Tool for continuously measuring total flow in lowland weedy streams

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Executive summary

Currently, it is difficult to accurately measure flows in low-gradient, slow-moving streams, mainly because aquatic plants alter the stream cross-section and flow profile in a complicated way. This can defeat conventional measurement technology. Consequently, many streams are not monitored for flow, because available methods are not fit-for-purpose.

The Rising Bubble Method (RBM) Tool described in this report offers a solution because it is much less-affected by plant growth, is largely independent of stream channel characteristics, is intrinsically very accurate, defensible and can be automated to provide low cost-per-measurement data.

The RBM Tool will help regional councils and unitary authorities to monitor and manage lowland streams more effectively, in accordance with the National Policy Statement for Freshwater Management (NPS-FM), particularly during low flows.

This report captures all RBM development to date, over a four-year period. The work has been funded by NIWA, Hawke's Bay Regional Council, MBIE Envirolink Advice grants and, most recently, an Envirolink Tool grant.

Our overall aim was to develop practical, replicable RBM monitoring equipment to enable NIWA, Hawke's Bay Regional Council and Environment Canterbury to carry out trials and become familiar with RBM. Workshop presentations and publications in New Zealand Hydrological Society "Current" Newsletters have been progressively provided to keep potential end-users informed.

All project objectives have been met (see Appendix A), except for long-term trialling at a permanent station. Equipment exists, but choice of sites and timing is a decision for councils; NIWA will assist as required. Videos and other relevant files are stored on NIWA's secure intra-network.

To date, the most significant outcomes of this development are:

- We have built equipment for council trials;
- Twelve trials were carried out;
- We found where RBM works best;
- Measurement uncertainty is lower (better) than initially hoped for;
- We have verified the accuracy of RBM against available references;
- We have successfully taken instantaneous 'snapshots' of Q without the need for averaging;
- We have verified this simple, direct measurement works;
- Partial (from video) and full automation software is working; and
- It is proving easy to configure and deploy.

Initially, we see RBM as being very useful for validating or calibrating other methods. The system works well in partial-automatic mode, and at Raupare Stream in Hawke's Bay, works well in full-automation mode, as it has been trained for Raupare. It will require more training to work in full-automation mode at other sites.

1 Introduction

This report describes an MBIE Envirolink Tool-funded project to develop a prototype instrument that enables accurate, automatic, stream flow-rate monitoring. This tool transforms the Rising Bubble Method (RBM) into standard measuring equipment– transferable technology that works independently of depth, channel cross-section and boundary layer thickness. It uses the principle that a rising air bubble intrinsically integrates downstream displacement as it rises in the water column, from bed to surface. It will provide direct and continuous measurement of Total Discharge (Q) to within 5% (with 95% confidence) with little need for highly specialised skills or post-processing of data.

This report captures all RBM development to date, over a four-year period. The work has been funded by NIWA, Hawke's Bay Regional Council, MBIE Envirolink Advice grants and, most-recently, an Envirolink Tool grant.

This report is intended to meet two primary needs:

(1) to describe the end-to-end development of the RBM Tool to facilitate uptake by regional councils, unitary authorities, and other organisations who want to use it; and

(2) to address the contracted outcomes of Envirolink Tool funding.

In summary, the contracted outcomes were to:

- Develop a video-based method for detecting rising air bubbles in a flowing water body;
- Develop software for controlling the bubbler instrumentation and calculating stream discharge;
- Carry out laboratory and field-based testing of the methods; and
- Enable technology transfer to Regional Councils, including through the delivery of this report and make available information to enable prototype replication.

Full details of the contracted outcomes are provided in Appendix A of this report.

1.1 The main components of the RBM tool

The tool includes:

Bubble Velocimeter - for measuring bubble rise velocity V_r precisely in a still column of the stream water to enable calibration of the system to the prevailing aqueous conditions, when/if needed;

Bubble Line - for injecting a line of bubbles across the width of a streambed;

Video Camera - for recording rising bubbles as they surface;

Custom Software - for controlling the operation, including bubble detection to precisely identify each bubble's surfacing location;

Control Hardware – to provide the physical and electrical connectivity of the above items.

When in full automatic mode, to a datalogger, the Tool will look like a typical SDI-12 sensor (therefore compatible with most existing data collection platforms) – returning a single value of Q (in m^3/s or l/s) for each read request.

The Tool does not include:

The Tool is not yet 'production-ready'. It is currently at the 'functioning prototype' stage and, depending on its efficacy, and provided there is enough demand, a small pre-production run (e.g., 10) could be planned as a next step, followed by a production design stage.

1.2 Summary of the most significant outcomes

Twelve trials were carried out

- Two streams in Canterbury with NIWA (three trials);
- One river in Canterbury with ECan (four trials with a fifth planned);
- Five streams in Hawke's Bay with HBRC (five trials).

Where we found that RBM works best

- In slow streams with an un-broken water surface; broken is harder but still possible;
- Where other instrument types struggle with low-flow, muddy beds, vegetation etc.;
- When direct traceability is important for verification of measurements;
- When data quality verification is needed, video frames can be retained.

Equipment we have built for council trials

- Two Velocimeters;
- Two 20-injector Bubble lines;
- Two Control boxes.

Measurement uncertainty is lower (better) than initially hoped for

- Excellent repeatability/precision;
- Typical rise velocity (V_r, measured in Velocimeter) uncertainty < 0.4% at the 95% confidence level;
- Achievable uncertainty in Total Discharge Q typically < 2% at the 95% confidence level if V_r is measured;
- Or typically ~ 5% at the 95% confidence level if a Velocimeter calibration is not carried out but a standardised value of V_r is used instead (being verified by HBRC now).

We have verified the accuracy of RBM against available references

- RBM compares favourably with three-point FlowTracker reference gaugings;
- RBM compares favourably with ADCP boat reference gaugings.

It’s important to note that RBM measurement uncertainty is lower than that of the references.

<u>We have successfully taken instantaneous ‘snapshots’ of Q without the need for averaging</u>

- With simultaneous injection of one bubble from each injector on bubble line (one ‘shot’);
- Calculates instantaneous partial discharges across stream;
- Calculates instantaneous partial depth-integrated velocities across stream;
- Can calculate surface velocities while bubbles remain intact on surface;
- A ‘snapshot’ reduces the amount of compressed air needed;
- So reduces the amount of energy needed to power a site;
- Or lowers the number of compressed air tank refills needed.

<u>Simple, direct measurement has been verified</u>

- More ‘transparent’ than conventional methods;
- A ‘near-primary’ measurement tool;
- Uses fundamental units (metres and seconds); Q (m^3/s) = V_r (m/s) x Area (m^2);
- We verified that no knowledge of channel depth or cross-section is required;
- We verified that Q is not affected by changes in stream cross section;
- Shown to be linear at shallow depth and low flows;
- No surrogate relationships, empirical ratings, or assumptions were needed or used.

<u>Partial (from video) and full automation software is working</u>

- The future-proof Artificially Intelligent detector can be trained indefinitely to improve accuracy;
- Electronic control module designed and built for partial and full automation;
- Partial automation telemeters 5-second video clips from remote site for manual measurement;
- Partial automation is working well; full automation is working on the bench but not yet trialled;
- Difficulties accessing the High-Performance Computing (HPC) facility, for bubble detector training, have delayed the timeline;
- Full automation will calculate Q on site, log, then telemeter Q data to server/database.

<u>It is proving easy to configure and deploy</u>

- Can be configured for temporary or permanent deployment;

- Easy to transport, despite the portable version being heavy (lead ballasting);
- Little need for highly specialised skills or post-processing of data;
- Ideas for improving and reducing manufacturing costs are being captured.

1.3 Section summary

Here is what we cover in each section:

Section 2: We explain how RBM works, show how it shifts the paradigm to overcome the limitations of conventional methods, and provides an overview of how the RBM Tool works.

Section 3: We explain the necessity for producing bubbles with specific characteristics, repeatably, on command, and introduce the hardware that enables this – the bubble injector.

Section 4: We describe attributes of the bubble line to familiarise the reader with one possible physical configuration.

Section 5: We cover the factors that contribute to the uncertainty in Q, explain the role of the Velocimeter to provide local water calibration of bubble rise velocity Vr, look at the measurement uncertainty in Vr and state when the Velocimeter is needed.

Sections 6 and 7: We cover the 12 field trials carried out at streams in Canterbury and Hawke's Bay, the results and conclusions that drove the evolution of equipment and ideas.

Section 8: We introduce: partial automation, where video is processed manually by on-screen measurements; full automation, where we use Artificial Intelligence to locate the bubble surfacing locations needed to calculate the swept-out area.

Section 9: We describe how to retrieve short ('five second') video recordings of surfacing bubbles.

Section 10: We describe the Tool in detail, options for configuration and moving to production.

1.4 Appendix summary

Appendix A: We address how well each of the contracted Tools outcomes has been fulfilled.

Appendix B: We describe the main options for providing compressed air for driving the injector valves and supplying air to produce the bubbles.

Appendix C: We provide manufacturing drawings to facilitate replication of the injectors.

Appendix D: We provide information about the construction and operation of the Velocimeter.

Appendix E: We trial two configurations of wading RBM wading Rod and give a conclusion.

Appendix F: We give the method and results of a test we did to investigate if a shallow water correction might be required.

Appendix G: This shows how we carried out some earlier rating tank tests with nine injectors, at different depths and experimented with underwater LED strip lighting.

Appendix H: This is a discussion on the more important aspects of equipment configuration and site preparation. Here we construct the geometry needed to rectify the camera angle at Raupare Stream.

2 The Rising Bubble Method (RBM)

2.1 Overcoming the limitations of conventional methods

Conventional methods for continuous flow monitoring typically require a surrogate (water level), translated to discharge using a rating curve. The presence of aquatic vegetation makes this relationship insensitive and unstable, often resulting in ‘difficult-to-impossible’ measurement conditions.

RBM provides simple, direct measurement of flow and so is more ‘transparent’ than conventional methods. No surrogate relationships are needed (e.g., acoustic-to-flow), no empirical ratings are needed (e.g., depth-to-flow) and no assumptions are needed (e.g., ISO vertical velocity distribution).

RBM uses fundamental units – metres and seconds – therefore it’s easy to verify method and quantify measurement uncertainty.

2.2 How the Rising Bubble Method works

An air bubble released from a stream bed (Figures 2-1 and 2-2) is displaced downstream, by the water flow, as it rises to the surface, integrating velocity throughout the water column, from bed to surface.

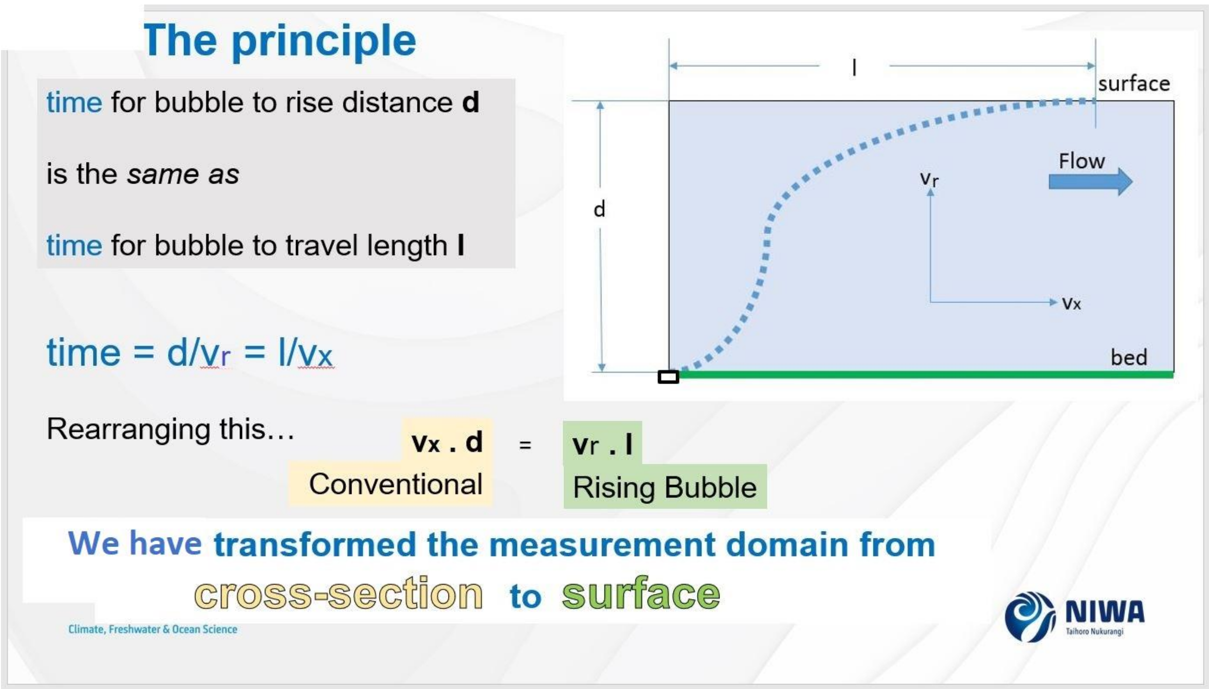


Figure 2-1: The principle of RBM and difference between conventional gauging and RBM gauging, illustrated by showing the path of a single bubble.

