers use and when it is used);
- good water accounting (this reports how much a farmer has used to date, and how much water remains in their "account"); and
- the operators having the authority and skills to "govern" the system.

The type of infrastructure influences what is possible as the greater flexibility that is provided by ordering requires a high level of control over offtakes and regulating structures, which can be demanding.

However modern communication devices (mobile phones, internet and "iPads") provide opportunities to adopt simple systems in a way that were previously quite difficult.

***Therefore, careful assessment is required before attempting to adopt the appropriate water ordering system. This needs to address technical feasibility, cost and the ability to remove existing constraints*.**

2.6 Alternatives to water ordering

A number of alternatives can be employed to improve existing levels of service without having to resort to the complexity of water ordering.

In canal systems, the most likely avenues for success are ones that allow greater flexibility and farmer control in accessing good water supply. This can be achieved by:

- converting to private groundwater systems;
- pumping directly from storages or rivers;
- constructing small on-farm storages;
- improving service delivery in channel networks which can be partially achieved by:
  - joint use of surface and groundwater;
  - delivery from smaller communal sources managed by local Water User Group; and
  - modernisation of canal systems to improve storage and operational flexibility;
- providing continuous flow with strong governance systems to rotate rights of access to this flow – a common way for farmers to access water. This rarely provides a good LoS but, if well implemented, can be effective, especially for rice-based agriculture.

Although piped irrigation supply is relatively uncommon in Asia today, a high LoS can be delivered through:

- high capacity pipes that provide water on daily or shorter intervals – this may be appropriate in small scale developments producing high value crops.
- piped systems, allowing pressure to be adjusted for increased demand by reducing the flow rate and sharing available flows more equitably than under gravity in canals.

In summary, there may be feasible and cost-effective alternatives to introducing water ordering.

2.7 Water ordering in medium and large-scale public irrigation systems

Water ordering is essential in larger schemes if you want a high level of irrigation service, the flexibility to grow high value crops and significantly increase land and water productivity throughout the *whole* irrigation-area.

Water ordering and associated metering also enables an improved operator understanding of an irrigation scheme's water balance, audit trail for scheme performance and ongoing targeting of enhancements to improve levels of service and scheme performance.

Water ordering is the best and most cost-effective option to improve the LoS and production from irrigated agriculture in large and medium scale public irrigation systems.

3 The principles behind water ordering

3.1 Levels of service

3.1.1 Water on demand is desirable, but rarely possible

The highest level of productivity that can be attained by a farmer is when water is supplied on-demand at a time, flow rate and duration of the farmer's choosing. On-demand irrigation incurs high costs, as the capacity of supply must be sufficient – probably twice the capacity – to satisfy the possibility that many users on a reach of canal (or pipeline) may take water at the same time. In the case of canals, it is technically quite difficult to provide water on demand, especially if there is limited canal storage or if losses are to be minimised.

Therefore, the practical goal is to achieve an acceptable LoS that enables maximum production, without providing water on-demand.

3.1.2 Level of irrigation service – what is it?

A high LoS incorporates flexibility for the user to irrigate when they need according to changing circumstances on farm, e.g. rainfall, evaporative demand, changes in crop pattern and dates, and possible use of localised water supplies such as groundwater and runoff/stored water.

Put simply, a desired LoS specifies *how much* water will be delivered to a user, *when* and *where*.

In practice, a more detailed specification of LoS may include:

- the annual volume to be delivered to a service point;
- the volume to be delivered per service point, at a specified time, maximum flow rate and duration of flow to complete an order or scheduled irrigation;
- the consistency of flow provided during supply (flow rate, supply head); and
- the reliability with which deliveries will be made on-time and at specified flow rate.

LoS is generally worst at the "tail-end" of systems when flows are low and erratically timed.

Level of Service is a measure of the farmer's ability to access water.

3.1.3 Urban water supply – water on demand, but not quite

Urban water supply is a common example of water access on demand, subject to some restrictions. A user may switch a tap on or off at any time they choose, for as long as they choose, but the pipe size is standardised and restricts the flow available. A user may also have to accept variable pressure over time.

The limitations of flow rate and variable pressure are normally addressed by the addition of a water tank (local storage), which may be positioned to give constant pressure (e.g. in the roof). Alternatively, a house holder may install an automatic garden watering system to irrigate at night when the demand is low.

The urban water supply approach is not applicable to canal irrigation systems and is too expensive for piped irrigation supply systems.

3.1.4 Water ordering enables a good Level of Service

Water ordering allows users flexibility in choosing how much water they apply and when. It aims to achieve a LoS that approaches on-demand irrigation, at a more reasonable cost.

When a farmer in Australia places a water order for a particular farm outlet, they specify:

- the desired start time;
- the desired finish time; and
- the desired flow rate.

Orders must typically be made four days in advance of the start date and time. In some systems, irrigation duration is set in blocks of 24 hours, with a fixed start time, which in turn allows the notice period to be reduced to two days. Automation and modernisation means that the order time has now dropped to as little as two hours.

If the capacity of the channel will be exceeded by trying to satisfy all orders simultaneously, the irrigation scheduling team will move one or more orders forwards or backwards. The change in timing is quite small, often a few hours in canals, and rarely reduces the LoS to the farmer.

