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Final report

Small research and development activity

project	**Low cost water salinity sensor for smallholder irrigators in developing countries**
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1 Acknowledgments

We acknowledge the generous funding of the Australian Centre for International Agricultural Research and their continued support in developing accessible measurement technologies that enable small holder farmers to learn to manage and improve their irrigation practices.

Andrew Skinner of Measurement Engineering Australia Pty. Ltd., developed and manufactured the SaltLight, a simple, portable salinity meter for displaying solution EC by coloured indicator light.

Yacob Beletse and Roy Zandona, research project officers with CSIRO Agriculture and Food, conducted much of the practical work including evaluation of SaltLights, sourcing and testing alternative low-cost commercial salinity meters, sourcing and designing open-source microprocessor-compatible salinity modules, developing test methodology, apparatus and sensors and evaluating salinity module performance.

Tony Nadelko, research project officer with CSIRO Agriculture and Food, reviewed the work and prepared the bulk of the report.

2 Executive summary

Purpose

Depletion of surface and groundwater resources has resulted in farmers using irrigation water with unsuitable salinity levels. Farmers only know if water is too saline after it has impacted their crop. There is a need for a simple, low cost sensor that small scale farmers can intuitively use to decide whether or not water is suitable for irrigation or whether leaching is required. The purpose of this Small Research and Development Activity is to develop technologies for smallholder irrigators that will help them manage water on their farms.

Three low cost salinity measurement alternatives were evaluated:

1. The SaltLight electrical conductivity (EC) meter developed to proof of concept stage by Measurement Engineering Australia (MEA).
2. Commercially available, low cost EC wands in common use by the hydroponics industry.
3. Commercially available open-source EC modules, compatible with the 'Arduino' microprocessor platform that can be the foundation of a low cost custom meter.

Results

SaltLight

The SaltLight meter includes three models, A, B and C with measurement ranges of 0.1 dS/m to 3, 12 and 24 dS/m, respectively. An indicator light displays seven different colours, corresponding to EC bands within its range. Power stored internally is charged by manually shaking it prior to use. The current cost of these meters is approximately $1000.

Ten of each model were tested against three commercial EC meters with verified accuracy. Not one of the thirty units measured accurately across their measurement ranges. All model A units indicated EC values too low across their entire range by as much as 5 colour bands. All model B and C units underestimated EC's at lower ranges by up to 4 colour bands and overestimated at high ranges by as much as 2 colour bands. Cleaning the sensor electrodes could not remedy the measurement variability.

None of the units charged in the time specified by the MEA manual, requiring either much longer shaking time or failing to charge at all. Two of the units failed to indicate the correct signal for being charged.

Hydroponics Salinity Meters

Five commercially available hydroponics nutrient meters (in reality EC) were sourced from an internet search. One of each unit was purchased and evaluated for its accuracy, ease of use and cost.

Hydroponics Salinity Meter	Cost (USD)	EC Range (dS/m)	EC Bands
Home Med Salinity Checker model NS01	$15.00	0.3 to 2.0% TDS	7
CF ECOStick model EC-2385I	$45.00	0.4 to 5.2	16
Green Nutra-Wand	$45.00	0.4 to 4.4	18
Blulab Truncheon	$120.00	0.2 to 3.6	18
Nutrient Meter model YM-2005A	$45.00*	0.4 to 4.4	16

* bulk quantity pricing available

All of the meters displayed salinity by multiple light emitting diodes corresponding to numerical EC bands. All were simple to use and powered by commonly available disposable batteries.

Accuracy of the Green Nutra-Wand was extremely poor, measuring low across its entire range by as much as 2 dS/m. The HomeMed Salinity Check was the lowest cost meter but its % salinity indicator was scaled incorrectly and corrected measurements were slightly low over much of its range. The Blulab Truncheon had the smallest measurement range of all meters and was the most accurate but costly. CF ECOStick measurements were low at bands above 4.4 dS/m.

The Nutrient Meter model YM-2005A was accurate throughout its measurement range, was user friendly and its moderate cost is further reduced with bulk quantity purchases. This meter is now supplied to VIA users with a re-labelled scale for colour-coded indication of salinity risk groups so as to fit in with the “Chameleon philosophy”.

Open-Source ‘Arduino’ Salinity Modules

The open-source salinity modules were required to be capable of being powered by the ‘Arduino’ based circuit board, exciting and measuring a two-electrode EC sensor, and providing a signal compatible with measurement by an ‘Arduino’ board. Three commercially available open-source salinity modules were sourced. One each of the ‘Cyberplant EC Mini’, ‘DF-robot’ and the ‘Atlas’ were purchased for evaluation.

The ‘Atlas’ had greater memory requirements than available in the version of the “Arduino’ board being used. The power requirements of the Cyberplant EC Mini would require additional costly power conversion for compatibility with the version of the ‘Arduino’ being used and its in-built calibrations were poor with no documentation. The DF-robot EC signal was only a relative number, and was the largest and most costly module.

A forth module was designed in-house, the Chameleon EC Test Circuit, to address the deficiencies of the commercial modules. It best met the design requirements at the lowest cost, integrating with an 'Arduino Mini' board and providing a compatible variable-frequency signal. Further measurement of its sensor excitation specifications are yet to be completed.

Conclusions

- The SaltLight had very large measurement inaccuracy, extremely high cost and some operational hardware faults.
- The Nutrient Meter model YM-2005A provided the best combination of measurement accuracy, ease of use and cost of the five commercial hydroponics salinity meters. This unit has been supplied to users with re-labelling to indicate salinity risk in colour-coded groupings.
- The in-house designed Chameleon EC Test Circuit best met the operational requirements. It was fully compatible with the 'Arduino Mini' board at the lowest cost. Further work will be needed to determine if it can successfully incorporated into a low cost custom built meter.

Recommendations

- We cannot recommend the SaltLight salinity meter for use in agricultural development in its present state of development due to its unacceptable degree of inaccuracy and its high cost.
- We recommend the Nutrient Meter model YM-2005A with re-labelled scale as a simple and low cost salinity meter that small hold farmers can easily use to check water salinity before irrigating. We have made this unit available at https://viashop.csiro.au/
- We recommend the Chameleon EC Test Circuit as the preferred 'Arduino' salinity module for use in a low cost custom built EC meter compatible with the existing Chameleon Wi-Fi database system. We propose to develop a soil solute EC sensor for use with this system.

3 Introduction

Much of the world's food come from smallholder irrigated agriculture but these farmers are facing resource depletion and degradation. This resource depletion of freshwaters leads smallholder farmers to the exploitation of water sources (surface and groundwater) of marginal quality, especially waters affected by salinity. This is common in deltaic and coastal area such as Vietnam, Egypt, Bangladesh, India and Iraq. In other areas groundwater has variable salinity and so exploitation can be problematic e.g. India, Pakistan, Bangladesh.

Work has focused on developing technology for smallholder irrigators that will help them manage water on their farms. In most cases farmers don't know if the water is too saline to use until after they have already used it. There is a need for a simple low cost sensor that farmers can use intuitively (many are illiterate) to guide their decision as to whether or not to use the water.

This project seeks to develop a simple new sensor to proof-of-concept stage. The sensor needs to provide output in easily understandable form e.g. colours, rather than scientific units of conductance. The design of the sensor needs to combine an understanding of science in water salinity measurement techniques and the social process of adaptive learning amongst small holder farmers.

This small research and development activity evaluated three different salinity measurement alternatives.

The project is related to several others in the Land and Water Resources project, in particular the SRA 'Pilot testing of the Chameleon sensor' and FSC/2014/85 'A Virtual Irrigation Academy to improve water productivity in Malawi and Tanzania'. The central thesis is that a few simple strands of information are much more useful to the farmer than detailed information of one production factor.

4 Objective 1: Liaise with MEA for supply, range and switch points of SaltLights

Objective 1.1 Set switch points for each model as required for Objective 2

Objective 1.1 was completed:

- The SaltLight electrical conductivity (EC) meters designed by Measurement Engineering Australia (MEA) are comprised three separate meters, each with a different overall measurement range (photo 1). The ranges were based on discussions with practitioners operating in the horticultural, rice and aquaculture industries.
- Each model is equipped with an indicator light capable of displaying seven different colours, corresponding to seven EC bands distributed across its overall range (Table 1).