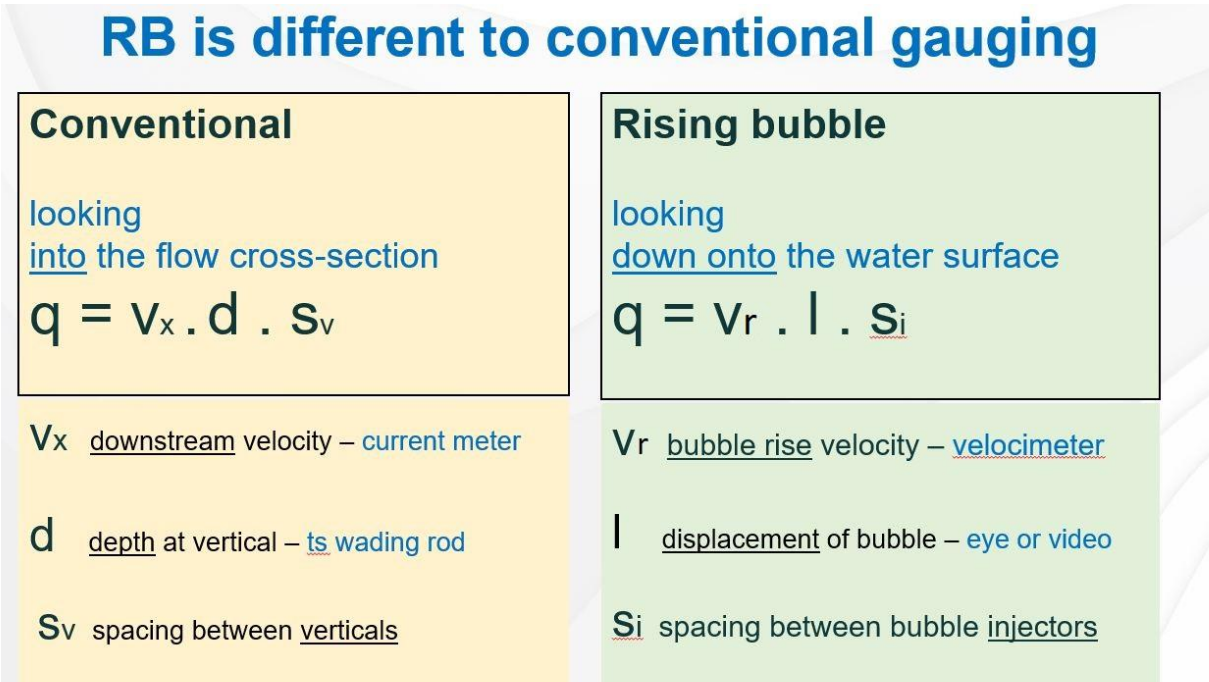


Figure 2-2: The difference between Conventional and RBM gauging.

Our bubble injector module injects bubbles of the precise diameter needed to achieve constant rise velocity (V_r). A bubble is injected simultaneously from each of the injectors (typically 20) spanning the streambed. The horizontal (surface) distances, from the line of bubble injectors (the origin) to where the bubbles break the water surface, are directly proportional to discharge. Because it is not humanly possible to accurately locate where a line of bubbles just breaks the water surface, we capture the event with video.

Total Discharge (Q) is calculated directly using $Q = V_r * A$.

V_r is the bubble rise velocity (measured in the NIWA Velocimeter) and A is the displacement area on the water surface. By doing this we transform the conventional measurement domain (the stream cross-section) to the water surface. To determine A, we identify the surfacing location of each bubble. From this we measure the downstream displacement of each surfacing location, from its origin, and calculate A.

2.3 Tool overview

Figures 2-3, 2-4 and 2-5 show how the concepts outlined above are captured in our development of the RBM tool and how this leads to the direct calculation of Total Discharge Q.

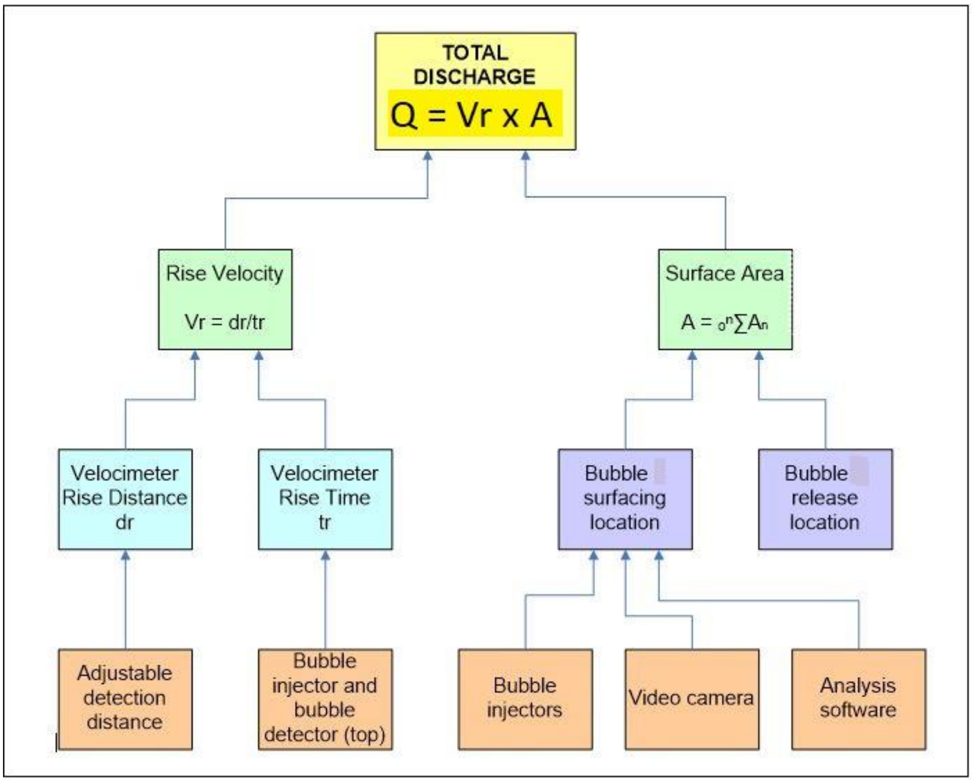


Figure 2-3: Overview of the process we are using, where there are n (typically 20) bubble injectors.

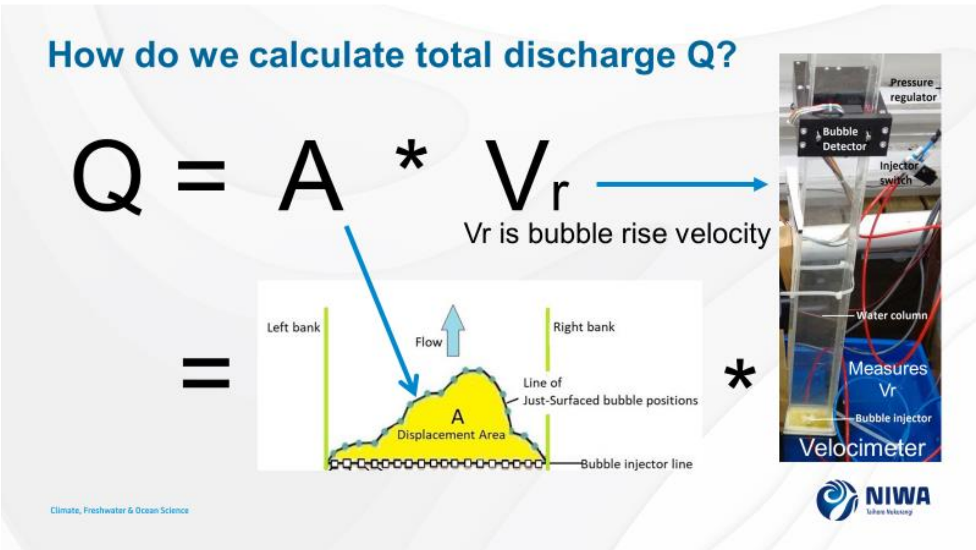


Figure 2-4: Showing how Q is calculated from A and the bubble rise velocity V_r measured in the velocimeter.

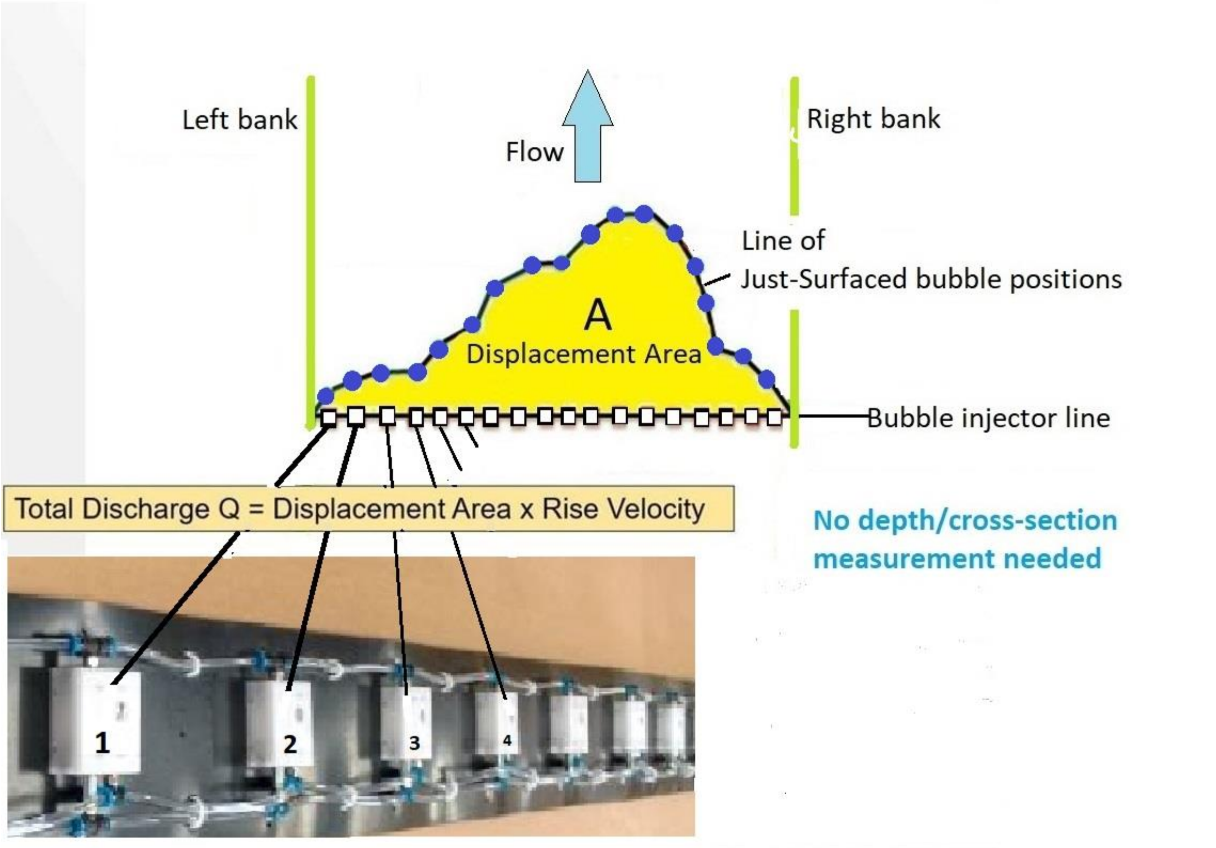


Figure 2-5: Showing the role of the bubble line and how 'joining the dots' of just-surfaced bubbles defines the area A used for calculating Q.

