IRRIGATION EFFICIENCY CRUCIAL FOR ENSURING SUSTAINABLE WATER RESOURCE

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ABSTRACT

Irrigation network efficiency is a fundamental component in ensuring a sustainable water resource and this has become more pertinent with the expansion of irrigation areas, aging infrastructure and climate change.

There are number of aspects that drive an efficient irrigation network, with water resource planning, maintenance programs and flow monitoring network that form the key components. The knowledge of water lost due to evaporation, leakage or unauthorised abstractions as a result of a well-designed monitoring network is invaluable, as this assists in decision making processes for future expansion or maintenance of the irrigation network.

The ability to accurately monitor flows within irrigation networks, even under stress during peak demand can highlight structures that exceeds their hydraulic limit during certain flow conditions. Most importantly, it gives both the customers and operators the confidence that the flow and associated billing from water releases are accurate.

Murrumbidgee Irrigation (MI) implemented a validation process to review the flow monitoring network at strategic points over a 3-month period. The process consisted of temporary installation of SonTek SL1500-3G acoustic Doppler instruments at nine predefined measurement sites. An index velocity rating was developed that is based on velocity measurements from these instruments and discharge measurements from RiverSurveyor M9 acoustic Doppler current profiler. The index velocity rating is robust against variable backwater conditions, normally encountered during peak demand.

The process implemented by MI to automate the data collection, audit and index velocity rating development is sophisticated to ensure accurate assessment of the flows. The SL1500-3G instruments sends velocity and diagnostic data at fixed sample intervals via serial output over TCP/IP to an SQL data base. The RiverSurveyor M9 discharge measurements performed during the week are processed at the office, from where the information is captured into custom designed application. The application compares the data captured from the discharge measurements against the velocity data stored on the SQL database. Index Velocity rating is developed based on information entered, from where a detailed assessment is performed to determine if the index velocity rating is valid. During the verification period, field personnel has the option to request that no flow changes are made during the discharge measurements. This ensures that the flow in the channel is relative stable during the discharge measurements.

The flow results from the index velocity ratings are used to further improve the existing stage-discharge relationships at each of the flow measurement sites selected within the irrigation network.

Keywords: Acoustic, Velocity, Index Velocity, Discharge, Irrigation, Resource, Sustainable

1. INTRODUCTION

Irrigation network efficiency is a fundamental component in ensuring a sustainable water resource and this has become more pertinent with the expansion of irrigation areas, aging infrastructure and global warming.

There are number of aspects that drive an efficient irrigation network, with water resource planning, maintenance programs and flow monitoring network forming the key components. The knowledge of water lost due to evaporation, leakage or unauthorised abstractions as a result of a well-designed monitoring network is invaluable as this assist in decision making process for future expansion or maintenance of the irrigation network.

Murrumbidgee Irrigation (MI) is one of the largest private irrigation companies in Australia supplying water to over 3,260 landholdings within an area of 378,911ha in the Murrumbidgee Irrigation Area (MIA). The MIA is a highly productive agricultural region where most farmers rely heavily on the water supplied by MI for their irrigation needs. During 2019/2020 season, MI's delivery network incurred water losses of ~15% which amounts to 64GL. Improving the irrigation efficiency of the network can result in substantial water savings that can be reallocated to farmers for productive use.

The ability to accurately monitor flows within irrigation network can help identify and address sources of water loss, it can also highlight structures that exceed their hydraulic limit during certain flow conditions. Most importantly, it gives both the customers and operators the confidence that the flow and associated billing from water releases are accurate.

MI uses flow measurements at the supply regulators to monitor flow in the irrigation network. The regulators use water levels and gate openings to compute flow and thus the accuracy relies on the calibration and maintenance of the sensors. There is a need to independently measure and validate the flows for improving the overall efficiency of the irrigation network.

Murrumbidgee Irrigation implemented a flow verification process during the 2019 / 2020 season to verify flow accuracy of the irrigation network. The flow measurement sites selected for the verification process are of strategic importance to the overall operation of the irrigation network. The following sections will cover the verification approach, instruments used and process for measuring flow.

2. METHODS

2.1. Flow Verification Approach

The flow verification approach adopted comprised of the index velocity method for continuous flow monitoring at the respective flow measurement sites. The index velocity method is not affected by variable backwater affects and is less sensitive to changes in cross sectional area, two common aspects normally encountered in open channel flow such as irrigation channels. The index velocity method requires the following two components for accurate and reliable flow computation.

- Real-Time velocity and stage measurements to capture actual flow conditions at the measurement site - Acoustic Doppler Velocity Meter (ADVM).
- Calibration discharge measurements performed during each scheduled site visit - Acoustic Doppler Current profiler (ADCP).

Stage-Area and Index-Velocity ratings were developed from synchronous velocity-stage (ADVM) and discharge (ADCP) measurements. The flow at each measurement site was computed by applying real-time velocity-stage measurements against Stage-Area and Index-Velocity ratings.

The workflow adopted for the flow verification process of Murrumbidgee Irrigation network is outlined in Figure 1.

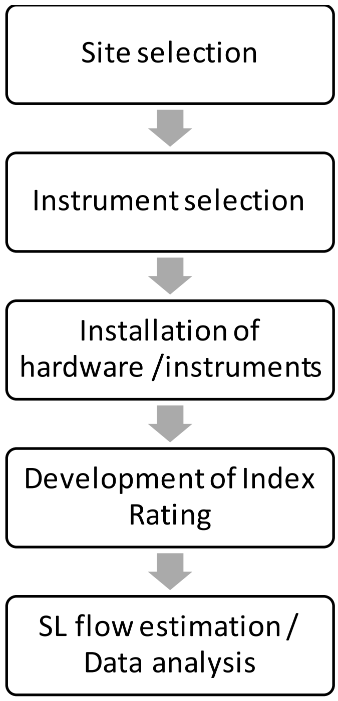

Figure 1: *Workflow of MI's Flow Verification Approach*

2.2. Measurement Site Selection

The measurement site selection process is essential for accurate and reliable data collection during the verification process. The selection criteria implemented during the site selection process was based on several measurement site and hydraulic requirements provided in Table 1.