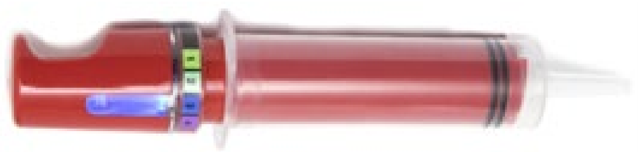

Photo 1: The SaltLight salinity meter developed by MEA

Table 1: SaltLight indicator colours and corresponding model EC measurement bands

Indicator Light Colour	SaltLight EC Range (dS/m)		
	Model A	Model B	Model C
	< 0.1	< 0.1	< 0.1
	0.1 to 0.5	0.1 - 2.0	0.1 - 4.0
	0.5 to 1.0	2.0 - 4.0	4.0 - 8.0
	1.0 to 1.5	4.0 - 6.0	8.0 - 12.0
	1.5 to 2.0	6.0 - 8.0	12.0 to 16.0
	2.0 to 2.5	8.0 - 10.0	16.0 to 20.0
	2.5 to 3.0	10.0 - 12.0	20.0 - 24.0
	> 3.0	> 12.0	> 24.0

Model A was considered suitable for horticultural crops, Model B for more salt tolerant field crops and Model C for aquaculture.

Objective 1.2 Negotiate supply and testing procedures and feedback required by MEA

Objective 1.2 was completed:

- Thirty SaltLight meters were supplied by MEA and further 20 purchased by the project
- Ten SaltLights of each model A, B and C were thoroughly tested against three commercially available EC meters for its measurement accuracy at all seven EC colour bands, and its calibration.
- Each meter's power recharge performance was also tested for compliance with the MEA operating manual specification.
- Feedback was provided to MEA in a report entitled 'Evaluation of the SaltLight', by Richard Stirzaker and Yacob Beletse, October 2015.
- MEA made adjustments to the SatLight based on the above report and the entire testing regime was repeated.

A detailed report on the testing results in shown under Objective 4.

Objective 1.3 Conduct internet search for commercially available low cost salinity meters that could be used in developing country context (e.g. nutrient wands as used for hydroponics)

Objective 1.3 was completed:

- Five different commercially available low cost hydroponics salinity meters were sourced and tested (photo 2).
- The maximum range is 5.2 dS/m, which means these do not suit all of the applications contained in the original specifications gleaned from five ACIAR projects where salt measurement was of interest (photo 3).

The meter selection criteria were cost, ease of use, measurement accuracy and measurement range. Five different meters were sourced through an internet search and one of each model was purchased on-line; Table 2 summarises their cost and measurement ranges.

Table 2: Summary of commercially available hydroponics salinity meters evaluated

Hydroponics Salinity Meter	Cost (USD)	EC Range (dS/m)	EC Bands
HomeMed Salinity Checker model NS01	$15.00	0.3 to 2.0% TDS	7
CF ECOStick model EC-2385I	$45.00	0.4 to 5.2	16
Green Nutra-Wand	$45.00	0.4 to 4.4	18
Blulab Truncheon	$100.00	0.2 to 3.6	18
Nutrient Meter model YM-2005A	$45.00	0.4 to 4.4	16

Photo 2: Five hydroponics salinity meters sourced from an internet search; top to bottom: HomeMed Salinity Checker, CF ECOStick, Green Nutra-Wand, Blulab Truncheon and Nutrient Meter

Objective 1.4 Added - Evaluate commercially available open source ‘Arduino’ salinity modules which could be low cost foundation for custom built meters

Objective 1.4 was completed:

- Three commercially available open-source ‘Arduino’ salinity modules were sourced and tested
- A forth salinity module was developed in-house based on one of the most favourable commercial modules but without its calibration limitations and power supply incompatibility

The salinity modules would provide the measurement interface between EC soil/water sensors currently in development and an ‘Arduino Mini’, an open-source electronics platform with an Atmel ATmega168 microprocessor, in use at the time.

The module would need to be capable of being powered by the ‘Arduino Mini’ board, to be capable of exciting and measuring a two-electrode EC sensor, and be capable of supplying a measurement signal compatible with the Arduino board for subsequent processing, display and transmission.

Further selection criteria, in order of significance, were cost, Arduino compatibility, measurement accuracy, and physical size. The three modules sourced for evaluation were ‘The Atlas’ (photo 3), the Cyberplant EC mini (photo 4) and the DF-robot (photo 5).

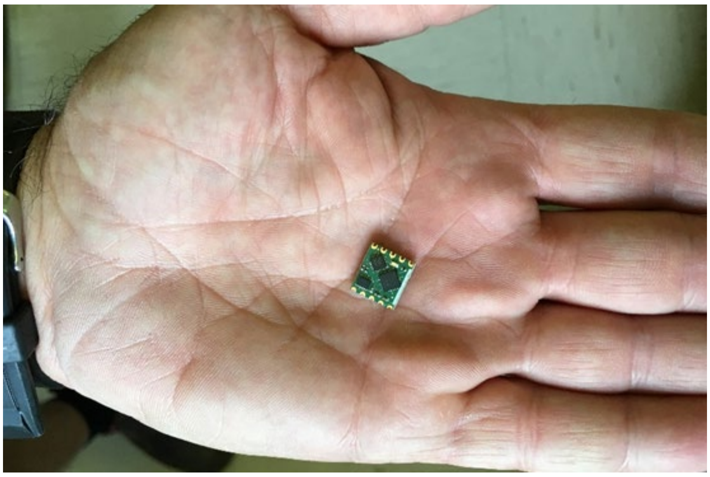

Photo 3 “The Atlas”, a commercially available chip containing the electrical conductivity measurement components

Photo 4: ‘Cyberplant EC mini’, a commercially available EC module for the ‘Arduino Mini Pro’

Photo 5: ‘DF-robot’, a commercially available EC module for the ‘Arduino Mini Pro’

Initial evaluation of the three commercially available salinity modules showed none met all of the selection criteria. The Cyberplant EC Mini was the most promising module due to its cost and design while its calibration and power supply disadvantages were not unsolvable. This module is designed around a 555 timer chip requiring a greater supply voltage than the Arduino board can supply. However, it was found that the additional cost of power conversion was high in comparison to the cost of the module.

As such, it was decided to build a similar circuit in-house using the 556 timer chip. This design, designated the Chameleon EC Test Circuit, had the performance and design simplicity of the Cyberplant EC Mini while its total cost to implement was the lowest due to its native supply voltage requiring no additional power conversion to be compatible with the Arduino board. The Chameleon EC Test Circuit was selected to further test as the low cost foundation for custom built meters. Table 3 summarises the EC module evaluation results.

Table 3: Summary of EC module evaluation characteristics

EC Module	Cost (USD)	Advantages	Disadvantages
The Atlas	$58.00	• Good accuracy • Moderate cost module • Compatible with the Arduino board in use	• Memory requirements greater than available in the Arduino board in use
Cyberplant EC mini	$18.00	• Simple circuit design • Least expensive module tested • Good performance	• Lack of documentation for its in-built calibrations • Power requirements incompatible with the Arduino board in use
DF-robot (kit with probe)	$83.00	• Compatible with Arduino board in use • Good accuracy	• Circuit board twice as large as the Arduino board in use • Requires conversion of non-quantitative number output to EC units • Most expensive module tested; probe included in kit is not required
Chameleon EC Test Circuit	$18.00 estimated	• Simple circuit design • Good accuracy • Least expensive module tested • Compatible with Arduino board in use	• none

5 Objective 2: Liaise with ACIAR project leaders, supply SaltLights and scope out evaluation procedures

Objective 2.1: Select ACIAR projects and the Salt Light model appropriate for each application.