3 The bubble injector

3.1 The problem

All bubbles injected (both in the velocimeter and at every point on the bubble line) need to have the same rise velocity and this must be a constant value (terminal velocity) from injector to surface. In Figure 3-1, the composite characteristic curve [1] for bubble rise time vs bubble diameter shows that bubbles with diameter of 6 or 7 mm are about optimum – a 'sweet-spot' in the characteristic curve where rise velocity is insensitive to small changes in bubble diameter. The x-axis is logarithmic and smaller bubbles show a significant and unacceptable change in rise velocity for a small change in diameter. Our challenge was to consistently produce bubbles of optimum size.

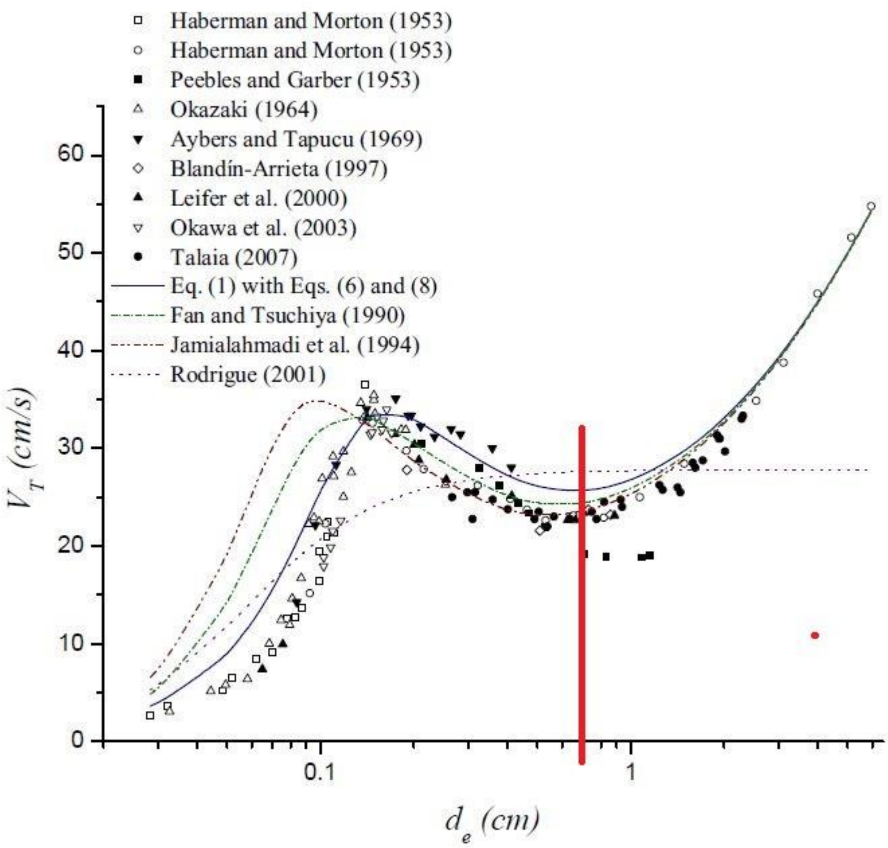


Figure 3-1: Characteristic curve - bubble rise time vs bubble diameter.

3.2 The solution

To achieve these depth-independent 'designer bubbles', we needed to release a precise volume of air at a fixed pressure.

We designed a bubble injector (Figure 3-2) employing a small bobbin valve that would inject this precise volume of air when the bobbin was actuated, driven with compressed air (~ 2 Bar). Pressure-regulated air (0.9 Bar) is used as the bubble source. We chose 0.9 Bar as it was enough to overcome the weight of the water above it and produce the right-sized bubble. Figure 3-3 shows the compressed air circuit.

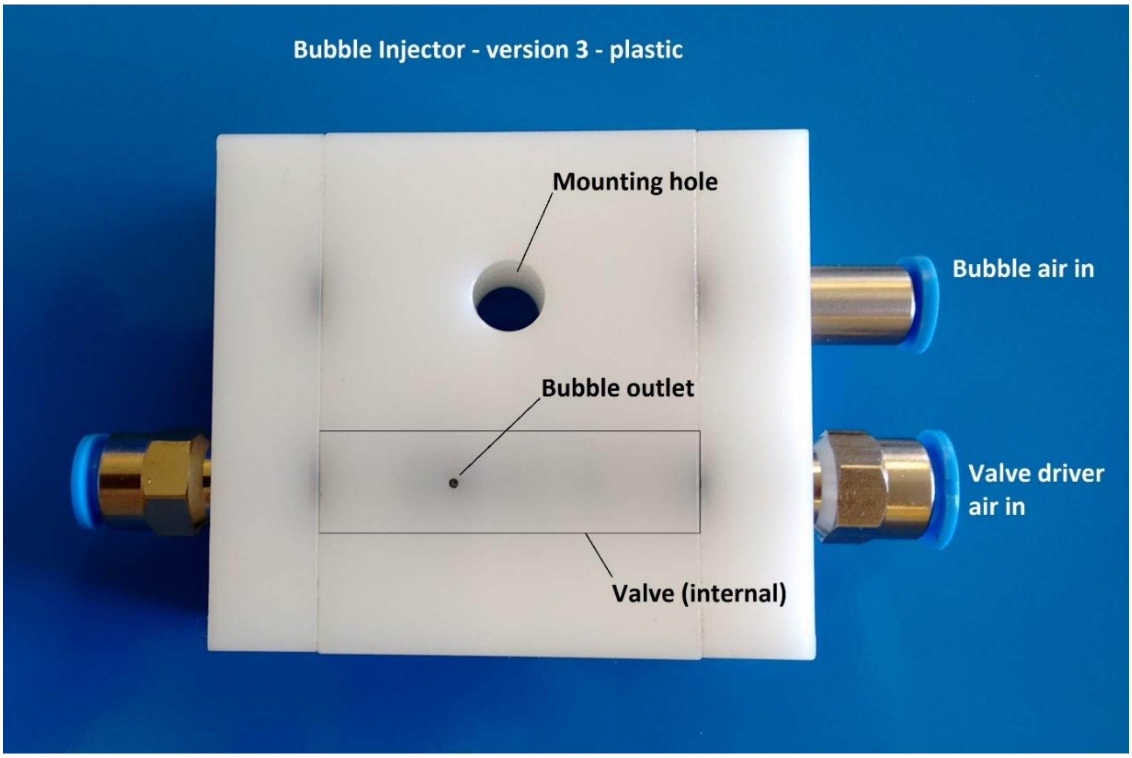


Figure 3-2: A bubble injector showing the compressed air ports.

Alternatively, we could have designed an injector actuated by an electric solenoid, but at this 'proof-of concept' stage, air was needed for the bubble anyway, we didn't want to risk electrolysis through leaking (though ac rather than dc drive might solve that) and we had a purge option if dirt were to get into the bubble outlet hole. See Appendix C for dimensioned drawings.

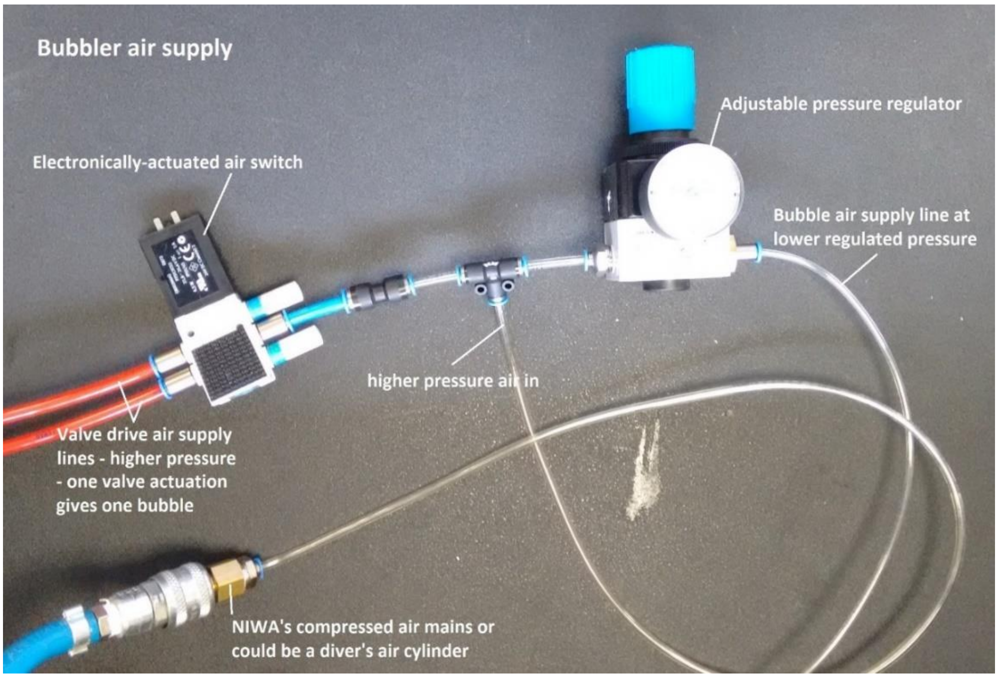


Figure 3-3: The compressed air circuit.

4 The bubble line

We have made two bubble lines. One for Hawke's Bay Regional Council and one for ECan. Each is mounted on a rubber strip and ballasted with a lead weight under each injector. We've found this arrangement to be nicely balanced for deployment, and stable on a streambed. This arrangement is more suitable for short-term deployment than permanent deployment as it is very transportable. The injectors are modular and can be configured as needed (e.g., Figure 4-1).

Figure 4-1: Left - 20-injectorline assembled for HBRC; Right - the line rolled up in its carry case. It fits in the boot of an ordinary car. One person can carry it, but two are recommended, as with the lead ballast it weighs about 30 kg. Protective closed-cell foam has been rolled up with the bubble line.

On the HBRC bubble line the 20 injectors were spaced 0.2 metres apart and spanned four metres (the width of the Raupare Stream in Hawke's Bay). On the ECan version 2 bubble line the 20 injectors were spaced 0.3 metres apart and spanned six metres (the width of the Halswell River in Christchurch).

5 Measurement uncertainty

5.1 Uncertainty in total discharge Q

Because Q = V_r x A, the uncertainty in Q comes directly from the uncertainty in both the bubble rise velocity (V_r) (Section 5.2) and the uncertainty in the area (A) (Section 5.3).

5.2 Uncertainty in rise velocity

Measurements with the Velocimeter can be thought of as a local stream water calibration. To determine the uncertainty in the rise velocity V_r, we first needed to know how precise the Velocimeter is - we developed it to measure V_r. V_r is the distance the bubble rises, divided by the time it takes to travel this distance (rise time). We developed a Smartphone application for measuring rise time in a Velocimeter.

The precision/repeatability in rise time can be reduced by releasing a statistically robust number of bubbles (samples). The uncertainty in the bubble path distance (± 1 mm) can be measured directly by placing a precision steel rule in the column and reading the distance where the laser line crosses it (see Appendix D, Figure D-5). We have carried out long-term trials, releasing thousands of bubbles in a Velocimeter to investigate variables such as temperature, bubble air supply pressure etc.

During rise time measurement trials we standardised on releasing 30 bubbles (samples), at a regulated air pressure of 0.9 Bar (0.9 Bar must also be used on the bubble line), to achieve acceptable uncertainty without excess use of air. The estimation of the 68% confidence level uncertainty is shown in Figure 5-1.

