Seepage rate estimation from total channel control data during periods of shut down: preliminary data quality assessment case study – Coleambally irrigation system

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Abstract

In recent years, major south-eastern Australian irrigation companies have invested heavily in modernization which includes installation of automatic control structures with remote monitoring, the so called total channel control technology (TCC). Main objectives of using TCC technology are to supply water near-on-demand and to control channel water levels. TCC includes supervisory control and data acquisition (SCADA) technology which will result in production of integrated databases based on real time measurements of the whole system. This data has the potential to be used to identify sections of channel with high rates of seepage or leakage. Pondage tests are acknowledged as the best direct method for seepage measurement, and the recorded water level data from automated systems during periods of gate closure can be treated as pondage test data. The purpose of this paper is to report on a preliminary quality analysis of such data during periods of shut down in the system in order to investigate the feasibility of using such data in seepage rate estimation. Coleambally irrigation district in southern NSW was chosen as the case study it being one of the first automated irrigation districts in the world and having three years of historical data. The analysis was done for all pondage conditions during the 2010 irrigation season and based on criteria requirements, accepted samples were categorized in different groups. The analysis showed that out of the total number of 1073 possible pondage conditions, 51% of them met the 70% criteria requirements and

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can be used for the purposes of this study. Examples of some individual periods of ponding are provided. Furthermore, it is concluded that TCC data is suitable for seepage and water loss analysis.
Keywords: Seepage estimation, total channel control, pondage test, irrigation channels, Coleambally irrigation.

1 Introduction

Earthen channels have always been one of the main mechanisms for the transport and delivery of water. Earthen channels in Australia have mostly been constructed using local materials, often with poor water-retaining characteristics. Recent surveys have indicated that around 4% of the total water supplied for rural use is lost due to channel seepage [1]. Channel seepage involves the relatively uniform passage of water through the wetted perimeter of the channel profile due to poor quality of substrate material [2].

Pondage tests are acknowledged as the best direct method for seepage measurement. Pondage testing may require the construction of earthen banks to create leak-proof section in channels where the drop in water level can be measured. The location of the barriers depends on project objectives and might be determined by geophysical surveys or perhaps anecdotal information. However in many cases existing structures can be used, particularly when automated regulating and measurement equipment has been installed. The application of pondage tests as a useful technique for seepage estimation has been shown in several studies conducted in irrigation districts in Australia [1–11]

Total channel control (TCC) is a breakthrough in both irrigation management and flow measurement that has transformed the inefficient manually operated open channel networks into automated, integrated and remotely controlled systems with high efficiencies [12]. The system is based on two aspects: 1) The control of large networks of solar-powered canal regulators and gates, which are linked through radio telemetry and 2) Advanced computer software, which enables the automatic and remote operation of the entire canal network.

The main objectives of using TCC technology are to supply water near-on-demand and to control channel water levels [12]. TCC includes supervisory control and data acquisition (SCADA) technology which results in production of integrated databases containing real time measurements of flow and depth over the whole system. This data has the potential to be used to identify sections of channel with high rates of seepage or leakage. The recorded water level data from automated systems during periods of gate closure can be treated as pondage test data. The purpose of this paper is to report on a preliminary quality analysis of such data during periods of shut down in the system in order to investigate the feasibility of using such data in seepage rate estimation.

TCC data has been shown to be a useful database in channel loss assessment [13]. Schulz (2009) used TCC data of Goulburn-Murray Water to develop a model to assess channel pool losses pre and post channel remediation. He suggested that hydrographs must be processed prior to concluding channel loss rates. He eliminated noise associated with measurement error and other factors by converting the hydrographs to loss rates as a function of water depth, which was followed by modeling of loss rates to predict losses at selected water depths [13].

2 Case study – Colleambally irrigation

The Coleambally Irrigation District (CID) is located south of Griffith between Darlington Point and Jerilderie, New South Wales in the southern Murray-Darling Basin of Australia (Figure 1). The area consists of 477 irrigation farms containing 79,000 ha of irrigated land supplied through open earthen channels. Water is sourced from Gogelderie Weir on Murrumbidgee River, one of the major tributaries of the Murray River. Water supplies are regulated from two major Snowy River Scheme dams, Burrinjuck and Blowering [14].