Objective 2.2: Identify two ACIAR project leaders, supply with meters

Two ACIAR projects were selected

- Project 1 Cropping system intensification in the salt-affected coastal zones of Bangladesh and West Bengal, India. Project leader: M. Mainuddin
- Project 2 Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains. Project leader: E. Schmidt

SaltLight meter models were not selected for project use due to the unacceptably poor measurement accuracy identified in the testing for objective 4.1.

We have liaised with both project leaders above, and project 1 above is using the "Chameleon EC meter" based on the YM-2005A Nutrient wand. In addition the Chameleon EC meter is being evaluated in Pakistan, Mozambique, Tanzania, South Africa and Malawi in three other related ACIAR projects. We purchased 100 of these meters and produced stickers to change the EC units into 4 colour bands, each with four gradations.

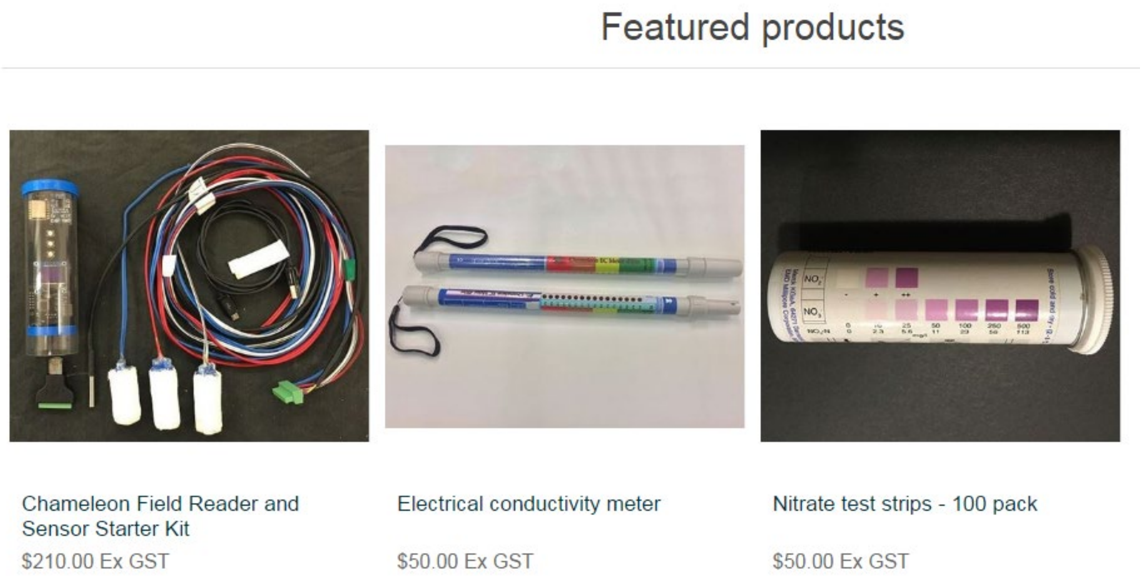

Photo 6: Screen shop of the VIA shop website where the Chameleon EC sensors in available for purchase and evaluation https://viashop.csiro.au/.

6 Objective 3: Collect feedback from ACIAR projects on how SaltLights were used and preliminary impacts on the irrigation decision

Objective 3.1: Work with two project leaders above** to supply them with equipment and assist interpretation of water and salt data

Objective 3.1 was not completed

- The two projects leaders identified in objective 2.2 were not supplied with SaltLight meters due to the unacceptable level of performance of these meters identified in the test results of objective 4.1.
- The project leaders were supplied with commercially available low cost salinity meters and assisted with interpretation of water and salt data; refer to objective 2.2.
- Given the unexpected amount of time spent liaising with MEA and trying to get the SaltLights to work, we were unable to get feedback from users.

Objective 3.2: Prototype the integration of Arduino salinity module into Chameleon web based data delivery and display system

Objective 3.2 was partially completed

- The Chameleon EC Test Circuit salinity module was successfully tested to confirm operation when installed between prototype FullStop water sensors and an Arduino Mini board.
- The module was able to be powered by the Arduino board and its variable-frequency output signal was able to be measured by the Arduino
- Additional calibrations of the module and any sensor, not yet completed, are required to convert the sensor measurements to EC units
- A soil solution EC sensor is intended to be next stage in the development process, rather than a FullStop EC sensor which was prototyped for test purposes only.
- The integration of the salinity module into the Chameleon web based data delivery and display system is inherently achievable as the module was successfully operated by the same microprocessor used in the Chameleon soil water sensor reader, data and display system.

7 Objective 4: Test accuracy of SaltLight in new and used conditions. Compare with other commercially available salinity meters

Objective 4.1: Evaluate new Salt lights for accuracy against laboratory standards before shipping to partners

Objective 4.1 was completed

- The SaltLights were evaluated against laboratory standards. Refer to report entitled 'Evaluation of the SaltLight', Richard Stirzaker and Yacob Beletse, October 2015, Parts 1 & 2.

Methods

The experiment was carried out at the CSIRO laboratory in Canberra. The setup of the experiment consisted of comparing the SaltLight against three Electrical Conductivity meters, namely a TPS (WP-81*pH-cond-Salinity*) and two pocket EC meters (ECTestr11 and ecoTestr *EC High*), (photo 7). Ten SaltLights from each models ranges A, B and C were evaluated at all seven colour bands.

Photo 7. Three EC measuring devices used in the experiment; 1) TPS WP-81*pH-cond-Salinity* 2) ECTestr11 and 3) ecoTestr *EC High*

Table 4 shows the main features of each of the EC meters including measurement range, power supply and cost.

Table 4. Description of standard EC meters used in the experiment as compared to SaltLight

EC meter	EC range (dS/m)	Power	Battery life (hours)	Operating temperature	Display	Cost
TPS (WP-81*pH-cond-Salinity*)	0 to 200	Electric and 6V NiMH rechargeable battery	40	-10.0 to 120.0 °C (Sensor limit 60 °C)	Digital	$960
ECTestr 11	0 to 20	4 x 1.5V 'A76' micro alkaline batteries	150	0-50 °C	Digital	$175
ecoTestr	0 to 19.9	4 x 1.5V 'A76' Micro alkaline batteries	150	0-50 °C	Digital	$115
SaltLight	0 to >24	Powered by Shaking	Capacitor life?	Temperature compensation?	Colour scheme	?

Twenty one beakers were prepared and divided into 3 groups (Group A, Group B and Group C) each group containing 7 beakers. Each beaker was filled with water and allowed to equilibrate to room temperature (21 degrees). Swimming pool salt (NaCl) was then added and mixed thoroughly with the water to give an EC reading that fell in the mid-point of the colour range for each model of SaltLight.

Calibration and testing of the EC meters

TPS (WP-81*pH-cond-Salinity*) was calibrated at 1.413 and 12.88 $dS.m^{-1}$ using the calibration procedure provided by the manufacturer. The two pocket EC meters, which were in a used condition (> 1 year), were not calibrated. However their accuracy at the low standard was excellent and both meters read slightly below the high standard.

Measurement of EC using SaltLights (in colours)

Thirty new SaltLights, ten from each of Model A, B and C, were evaluated against the seven EC standards applicable to each model according the procedures in the MEA user manual. Each SaltLight was powered up by manual shaking for about a minute until it blinked a green light. A solution was drawn from each beaker using the syringe, the

SaltLight was positioned vertically and excess solution expelled. The colour diode was then recorded. The procedure was repeated for 30 SaltLights (A (1-10), B (1-10) and C(1-10)) by taking sample from each beaker in group A, B and C. A total of 210 data points were recorded.

Results

Tables 5-7 present EC (dS/m) of the water samples measured using three standard EC meters. Results indicated the three EC meters provided quite close EC measurements for A, B and C solutions. The pocket EC meters however could not measure highest two EC values for solution C (Table 7).