Table 1: *Selection criteria for measurement sites.*

Criteria		Comment
1	Steady Uniform flow with sub-critical flow conditions	Channel cross-section surveyed using ADCP. Measurements used to document velocity distribution, channel shape and bathymetry.
2.	Uniform velocity distribution over the width of the cross-section.	Channel cross-section surveyed using ADCP. Measurements used to document velocity distribution, channel shape and bathymetry.
3.	Channel section relatively straight for 10* channel width upstream of measurement site with uniform cross-section.	Aerial Imagery used to measure reach lengths. Channel cross-section surveyed using ADCP.
4.	Distance of > 10* channel widths from any control / hydraulic structures	Distances from control structures verified via aerial imagery
5.	Channel bed and slopes free of aquatic vegetation, debris and sediment	ADCP used to survey upstream and downstream of SL location. Maintenance team required to clean 2 channels.

An initial shortlist of measurement sites located on Murrumbidgee Irrigation main supply channels was generated based on their strategic importance and the need for accurate flow measurements. A final list of 9 measurement sites were compiled from the short list based on their suitability to accurate apply the index velocity method provided in Table 2.

The measurement sites selected are located on 2 of the major supply channel systems in Murrumbidgee Irrigation network, the Lake View Branch Canal LVBC and the Northern Branch Canal. The channel geometry, bathymetry and flow/velocity distribution were surveyed using ADCP instrument. Figure 3 shows the cross-section from the ADCP survey at one of the selected sites, Rosetto. This concrete lined channel has a uniform trapezoidal cross-section and a uniform velocity distribution as shown in Figure 3.

Table 2: *The names, channel types, dimensions and max design capacities of the sites selected for flow verification.*

Asset ID	**Name**	**Channel Type**	**Top Width (m)**	**Bottom Width (m)**	**Max Flow(ML/d)**
RG-2-698	Scotts Rd	Concrete	9	3.2	395
RG-2-950	Apolonis	Concrete	7.8	2.6	310
RG-2-951	Overs	Concrete	7.9	2.6	300
RG-2-640	NBC-1	Earth	16.5	8	677
RG-2-679	NBC-Offtake	Earth	16.6	8.8	690
RG-2-949	Nericon	Concrete	8	2.6	340
RG-2-680	Temora Rd	HDPE lined	6	2.3	260
RG-2-681	Rossetto	HDPE lined	6.8	2.3	242
RG-2-621	Andreattas	Concrete	8.3	3.2	370

Figure 2: *Aerial View of SL1500-3G Site Installation on the NBC.*

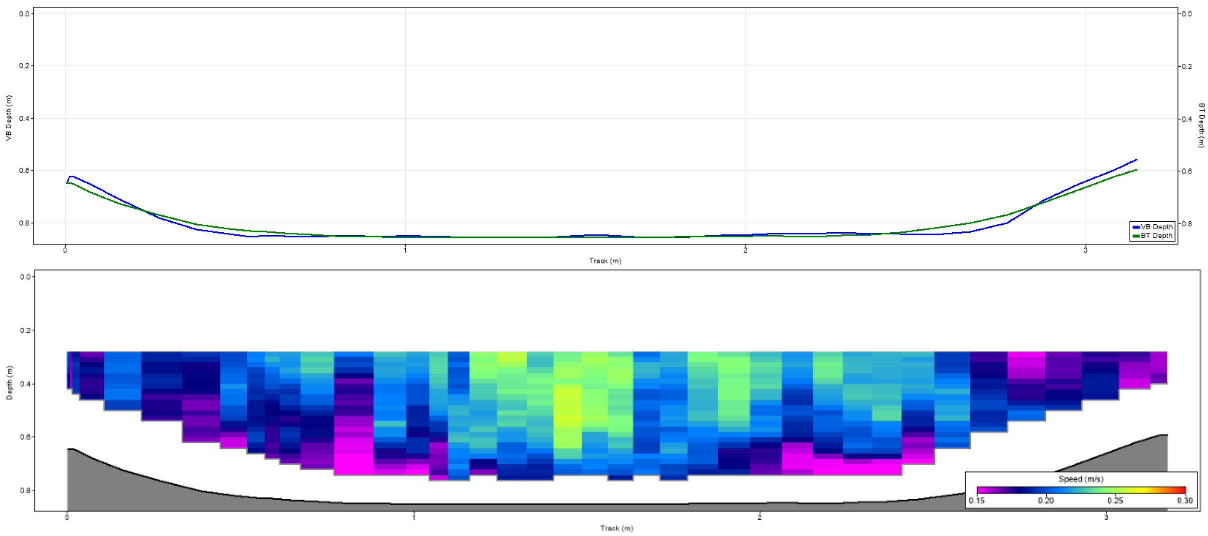

Figure 3: *Channel Cross-Section (top) and Velocity Distribution (bottom) at the Rosetto site on NBC.*

2.3. Instrument Selection and Integration

2.3.1. Instrument selection

The instrumentation adopted for developing rating at each measurement site can be grouped under Real-Time (ADVM) and Calibration (ADCP) flow measurement devices, shown in Table 3.

Acoustic Doppler Velocity Meter (ADVM) instruments are mounted on the channel bank, with fixed orientation and elevation. Continuous velocity and stage measurements are performed that is reported based on user specified sampling interval and sampling duration.

Acoustic Doppler Current Meter (ADCP) instruments are used to perform instantaneous flow measurement at a monitoring site. The flow is measured by traversing the channel comprising of reciprocal transects with the instrument deployed on either a board or remote-controlled boat.

Table 3: *Acoustic Doppler Measurement Devices.*

Group	Type	Model	Measurement	Calculated
Real-Time	ADVM	SonTek SL1500-3G	• Stage • X-Velocity • Y-Velocity	• Flow • Area • Mean Velocity • Velocity Magnitude
Calibration	ADCP	RiverSurveyor M9	• Depth • X-Velocity • Y-Velocity • Bottom Tracking	• Flow • Area • Mean Velocity

2.3.2. Hardware Integration

(i.) ADVM Mounting Frame

ADVM (SL1500-3G) instruments were installed at each of the 9 measurement sites identified for flow verification, illustrated in Figure 4. The SL1500-3G was mounted on a sliding mount secured in between two sliding rails on the side of the channel, shown in Figure 5. The sliding rails were fixed in place by a steel frame secured to a 500L road barrier filled with water. The mounting system allows for quick installation without the need for establishing permanent infrastructure or modification to the existing channel lining. The design of the mounting system makes it easy to redeploy at other measurement sites and perform maintenance on the instrumentation.