Figure 1: Location of Coleambally in Australia [14].

The CID was developed over the period 1958 to 1970. It consists of 47km of main canal from the Murrumbidgee River, 469km of supply channel, and a further 711km of drainage channels. Trough the development of CID about 35,000 hectares of total irrigation area is effectively irrigated [14]. In 2002, in response to declining water availability, Coleambally Irrigation Co-operative Limited (CICL), made the decision to install TCC automation technologies to improve the efficiency of the channel delivery system. As of September 2007 CICL's entire channel system, 514 km of channels with flow capacities ranging from 15 ML/day to 6,000 ML/day, is remotely operated [14]. The CID is the first open channel system in the world to automate regulators over its entire channel delivery system. The channel system is consisted of 322 channel regulating and control structures and 435 farm outlets.

With the main objective of supplying water near-on-demand and controlling water levels in different channels of the system, SCADA technology enables the CICL system operators to monitor the behavior of the irrigation supply system and to control the key system components from the office computer. The control center computer is based on the real-time development environment, which enables full integration of real-time data into production of flow and water level databases for the entire channel system. The database includes a variety of measurements, including water flow measurements for each gate, water level elevations for upstream and downstream side of each gate. The data required for this paper, provided from the TCC system of CICL consists of:

- Flow measurements at all automated main gates and farm outlets, recorded irregularly at changes in the flow rate.
- Water level elevations at all automated main gates and farm outlets, usually recorded irregularly at changes in the flow depth; each main channel gate has two water level records (upstream and downstream). The data used in this paper is the upstream side only as the downstream data was considered by the data provider to be poor quality
- Rainfall data usually recorded regularly every 30 min
- Evaporation data usually recorded regularly every 30 min

3 Model

In order to be able to retrieve and analyse the large quantity of data efficiently, Microsoft SQL server software, one of the best available database management programs was chosen. Furthermore additional code was written in c sharp environment in conjunction with the SQL server software to accomplish the pre quality analysis of data. Figure 2 shows the algorithm applied to model the CID with the main steps detailed in the following sections.

3.1 Mapping

Initially in order to map the whole system, number of tables were defined in SQL server software to create a database. These tables included:

- Main Reach
- Gate
- Pool
- Flow data
- Water level elevation
- Automatic weather station (AWS) ID
- Evaporation
- Rainfall