Table 5: EC of the solutions (samples) A1-A7 measured using TPS and pocket EC meters (ecoTestr and ECTestr 11)

EC meter	EC (dS/m)						
TPS	0.29	0.71	1.26	1.72	2.29	2.79	4.02
ecoTestr	0.3	0.7	1.2	1.6	2.1	2.5	3.7
ECTestr 11	0.29	0.69	1.18	1.62	2.1	2.6	3.7

Table 6: EC of solutions (samples) B1-B7 measured using the TPS and Pocket EC meters (ecoTestr and ECTestr 11)

EC meter	EC (dS/m)						
TPS	0.96	2.73	4.68	6.46	9.03	10.9	13.4
ecoTestr	1.0	2.7	4.6	6.3	8.1	9.8	11.6
ECTestr 11	1.0	2.7	4.5	6.4	8.4	10.0	11.9

Table 7: EC of solutions (samples) C1-C7 measured using the TPS and Pocket EC meters (ecoTestr and ECTestr 11)

EC meter	EC (dS/m)						
TPS	2.10	5.99	10.49	14.02	18.11	23.0	26.3
ecoTestr	2.1	6.1	10.4	13.8	18.2	-	-
ECTestr 11	2.1	6.2	10.8	14.6	19.0	-	-

Tables 8-10 show EC (dS/m) measured using the TPS meter and corresponding SaltLight colour across the ten meters in each group. The first column of the table shows the colours that a SaltLight should give when submerged in solutions of known EC. The numbers in the table represent the number of SaltLight units displaying a particular colour when submerged in each EC sample (out of ten for each group). The colours in the table that move diagonally down from left to right show the expected response of the SaltLight.

Table 8 shows that none of the Model A SaltLights produced the correct colour. Up to 1.26 dS/m, no colour was reported, indicating a value >0.1 dS/m. The SaltLight value was always too low, and the error was not consistent. For example at a solution EC of 4.02 dS/m, 3 SaltLights reported the equivalent of 0.5-1.0 dS/m, 5 reported 1.0 to 1.5 dS/m and 1 reported 1.5 to 2 dS/m.

Table 8: SaltLight group A1-A10 response count to EC ranges

EC (dS/m) range SaltLight	EC (dS/m) measured by TPS						
	0.29	0.71	1.26	1.72	2.29	2.79	4.02
< 0.1	10	10	10	1			
0.1 to 0.5	0			9	7	4	
0.5 to 1.0		0			2	5	3
1.0 to 1.5			0				5
1.5 to 2.0				0			1
2.0 to 2.5					0		
2.5 to 3.0						0	
> 3							0
Total	10	10	10	10	9	9	9

Note: A1-A10 represent a SaltLight Model A.

Table 9 shows the responses for Model B SaltLights, where just one in 70 tests gave the correct colour (10.9 dS/m reading red). In this case the SaltLight underestimated the EC below 7 dS/m and over-estimated above 9 dS/m. Table 10 gives a similar result for Model C.

Table 9: SaltLight group B1-B10 response counts to EC ranges

EC (dS/m) range SaltLight	EC (dS/m) measured by TPS						
	0.96	2.73	4.68	6.46	9.03	10.9	13.4
< 0.1	10	10	1	1			
0.1 - 2.0	0		9	3			
2.0 - 4.0		0		4	1		
4.0 - 6.0			0		1		
6.0 - 8.0				0			
8.0 - 10.0					0		
10.0 - 12.0				2	4	1	
> 12.0					4	9	10
Total	10	10	10	10	10	10	10

Table 10: SaltLight group C1-C10 response to EC ranges

EC (dS/m) range SaltLight	EC (dS/m) measured by TPS						
	2.1	5.99	10.49	14.02	18.11	23	26.3
< 0.1	10	4					
0.1 - 4.0	0	4					
4.0 - 8.0		0					
8.0 - 12.0		1	1				
12.0 to 16.0		1		0			
16.0 to 20.0			1		0		
20.0 - 24.0						0	
> 24.0			6	8	8	8	8
Total	10	10	8	8	8	8	8

The data was presented graphically to see if there was a consistent error that could be corrected by recalibration. In this case the SaltLight output was converted back to an EC number within each colour range. To allow easy visualisation of the data, each Salt Light unit was given a slightly different EC value within each range, but still falling within the designated colour band (otherwise much of the data plots on top of itself). Figure 1 shows that the Model A SaltLights read too low and there is wide variability among units.

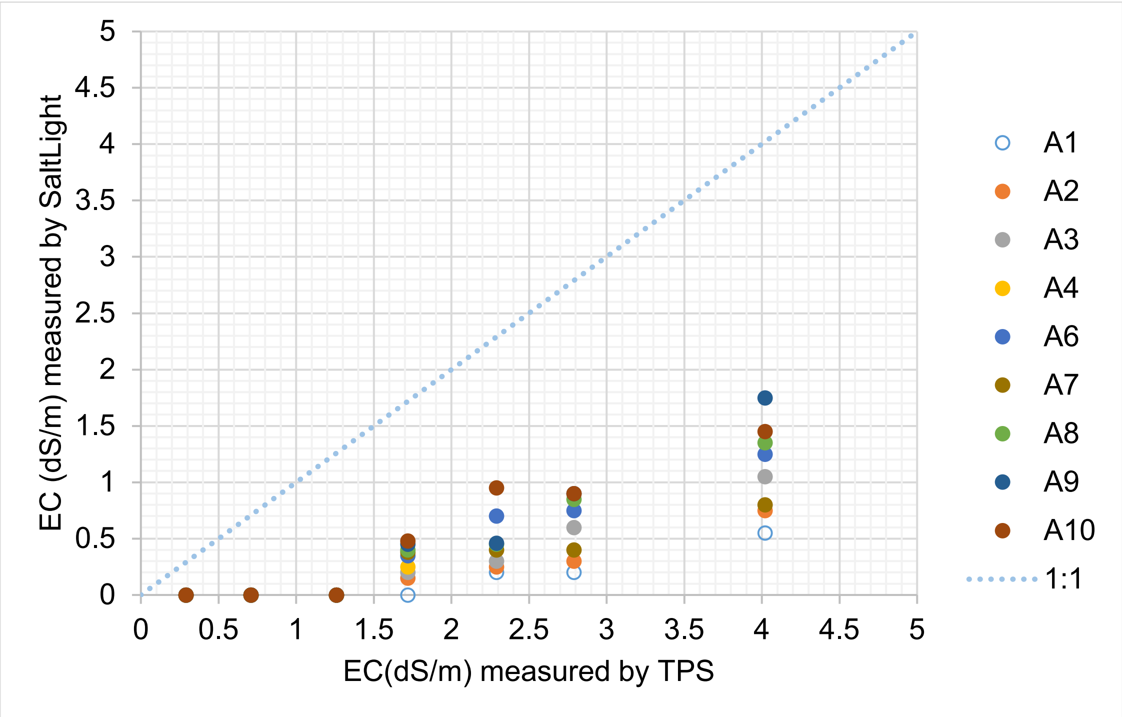

Figure 1. Relationship of EC measured using TPS and SaltLight Model A. SaltLights colours are translated to be within corresponding range

The relationships for models B and C, Figures 2 and 3 respectively, also show a huge variability among SaltLight units. Any SaltLight flashing red (over range) is plotted between 12-14 dS/m for Model B and 24-28 dS/m for Model C. So for most units, once the EC > 9 dS/m, the SaltLight records it as > 24 dS/m.