After an order has been placed, it is confirmed by the operator. Alternatively, in some systems the farmer can use a touch pad telephone to find their starting time from an answering service. If a farmer wishes to stop an irrigation early, they can do so, but must advise the irrigation supplier before doing so.

Ordering allows farmers to access water with a Level of Service that is almost on-demand, but is cheaper. Mobile phones provide the perfect medium to place and confirm orders using data transfer, or simply text messages.

3.2 Water ordering – types and possibilities

The primary aim of water ordering is to enable the operator to deliver water to meet a customer request. The ability of any system to deliver depends upon:

- the time required from when the order is placed to when it can be delivered, which includes the transit time from higher up the canal network;
- the control mechanisms that enable delivery;
- how frequently the operator is able to regulate the system to adjust water supply;
- the communication system the operator uses to operate the system; and
- the communication system between the customer and the operator.

There are two broad categories of water ordering:

- **Predictive**: when the operator needs to 'predict' future demand patterns. This occurs when demand and supply are separated by long physical and time distances (e.g. >12 days)
- **Customer request**: when orders are placed by the customer for the amount of water required in the right place at the right time.

There are different conditions under which ordering might operate and these can be thought of as "drivers" for the ordering process used. Three such drivers can be identified:

- **Scheduling**: where orders are arranged in a queue so that:
  - during peak demand, supply capacity is not exceeded within a service period;
  - during off-peak, users would see few changes to the order schedule and farmers get water at the requested times; and
  - if channel capacity is exceeded, the start times for one or more users are delayed or brought forward.
- **Sharing/allocating resource**: when there are limits on the water resources available to the system, then reduced water supply can be shared across all users. There are many ways to share water. In Australia, the reductions in supply to any user would be proportional to the user's announced allocation, which is a percentage of the nominal annual water right or "entitlement".
- **Predicting**: prediction is always required for the timing of a release of water from a storage; the transit time from the storage to the system or user; the ability to control the release and the communication required to satisfy the order. The ability to predict is reliant on the water allocation process, an understanding of crops being irrigated and seasonal accounting and may sometimes require the use of computer models.

Three broad types of water supply system can be defined from the preceding categories and drivers:

- **Rivers and large canal systems** with upstream storages that require predictive ordering based on forecast aggregate system demand (crop area X daily demand/Ha), allowing for delivery losses to enable operators to plan delivery and the associated regulation structure;
- **Canal systems**, in which orders are placed by customer request in advance (typically 1-4 days but with automation can be as little as two hours) to enable operators to queue orders and to plan delivery to enable structure regulation;
- **Piped systems**, where customer requests are made over the day. The operator's role is then primarily to queue the orders to match demand and capacity but have limited system regulation requirements compared to canals. In a pressure pipe, transit time does not need to be considered as changes in flow are effectively instant.

3.3 Water ordering improves Level of Service but is limited by canal/pipe capacity

3.3.1 There are differences between ordering systems in channels and pipes

Ordering systems within pipes and canals have many similarities but there are three major differences:

1. Control structures in pipes are much simpler to operate and automate. This usually creates more flexibility in when and how much water is delivered. By contrast canal structures are traditionally manually operated and less flexible, or if automated are technically more complicated (i.e. it is possible to store water in canal systems, but not in pipelines).
2. The operator's role in both pipes and canals is to take orders and manage who gets what, when. However, in canals the operators have an extra role in managing flows in the canals to ensure delivery and minimise the chance of overtopping, or end-of-system outfalls. This requires orders being placed further in advance of delivery compared to pipes. This is because pipes have almost instant access and flexibility compared to canals that have to consider the transit time from release to delivery.

3. In large canal systems, it often takes more than one day for water to travel from the source to the farm and this allows the flow to be averaged across the region, enabling smaller capacities in canals than is possible with large pipe systems.

In Australia, there has been significant conversion of smaller supply channels to pipes in recent modernisation work in order to facilitate a higher LoS. However, this conversion has been limited to systems with less than 5,000 ha in total.

Ordering systems in pipelines are similar to channels but different in detail.

3.3.2 Five Levels of Service that depend on canal/pipe capacity

In general terms, there are five possible Levels of Service (see **Figure 1**) that depend upon the pipe or channel capacity:

1. **Less than minimum capacity**: the peak demand cannot be provided and some form of sharing of a limited resource occurs.
2. **Minimum capacity**: water is provided under continuous flow (24 hours, day after day) or by rotation. The cycle period for *rotation* can vary from hours to several days.
3. **Almost-on-demand capacity**: if the capacity of a pipe or channel is further increased and combined with *ordering and associated scheduling and 24 hour operation*, peak daily demand can be delivered almost when the irrigator requires.
4. **Capacity to deliver higher flow over part of a day**: an increase in capacity allows delivery over a shorter period within a day. If daily peak crop demand is delivered in, daylight hours (12 hours) or in the morning (6 hours), for example, capacity needs to be doubled or quadrupled in each case.
5. **Capacity for water-on-demand**: a high level of capacity enables a customer to access water at any time and receive the volume they require. It requires the highest pipe capacity and is very expensive to build and to deliver.