Figure 4: *SL1500-3G deployment.*

Figure 5: *Temporary SL1500-3G Mounting Frame.*

The telemetry equipment and power supply was housed inside a junction box (refer to Figure 6) which included:

- NTC-100-01 4G LTE CAT M1 Serial IOT device: to collect serial data form the SL and send it to MI's database in real-time
- 12V battery: to provide power the SL1500-3G and IOT device

The junction box was mounted inside a stainless-steel frame, with a 20 W solar panel attached on top of the frame to charge the battery.

Figure 6: *Junction Box for Housing Electronics*

(ii.) ADCP Cableway

ADCP (RiverSurveyor M9) cableway's were installed adjacent to the SL1500-3G installation's at each of the measurement sites. The cableway allow a single operator to perform an ADCP discharge measurement with RiverSurveyor M9, shown in Figure 7. The use of a cableway improves the overall accuracy of the discharge measurement by achieving a more constant boat speed while traversing across the channel. A plastic mesh was used to attach the Hydro-board to the cableway at two points, thus reducing lateral movement on the Hydro-board and minimised the variance in discharge measurement results.

Figure 7: *Cableway Design at each Measurement Site for ADCP Discharge Measurements.*

2.3.3. Instrument Configuration

The criteria used for SL1500-3G configuration and installation was specific to each measurement site. The key aspects that was focused on during the initial configuration and installation comprised of the following in Table 4.

Table 4: *Criteria for configuration and installation of SL1500-3G.*

Aspect	**Criteria**
Cell Size	The number of cells and cell size was dependent on the channel shape and width. The measurement volume range of the instrument was restricted to exclude 10% of total width from the opposite bank. The number of cells and cell size in relation to the channel cross section is shown in Figure 8.
Number of Cells	
Sampling Interval	Sampling interval was selected based on the rate of change of the flow hydrograph
Sampling Duration	Sampling duration was selected based on sampling interval and power supply
Elevation	The instrument elevation was determined based on historic water levels, ensuring the instrument is located approximately 0.6 of the water depth from the water surface

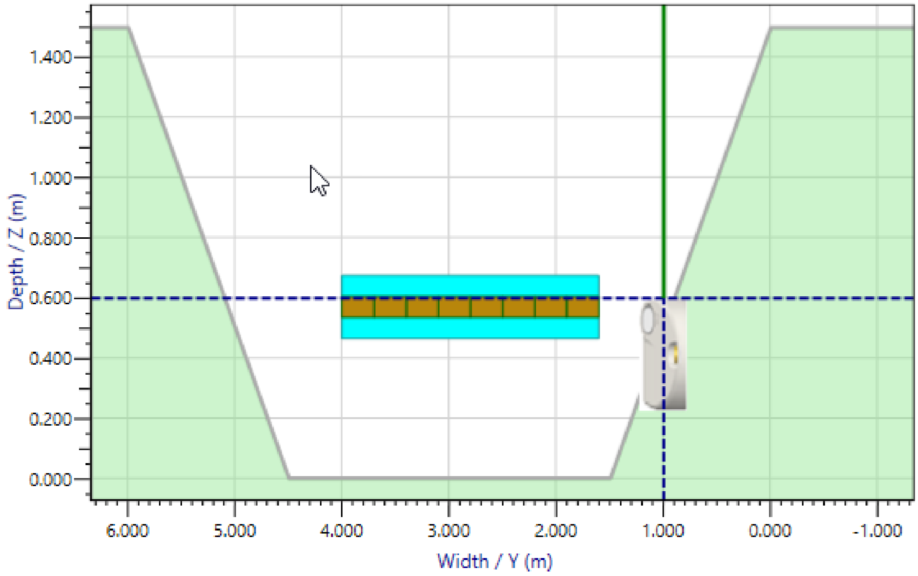

Figure 8: *Measurement Volume in Relation to Channel Cross Section.*

2.4. Instrument Maintenance

The operation of the SL-15003G was verified during each scheduled visit to ensure the instrument is functioning properly. The steps followed to verify operation is provided in Table 5.

Table 5*: Maintenance steps performed on instrument*

Step	**Procedure**
Beam Checks	Beam checks recorded and analysed by field hydrographer at every site visit to ensure acoustic beams are not being obstructed within the measurement volume.
Internal clock check	The instruments clock time checked for drift during site visits.
Clean instrument	Every month SL1500-3G were raised form the water and cleaned with a light brush to remove any sediment or biofouling if present.
Clean frame/ mount	The sliding rails and SL1500-3G mount were inspected during site visits to ensure no debris was impacting measurements.
Format recorder	The data from the internal recorder was downloaded and the recorder formatted periodically.

2.5. Data Transmission / Storage

All the SL1500-3G's instruments were configured with a sampling interval of 300s and a sampling duration of 240s. The sampling interval is dependent on the rate of change of flow hydrograph and the application of ADVM in irrigation or storm water channels, a 5 minute interval is regarded as the maximum to accurately record changes in flow conditions. The sampling duration is dependent on the sampling interval and power supply provided at the measurement site. A longer sampling duration averages the small scale turbulence affects in the channel and therefore improving the standard deviation of the measured velocity.

The instruments measures continuously during the 240 seconds sampling duration and the average of each measured variable is stored against every 5 minute sampling interval. A total of 32 variables are available through ASCII output.

At the end of each sampling interval the data is stored internally as well as providing an output via the RS232 serial port to the NTC Cat M1 modem in the form of ASCII characters.