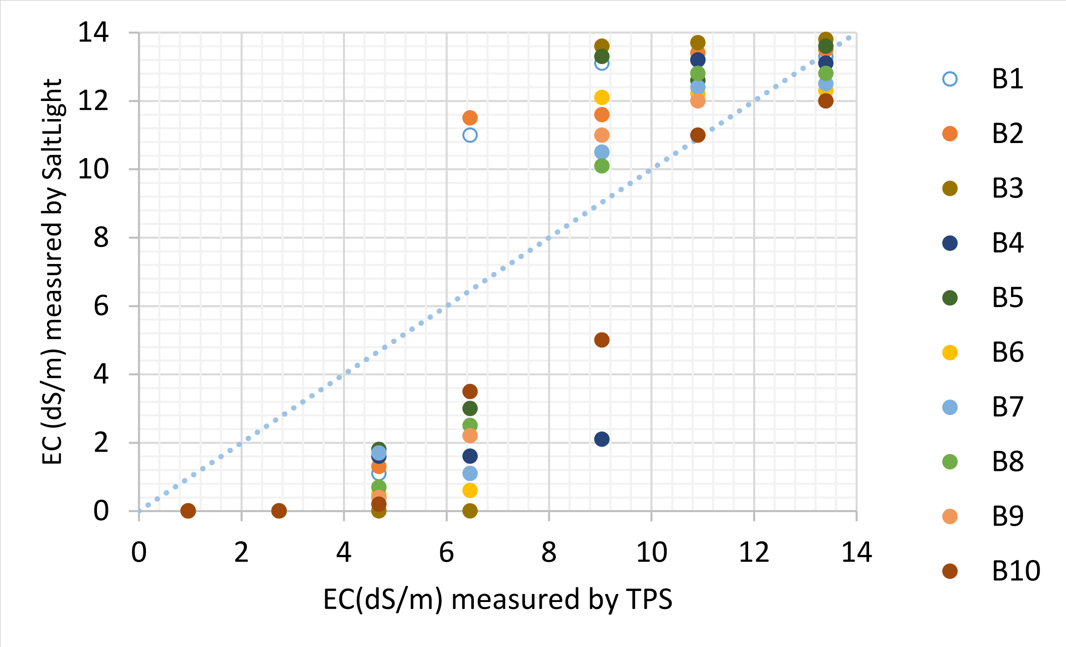

Figure 2: Relationship of EC measured using TPS and SaltLight model B. SaltLights colours are translated to be with in the corresponding range

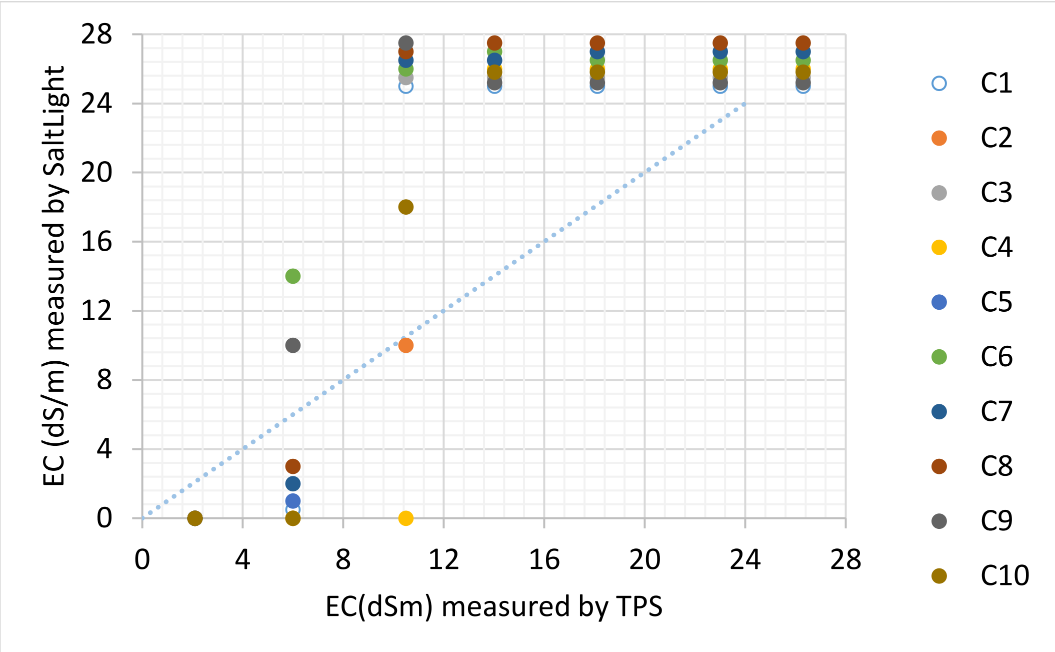

Figure 3: Relationship of EC measured using TPS and SaltLight Model C. SaltLights colours are translated to be within the corresponding range

Cleaning electrodes

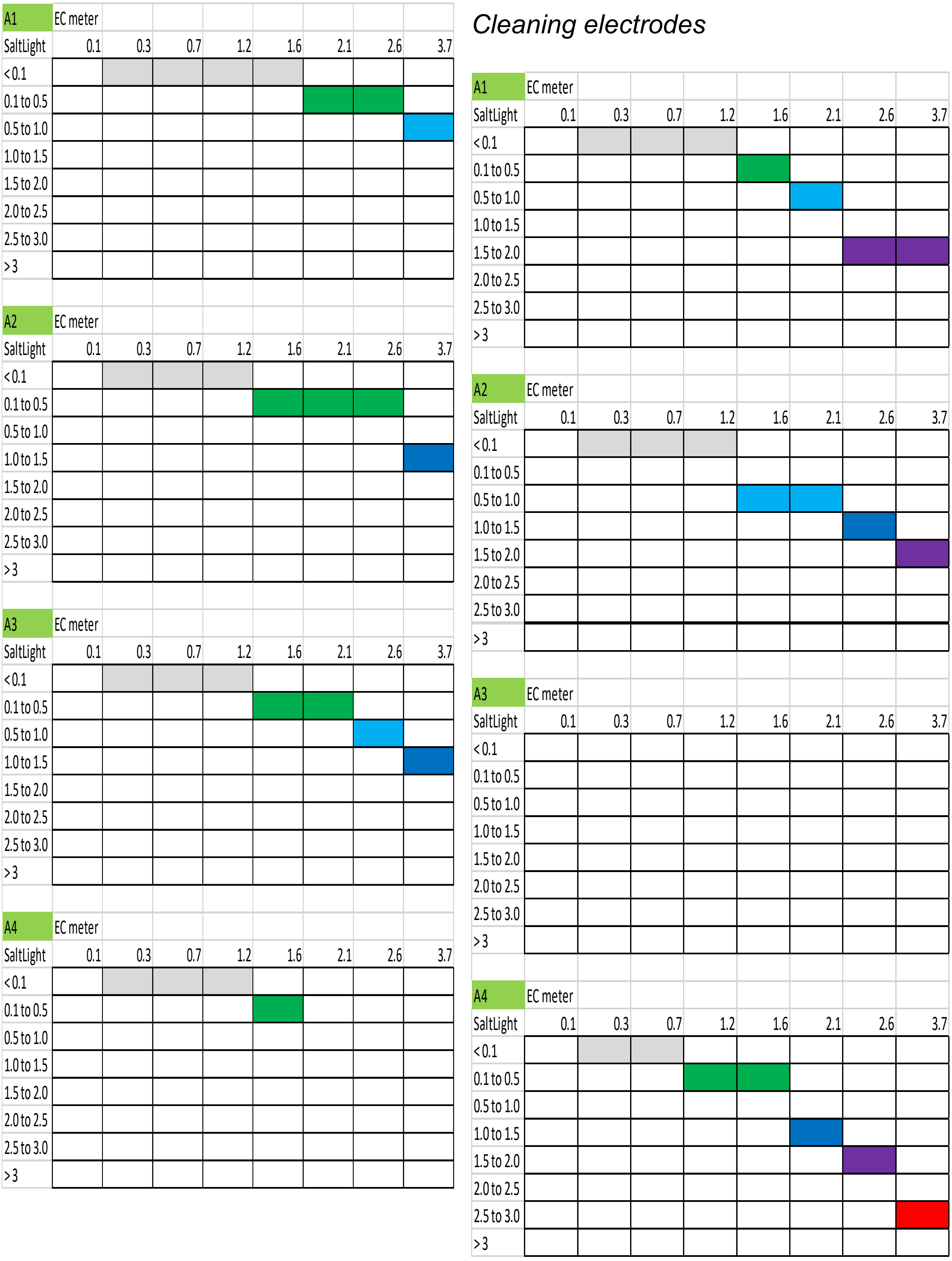

Figure 4. Four model A SaltLights before cleaning the electrodes in alcohol (left) and after cleaning (right)

Since the Model A SaltLights all read too low, the electrodes were washed in a weak base then a weak acid and then in alcohol to see if the problem was contamination. The left hand column shows the results before cleaning. The correct answers would be for the colours to plot as in Figure 4, i.e.in a diagonal from the top left corner to the bottom right corner. Cleaned electrodes still gave zero (no colour) over the first two or three colour band ranges. After this the cleaned electrodes did giver ‘higher’ colours, although all but one reading were incorrect.