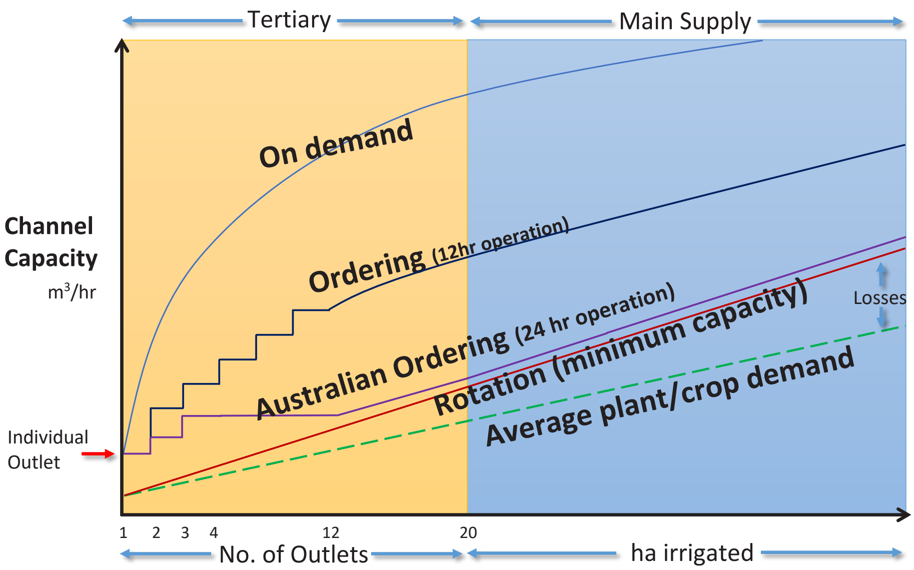


Figure 1. Ordering systems with different capacity canals

Ordering can improve the Level of Service for each of the above general capacities up to a point. Understanding the impact of canal capacity on potential LoS is critical to selecting the appropriate ordering system.

3.3.3 Outlet capacity determines the LoS possible in small canals (<30 customers)

The outlet size determines the capacity required in small systems, so all possible steps should be taken to ensure that individual outlets are not larger than necessary. If offtakes are oversized, compared to peak daily requirement, the number of offtakes that can be operated at the same time is restricted and the LoS to other farmers is reduced, as they have to wait more frequently, and longer, for their order.

The type of irrigation system determines the relative size of the outlet. For example:

- **Flood** irrigation requires higher flow rates, typically 5–7 times the peak daily demand;
- **Sprinklers** require medium flow rate, typically 2–3 times the peak daily demand; and
- **Drip** irrigation requires the lowest flow rate, typically 1.5 times the peak daily demand.

If offtake capacity is large, and offtake numbers are small and well-matched to canal capacity, it will be simple to schedule but will be quite costly in terms of canal capacity.

If there is a large number of offtakes of varying capacity, or the offtake capacity is high relative to channel capacity, the scheduling of orders and operation of the channel becomes complex, and it is also less likely that farmers will get water when they actually want it.

The Australian approach to determining channel capacity to provide 'almost water on demand' where the canals now operate over 24 hours is shown in **Figure 2.**

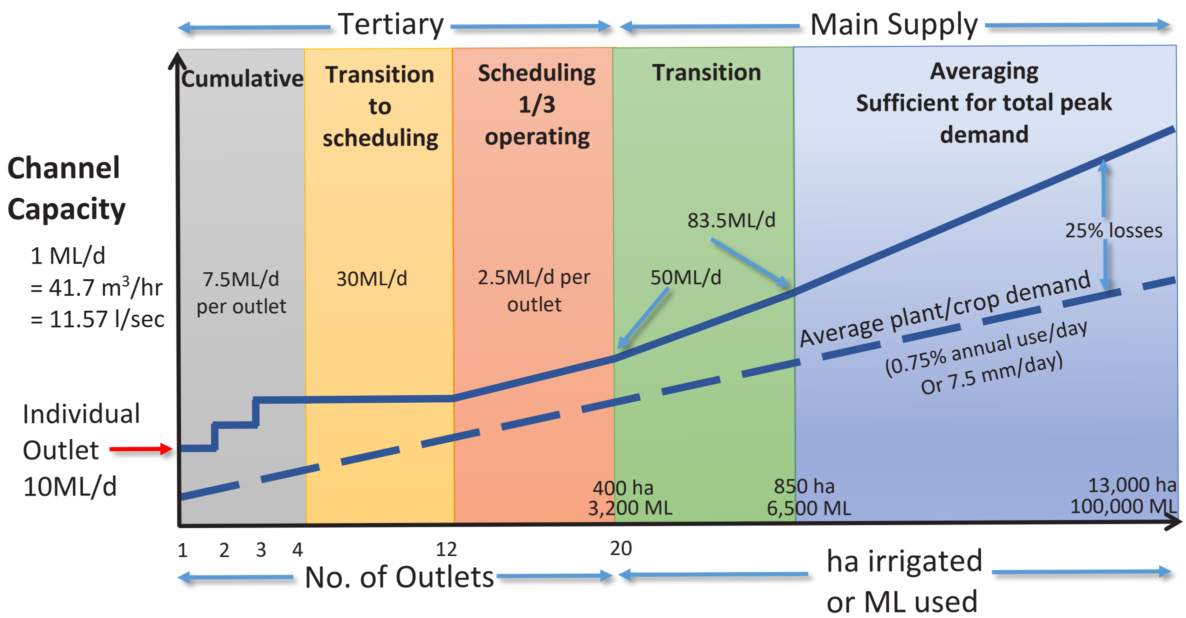


Figure 2. Australian canal capacity design with ordering

This example uses the Goulburn-Murray Irrigation District system (northern Victoria) but the principles apply equally to most of the systems utilised in Australia.