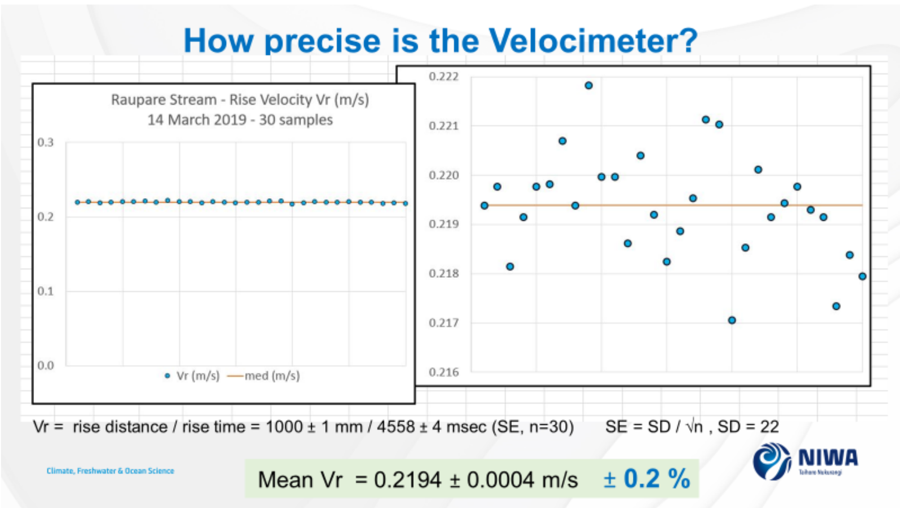


Figure 5-1: Calculation of Rise Velocity from 30 bubbles injected in the Velocimeter (right).

5.2.1 Do we always need a Velocimeter on site?

Earlier measurements carried out mainly around Christchurch indicated that, provided increasing the measurement uncertainty was acceptable for a given dataset, that it may be possible to accommodate V_r variability and standardise V_r (perhaps linked to a specific site, stream state, season or temperature). The advantage of not needing a Velocimeter on site would make RBM a much more practical operation and might, at times, outweigh the disadvantage of having to increase the measurement uncertainty. Since the earlier measurements HBRC has carried out further tests, using samples from different streams at about the same temperature (Table 5-1) and tap water at different temperatures (Table 5-2). These support the earlier conclusion.

Site Name	Median Vr (m/s)	Temperature (degC)
Awanui Stream at Flume	0.2076	21.4
Clive River upstream of Whakatu	0.2056	21.5
Here Here at Te Aute	0.2073	21.4
Karamu Stream	0.2079	22.1
Karewarewa Stream at Paki Paki	0.2080	21.4
Mangaone River at Rissington	0.2053	22.1
Mangaonuku Tributary 2	0.2067	23.6
Mangatutu	0.2069	22.1
Maraetotara River at Te Awanga	0.2053	22.1
Maraetotara River at Waimarama Road	0.2064	22.1
Puhokio Stream at Te Apiti Road	0.2065	22.4
Raupare at Ormond	0.2094	21.5
Raupare at Ormond	0.2072	21.5
Tutaekuri at Dartmore	0.2068	22
Tutaekuri at Lawrence Hut	0.2051	22
Tutaekuri River at Brookfields Bridge	0.2050	22.1
Waingonoro Stream at Waimarama Road	0.2074	22.2

Table 5-1: Showing the variation in median Rise Velocity measurements in streams around Napier.

Temperature trial	Median Vr (m/s)	Temperature (degC)
1	0.2042	48
2	0.2055	44.2
3	0.2071	34
4	0.2082	30
5	0.2095	26
6	0.2057	22
7	0.2090	10
8	0.2080	14

Table 5-2: Showing the variation of Vr with temperature for tap water.

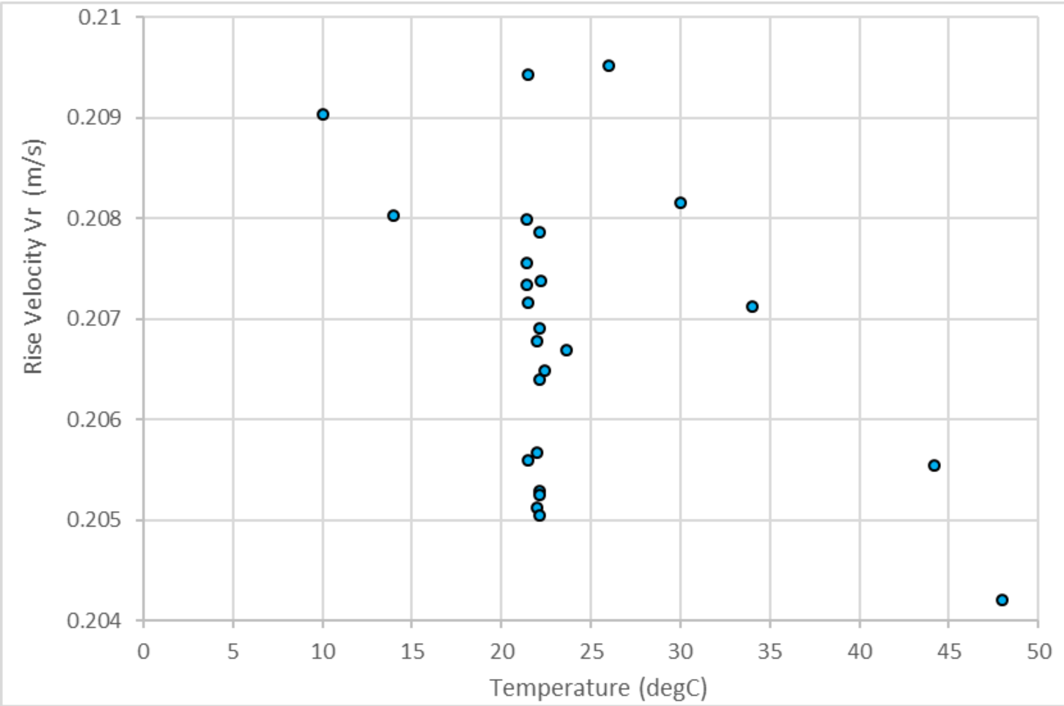


Figure 5-2: The variation in V_r (m/s) over samples across all sites and tap water at different temperatures.

From the data in tables 5-1 and 5-2, the 95% confidence level in V_r is 1.4%, so only using the Velocimeter for calibrating measurement where lower measurement uncertainty is required appears achievable. Further work, as we gather more data at different sites at different times and under different conditions, may well support the use of a standard value for 'un-calibrated uncertainty' to be applied in situations where an increase of approximately 1% (over the 0.4%) in measurement uncertainty (at the 95% confidence level) is an acceptable trade-off for the convenience of not having to use a Velocimeter. Temperature correction might lower the 'un-calibrated uncertainty' in V_r by about 0.2%.

5.2.2 Other factors we considered

Two other factors we considered were:

- Acceleration of the bubble from injection to terminal rise velocity V_r;
- Velocimeter wall effect and its impact on its specified dimensions.

From published data [2] the effects of drag from the walls of a column can be ignored if the ratio of the bubble diameter to the wall 'diameter' is < 0.125. Since we wanted to experiment with bubble size, we made the Velocimeter larger than it needed to be for the 6-7mm diameter bubble we are creating (Figure 3-1).

5.2.3 Conclusion

The Velocimeter is sufficiently precise, and accurate, to provide local water calibration data and easily meets our proposed uncertainty target.

From the evidence shown in Appendix F we have concluded that a bubble accelerates to terminal rise velocity V_r so rapidly that no correction is needed to allow for acceleration time. It appears that, in addition to the upward buoyancy force acting on the bubble there is also the net pressure acting on the bubble area, imparting further upward impetus.

The size of the Velocimeter could be reduced from 130x130 mm to as little as 50x50 mm without wall effect coming ‘into play’; possibly smaller if a correction was made to account for wall effect. If we were also to reduce its height it would become a more usable size. Scaling the Velocimeter dimensions would also reduce manufacturing cost, require less sample water, enable higher turbidity water to be measured (shorter path length) and would be easier to transport or house.

5.3 Uncertainty in area A and total discharge Q

There are two ways to calculate the uncertainty: (1) by combining the uncertainties in each of the measurements used to calculate A (e.g., Figure 6-12 – in Section 6.4), and (2) by using a statistical approach when we can measure enough values of Q (Figure 5-3). In this example we have summed the partial discharge contributed by each of 20 injectors (column Inj), and have calculated 10 values for Q (Q1 – Q10), 1.7 seconds apart. The median value is 0.462 m^3/s with a standard deviation of 0.49%.

Inj	Ref	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	1230	0.018	0.020	0.020	0.017	0.017	0.019	0.021	0.020	0.019	0.021
2	1230	0.025	0.024	0.023	0.022	0.021	0.022	0.022	0.023	0.025	0.025
3	1230	0.028	0.027	0.022	0.024	0.025	0.023	0.023	0.025	0.025	0.025
4	1230	0.026	0.025	0.023	0.022	0.024	0.022	0.021	0.023	0.026	0.025
5	1230	0.028	0.026	0.025	0.023	0.026	0.028	0.024	0.027	0.026	0.025
6	1230	0.026	0.024	0.027	0.029	0.026	0.025	0.024	0.025	0.022	0.022
7	1230	0.022	0.022	0.025	0.025	0.023	0.025	0.021	0.022	0.021	0.022
8	1230	0.024	0.026	0.026	0.026	0.026	0.023	0.022	0.024	0.023	0.021
9	1230	0.024	0.024	0.025	0.022	0.022	0.023	0.021	0.020	0.022	0.023
10	1230	0.025	0.030	0.026	0.026	0.026	0.026	0.029	0.028	0.024	0.022
11	1230	0.021	0.025	0.025	0.029	0.029	0.029	0.029	0.026	0.026	0.027
12	1230	0.023	0.025	0.028	0.028	0.032	0.029	0.027	0.026	0.029	0.025
13	1230	0.021	0.023	0.023	0.025	0.021	0.027	0.028	0.028	0.026	0.026
14	1230	0.017	0.017	0.024	0.022	0.019	0.022	0.023	0.025	0.021	0.021
15	1230	0.022	0.024	0.021	0.019	0.022	0.022	0.023	0.022	0.022	0.022
16	1230	0.020	0.019	0.017	0.024	0.020	0.021	0.021	0.020	0.020	0.019
17	1230	0.023	0.021	0.021	0.019	0.019	0.017	0.016	0.016	0.017	0.018
18	1230	0.021	0.021	0.021	0.017	0.021	0.020	0.019	0.020	0.021	0.019
19	1230	0.021	0.023	0.018	0.020	0.026	0.024	0.024	0.023	0.024	0.025
20	1230	0.023	0.023	0.019	0.023	0.023	0.024	0.020	0.024	0.025	0.026
Totals (m^3/s)		**0.458**	**0.469**	**0.460**	**0.461**	**0.468**	**0.471**	**0.457**	**0.466**	**0.463**	**0.458**
	median			0.462	m3/s						
	1 SDev	68% confidence		0.49%							
	2 SDev	95% condidence		0.94%							

Figure 5-3: A statistical approach to calculating the uncertainty in Q using the results from 10 values of Q. This does not take any uncertainty in the alignment of the origin into account.

6 Canterbury trials

6.1 Trial 1 – Cashmere Stream @ Penruddock Rise (1 May 2017)

In May 2017 we carried out the first two trials of the equipment at this local, unrated, four-metre-wide urban stream in Christchurch.

6.1.1 Aim

To investigate whether the proposed setup was sufficiently practical and usable in the field.

6.1.2 Method

We installed two taglines approximately 1.3 metres apart and laid the new version 2 bubble line across the streambed (Figure 6-1). We then carefully measured the tagline position at several points along it (Figure 6.2).

Figure 6-1: The very first attempt at RBM deployment. The steep slope made it hard to set up the taglines.