The modem sends this data as packets via TCP/IP to a Virtual Machine (VM) hosted on MI's server. A python application running on the VM parses the ASCII characters, transforms them into a table based on predefined rules and uploads the records to MI's SQL database. The data flow from the SL1500-3G to MI's SQL server is illustrated in the Figure 9.

Data Telemetry Architecture

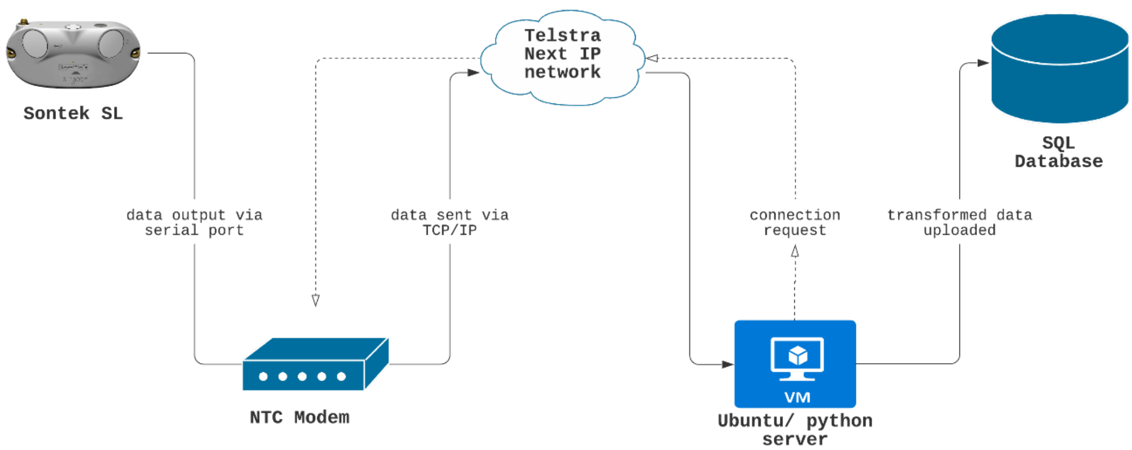

Figure 9: *Flow Chart of Data Flow from the SL1500-3G to MI's SQL Server.*

The python application identifies the source of the data based on the unique IP address associated with the SIM card installed in the modem at each location.

Technologies used:

- *Python*: a general-purpose programming language used for data engineering and analysis tasks in this project
- *SQL Server*: a relational database management system that was used for storing and managing data in this project.

2.6. Database Structure

The SQL database developed for the flow verification process contains of four tables to store the index-velocity and discharge data, shown in Table 6. The SL1500-3G sites are treated like objects in the SQL database and are given a unique OBJECT_NO shown in Figure 10. The objects table is used to store the details of each site such as channel name, location coordinates and unique keys used to identify the sites.

Table 6: SQL Database Tables

Table	Description
Objects	Information on the unique locations
Tags	Tag Ids for unique parameters for each object
Events	Timestamped values for the parameters
Survey-Compilation	Contains discharge summary for each ADCP measurement

OBJECT_NO	ASSET_CODE	SITE_NAME	LATITUDE	LONGITUDE	CHANNEL_NAME
6857	RG-2-679	NBC OFFTAKE	-34.288	146.252	NBC
29355	RG-2-698	SCOTTS RD REGULATOR	-34.26	146.031	LVBC
30525	RG-2-949	NERICON REGULATOR	-34.209	146.057	LVBC
30822	RG-2-950	APOLONIS REGULATOR	-34.198	146.06	LVBC
30840	RG-2-951	OVERS REGULATOR	-34.188	146.056	LVBC
31412	RG-2-640	NBC-1	-34.274	146.248	NBC
33482	RG-2-680	TEMORA ROAD REG	-34.243	146.229	NBC
33596	RG-2-681	ROSSETTO CHECK	-34.239	146.228	NBC

Figure 10: *Structure of the Objects Table in MI's database.*

A unique TAG_ID value is used to reference each output attribute for each SL1500-3G object shown in Figure 11 (left). As data is received from the instrument, it is uploaded to the Event table shown in Figure 11 (right) where the EVENT_TIME column represents time when the SL1500-3G starts sampling, the EVENT_VALUE column shows the measured value and TAG_ID column identifies the type of measured attribute.

TAG_ID	TAG_DESC	TAG_UNITS	OBJECT_NO
1503628	Adjusted pressure	dbar	23635
1503629	Battery Voltage	V	23635
1503636	Flow Area	m^3	23635
1503635	Flow Rate	m^3/s	23635
1503620	Heading offset	deg	23635
1503632	Noise Beam 1	counts	23635
1503633	Noise Beam 2	counts	23635
1503634	Noise VB	counts	23635
1503621	Pitch	deg	23635
1503627	Pressure	dbar	23635
1503622	Roll	deg	23635

TAG_ID	EVENT_TIME	EVENT_VALUE
1503618	2020-10-28 07:50:00.0000000	424
1503618	2020-10-28 07:55:00.0000000	423
1503618	2020-10-28 08:00:00.0000000	422
1503618	2020-10-28 08:05:00.0000000	421
1503618	2020-10-28 08:10:00.0000000	415
1503618	2020-10-28 08:15:00.0000000	412
1503618	2020-10-28 08:20:00.0000000	413
1503618	2020-10-28 08:25:00.0000000	418
1503618	2020-10-28 08:30:00.0000000	410
1503618	2020-10-28 08:35:00.0000000	410
1503618	2020-10-28 08:40:00.0000000	412

Figure 11: *Tags Table (left) - Events Table (right).*

The data collected from ADCP discharge measurements were compiled and uploaded to the Survey-Compilation table. A new row is appended to this table after each completed discharge measurement. The survey-compilation table contains a summary from each ADCP discharge measurement and the corresponding IV and stage measurements from the SL1500-3G. Each data entry is referenced to the OBJECT_NO of the measurement site as show in Figure 12.