In small canals, the Level of Service possible depends upon the outlet size and number of outlets operating relative to the canal/pipe capacity. For a channel of given capacity, the bigger the outlets, the greater the queueing and rostering required.

3.3.4 There are ways of overcoming capacity limitations

Whilst it is desirable to have a canal system with sufficient capacity to provide water almost on-demand, there are ways of minimising the capacity requirements. These include:

- combining supply with groundwater sourced on farm at peak times;
- augmenting supply from localised surface water storages, such as ponds;
- within system (balancing) storages;
- access from on-farm storage; and
- the use of ring mains or cross connecting canals which can smooth out demand patterns.

An interesting feature of rice production (from an ordering/scheduling perspective) is that the water ponded on the surface of the field relaxes the need for precise timing irrigation, and allows some flexibility in delivery, providing it does not dry down too far.

There are practical ways of overcoming capacity limitations which when combined with water ordering can enhance the Level of Service.

3.4 The number of regulations to structures in a day affects ordering and Level of Service

There is a limit to the number of manual changes that can be made to regulators and valves in a water supply system – typically twice per day in gravity canals. If automation is used, regulators and valves can be operated continuously. The type of regulating structures and operational management choices determine the frequency of regulation (see **Figure 3**). This is a key factor in the ordering system devised and hence in the LoS adopted.

The system of canal/pipeline regulation is a key factor in the selection, design and implementation of an ordering system.

a. Overshot channel regulator, Goulburn Murray Water

b. Manual drop bar adjustment of water level at tail regulator (Source: State of Victoria)

c. Multibay flumegate regulator, Macalister Irrigation District (Source: Southern Rural Water)

d. Dethridge wheel measuring irrigation water consumption by vineyard, Griffith, NSW. (Source: CSIRO. By: Willem van Aken on 8 November 1995)

Figure 3. Alternative canal regulation systems

4 Case Studies

The following case studies illustrate the range of options for water ordering that currently exist within Australia.

4.1 Australian context and practice

Australian irrigation has evolved over 100 years to serve commercial agriculture.

Water ordering was not originally designed into the operation of early Australian canal systems. Initially, water was delivered by strict rotation between properties to supply peak average demand over a given period – for example seven days. Over time, it was observed that adjustments could be made to the system that made operators' lives easier and better met the requests of farmers. The infrastructure was found to be more adaptable and much more responsive than first thought.

The ordering system was a manually operated system with manual structures, written orders delivered four days in advance to the operator and twice-a-day regulation, until the emergence of computers and information technologies in the 1990s. System modernisation began with innovations such as telephone ordering, push button telephone messaging and limited application of remote sensing, then SCADA to strategic control structures. At the present time, there are irrigation systems with automation along the full length of the supply canal down to individual farm turnouts, which are centrally controlled and also measure flows continuously. The channel control system is linked to the water ordering process and advance notice periods for orders have shortened considerably – down to as little as two hours.

In some piped systems, an order may be satisfied instantly if capacity is available.

Irrigation service in Australia is generally of a high standard and has been underpinned by:

- good design, good quality structures that have been easy to operate and provide good water level control;
- measurement of water deliveries to individual farms, using a range of simple meters that accumulate volume delivered. This has provided the platform for water charges paid by farmers;
- an *entitlement* system that, each year, provides a quantity of water as a "right" that can be accessed in a year, with a high confidence of delivery; and
- good governance including both community oversight, and rule-of-law.

In contrast to most Asian irrigation systems, land holdings per household in Australia are very large and farm sizes may occasionally reach several thousand hectares and may also be as small as 5–10 ha. However, only a proportion of the land owned on many large farms can be irrigated as water entitlements are often insufficient.

A typical irrigated property in Australia can cover a similar area to a tertiary outlet in a large surface irrigation canal in Thailand (e.g. around 200 ha), which corresponds to the jurisdiction of a single Water User Association.

4.2 A number of approaches to ordering

The following examples present a range of scales, contexts and approaches to water ordering in Australia (and Vietnam), as follows:

1. River level ordering

- The Goulburn System – primarily based on predictive ordering

2. Canal systems

- Coliban Water – mixed urban and agricultural supply that is manually operated and could be adopted in Asian systems. It also includes some local canal operation and ordering in conjunction with the wider system ordering.
- Eagle Creek scheme (from the Murray, near Barham NSW) – mixed irrigation farming supplied through a system where a shared river pumping station delivers water to the creek which can be regulated. This enables 15 dairy/citrus/vegetable/cropping farms to obtain water by using individual pumps to divert water onto their crops. The river pumps are operated based on collective orders from water users, with an allowance for system losses, supply variability is managed through the inherent storage capacity provided within the 15 kilometre-long Eagle creek pondage.
- Murray Irrigation – a large semi-automated canal system, which provides a practical modernised system approach but limits the sophisticated technology.
- Coleambally Irrigation – a highly automated irrigation supplier, which is aspirational for a modernised system.