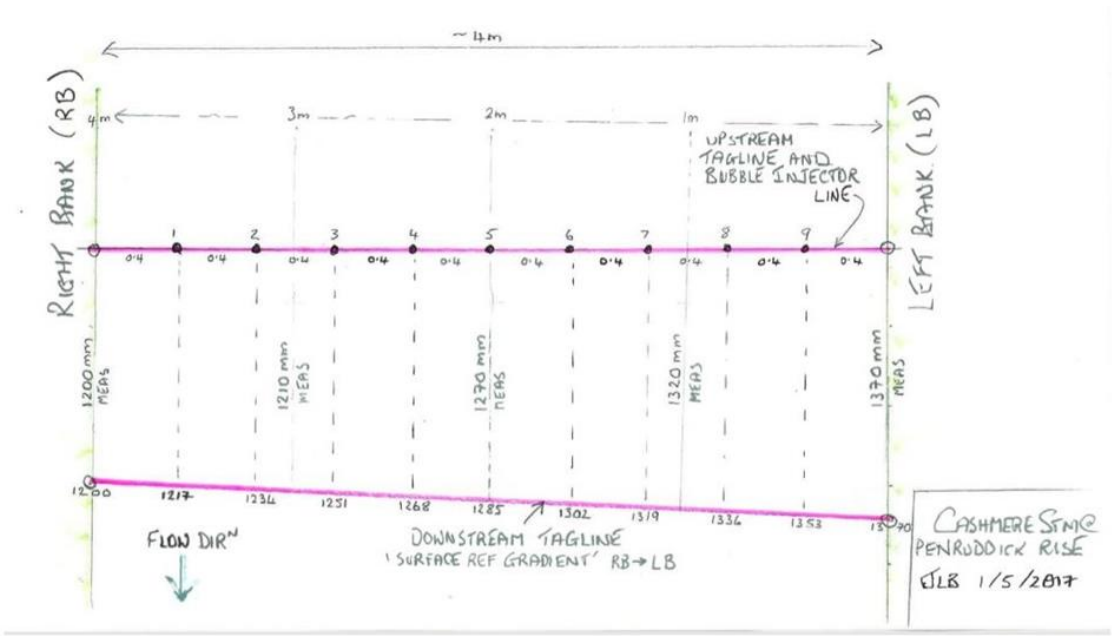


Figure 6-2: The layout of the reference area.

6.1.3 Result

During the first trial we experienced the differences between theory and field operation: setting up the camera correctly, experimenting with underwater lighting, aligning the bubble line with the upstream tagline and diverting to Dive HQ to refill the air cylinder. These were valuable lessons. At the time, the stream was running high and receding, so measurement uncertainty was high. We did four transects with the reference Q boat which calculated an average discharge of 0.626 m^3/s. The RBM result, manually calculated later from video frames, was reasonably encouraging (Figures 6-3 and 6-4) at 0.568 m^3/s.

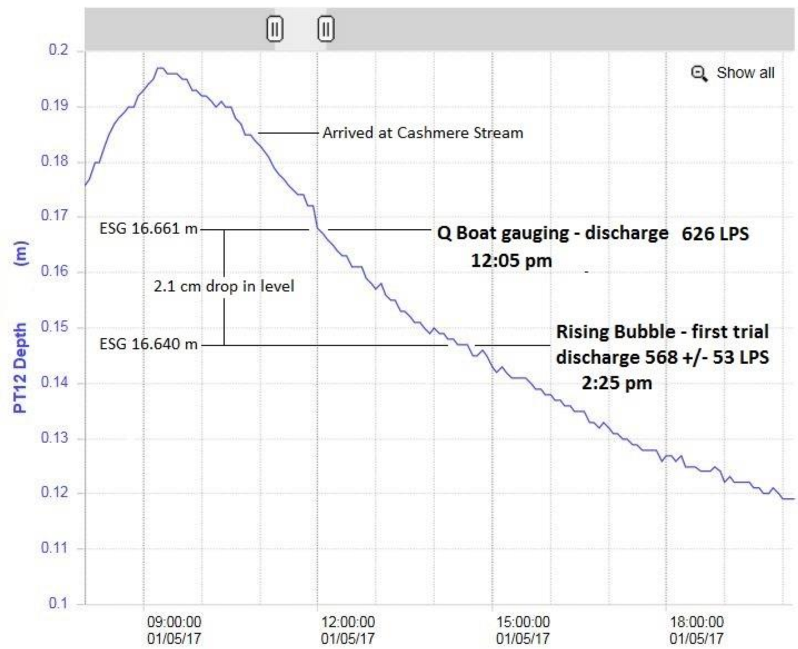


Figure 6-3: Results during recession of the stream.

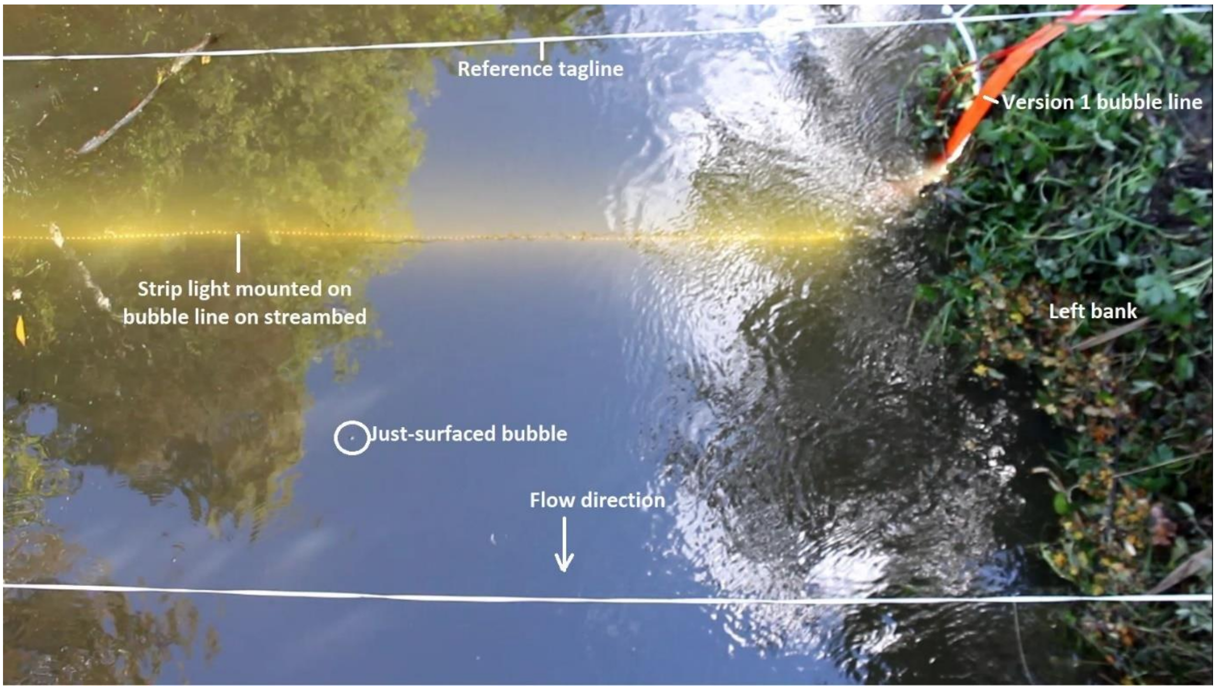


Figure 6-4: Taglines set up at Cashmere Stream with experimental underwater light. The camera was mounted on the bridge looking down at the water surface.

6.1.4 Conclusion

The trial provided us with enough confidence to continue our trial/modification regime to the next stage. Careful documentation is important. Caveat… it's easy to leave out an important V_r measurement or forget to take a water sample to measure V_r off-site.

6.2 Trial 2 – Knight's Stream (1 May 2017)

After visiting Cashmere Stream, we detoured to nearby Knight's Stream. This was very worthwhile.

6.2.1 Aim

To test the version 1 bubble line in a very weedy stream with a very soft bed (Figure 6-5).

Figure 6-5: Knight's Stream is choked with weed and extremely difficult to gauge. Here, the bed is very soft, making the depth ambiguous.

6.2.2 Method

We cleared weed from a 2m swathe, set up two taglines about two metres apart and laid the bubble line (Figure 6-6). We used a diver's tank to supply the compressed air. The camera was a Canon recording at 50 frames per second.

6.2.3 Result

The bed was so soft we could hardly walk on it. The version 1 bubble line sank into the soft bed and twisted so, while we were able to locate surfacing bubbles and calculate a few displacement values (Figure 6-6), the location of the origin was uncertain because of the mud and we were not able to get a value for Q. However, the videos were a useful supply of AI training images.

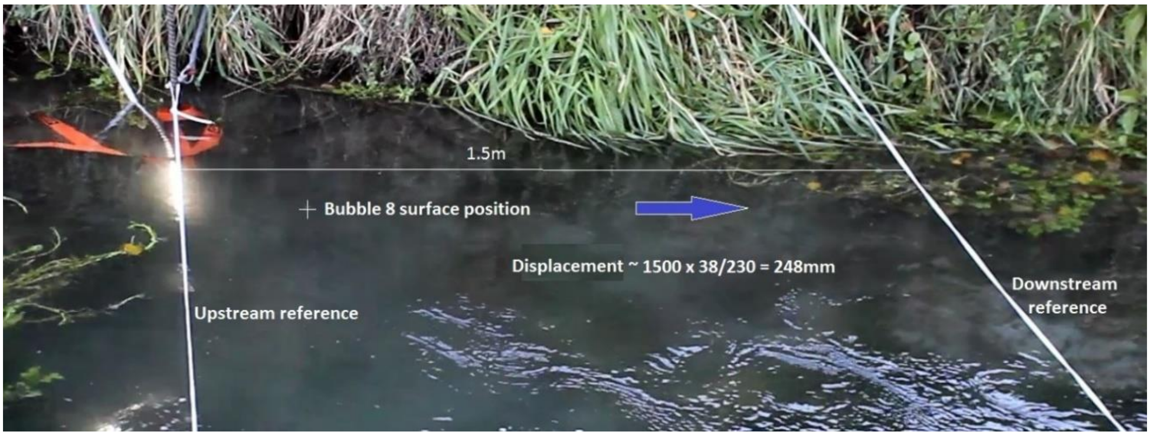


Figure 6-6: An early attempt to calculate displacement from each of the nine injectors

6.2.4 Conclusion

The experience with the version 1 bubble line twisting in the mud led to a successful redesign. We mounted the injectors on a 150 mm-wide rubber strip, 6 mm thick to spread the load and better-define the origin. The underwater light was not helpful.

6.3 Trial 3 – Cashmere Stream @ Penruddock Rise (9 May 2017)

6.3.1 Aim

To install and test the version 2 bubble line and to get an approximate result, now that the stream had returned to base-flow conditions. To obtain video record using a Canon camera at 50 fps.

6.3.2 Method

Set up the equipment, as we did previously on 1/5/2017 (when the stream was in recession), but with the version 2 bubble line. We needed to take enough video for training images and to enable manual calculation by stepping through video frames and tracking the bubbles to locate their just-surfaced positions. Take a 20-litre water sample back to the office to measure V_r.

6.3.3 Result

We averaged the 12 displacements obtained from each of the nine injectors, and summed the partial discharge contributed by each of the nine 'slices' of water to give an estimate of Q. The RBM estimate (Figure 6-7) was 0.397 m^3/s, the ADCP boat reference (Figure 6-8) was 0.375 m^3/s.