OBJECT_NO	BEG_DATE	END_DATE	FLOW_RATE	AREA	MCV	IV	DEPTH	SURVEY_QUALITY
29355	2019-10-11 05:30:00....	2019-10-11 06:00:00....	1.038	7.052	0.14719...	0.157...	0.6042...	Good
29355	2019-10-11 22:25:00....	2019-10-11 22:40:00....	1.773	7.219	0.24560...	0.2698	0.6234...	Good
29355	2019-10-12 00:00:00....	2019-10-12 00:15:00....	2.063	7.322	0.28175...	0.296...	0.6356...	Good
29355	2019-10-12 01:00:00....	2019-10-12 01:15:00....	2.104	7.408	0.28401...	0.304...	0.6423...	Good
29355	2019-10-14 21:45:00....	2019-10-14 22:00:00....	1.481	7.387	0.20048...	0.2095	0.6383...	Fair
29355	2019-10-24 22:41:00....	2019-10-24 22:55:00....	2.053	7.528	0.27271...	0.29	0.6683...	Good
30239	2019-10-25 01:55:00....	2019-10-25 02:30:00....	2.166	7.997	0.27085...	0.295...	0.5185	Poor
29355	2019-11-04 01:05:00....	2019-11-04 01:20:00....	0.493	6.88	0.07165...	0.070...	0.5770...	Good

Figure 12: *Survey-Compilation Table.*

2.7. Data Monitoring and Error Reporting

The selected timeframe of 3-months for instrument deployment at a measurement site ensured that a range of flow conditions were monitored during this period. Real-time telemetry and diagnostic data provided from the SL1500-3G instrument were assessed with python applications and SQL database to monitor the state of the instrument.

A python program was created to monitor the transmitted data samples, which were expected from each site every 300s (based on the sampling duration). If an Instrument failed to transmit a sample for three successive sampling durations, an email alert was sent to the Hydrological team. The team would then send a field personnel to inspect the instrument.

Additionally, some attributes of the SL1500-3G were also monitored to detect issues with the instrument. The following attributes were analysed:

- Pitch and Roll: These attributes were monitored to detect any changes to the instrument's alignment. Any changes in positioning could impact the index rating.
- Battery Voltage: Voltage was monitored to ensure the battery powering the SL1500-3G was being charged by attached solar panel. Figure 13 shows an instance where the battery failed to charge due to cloudy weather and failed to supply the required power to the instrument. An alert was received which allowed the field hydrologist to extract the battery and charge it.
- Signal to Noise Ratio (SNR): The ratio signal strength of the acoustic beams and the ambient instrument noise was monitored over time to track any changes which could be a result of a failing transducer, excessive biofouling on transducer or beams being obstructed. Figure 14 shows the instrument at RG-2-681 within the acceptable range of SNR > 3.

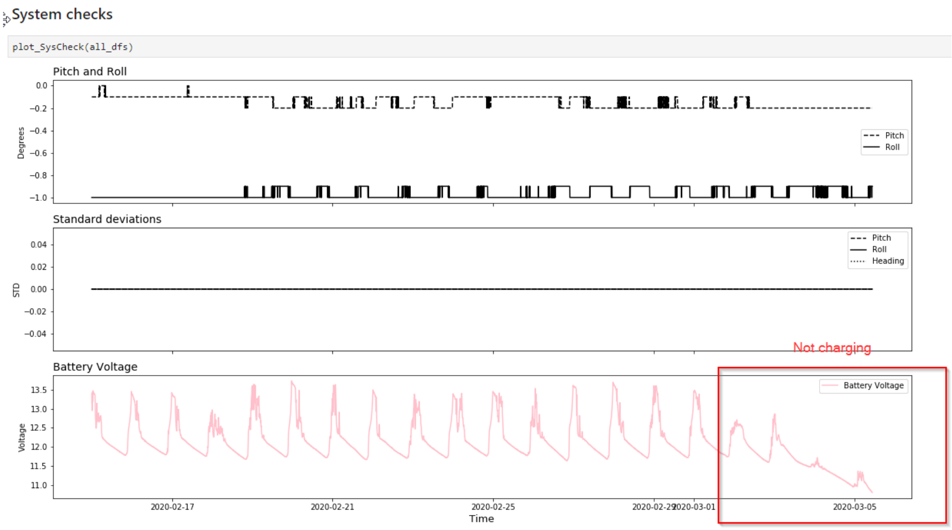

Figure 13*: Pitch/Roll and Battery Voltage Plots*

Figure 14: *Signal Amplitude and Noise Levels at the RG-2-681.*

2.8. Identification of Flow Ranges to Target

The Events table in the SQL database also contains gate flow data from pre-existing regulators at the selected sites. The historical data was used to identify the range of flows at each site and thereby the flow values at which ADCP discharge measurement would need to be done for developing robust ratings. The red crosses mark the flow rate/ bins where ADCP discharge measurements where completed.

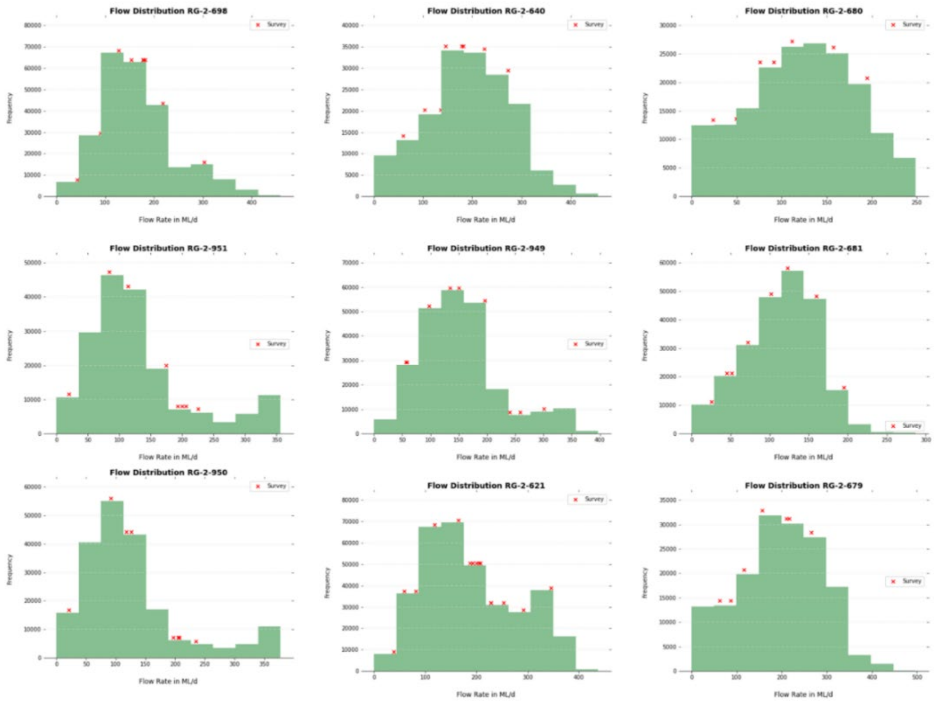

Figure 15: *Distribution of Flow Rate through the Regulators at Selected Measurement Sites.*