3. Pipelines

- Campaspe Irrigation – a small irrigation cooperative of twelve farmers in Victoria that nearly has water on demand, with a very simple ordering system.
- Sunraysia – water on-demand in New South Wales: a sophisticated web-based ordering system.
- Vietnam – Two examples of proposed piped irrigation systems in Vietnam are also given as an alternative approach: these schemes are being developed using the principles and practice of improved service that have evolved in Australia. These systems utilise smart meters and simple design techniques to minimise the need for water ordering.
  - The first system does not employ ordering but delivers a high LoS by enabling all irrigation to occur within a 6-hour time period per day. Each individual is provided with a specified “time slot” and the system has real time “smart meter” monitoring.
  - In the second example, the system capacity is sufficient so that all irrigation is potentially possible over a 12-hour period. There is no system wide ordering but individual hydrants serve 5 ha with a manifold of individual outlets for approximately five farmers who are required to develop their own local sharing roster in peak demand periods. Each individual outlet has a smart meter for monitoring.

It is the first two examples which are considered immediately applicable to Thailand, and these have been described in the following.

Case study 1: Lake Eildon - Goulburn River, Victoria

Lake Eildon captures flows from the Goulburn River in northern Victoria. The river basin covers 3,885km^2 and yields 1.958 billion cubic metres (BCM) of which 1.54 BCM is used.

52 per cent of the Goulburn's mean annual flow occurs over the three months, between July and September. Lake Eildon typically harvests about 20 per cent of annual streamflow through this period.

Lake Eildon's present capacity is 3.34 BCM, which is sufficient to ensure irrigation supply over two consecutive drought years.

90 per cent of the water released from the storage is used for irrigation and accounts for 60 per cent of the supplies used in the Goulburn-Murray Irrigation District (GMID). Water is also released for environmental flows and to supply water to other districts. The releases generate 226 GWh of hydro-electricity per year.

Releases are subject to a set of rules:

- To limit the rate of rise and fall of water levels in the river channel to avoid bank slumping
- To maintain passing flows
- To minimise flooding risk at the downstream floodplain, with special reference to the city of Shepparton.

The Goulburn River discharges into the River Murray, where minimum flow and environmental flow requirements have to be met. At the same time, flows in the lower Goulburn must be limited to minimise risks of flooding, whilst providing a good balance of environmental and consumptive needs.

Travel time from Lake Eildon to the River Murray is seven days, and two days to the nearest large irrigation offtake at Goulburn Weir. This is a relatively short time period in the Murray-Darling Basin, where the travel time from Lake Hume to the South Australian border is 40 days.

The control structures along the Goulburn have changed little over the last 30–40 years, but their operability has improved considerably with the introduction of automation (SCADA), which has allowed observation and control close to real-time. Improvements have been focused on management, rather than on capital works and most of the SCADA technology has been retrofitted into the existing infrastructure.

The majority of the flow metering sites and associated telemetry is located at the head and tail of the river and at the main structures along the river (example is Goulburn Weir, see **Figure 4**). The telemetry at the confluence with the River Murray has been in place for 20 years and provides good monitoring and water accounting information but has had limited use for predictive management of releases.

The operations team have had an effective flood prediction model for the past ten years. Orders and estimated needs are accumulated from the junction with the Murray back up to the storages.

Release of flows from Lake Eildon is based on a combination of orders from irrigation systems and private diverters (70 per cent) and predicted needs and resources (30 per cent).

Larger releases are required when environmental flows and irrigation needs must be supplied at the same time. Irrigation needs may fall in wet periods, but there is often a requirement to release larger environmental flows to coincide with tributary runoff in order to achieve over bank watering in flood plain ecosystems.

The irrigation districts place orders four days ahead (to allow sufficient travel time). Irrigation districts are supplied both directly from Lake Eildon and from inflows from tributaries below the dam which need to be accounted for in planning and managing releases from the dam.

The operators use a mix of technology, prediction, Australian Government Bureau of Meteorology (BoM) weather forecasts and professional judgement to decide how much water is released to meet the downstream demands.

Management of river operations and orders began 20 years ago and has transitioned through:

- a manual system;
- computer assisted order management based on manual procedures; to
- total Channel Control system.

At present, the inflowing tributaries are not well monitored and plans are in place to enhance monitoring of tributary rainfall, runoff and conditions in order to get better estimates of catchment yields and real-time responses (see **Figure 5**).

There have been significant improvements in climate recording and availability and in climate prediction:

- The team now has access to a direct feed of climate data, which is updated every 15 minutes. This has enabled a good understanding of the temporal shifts in rainfall over a day.
- Forecasts from the BoM extend to eight days, with a higher level of certainty over the first four days. In wet periods, the predicted flows will be more conservative than in dry ones.

Professional judgement relies on experience from past efforts to correlate climatic conditions with flows, using spreadsheets and historical data. This has evolved though analysis of:

- good historical results;
- what went wrong in the past; and
- the responses to both good and bad outcomes.

The team stress the importance of collective or institutional memory in understanding and managing the system.