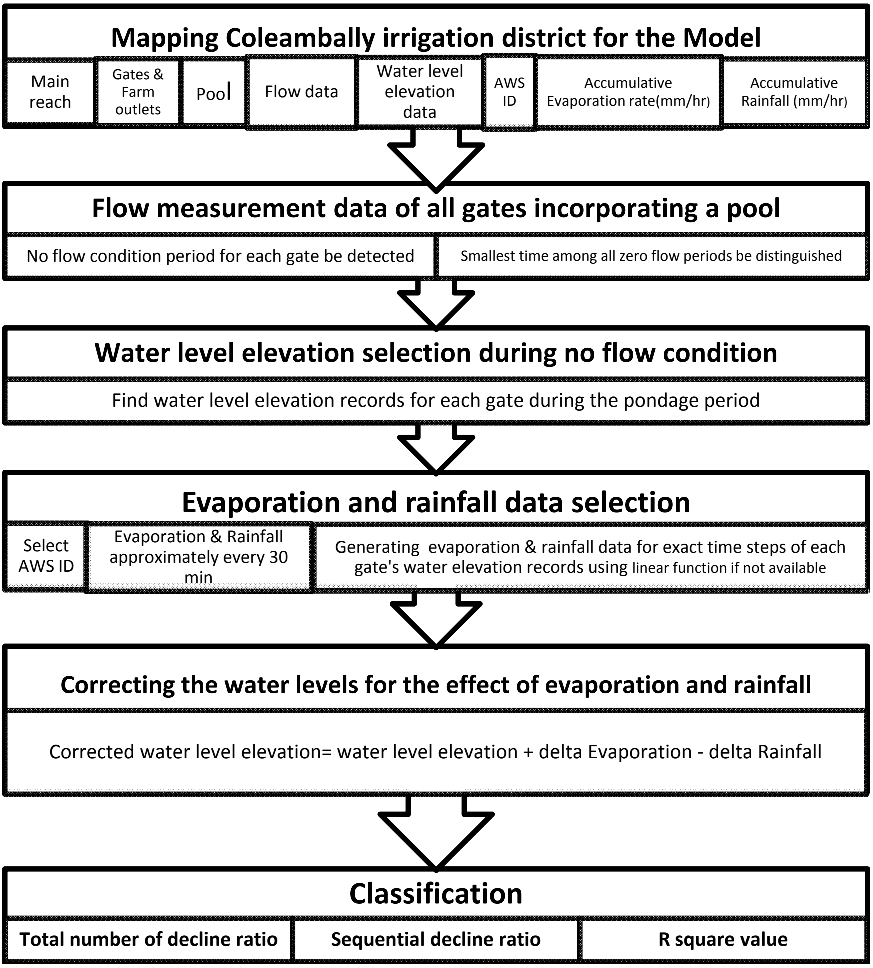

Figure 2: Algorithm applied in the model.

At first CID was divided in to 7 main reaches. Afterwards a table for all the gates in the district was defined for the system. In the gate table, 4 columns were defined including, name of the gate, the main reach where the gate is located, whether the gate is a farm outlet or not and the related AWS ID that AWS data should be selected from. The next table was pool table in which considering Coleambally schematic map, each pool and the main reach where the pool is located were defined for the system. All the gates incorporating each pool and upstream gate of the pool were defined in the next table that is called pool detail table. Total number of gates and farm outlets per main reach is provided in Table 1.

Table 1: Number of gates, outlet farms and possible pools in each main reach.

Main reach	Gates	Outlet farms	Pools
ARGOON	25	35	22
BOONA	36	45	28
BUNDURE	60	79	48
COLY	93	126	79
MAIN CHANNEL	33	44	24
TUBBO	19	26	14
YAMMA	56	80	47
TOTAL	322	435	262

3.2 Zero flow period detection

After the whole district was defined for the system, the next step was to define a pondage condition for each pool. First a table containing the flow measurement data for all gates for the year 2010 was defined in the database as gate flow table. Afterwards a minimum optional time for pondage duration was defined for the model and it was expected that if the flow information for all the gates in each pool were available, the model starts to find and show zero flow duration for each of the gates. Consequently if all the gates had a same zero flow time in common, the smallest time among all zero flow periods would be distinguished and introduced as the pondage condition.

3.3 Water level elevation selection

Having selected the pondage condition period the next step is to find water elevation records of each gate during the pondage period. First a table containing the water level elevation data of all gates for year 2010 was defined in the database as gate elevation table. The gate water elevation table contains 3 columns presenting gate name, reading date and water level elevation measurement. Since the time steps of water elevation measurement records do not necessarily match with flow measurement records, the model will search among all water elevation record time steps to find the closest one to the start and end date of the zero flow period and then all water level elevation records in between the selected start and end date would be extracted from the database.

3.4 Evaporation and rainfall data

The next step is to select the related value of evaporation rate and rainfall during the pondage period. First the AWS data had to be defined in the database. The evaporation rate estimated in the both weather stations is in mm per hour. Since all the variables should be homogeneous and in the same units (millimetre), using the time difference between two sequential rates, the evaporation data was first converted from a rate in millimetre per hour into a cumulative depth in mm and then the evaporation table was defined in the database. Similarly rainfall was first converted from mm per hour to a cumulative depth in mm and then the rainfall table was defined in the database. Each of the two AWS tables contains 3 columns indicating AWS ID, reading date and the value estimated or measured.

AWS measurements are recorded at least every 30 min but recorded time steps do not necessarily correspond to the times that the water levels at the gates are read. Therefore the next task was to generate evaporation and rainfall values using linear interpolation corresponding to the exact time of each gate reading during the pondage condition.

3.5 Correcting the water levels for the effect of evaporation and rainfall

Having provided the AWS data for each gate, the next step is to eliminate the effect of evaporation rate and rainfall value from the water elevation measurement records at each time step. The evaporation and rainfall corrected data for each time step is calculated using the following equation:

$$Corrected\ water\ elevation_{\,n} = water\ elevation_n + (Evaporation_n - Evaporation_1) - (Rainfall_n - Rainfall_1) \qquad (1)$$

In which n represents any of the time steps during the pondage period and 1 represents the initial value in the zero flow period.