2.9. Flow verification process

At the measurement site, the field hydrographer requested the channel operators to set the regulator to a constant flow mode. This ensured a steady flow in the channel while an ADCP discharge measurement was made as shown in Figure 16. After completing the measurement, the data was uploaded to MI's shared network drive from the field.

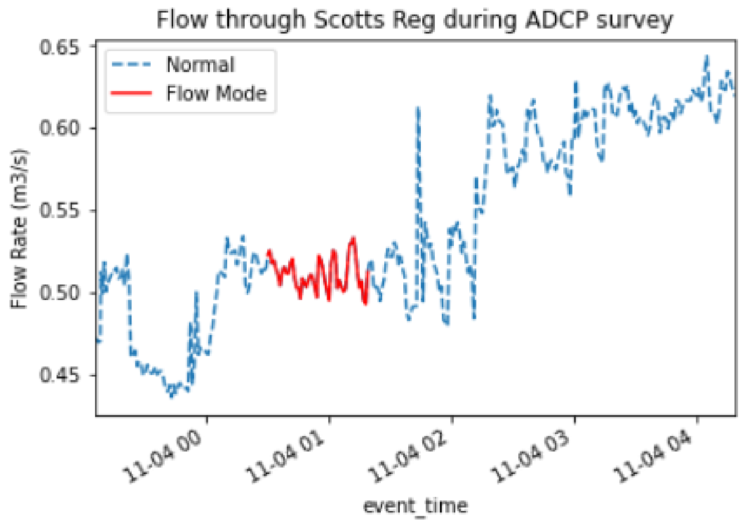

Figure 16: *Flow Rate at Scotts Rd Regulator during Standard Operation and Constant 'Flow Mode'.*

A standard set of guidelines were followed for collecting discharge measurement data for accurate calibration of the rating.

- The total duration of discharge measurements >= 800s.
- RTK GPS for track reference
- Bottom Track depth reference
- Reciprocal transects

Only discharge measurements with COV < 5% in flow rate measurement were used for rating calibration.

After completing the measurement, the data was uploaded to MI's shared network drive from the field. At the office the discharge measurements were reviewed using the RiverSurveyor Live and QRev software. The discharge summary was input into a custom python application to develop the index-velocity and stage-area ratings. The application required the following inputs:

- Site's ID / OBJECT_NO
- Start and end times of measurement
- Total discharge (Q) measured (m^3/s)
- Area (A) measured (m^2)

After receiving these inputs, the python application executes the following steps:

1. Mean channel velocity is calculated from measured flow rate and area
2. The Site ID is used to locate the site's SL1500-3G data in the database.
3. The start and end times are used to extract the average depth and index velocity (X-velocity) measured by the SL1500-3G during the ADCP discharge measurement.
4. The compiled SL1500-3G and M9 ADCP data is uploaded to the Survey-Compilation table shown in Figure 10.
5. If the database contains a backlog of more than one discharge measurement for the site, the ratings are developed and displayed.

Two ratings were developed to compute continuous flow, the Stage-Area rating and the Index-Velocity rating shown in Table 7.

Stage-Area Rating was used to model the relationship between the measured depth by the SL1500-3G and the cross-sectional area of the channel. The rating can be described by the following equation:

$$A = w_a * D + c_a \quad (1)$$

Where *A* is the cross-sectional area, *D* is the depth measured by the SL1500-3G, w_a is the area rating coefficient and c_a is the area rating intercept.

Index-Velocity rating is used to model the relationship between the index-velocity measured by the SL1500-3G and the mean channel velocity. The rating can be described by the equation:

$$V = w_v * I \tag{2}$$

Where *V* is the mean channel velocity, I is the index velocity and w_v in the index rating coefficient.

Murrumbidgee Irrigation developed a standard procedure for performing ADCP discharge measurements and developing ratings to ensure consistent and accurate results, with the workflow provided in Figure 17. The process involves 3 components: desktop analysis, field survey and the automated parts of MI's custom application. The real-time flows at the regulator were monitored along with the previously identified flow targets, to select the measurement site where further discharge measurements are required.