Figure 4. Goulburn Weir built 1891 (Source: Josh Meertens)

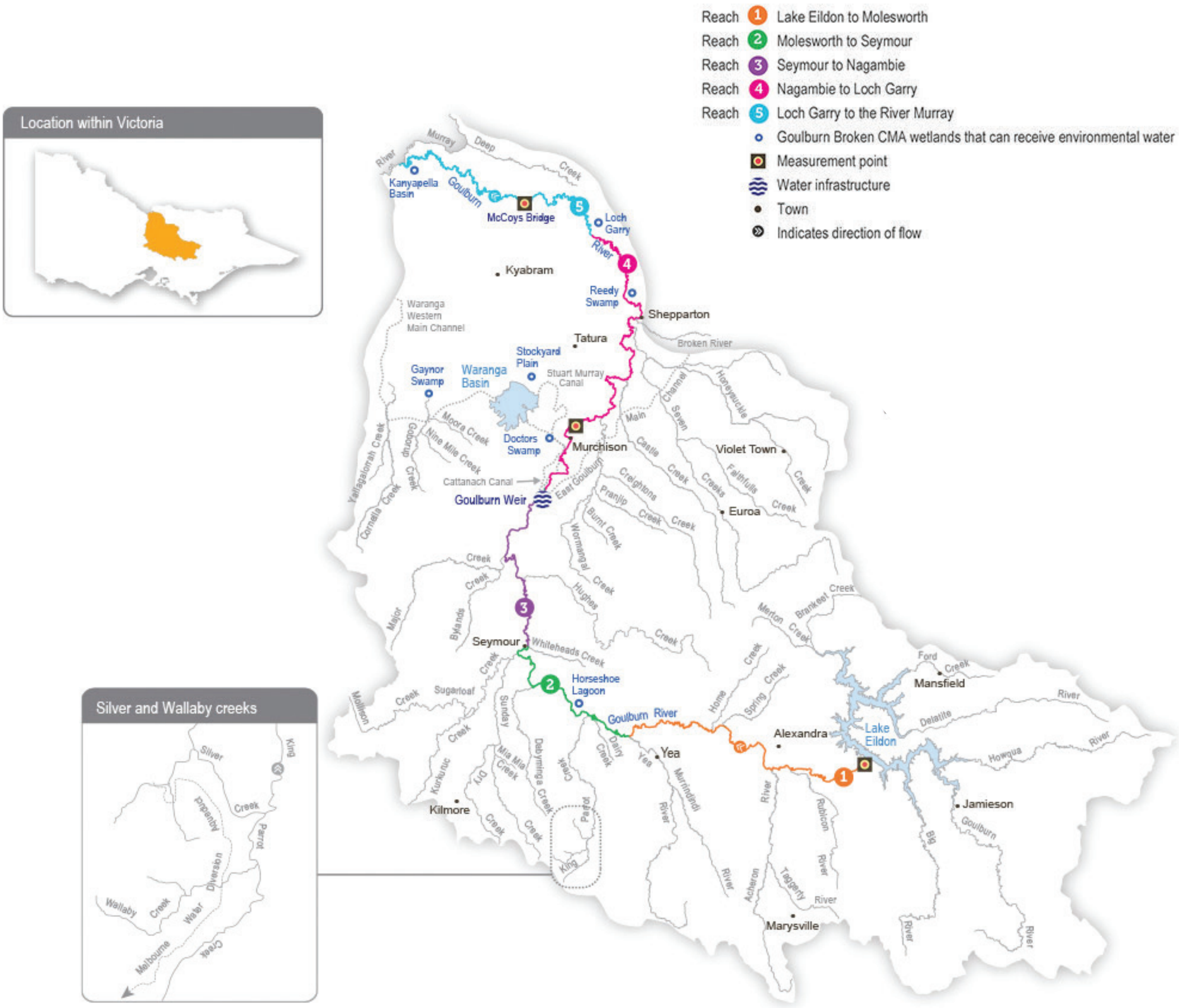


Figure 5: Goulburn River system below Eildon Reservoir (Source: Victorian Environmental Water Holder)