The incomplete data in SaltLight A4 above 1.6 dS/m was due to this unit failing to recharge again, regardless of length of shaking. The missing data in A3 after cleaning was due to the fact that the plug between the two electrodes fell out. We were concerned that this was due to the alcohol and therefore discontinued further cleaning. Note that cleaning would be unlikely to improve the performance of B and C models because they were both reading under and over the correct reading over different parts of the range.

Power

The MEA manual stated that the SaltLights could be charged with 30 seconds of shaking. We used ten different individual to charge SaltLight and none managed it in 30 seconds. The average time to charge was 60 to 80 seconds. A recently charged SaltLight could be recharged in under 20 seconds for a new reading. However we encountered a few units that would not recharge after 3 or 4 consecutive measurements, no matter how long the shaking continued for (see missing data in tables 5 and 7).

The signal for a charged unit is a green flash, but one unit flashed white and another purple and then failed to read the solution. However Salt Lights that failed to recharge during a sequence of measurements were able to recharge after a few hours.

Objective 4.2: Evaluate Salt Lights of varying levels of use for accuracy against laboratory standards

Objective 4.2 was not completed

- The SaltLights were not evaluated under varying levels of use due to their unacceptably poor measurement accuracy identified in the testing for objective 4.1.
- an alternative EC meter was supplied, the Nutrient Meter Nutra-Wand model YM-2005A 0.4 to 4.4 EC (rebadged as the Chameleon EC Meter), determined as the best of the five hydroponics salinity meters evaluated for objective 4.3.
- No data evaluating them under varying levels of use was available at the time of this report.

Objective 4.3 Test salinity meters identified in objectives 1.3 and 1.4 above for i) Functionality and ease of use and ii) Accuracy against laboratory standards

Objective 4.3 was completed:

- Five commercially available low cost salinity meters evaluated for objective 1.3 were tested for accuracy, function, and use
- Three commercially available open-source ‘Arduino’ salinity modules and a forth module developed in-house, were initially evaluated for objective 1.4
- The salinity module developed in-house, the Chameleon EC Test Circuit, was then selected for more rigorous testing for accuracy, function and use

Commercially available low cost salinity meters

The measurement accuracy of the hydroponics salinity meters was tested by comparing them against a laboratory quality EC meter and measuring the conductivities of a range of prepared solutions.

A TPS model WP-81 pH-cond-salinity meter was used as a comparison reference. It was calibrated at 1.413 and 12.88 dS.m-1 using the calibration procedure provided by the manufacturer.

One beaker of test solution was designated for each of the five meters. The initial test solutions were prepared by adding approximately 0.5 grams of swimming pool salt (NaCl) to each beaker of water, mixing thoroughly and allowing the temperature to equilibrate to room temperature. The EC of each solution was measured with its designated test meter, then measured again with the TPS reference meter.

Another 0.5 grams of salt was then added to each beaker, thoroughly mixed and allowed to equilibrate to room temperature. The EC measurements were repeated with each test meter and the reference meter. This step was repeated until seven different solutions, ranging in EC from approximately 0.5 to 5.0 dS.m-1, had been measured by each meter.

This procedure was repeated three times, resulting in each meter measuring a total of twenty-one different solution EC’s. The measurement results are shown in Figure 5.

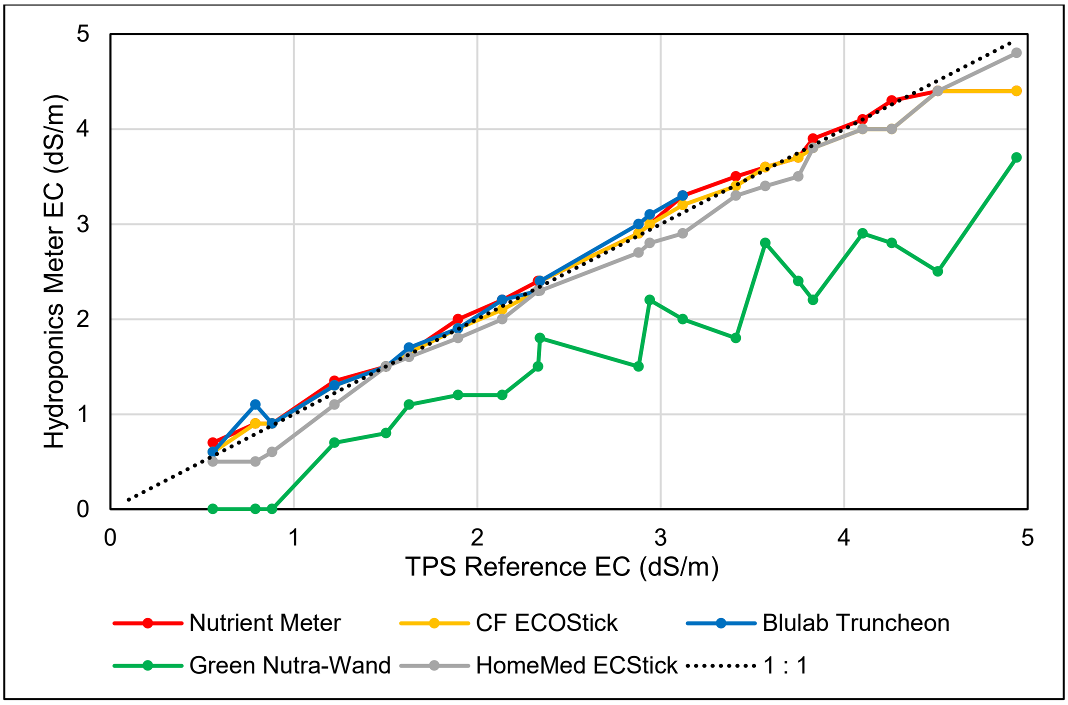

Figure 5: Test comparison of five hydroponics salinity meters

All of the meters provided equal ease of use and all were powered by commonly available disposable batteries.

The Nutrient Meter model YM-2005A and Blulab Truncheon provided the best accuracy across their entire measurement ranges. However, Blulab had the smallest measurement range and greatest cost of all meters evaluated. The CF ECOStick accuracy was good only within the range of the Nutrient Meter, measuring low beyond 4.4 dS/m

The Blulab Truncheon had measurement accuracy as good as the Nutrient Meter, but a smaller measurement range and much greater cost.

The HomeMed Salinity Checker model NS01 indicated % salinity. Measurements converted to dS/m for comparison were incorrect by a factor of 10, coincidentally equivalent to the unit conversion factor for EC to conductivity factor (CF). After converting units correctly the measurements were slightly but consistently low over its measurement range.

The Green Nutra-Wand measurement accuracy was clearly very poor measuring low across its entire range measurement with errors as great as 2 dS/m at the high end of its range.

Table 11: Summary of commercially available hydroponics salinity characteristics

Hydroponics Salinity Meter	Advantages	Disadvantages
HomeMed Salinity Checker model NS01	• Lowest cost • User friendly	• Incorrect indicator scale • Low measurements
CF ECOStick nutrient meter	• Moderate cost • Good measurement accuracy up to 4.4 dS/m • User friendly	• Poor measurement accuracy above 4.4 dS/m
Green Nutra-Wand	• Moderate cost • User friendly	• Very poor measurement accuracy
Blulab Truncheon	• Good measurement accuracy • User friendly	• Highest cost • Smallest measurement range
Nutrient Meter model YM-2005A	• Moderate cost • Good accuracy • Bulk quantity pricing • User friendly	• none

The Nutrient Meter model YM-3006A provided the best combination of cost, user friendliness, and measurement accuracy and range. This unit has been supplied with re-labelling to indicate salinity risk in colour-coded groupings (photo 8).