Cashmere Stream at Penruddick rise calculations from 9 May 2017 field trip

Jeremy Bulleid and Alec Dempster

Date	9 May 2017 14:40 to 15:20
ESG	16.535m to 16.535m +/-0.003m Qboat
Water Ten	12.9 degC
Bubble spa	9 x 0.4 m
Video ref	5378.MOV and 53xx.MOV
Rise Vel	**0.223** m/s ref Velocimeter tab

			*Raw **unscaled** on-screen 'displacement' measurements*														*Scaled for on-screen m*	1.00
														Med	**Avg**	**Sc avg**	**Partial**	**Partial**
Source	**Inj**	**TagL sep**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**Displ**	**Displ**	**Displ**	**pA (msq)**	**q (lps)**
5378.MOV	**1**	**990**	194	202	194	215	198	202	228	215	207	207	224	232	207	210	210	0.08	19
5378.MOV	**2**	**990**	367	337	316	376	371	367	380	384	363	307	333	367	367	356	356	0.14	32
5378.MOV	**3**	**995**	601	640	593	614	597	610	584	627	632	593	571	627	606	607	607	0.24	54
	4	**1000**	642	633	619	646	637	597	646	637	673	619	606	637	637	633	633	0.25	56
5379.MOV	**5**	**1000**	623	570	627	627	662	618	649	627	623	667	605	627	627	627	627	0.25	56
	6	**995**	560	654	650	623	605	556	605	610	681	610	632	645	616	619	619	0.25	55
5381.MOV	**7**	**990**	547	577	572	577	585	564	581	637	607	551	585	564	577	579	579	0.23	52
	8	**995**	547	576	518	609	621	621	617	613	535	485	502	436	561	556	556	0.22	50
	9	**995**	233	211	259	247	296	281	278	239	244	264	284	268	261	259	259	0.10	23
Totals																	494	**1.778**	**397**

Figure 6-7: Calculation sheet for RBM using manual on screen measurement.

ents\Cashmere@PenruddockRISINGBUBBLE2_20170509_0\

Measurement Details (Units: SI)

PARAMETERS	MEASUREMENT	170509_0_000	170509_0_...	170509_0_...	170509_0_...
DISCHARGE					
Use		☑	☑	☑	☑
Total Q (m3/s)	**0.375**	**0.368**	**0.382**	**0.393**	**0.356**
Top Q (m3/s)	0.107	0.105	0.111	0.112	0.099
Middle Q (m3/s)	0.208	0.202	0.213	0.215	0.203
Bottom Q (m3/s)	0.065	0.070	0.066	0.068	0.054
Left Q (m3/s)	-0.001	-0.003	-0.004	0.002	0.002
Right Q (m3/s)	-0.004	-0.006	-0.003	-0.004	-0.003
TIME					
Duration (s)	738.4	197.7	177.0	191.5	172.2
Start Time (05/09/2017)	16:02:26	16:02:26 R	16:05:52 L	16:08:51 R	16:12:05 L
End Time (05/09/2017)	16:14:57	16:05:43	16:08:49	16:12:02	16:14:57

Measurement Quality Assessment

	COV %		% Q
Q:	4.35	Left/Right Edge:	-0.21 / -1.13
Width:	0.68	Invalid Cells:	0.02
Area:	0.82	Invalid Ens:	40.37

Parameter	Automatic	User
Random 95% Uncertainty	6.9	
Invalid Data 95% Uncertainty	8.1	
Edge Q 95% Uncertainty	-0.4	
Extrapolation 95% Uncertainty	2.3	
Moving-Bed 95% Uncertainty	1.0	
Systematic 68% Uncertainty	1.5	
Estimated 95% Uncertainty	11.3	11.3

Figure 6-8: Results from the ADCP boat reference.

6.3.4 Conclusion

The version 2 bubble line was a success. We obtained a credible result for Q (0.397 m^3/s) by using median displacements.

6.4 Trial 4 – Halswell River @ Ryan's Bridge (19 February 2018)

Halswell River is rated via a permanent water-level to discharge monitoring station (Figure 6-9). However, there is significant weed growth that necessitates frequent rating changes.

6.4.1 Aim

To carry out our first exploratory trip to the Halswell River, located at Taitapu, 15 minutes' drive from Christchurch. To obtain usable video record with a GoPro Hero 5 Black video camera at 60 fps.

6.4.2 Method

We set up the two taglines, and as our 9 x 0.4 version 2 bubble line was too short to span the full width (Figure 6-10), we adjusted its position so that the deficiency in coverage was at the edges where there was least flow. The camera was mounted from the bridge looking directly down.

Figure 6-9: The reference site at Halswell showing taglines and prototype bubble line. The level to flow station stilling well is on the left.

6.4.3 Result

The reference FlowTracker measured 0.579 m^3/s and the RBM 0.700 m^3/s. RBM uncertainty (Figures 6-11 and 6-12) at the 68% confidence level (one standard deviation) was 8.8%. The 95% confidence level was 17.4%.

Figure 6-10: View from the left bank showing the 'undersized' bubble line on the streambed.

Halswell River@Ryans Bridge 19 February 2018						
Jeremy Bulleid and Martin Webb						
Date	19 February 2018	~11am				
Flow (Ecan ref)	**579 LPS**	resolution 5 LPS				
Water Temp						
Bubble spacing	9 x 0.4 m					
Video ref	Gopro					
Rise Vel approx	**0.201**	m/s				
				One off	Partial	Partial
Video File	**Bubble Posn**	**TagL separt'n**	**A**	**Displ**	**Area (msq)**	**Discharge (lps)**
Left bank	**1**	**2000**	743	743	0.30	60
	2	**2000**	1491	1491	0.60	120
1003 1:03	**3**	**2000**	1626	1626	0.65	131
1003	**4**	**2000**	1204	1204	0.48	97
1003	**5**	**2000**	915	915	0.37	74
1003	**6**	**2000**	1284	1284	0.51	103
1003	**7**	**2000**	640	640	0.26	51
1003	**8**	**2000**	488	488	0.20	39
1003 Right bank	**9**	**2000**	310	310	0.12	25
Totals					**3.480**	**700**

Figure 6-11: Our first (high uncertainty) result from Halswell was primarily intended as an operational trial.

	A	C	D	E	G	H	I	K	L	M	N
1	**Uncertainties in the Rising Bubble Method for Measuring Total Discharge**										
2	***Halswell River @ Ryan's Bridge 19/2/2018***										
3	Total Discharge =	Rise Velocity	*	Area							
4	Q ± U(TD)	Vr ± U(Vr)		A ± U(A)	Where U is the standard Uncertainty						
5											
6		*velocimeter*	*stream*	*stream*	*calculated*						
7		***Rise Time***	***Depth***	***W Veloc***	***DS Displ't***						
8		*tr (sec)*	*D (m)*	*Vw (m/s)*	*L (m)*						
9	***Enter these three variab***	*3.480*		*0.300*	*0.086*						
10											
11	Rise Velocity (dh/ts)	**Detection**	**dh**	**U(dh)**	**Rise Time**	ts	U(ts)	**Rise Velocit**	**Vr**	**U(Vr)**	
12		height	(m)	(± m)		(± sec)			(m/s)	(± m/s)	
13											
14			0.700	0.001		3.480	0.017		0.201	0.001	
15											
16	Area ($\sum_1^9$ (W*L))										
17											
18											
19	D'stream Displacement	Displacemen	Length	Time		U(L)					
20			(± frames)	(± sec)		(± m)					
21											
22		Surfacing Loc	1	0.020		0.002					
23	Need to include this	Upstrm ref									
24		Dnstrm ref									
25	**Bubble Injectors**	**Slice Width**	**W**	**U(W)**	**Displacemen**	**L**	**U(L)**	**A = W * L**	**A**	**U(A)/A**	**U(A)**
26			(m)	(± m)		(m)	(± m)		(m^2)		(± m^2)
27											
28	Bubble 1	W1	0.4	0.002	L1	0.743	0.002	A1	0.297	0.005679	0.001687
29	Bubble 2	W2	0.4	0.002	L2	1.491	0.002	A2	0.596	0.005177	0.003087
30	Bubble 3	W3	0.4	0.002	L3	1.626	0.002	A3	0.650	0.005149	0.003348
31	Bubble 4	W4	0.4	0.002	L4	1.204	0.002	A4	0.482	0.005269	0.002537
32	Bubble 5	W5	0.4	0.002	L5	0.915	0.002	A5	0.366	0.005456	0.001998
33	Bubble 6	W6	0.4	0.002	L6	1.284	0.002	A6	0.513	0.005237	0.002689
34	Bubble 7	W7	0.4	0.002	L7	0.640	0.002	A7	0.256	0.005895	0.001510
35	Bubble 8	W8	0.4	0.002	L8	0.488	0.002	A8	0.195	0.006467	0.001261
36	Bubble 9	W9	0.4	0.002	L9	0.310	0.002	A9	0.124	0.008162	0.001012
37											
38	**Totals for all 9 'slices' (A)**								**3.480**	**0.018**	**0.062**
39											
40	**Discharge Uncertainty**	**U(Vr)**	**U(A)**		**U(TD)**						**Q**
41	Q = Vr * A	(± m/s)	(± m^2)		(± LPS)						%
42											
43		0.001	0.062		**62**		for	Q =	**700**	LPS	**8.8%**
44	Range of uncertainty	638	to	762	LPS						
45											
46	**Uncertainty at the 95% confidence level**			**17.4%**							

Figure 6-12: First attempt to calculate standard uncertainty (at the 68% confidence level) and uncertainty at the 95% confidence level.

6.4.4 Conclusion

The result was encouraging (Figure 6-11) despite the high uncertainty (Figure 6-12). We needed to extend the bubble line so that it would span the entire width of the river. This would require the addition of four more injectors, taking the injector count from nine to 13.

6.5 Trial 5 – Halswell River @ Ryan's Bridge (3 October 2018)

6.5.1 Aim

To obtain an accurate RBM Total Discharge measurement, with the 13-injector modification, that compared favourably with a three-point FlowTracker gauging. Measure V_r.

6.5.2 Method

The setup is shown in Figure 6-13.

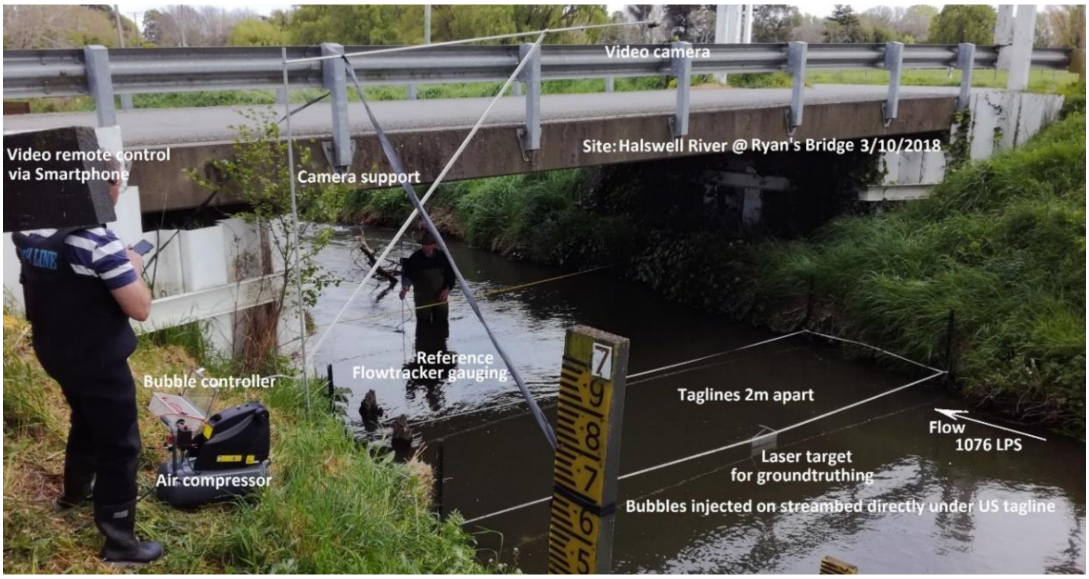


Figure 6-13: We mounted the camera so that its field of view covered the area of interest. The camera was looking directly down onto the water surface – this was visually challenging.

6.5.3 Result

Thomas Wilding (HBRC), Bruce Digby (ECan) and Jeremy Bulleid (NIWA) carried out trials in windy conditions that ruffled the water surface and made the camera move around. The details of the RBM result (1.074 m^3/s) are given in Figures 6-14 and 6-15. Rise velocity V_r was 0.2066 m/s (Figure 6-16).