3.6 Classification

In order to classify the corrected water elevation data of all possible pondage pools throughout the whole district three criteria were applied to the data.

- Total decline ratio
- Sequential decline ratio
- R squared

3.6.1 Total decline ratio

The first criterion applied in the classification of the corrected water elevation data, is called the total decline ratio. Using the following equation, the ratio is calculated for each gate and pondage condition.

$$Total\ decline\ ratio = \frac{Total\ number\ of\ points\ showing\ \ a\ decline}{Total\ number\ of\ points - 1} \qquad (2)$$

In order to define the ratio for the model the difference between each two sequential corrected elevation data values was calculated and if shown to have a decrease was counted in the dividend. Furthermore if there was no difference between two points, meaning that the elevation remained constant, it also was counted in the dividend. Since the first point cannot be counted in the calculation of the dividend, the divisor is one unit smaller than the total number of points.

3.6.2 Sequential decline ratio

The sequential decline ratio is the result of total number of points in a row showing a decrease divided by total number of points. Using the following equation, the ratio for each gate was calculated

$$Sequential\ decline\ ratio = \frac{Total\ number\ of\ points\ in\ a\ row\ showing\ a\ decline}{Total\ number\ of\ points - 1} \quad (3)$$

As there might be more than one possible ratio in a pondage, all are calculated and the maximum value among all ratios is selected as the sequential ratio.

3.6.3 R^2 value

The final criteria used for the data classification was R^2 value, determined by application of linear regression to the plots of corrected water elevation readings versus time for each gate. The linear regression model also gave a first estimate of the seepage rate for each pondage.

4 Result

Having all the pondage condition samples reported by the model, the next step was to classify the accepted and rejected ones into different groups and also make a full assessment of all the samples. The concept of classification was based on the behaviour of corrected water elevation changes of each gate in the pool during the pondage time, evaluated using the three criteria mentioned earlier. A full assessment of all samples based on different main channels were done and the results show that out of 262 pools, 35 of them were excluded from the study due to lack of data and 33 of them did not have the minimum duration of 48 hours of zero flow condition (Figure 3). Details of excluded pools from the analysis in each main reach are provided in Table 1.

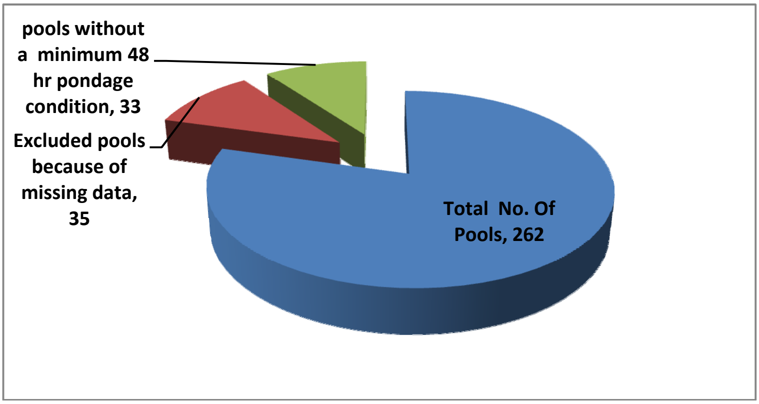

Figure 3: Proportion of pools excluded from the analysis.

Studying the distribution of pools having one or several pondage conditions show that out of the total number of 1073 pondage conditions almost 47 percent of them occurred in pools having one to three zero flow conditions in the year

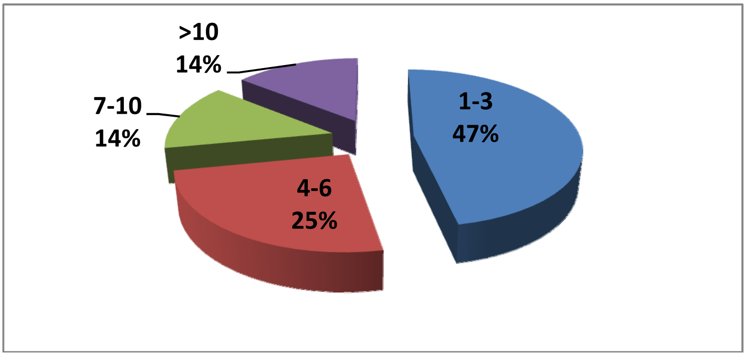

Figure 4: Distribution of pools having one or more pondage conditions during 2010–2011.