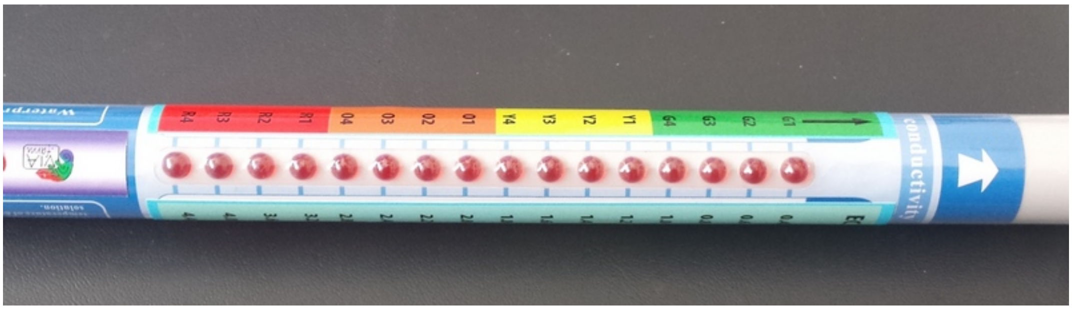

Photo 8: Nutrient Meter model YM-2005A with re-labelled scale showing salinity risk colour groups

Commercially available open source 'Arduino' salinity modules

Three commercially available open-source 'Arduino' salinity modules and a forth module developed in-house, were initially evaluated for objective 1.4. The salinity module developed in-house, designated the Chameleon EC Test Circuit, was selected from these for further testing of accuracy, function and use.

The salinity module test apparatus consisted of an 'Arduino Mini' board with external digital display, five EC sensors connected through a rotary selector switch and a bath of reference test solution constantly mixed by a recirculation pump. The salinity test modules were `connected between the Arduino board and the sensor selector switch (photo 9). A TPS model WP-81 pH-cond-salinity meter measured the reference bath EC. The TPS meter was calibrated at 1.413 and 12.88 dS.m-1 using the calibration procedure provided by the manufacturer.

The EC sensors were two-electrode prototypes designed to fit inside the Full-Stop wetting front detector. Based on initial evaluation of a variety of electrode configurations version EC3 was selected for use in testing the Chameleon EC Test Circuit module. Five version EC3 sensors were made. Being in early development stage close manufacturing tolerances were not required for the first module test stage. Small variations in electrode alignment resulted in the cell constants (i.e. k values), being similar but not identical.

For this test stage the salinity module's raw variable-frequency signal was recorded along with the reference solution EC and temperature. Temperature correction of the raw module signal is not possible until additional calibrations are completed.

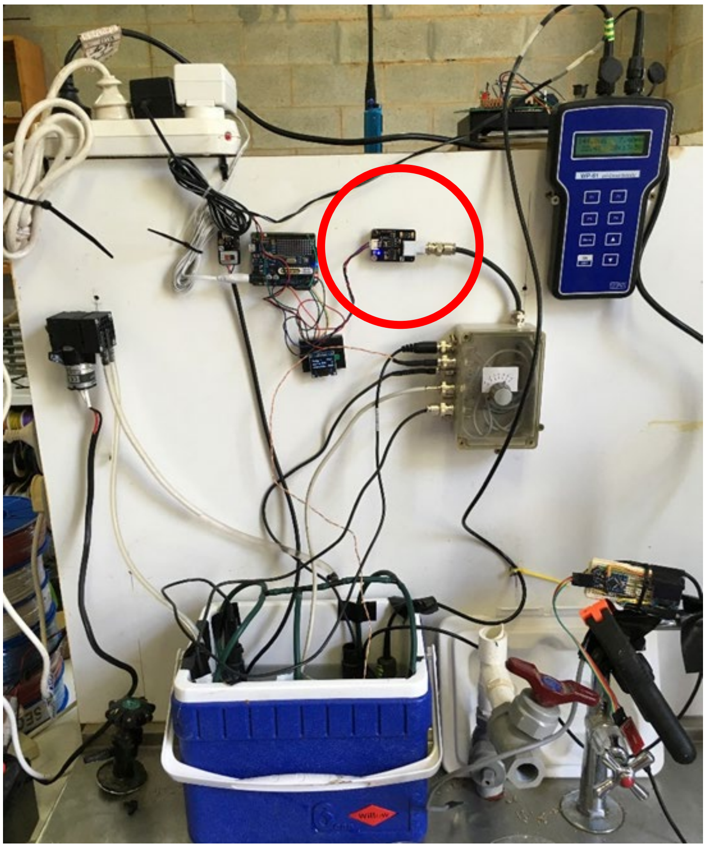

Photo 9: EC Module test apparatus shown with a 'DF-robot' EC module (red circle) connected between the EC sensor selector and the Arduino board, with five full-stop EC sensors submerged in the recirculating reference bath.

All five EC sensors were placed in the same reference solution bath. The initial test solution was prepared by adding approximately 0.5 grams of swimming pool salt (NaCl) to the bath, mixing thoroughly with the recirculation pump, and then allowing the temperature to equilibrate to room temperature. The frequency signal from Chameleon EC Test Circuit module was recorded and the bath solution EC and temperature measured with the TPS reference meter.

Another 0.5 grams of salt was then to the bath, thoroughly mixed, and allowed to equilibrate to room temperature. The test module signal was again recorded and the solution bath EC and temperature recorded. This step was repeated until at least thirteen different solutions, ranging in EC from approximately 0.1 to 9.0 dS.m-1, had been measured.

This test run procedure was repeated four times. In test runs 1 and 2 the sensors were placed inside Full-Stop tubes but the reference solution recirculation through the connecting manifold did not flow sufficiently through all Full-Stops. Test runs 3 and 4 were conducted with the sensors outside the Full-Stop tubes.

The results in figures 5 and 6 show very consistent and smooth responses of the Chameleon EC Test Circuit output signal. The offsets between the five sensor response curves are attributed to differences in the individual cell constants. A polynomial regression is also shown for one sensor, EC3-E, in each of the two test runs. The regressions are a near exact match to the raw response data, with coefficients of determination of 0.9997 and 0.9993 in test runs 3 and 4, respectively.

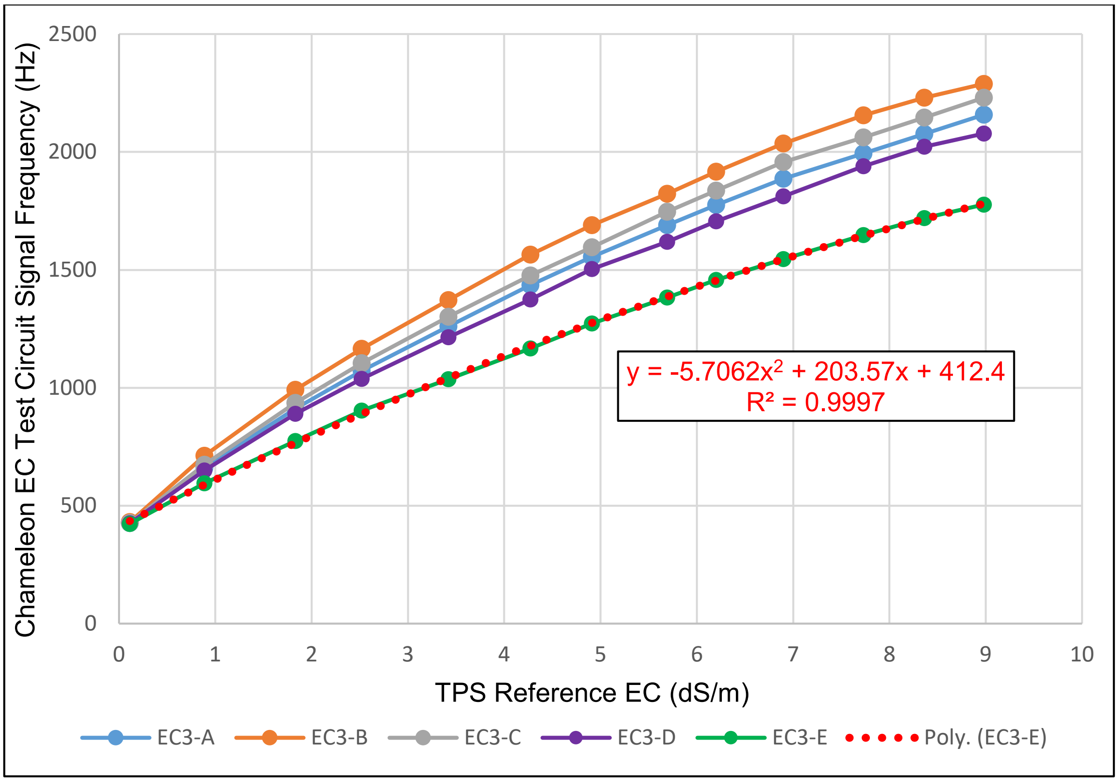

Figure 6: Results of test run 3 of Chameleon EC Test Circuit using an "Arduino Mini' board and five of the prototype version EC3 Full-Stop EC sensors