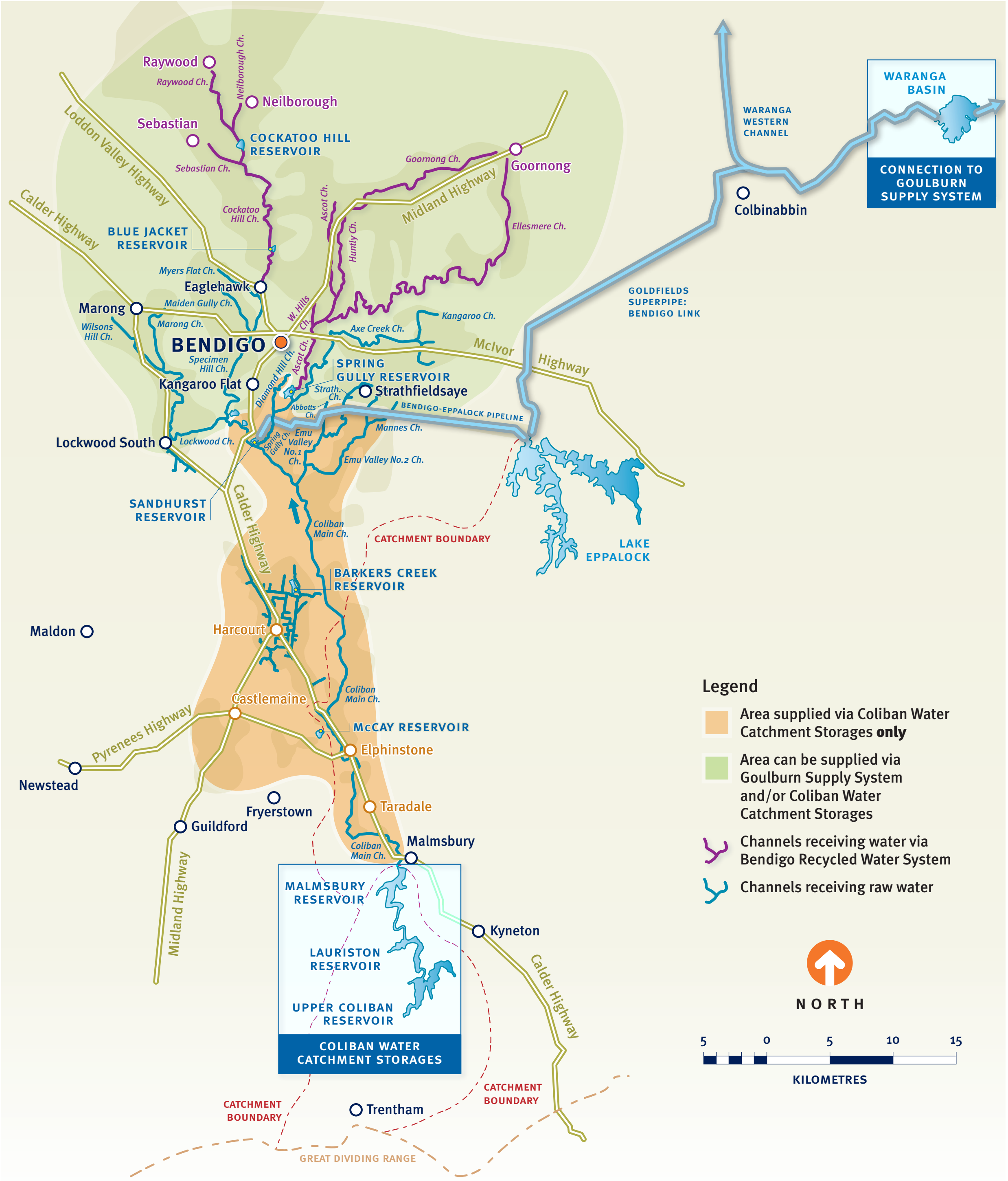


Figure 6: Coliban irrigation system (Source: Coliban Water)

Case study 2: Coliban Water, Victoria

Overall canal system

Coliban Water supplies water to urban, agricultural and stock and domestic licence holders in central Victoria (see **Figure 6**).

Coliban Water has a bulk entitlement of 4.37 million cubic metres (MCM) (4,370 ML), which is delivered through 520km of channels and three pipelines. Water is sourced from four large reservoirs. Following Australia's Millennium Drought (2006–2009), a canal was built to link the Coliban system to the Goulburn-Murray Irrigation District to ensure urban supply.

The system contains distribution storages within the network, and some users to the north of Bendigo are supplied with recycled water from Bendigo city.

The main commercial crops are orchards with apples, pears and stone-fruits.

Rural water supply system

Water for rural users is supplied from October through to May. A variety of different operating rules apply including cycles ranging from:

- 1 week on: 3 weeks off
- 1 week on: 1 week off
- A limited time period with constant supply.

Water is supplied in response to customers' orders. Users from canals mostly fill small on-farm reservoirs or tanks. Outlet capacity ranges from 1–5 l/s and is delivered though a 50mm gated pipe or orifice. Flow is measured once per day by the water bailiff.

Users on pipelines fill local storages and pump direct to their sprinkler or drip irrigation systems. Water is delivered through a gate valve with an in-line meter and a flow restrictor to limit the maximum delivery rate. Users may operate the offtakes themselves in accordance with their agreed ordering schedule.

Substantial penalties exist if users divert more water than their water allocation. Coliban plans to install Smart Meters on all pipe offtakes.

There are also 20 uncontrolled outlets which flow whenever there is water in the channel. The outlets are 20mm cuts and are assumed to deliver 10.9 m^3/day and incur water charges on that basis whenever they flow. No ordering is required for these offtakes.

In addition to individual and business users, there are shared outlets with up to 30 users served from one supply point. The group is usually coordinated by a volunteer, who aggregates and places orders, arranges distribution and organises communal maintenance. In essence, these groups operate like a small Water User Association or water user group. Some of these groups work well and some do not. Supply is to individual dams, and the cost of the water needed to wet up the channels is shared by the users.

The canal water ordering system

Water ordering relies on a mix of manual and computerised operation. Orders must be placed with four days' advance notice to Coliban Water and the delivery period runs for 24 hours. Orders must be placed between 7am and 2.30pm.

Water bailiffs travel to all the properties with scheduled orders and start times beginning in the late morning and continuing through to around 4pm.

The process of ordering is as follows:

The user telephones the scheduler at Coliban Water to request a date for irrigation. The operator enters the request manually into a computer package using a *Booking Form*, based on the earlier paper ordering system.

The operator collates all the orders and queues them. If there are capacity constraints, then the start times are adjusted and the operator confirms the order by telephone. The channel operator will phone the user on the day that water is to be delivered to check that they are there and ready to receive water.

There are five status conditions for orders:

1. Tentative – until water available or demand date is confirmed;
2. Canal supply in 48 hours' time;
3. Orders being delivered now;
4. Rescheduled orders; and
5. New orders.

If a user wishes to stop early they must ring Coliban Water and inform them. They can close the off-take themselves if necessary, for example if water bailiffs are far away. It is not possible to stop early overnight as the channel system is manually operated and staff will not be on site.