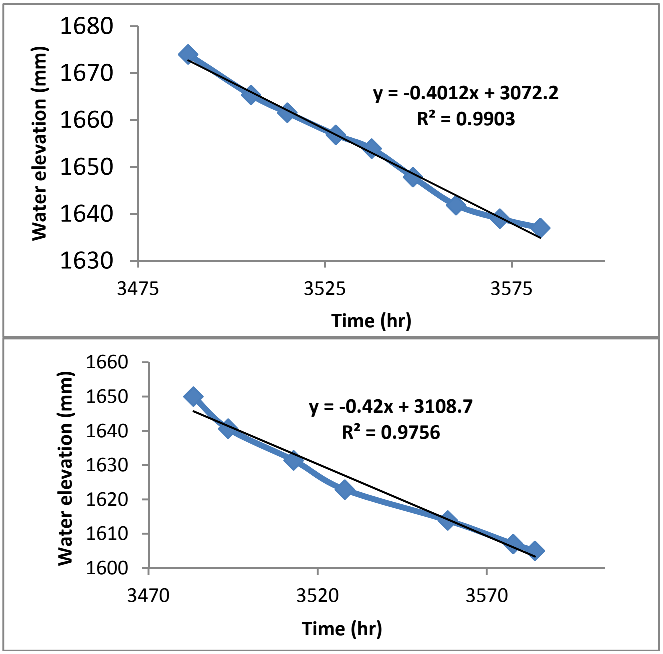

Figure 5: Example of a pool classified in group 1.

2010–2011, while pools with 4 to 6 pondage conditions had the second highest attribute of 25 percent of the total number of pondage conditions (Figure 4).

4.1 Accepted samples

Accepted samples were classified into 5 different groups as follows:
Group 1: In pools with several gates, if all gates have a total decline ratio and R^2 of more than 70%, the pool was classified as group 1. Figure 5 shows the

corrected water elevation pattern of gates in one of pools as an example of group 1.
Group 2: If a pool had information from only one gate and that gate had a total decline ratio and R^2 greater than 70%, it was classified in group 2.
Group 3: Depending on number of gates in the pool if some of the gates but not all of them had a total decline ratio and R^2 greater than 70%, the pool would be classified in group 3. Figure 6 shows the corrected water elevation pattern of gates in one of pools as an example of group 3.
Group 4: In pools with several gates, if all gates had a total decline ratio and R^2 greater than 50% but less than 70%, the pool was classified as group 4.
Group 5: If a pool had only one gate and that gate had a total decline ratio and R^2 greater than 50% but less than 70%, the pool was classified in group 5.

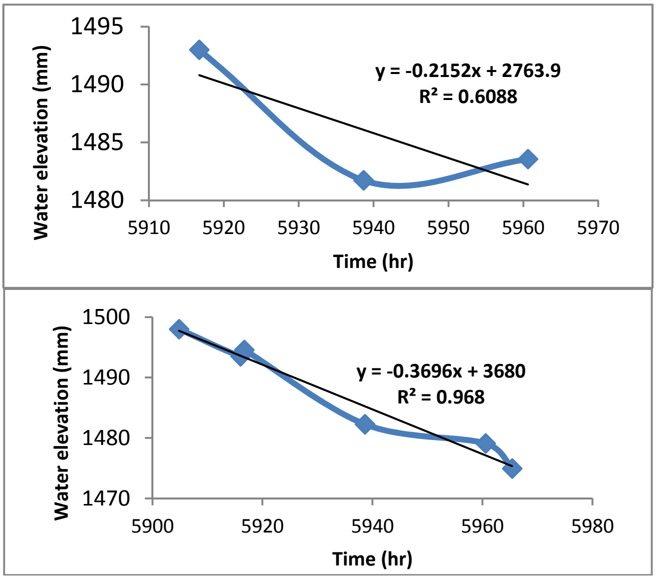

Figure 6: Example of a pool classified in group 3.