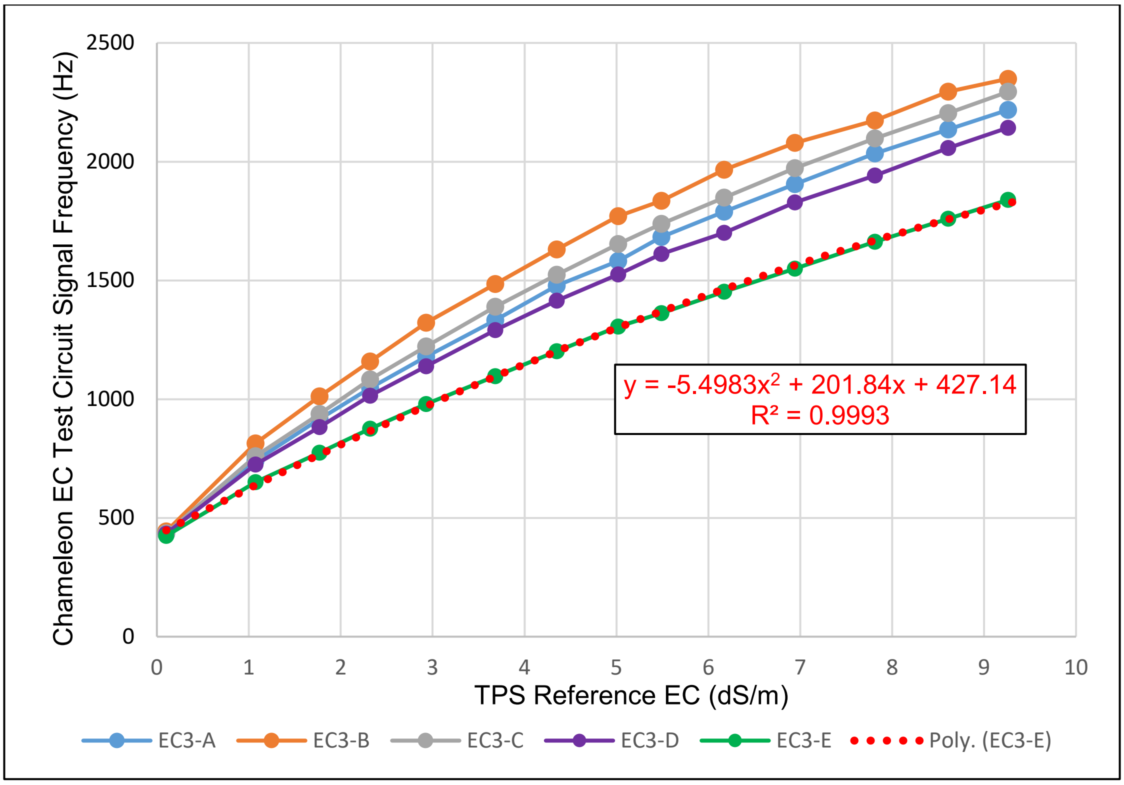

Figure 7: Results of test run 4 of Chameleon EC Test Circuit using an “Arduino Mini’ board and five of the prototype version EC3 Full-Stop EC sensors

Reference solution temperatures within each test run were similar. However, temperatures varied between the four test runs and without the frequency signals being temperature-normalised the records from the different test runs are not directly comparable.

Further work is required to be undertaken before the module could be incorporated into an EC measurements system. The electrical properties of the excitation the module applies to the sensor has yet to be verified (i.e. current mode, voltage, frequency). If the native excitation is not suitable then module design would require modification for implementation to proceed. In addition, all EC sensors used will need to be manufactured with a uniform cell constant that corresponds to the value required by the module’s resistance: frequency relationship for the intended EC measurement range.

8 Objective 5: Recommendations to ACIAR usefulness of the SaltLight in agricultural development

We found that SaltLight colours did not match the EC measurements from three independent commercial meters. Ten of the SaltLight model A test units gave lower readings, whereas ten each of the model B and model C test units resulted in both very high and very low values compared to the actual EC.

There was large variability among units within each model range, so calibration does not seem to offer a solution. Cleaning electrodes did change the readings of Model A but they were still not correct.

We cannot recommend the SaltLights for use in agricultural development until the test results can be understood and corrected.

Objective 5.1: Report to ACIAR on how the Salt lights were used and preliminary evaluation on impact on irrigation decisions

- No SaltLights were supplied for evaluation of their use or impact on use in irrigation decisions due to their unacceptably poor measurement accuracy identified in the testing for objective 4.1.
- Nutrient Meter model YM-2005A, re-labelled to indicate salinity risk in colour-coded groupings, is being supplied as a replacement for the SaltLight; no user feedback had been received at the time of this report.

Objective 5.2 Recommendations for next round of design

The recommendation for the next round of design is a soil solution EC measurement system consisting of:

- A newly developed Chameleon Soil Solute sensor similar to the current Chameleon Soil Water sensor. It is to utilize a proprietary fill material that has already been sourced and had water release testing to confirm it remains saturated under the range of soil moistures necessary to be sensitive only to changes in soil solute concentrations (EC). This novel sensor is buried in the ground and senses the in-situ EC of the soil solution through passive ionic equilibration with the sensor’s fill material.
- A Chameleon EC reader based on the Arduino platform and incorporating either the Chameleon EC Test Circuit, or a modified Chameleon soil moisture resistance circuit.

It would read one Chameleon Soil Water sensor, one Chameleon Soil Solute sensor, and one soil temperature sensor, while retaining the WiFi data capabilities of the existing Chameleon soil moisture reader.

This system would be compatible with the current web-based data storage and display system. The solute and moisture sensors measurements are required to be paired to prevent invalid solute measurements being recorded when soil moisture decreases below the working range of the solute sensor; the soil temperature sensor is required to normalise the EC measurements.

9 Conclusions and recommendations

9.1 Conclusions

- The SaltLight had very large measurement inaccuracy, extremely high cost and some operational hardware faults.
- The Nutrient Meter model YM-2005A provided the best combination of measurement accuracy, ease of use and cost of the five commercial hydroponics salinity meters. This unit has been supplied to users with re-labelling to indicate salinity risk in colour-coded groupings.
- The in-house designed Chameleon EC Test Circuit best met the operational requirements. It was fully compatible with the 'Arduino Mini' board at the lowest cost. Further work will be needed to determine if it can successfully incorporated into a low cost custom built meter.

9.2 Recommendations

- We cannot recommend the SaltLight salinity meter for use in agricultural development in its present state of development due to its unacceptable degree of inaccuracy and its high cost.
- We recommend the Nutrient Meter model YM-2005A with re-labelled scale as a simple and low cost salinity meter that small hold farmers can easily use to check water salinity before irrigating. We have made this unit available at https://viashop.csiro.au/
- We recommend the Chameleon EC Test Circuit as the preferred 'Arduino' salinity module for use in a low cost custom built EC meter compatible with the existing Chameleon Wi-Fi database system. We propose to develop a soil solute EC sensor for use with this system.

10 References

10.1 References cited in report

‘Evaluation of the SaltLight’, Richard Stirzaker and Yacob Beletse, October 2015, Parts 1 & 2.

10.2 List of publications produced by project

nil

11 Appendixes

11.1 Appendix 1:

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11.2 Appendix 2:

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11.3 Appendix 3:

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