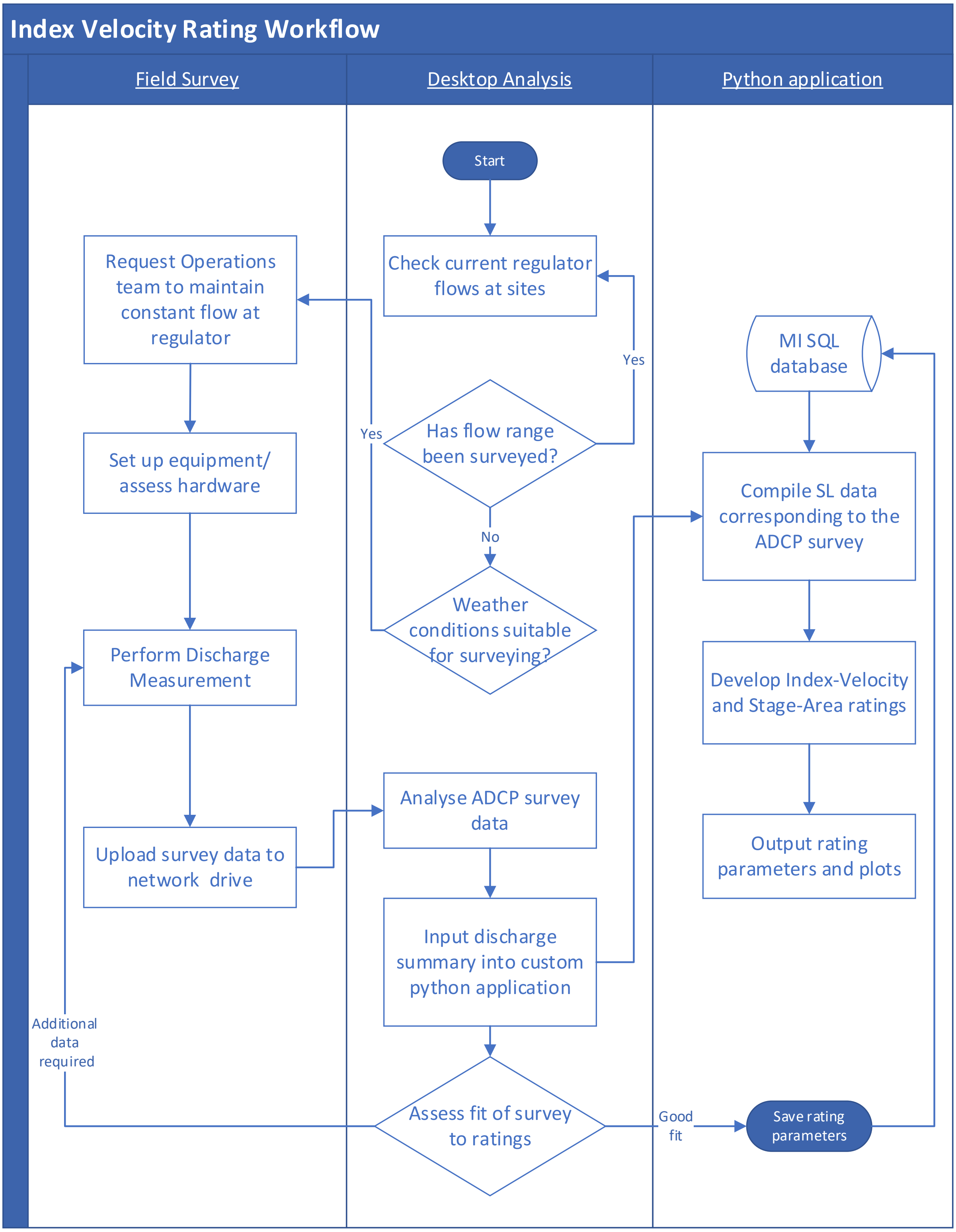

Figure 17: *Workflow for Index Velocity Rating Development.*

Table 7: *Index Velocity Rating Method and Parameters.*

Rating name	**Method**	**X-variable**	**Y-variable**	**Comments**
Index-Velocity rating	Linear Regression	Multi-Cell X-Velocity (Index Velocity)	Mean channel velocity	Intercept set to zero to force the rating through the origin
Stage-Area Rating	Linear Regression	Depth	Area	Intercept fitted.

The ratings were visualised and analysed after each discharge measurement to validate the measurements. If the data fit the rating, the parameters of the rating were saved to the database, otherwise additional discharge measurements were requested from the field.

2.10. Data Analysis

Discharge measurements collected over the defined flow range at each measurement site during the 3-month measurement period greatly enhanced the rating development. A graphical and statistical analysis of the ratings were performed to determine the applicability of each individual rating developed.

By default, the python application fits a simple linear regression model to develop the rating. The Figure 18 shows the type of scatter plot used to visualise the ratings for each site. The visualisation along with the residual analysis was used to assess the rating. A statistical measure, the coefficient of determination (R^2) was used as a goodness of fit measure. In figure 18, the plot shows that the model fits well and the R^2 of 0.998 means that the result is acceptable.

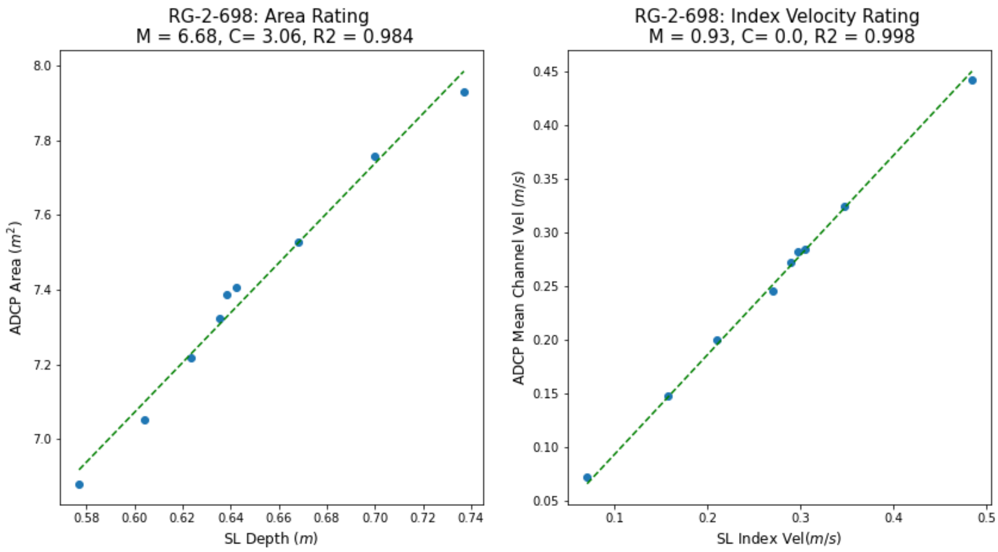

Figure 18: *Scatter Plot to Analyse Stage-Area and Index Velocity Ratings.*

The visual and statistical tests were repeated for all 9 measurement sites. The ratings developed for all the measurement sites are collated graphically in Figure 19.