Halswell River@Ryans Bridge (Rated but changes because of weed) 3 October 2018

Jeremy Bulleid, Bruce Digby ECan and Thomas Wilding HBRC

Date ##### ~11am

Q from SonTek Flowtrack 1076 +/- 14 LPS (UC 1.3%)

Q from Ecan website note there was a small tree in the river at the DS edge of the bridge. This would likely make the depth/rated flow a bit higher

WTemp 12C

Bubble 13 x 0.4 m

Video r Gopro

Vr 0.2066 m/s sample taken 12pm and tested 4 hours later at Kyle St

On screen measurements 0.035

These measurements done from video measuring displacement on screen and scaling

Bubble	TagL se	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Median Displ(mm)	RealDis (m)	Correct edge to nozzle	Partial Area (msq)	Partial Q (cums)	Gopro video.mp4
1	138	27	25	25	24	26	27	24	25	27	28	25	25	27	26	26	27	26	27	28	29	25	0.362	0.327	0.131	0.027	1257
2	139	39	38	39	38	38	38	39	43	41	41											38	0.547	0.512	0.205	0.042	1257
3	139	115	114	106	117	115	106	108	99	100												114	1.640	1.605	0.642	0.133	1254
4	138	112	108	113	116	107	111	107														111	1.609	1.574	0.629	0.130	1254
5	136	91	88	89	88	88	86	89	88	88	82	84	87	87	87	88	99	98	98	90	92	88	1.294	1.259	0.504	0.104	1254
6	136	97	100	91	89	74	87	99	90	84	91	87	85	87	81	87	81	85	88	82	90	89	1.309	1.274	0.510	0.105	1254
7	136	107	108	94	95	85	88	95	88	86	86	96	100	89	94	97	97	88	80	91	87	94	1.382	1.347	0.539	0.111	1254
8	136	80	69	73	70	71	73	72	70	76	72											71	1.044	1.009	0.404	0.083	1254
9	136	65	69	65	65	68	66	61	66	64	61	56	54	62	61	56	59	60	58	62	65	66	0.971	0.936	0.374	0.077	1254
10	136	58	65	66	68	58	60	63	57	62	61	62	56	55	59	64	60	59	59	55	61	65	0.956	0.921	0.368	0.076	1254
11	136	63	60	54	55	54	58	63	56	61	54	61	64	66	67	65	60	60	61	66	62	55	0.809	0.774	0.310	0.064	1254
12	136	50	52	52	62	57	55	57	44	44	48	44	40	41	47	48	45	55	44	44	41	55	0.809	0.774	0.310	0.064	1254
13	136	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	0.721	0.686	0.274	0.057	1254
Totals																									**5.199**	**1.074**	**2.7%**

Figure 6-14: Results from manually processing the video.

Bubble Injectors	Slice Width	W (m)	U(W) (± m)	Displacement	L (m)	U(L) (± m)	A = W * L	A (m^2)	U(A)/A	U(A) (± m^2)
Bubble 1	W1	0.4	0.001	L1	0.327	0.005	A1	0.131	0.015478848	0.002027
Bubble 2	W2	0.4	0.001	L2	0.512	0.005	A2	0.205	0.010084936	0.002064
Bubble 3	W3	0.4	0.001	L3	1.605	0.005	A3	0.642	0.00399392	0.002565
Bubble 4	W4	0.4	0.001	L4	1.574	0.005	A4	0.629	0.004042873	0.002545
Bubble 5	W5	0.4	0.001	L5	1.259	0.005	A5	0.504	0.004692453	0.002363
Bubble 6	W6	0.4	0.001	L6	1.274	0.005	A6	0.510	0.004653721	0.002371
Bubble 7	W7	0.4	0.001	L7	1.347	0.005	A7	0.539	0.004474525	0.002412
Bubble 8	W8	0.4	0.001	L8	1.009	0.005	A8	0.404	0.0055498	0.002240
Bubble 9	W9	0.4	0.001	L9	0.936	0.005	A9	0.374	0.005900069	0.002208
Bubble 10	W10	0.4	0.001	L10	0.921	0.005	A10	0.368	0.005977482	0.002202
Bubble 11	W11	0.4	0.001	L11	0.774	0.005	A11	0.310	0.006928201	0.002144
Bubble 12	W12	0.4	0.001	L12	0.774	0.005	A12	0.310	0.006928201	0.002144
Bubble 13	W13	0.4	0.001	L13	0.686	0.005	A13	0.274	0.007709602	0.002114
Totals for all 13 'slices' (A)								5.1989	0.0263	0.1370
Discharge Uncertainty Q = Vr * A	U(Vr) (± m/s)	U(A) (± m^2)	U(TD) (± LPS)							
	0.0009	0.1370	29	for	Q=	1074	LPS	2.7%	Standard UC (63%, k=1)	
%	0.36	2.63	2.66	%				5.3%	Expanded UC (95%, k=2)	
Range of uncertainty	1045	to	1103	LPS						

Figure 6-15: Uncertainty calculation.

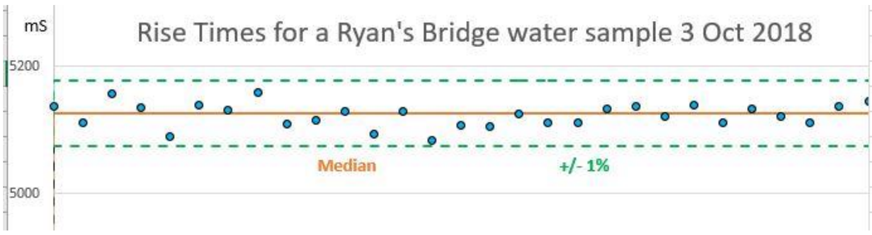


Figure 6-16: Velocimeter readings from water sample taken at Ryan's Bridge.

We looked at the Flowtracker uncertainty two ways: the FlowTracker's own estimate (Figure 6-17) and HBRC's standard method for estimation (Figure 6-18).

Start Date and Time	2018/10/03 08:51:38	Operator(s)	BRUCE

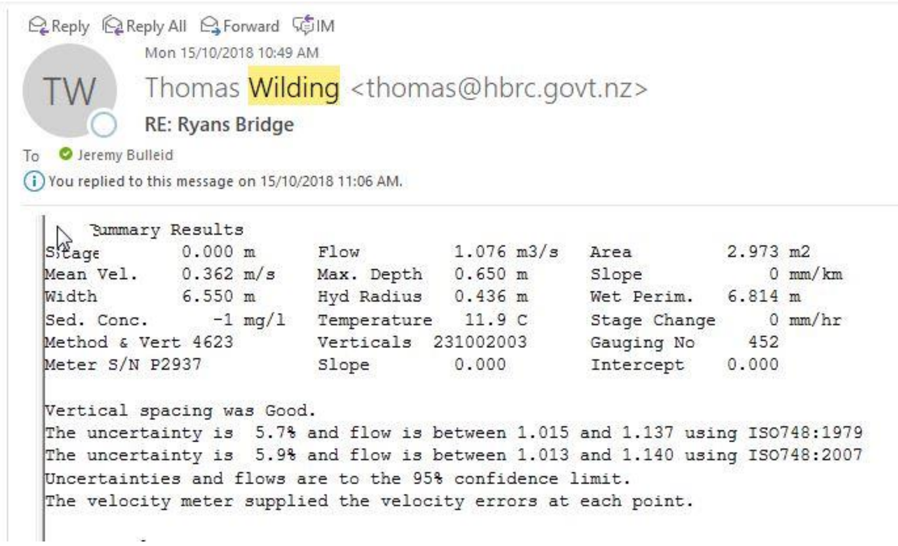
System Information	
Sensor Type	FlowTracker
Serial #	P2937
CPU Firmware Version	3.9
Software Ver	2.30
Mounting Correction	0.0%

Units	(Metric Units)
Distance	m
Velocity	m/s
Area	m^2
Discharge	m^3/s

Discharge Uncertainty		
Category	ISO	Stats
Accuracy	1.0%	1.0%
Depth	0.1%	0.4%
Velocity	0.4%	0.7%
Width	0.1%	0.1%
Method	1.7%	-
# Stations	2.0%	-
Overall	**2.9%**	**1.3%**

Summary			
Averaging Int.	40	# Stations	25
Start Edge	LEW	Total Width	6.550
Mean SNR	43.4 dB	Total Area	2.973
Mean Temp	11.95 °C	Mean Depth	0.454
Disch. Equation	Mean-Section	Mean Velocity	0.3619
		Total Discharge	**1.0759**

Figure 6-17: FlowTracker's own estimation of uncertainty.


Reply Reply All Forward IM

Mon 15/10/2018 10:49 AM

TW

Thomas Wilding <thomas@hbrc.govt.nz>

RE: Ryans Bridge

To Jeremy Bulleid

You replied to this message on 15/10/2018 11:06 AM.

```
Summary Results
Stage         0.000 m       Flow         1.076 m3/s    Area         2.973 m2
Mean Vel.     0.362 m/s     Max. Depth   0.650 m       Slope            0 mm/km
Width         6.550 m       Hyd Radius   0.436 m       Wet Perim.   6.814 m
Sed. Conc.       -1 mg/l    Temperature   11.9 C       Stage Change     0 mm/hr
Method & Vert 4623          Verticals   231002003      Gauging No     452
Meter S/N P2937             Slope        0.000         Intercept    0.000

Vertical spacing was Good.
The uncertainty is  5.7% and flow is between 1.015 and 1.137 using ISO748:1979
The uncertainty is  5.9% and flow is between 1.013 and 1.140 using ISO748:2007
Uncertainties and flows are to the 95% confidence limit.
The velocity meter supplied the velocity errors at each point.
```

Figure 6-18: HBRC's method for estimating FlowTracker uncertainty.

6.5.4 Conclusion

The 13-injector modification was successful. The RBM result (Figure 6-15) was 1.074 m^3/s; the standard uncertainty UC at the 68% confidence level was 0.36% for V_r, 2.66% for A and 2.7% for Q. The ECan FlowTracker reference gauging was 1.076 m^3/s. Camera movement is not a problem for manual calculations as measurements are always relative to visual references on any given frame. However, when fully automated, the camera will need to be fixed in position if virtual references are used. In any event, benchmark references will be used for validating results for QA purposes. The AI model would need to be improved or changed. Here, the model was trained to detect bubbles about 4 frames after the bubble had just surfaced (Figure 6-19). This made the image larger, making it easier to detect. Image resolution was limiting detectability. Because the flow increased sharply from injector 2 to injector 3 we considered that it may be beneficial to interpose a 14th injector between positions 2 and 3.

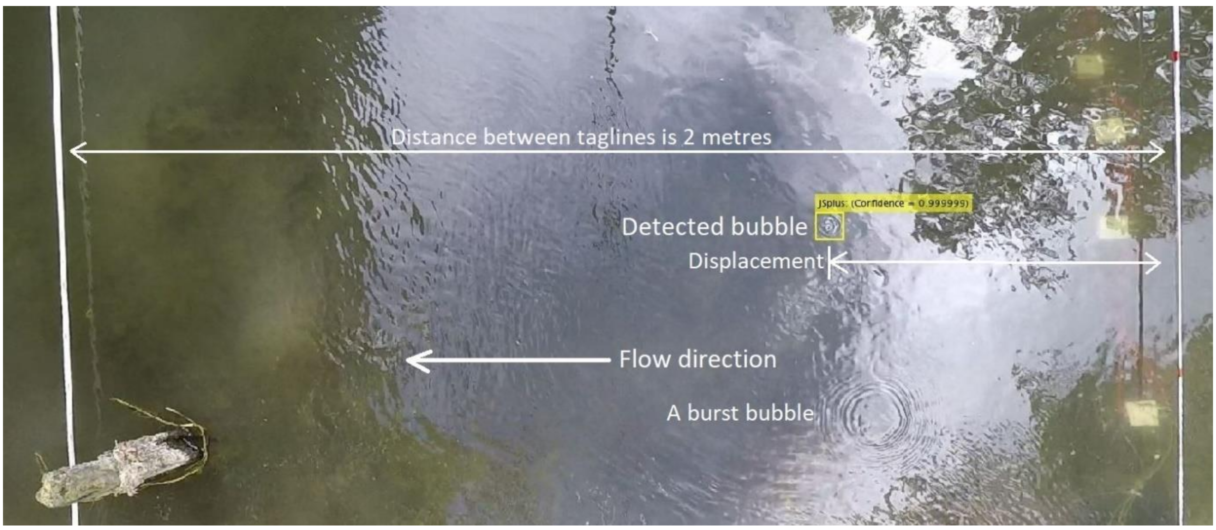


Figure 6-19: Early attempts at training a Regional CNN AI model.

6.6 Trial 6 – Halswell River @ Ryan's Bridge (4 December 2018)

This was our third trip to Halswell River.

6.6.1 Aim

To investigate the variability of the displacements from the first few injectors from the same 'shot'. To interpose a 14th injector between injectors 2 and 3 to sample the higher-flowing region that was identified on the previous trip.

6.6.2 Result

The displacements from each of the 20 shots (for the first four bubble locations from the left bank) are shown in Figure 6-20. The variability is shown in Figure 6-21.