4.2 Seepage magnitude

The linear regression model was also used to give a first estimate of seepage rate for each gate. Having plotted the frequency of seepage rate magnitudes for all the gates, approximately 93% of the accepted samples had seepage rates less than 1 mm per hour, among which only 19% of them had seepage rate greater than 0.5 mm per hour. On the other hand, only 6% of accepted samples had seepage rates greater than 1 and less than 3 mm per hour and only in thirteen cases the seepage rate exceeded 3 mm per hour (Figure 7).

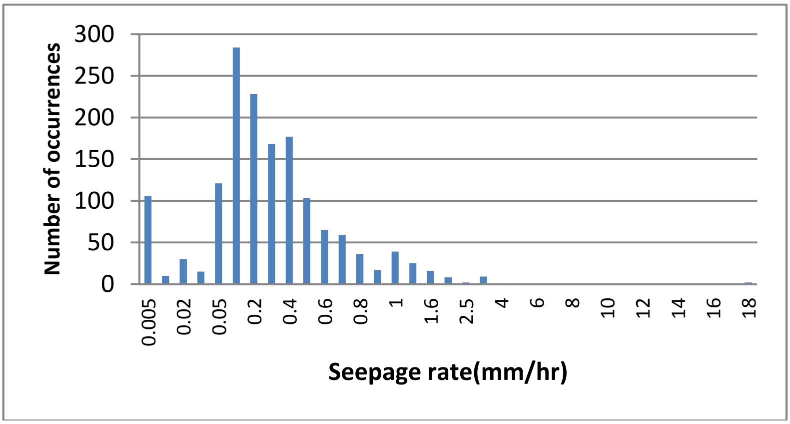

Figure 7: Frequency of seepage rate for all gates in 2010 using linear regression.

5 Conclusion

An analysis was done for all pondage conditions during the 2010 irrigation season and based on the nominated criteria, accepted samples were categorized into 5 different groups. The results of the assessment showed that out of 1073 possible pondage conditions, 778 met the criteria. On the other side, 295 samples were rejected due to having low values of R squared and total decline ratio.

Analysis of the results showed that Coly had the highest number of pondage conditions while the Main channel with only 52 had the lowest proportion of pondage conditions among all main reaches of the district. The analysis also showed that approximately 70% of the accepted samples met the criteria requirements of the first and the second group (Table 2), with 42% in first group and 28% in second group respectively (Table 2). Linear regression was used to calculate a first estimate of seepage rate for each gate. Analysis of results showed that 56% of gates had seepage rates around 6 mm per day, which seems to be a high potential of seepage and requires further investigation. Results of the

Table 2: Distribution of accepted samples in different main reaches.

Main reach	No. Of pondage condition	Accepted pondage conditions					Total no. of accepted samples	Ratio of accepted to total samples	Group1 &2 to total samples	Group1 &2 to accpted samples
		Group 1	Group 2	Group 3	Group 4	Group 5				
ARGOON	54	7	19	4	9	1	40	74.07%	48.15%	65.00%
BOONA	207	46	66	9	9	19	149	71.98%	54.11%	75.17%
BUNDURE	201	74	31	20	8	9	142	70.65%	52.24%	73.94%
COLY	366	114	65	40	13	27	259	70.77%	48.91%	69.11%
MAIN CHANNEL	52	13	13	5	2	6	39	75.00%	50.00%	66.67%
TUBBO	59	22	4	7	6	3	42	71.19%	44.07%	61.90%
YAMMA	134	51	24	20	8	4	107	79.85%	55.97%	70.09%
TOTAL	**1073**	**327**	**222**	**105**	**55**	**69**	**778**	**72.51%**	**51.16%**	**70.57%**

preliminary analysis showed that TCC data can be used as a reliable database for seepage analysis assessment. Future work will involve: (i) analysis of data from other years and other systems, (ii) correlation with soil type and EM38 survey data, and (iii) identification of high seepage loss reaches for remediation.

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