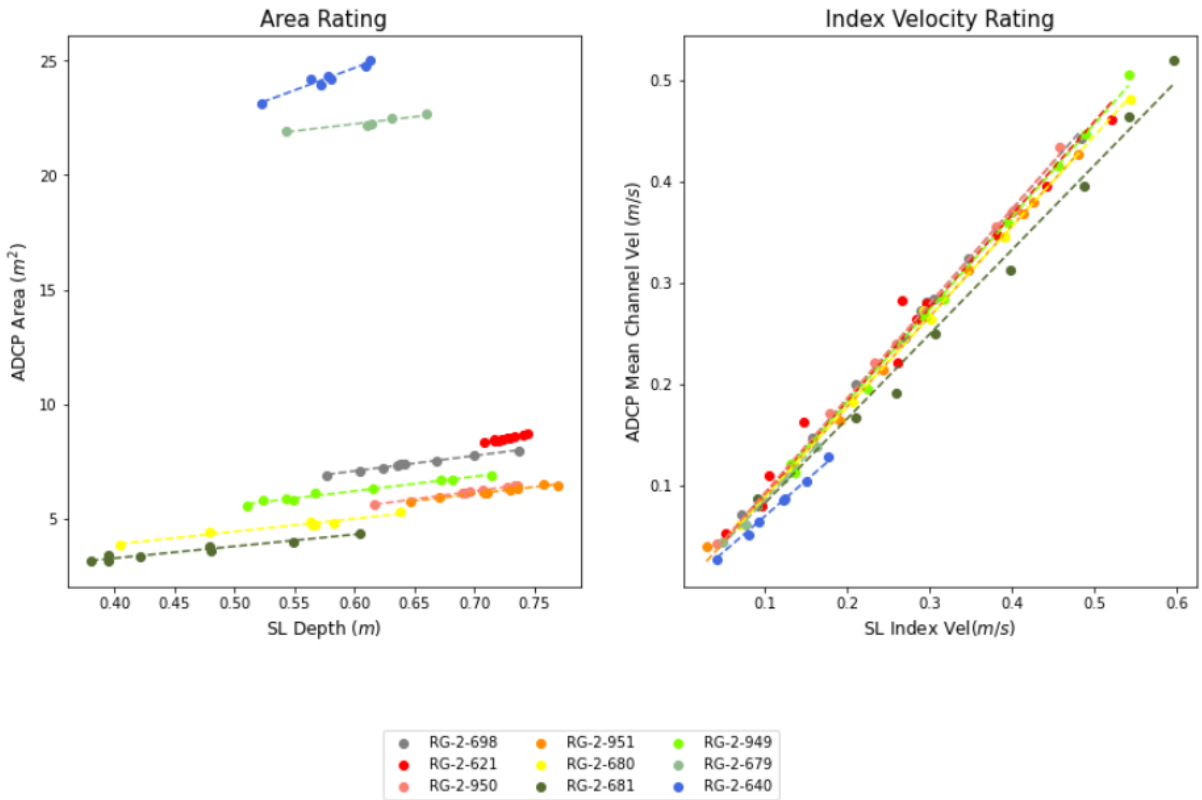

Figure 19: *Linear Relationship of Index Velocity Ratings for all 9 Measurement Sites.*

The results from the rating development procedure is summarized in Table 8. The coefficient of determination (R^2) was used as a goodness of fit measure that gives the percentage variance in a dependent variable that can be explained by an independent variable. The area rating, R^2 was >= 0.95 for all measurement sites except for RG-2-679, which showed a strong relationship between depth and area. RG-2-679 is a wide (22m) earth channel where the discharge measurements had a higher variance compared to other measurement sites, this explains the slightly weaker area rating for this site.

The R^2 values for the Index-Velocity ratings were >= 0.98 for all sites which shows a very strong relationship between the measured index velocity and the mean channel velocity.

Table 8: *The rating parameters and good of fit measure R^2 a Area rating and R^2 for the Index-Velocity rating for all 9 measurement sites*

Site ID	w_a	c_a	R^2 a	w_v	R^2 v
RG-2-698	6.68	3.06	0.99	0.93	0.99
RG-2-621	8.64	2.24	0.99	0.92	0.98
RG-2-949	6.35	2.38	0.98	0.91	0.99
RG-2-950	6.97	1.31	1	0.93	1
RG-2-951	6.11	1.79	0.99	0.89	0.99
RG-2-679	6.23	18.5	0.90	0.86	0.99
RG-2-640	19.5	13	0.95	0.7	0.99
RG-2-680	5.61	1.62	0.96	0.89	0.99
RG-2-681	5.47	1.03	0.98	0.83	0.98

The ratings were used along with the data collected by the SL1500-3G over the 3-month period to calculate the continuous flow rate and cumulative volume at each site. The percentage difference between the volume measured by the SL1500-3G and the regulator at each of the measurement sites is provided in Table 9. Except for two sites, RG-2-950 and RG-2-951, the measured volume at the regulator was within 5% of the SL1500-3G measurement.

Table 9: *Cumulative Error in Volume between the SL1500-3G Measurements and the Regulator at 9 measurement sites.*

Site ID	**Cumulative volume Error (%) (REG-SL)/SL**
RG-2-621':'Andreattas	2.70
'RG-2-950':'Apolonis	19.51
'RG-2-951':'Overs'	11.12
'RG-2-949':'Nericon'	3.99
'RG-2-680':'Temora'	4.03
'RG-2-681':'Rosetto'	3.18
'RG-2-698':'Scotts Rd'	2.49
'RG-2-640':'NBC-1'	2.92
'RG-2-679':'NBC Offtake'	-1.83

3. CONCLUSION

The flow verification process implemented by Murrumbidgee Irrigation resulted in accurate flow measurements at key sites in the network. Comparison of the flow measured by the SL1500-3G instruments against the reported regulator flow at the measurement sites showed that 7/9 sites were within 5%. The result gives Murrumbidgee Irrigation confidence in the regulator flows that are used primarily for operating the network.

The two sites with higher variance in flow, experience different flow conditions to the rest with the regulator gates being exposed to higher levels of submergence. This presents an opportunity to improve the flow calculation at these sites.

Furthermore, Murrumbidgee Irrigation now possess highly accurate instruments and have developed standard procedures that allows them to set up temporary flow monitoring sites, develop stable ratings and accurately measure flow anywhere within the irrigation network.