Water bailiffs are equipped with portable hand-held devices that can receive the daily irrigation schedule from the main office. At the end of the day they update the schedule and synchronise with the computer via the internet.

The *Booking Form* includes the licence-holder name and address, the running balance of allocation against licence volume for the year, the outlet number and type and the channel number.

The *Licence Owner details* include valid dates for licence; licence holder name and address; outlet number, water delivery history, and current balance; and water sales, purchases and transfers.

The *Allocation Record* provides a more detailed history of water deliveries and allocations over the years.

All water orders are linked to the *Billing System*, which generates invoices for users on a monthly basis.

The Pipeline system uses storages and low flows to avoid an ordering system.

The most recent upgrade to the Coliban system is the replacement of seven channels with the Harcourt Pipeline. In 2016-17, 576 ML (576,000 m^3) was delivered to 114 customers, who were the bigger users in the region, including orchards and agribusiness.

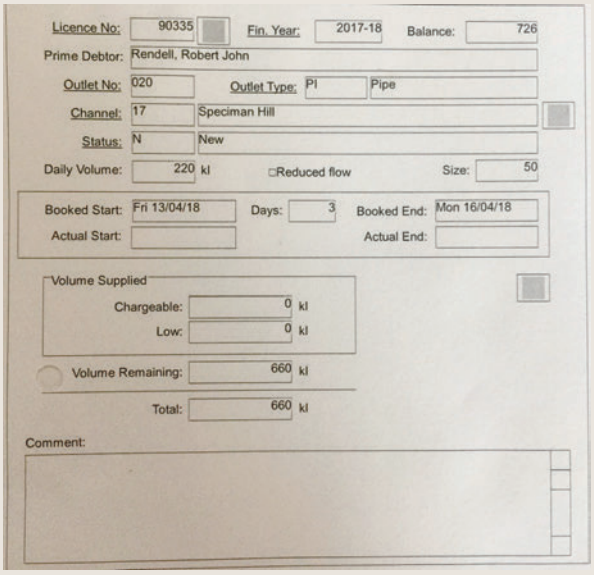
The pipeline is operated throughout the year with customers accessing water on demand, up to the limit of an individual's water allocation. The gate valve at an offtake is operated by the user and flow is metered continuously, although readings are only taken every three months by the bailiffs. If entitlement is less than 5ML/year (5,000 m^3), then customers must have a storage tank and if greater, then they should have a dam. Some of the orchards take water continuously.

Smart meters are being trialled at Harcourt in the near future.

The following images (**Figures 7–10**) show a typical canal and outlet along with a computer screen of an individual order and the canal ordering sheet (with no data).

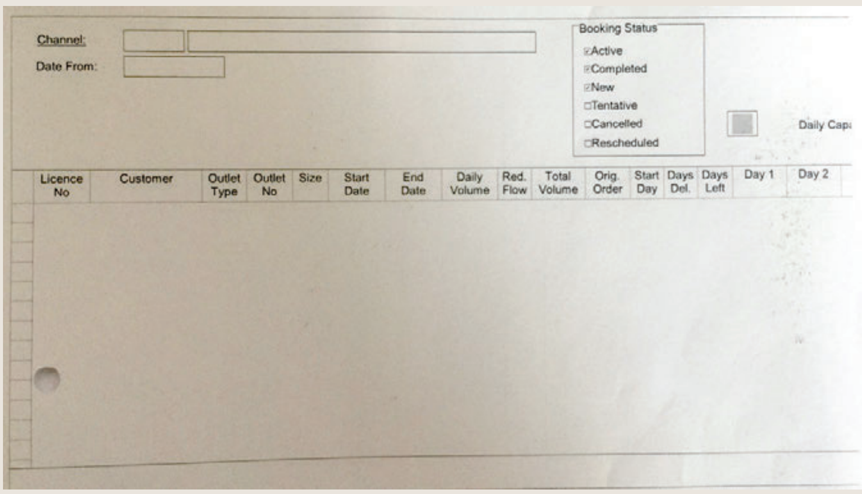
Figure 7. Coliban canal

Figure 8. 50mm outlet



Licence No: 90335 Fin. Year: 2017-18 Balance: 726
Prime Debtor: Rendell, Robert John
Outlet No: 020 Outlet Type: PI Pipe
Channel: 17 Speciman Hill
Status: N New
Daily Volume: 220 kl ☐Reduced flow Size: 50
Booked Start: Fri 13/04/18 Days: 3 Booked End: Mon 16/04/18
Actual Start: Actual End:
Volume Supplied
Chargeable: 0 kl
Low: 0 kl
Volume Remaining: 660 kl
Total: 660 kl
Comment:

Figure 9. Individual farmer's order



Channel:
Date From:
Booking Status
☑Active
☑Completed
☑New
☐Tentative
☐Cancelled
☐Rescheduled
Daily Capa

Licence No	Customer	Outlet Type	Outlet No	Size	Start Date	End Date	Daily Volume	Red. Flow	Total Volume	Orig. Order	Start Day	Days Del.	Days Left	Day 1	Day 2

Figure 10. Canal ordering sheet (no data)

Australia

water partners for development

The Australian Water Partnership is an Australian Government international cooperation initiative helping developing countries in the Indo-Pacific region, and beyond, work towards the sustainable management of their water resources.

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