Actual measurements - calculating 20 frames of bubbles 1 to 4. these 4 were within camera field at same time.

These measurements done from video measuring displacement on screen and scaling

Bframe	On screen tagL sep	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
WELB		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	365	0.378	0.586	0.526	0.487	0.427	0.602	0.526	0.597	0.641	0.564	0.482	0.372	0.454	0.575	0.460	0.471	0.493	0.438	0.542	0.416
2	368	0.827	0.631	0.680	0.669	0.810	0.707	0.702	0.729	1.022	0.810	0.843	0.832	0.783	0.713	0.620	0.821	0.767	0.810	0.778	0.718
3	370	0.974	0.834	0.785	0.866	0.731	0.704	0.850	0.910	1.077	0.839	0.850	0.866	0.904	0.872	0.942	0.742	0.834	0.791	0.910	0.915
4	372	1.301	1.177	0.800	1.279	1.048	0.918	1.107	1.064	1.064	1.031	1.064	1.064	1.166	1.231	1.166	1.366	0.972	0.810	0.961	1.085

Figure 6-20: Displacements from the first four injectors (from the left bank).

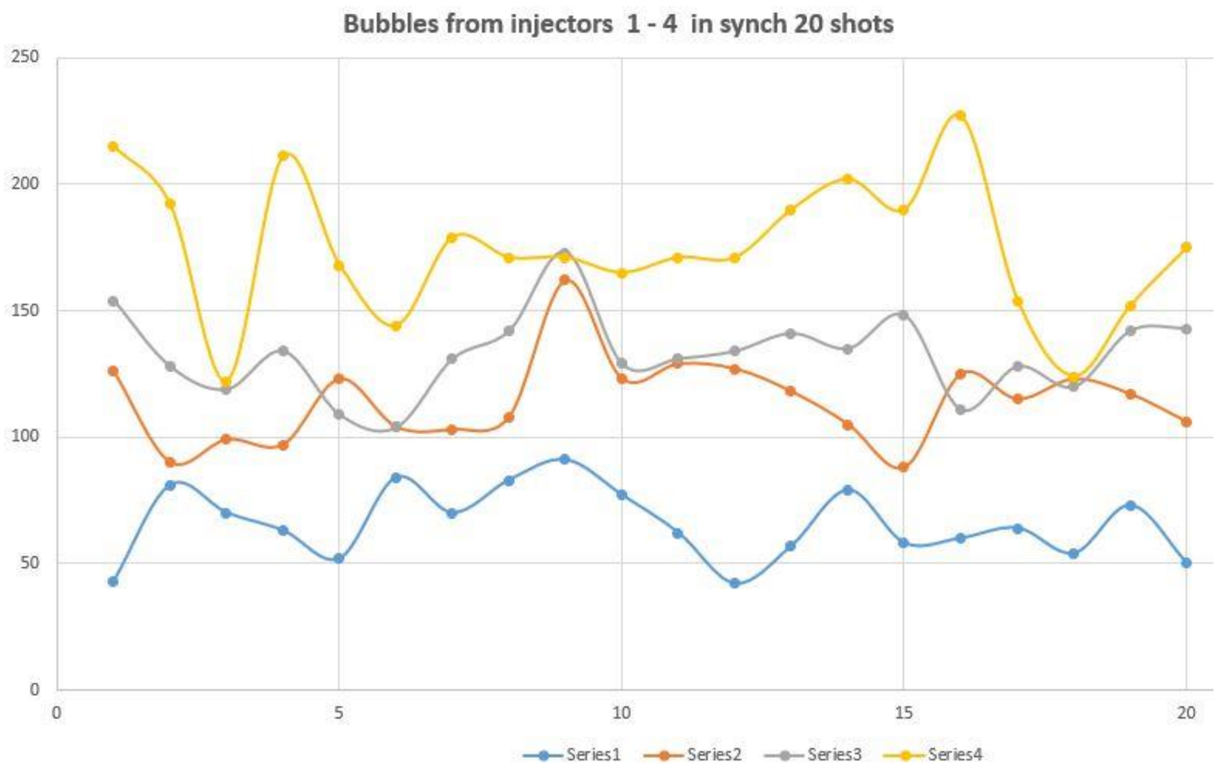


Figure 6-21: This shows how displacement (y-axis (mm)) varies at each of the 20 samples.

This trip was also a chance to obtain more training images of the surface (Figure 6-22) under different conditions and see what was going on under the water (6-23).

Figure 6-22: View from the right bank illustrating the visual challenges in recognising surfacing bubbles.

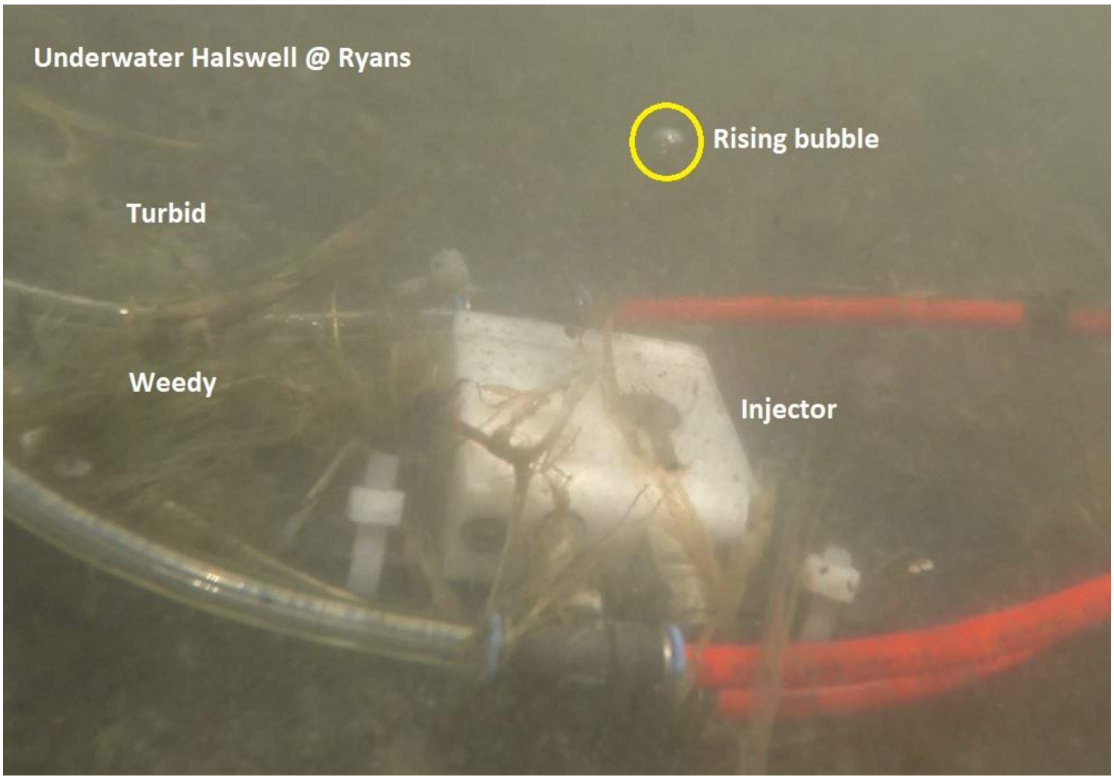


Figure 6-23: Turbid conditions underwater.

6.6.3 Conclusion

We were not able to reach any conclusion regarding the addition of the 14th injector as the flow rate had reduced considerably since our last visit and the sharp change was no longer present.

6.7 Trial 7 – Halswell River @ Ryan's Bridge (12 February 2019)

6.7.1 Aim

To investigate whether increasing the video resolution from 2k to 4k would make bubble detection easier.

6.7.2 Method

To set up the GoPro Hero7 Black on a pole deployed from the bridge in order to get the full river width into the camera's field of view. Because we increased the resolution, we were not able to use the camera's 'linear mode' and the maximum frame speed was reduced from 60 to 30 fps. Carry out a reference three-point FlowTracker reference measurement.

6.7.3 Result

Because we could not use linear mode, the camera introduced barrel distortion in wide mode (Figure 6-24). This is not particularly troublesome since the reference relativity is not lost. However, the lower frame rate may increase the detection uncertainty.

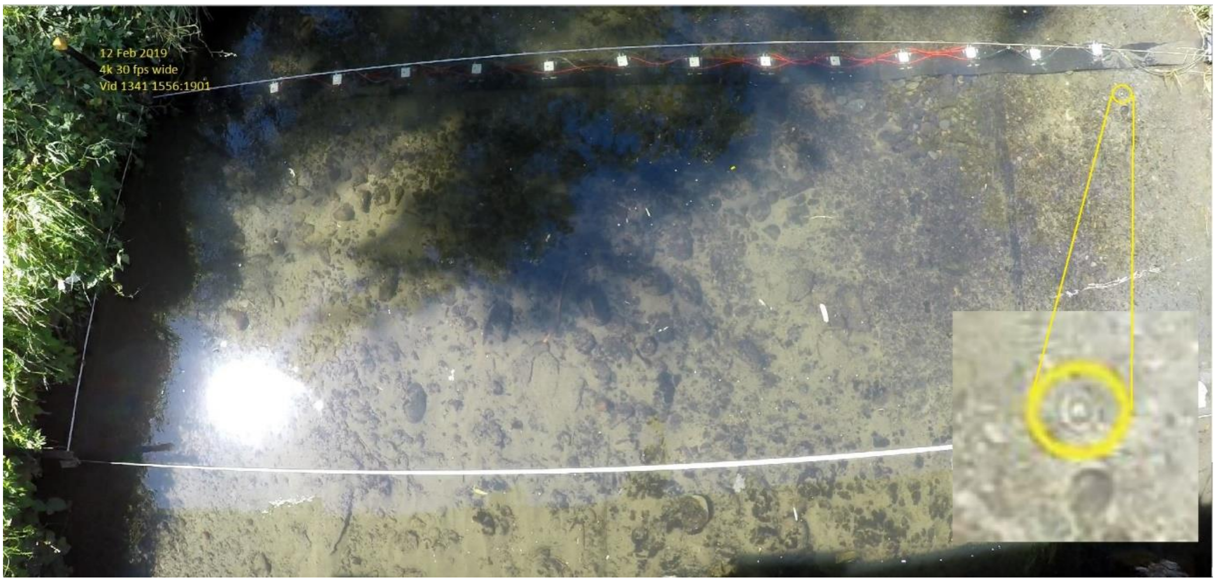


Figure 6-24: Not an AI detection, but manually annotated to illustrate the difficulty of resolving bubbles at these distances with one camera covering the full river width.

We carried out a quick check initially by standing in the water, identifying each surfacing location by eye and estimating the average downstream bubble displacement (for about 10 bubbles) from each bubble line injector. Our estimated flow was 0.675 m^3/s. The water-level to flow rated flow published on the ECan website was 0.620 m^3/s.

The FlowTracker measurement gave 0.702 m^3/s. Our RBM estimate, from manually processing the videos after the event, with 13 injectors and fewer displacements than desired, was 0.701 m^3/s (Figure 6-25).

Halswell River@Ryans Bridge 12 February 2019

Jeremy Bulleid (NIWA), Bruce Digby ECan

Date	12 February 2019	~11am
Q from SonTek Flowtracker gauging	702	LPS
Rated' Q from Ecan website	620	LPS
WTemp	19	degC
Bubble spacing	0.4	m
Video ref Gopro	1328 to 1341	
Vr	0.1978	m/s
Distance be 1980 mm Left bank, 1975mm right bank		

On screen measurements

These measurements done from video measuring displac

#	On scre	1	2	3	4	5	6	7	8	9	10	Median Displ(mm)	Sdev %	RealDisp (m)	Correct edge to nozzle (0.118)	Partial Area (msq)	Partial Q (cums)
1	154	17	15	16	16	20	17	16	14	16	16	16	9	0.206	0.324	0.129	0.026
2	154	31	31	27	31	31	30	30	30	31	31	31	4	0.399	0.517	0.207	0.041
3	154	37	38	38	44	39	38	36	35	35	38	38	6	0.488	0.606	0.243	0.048
4	154	51	55	57								55	5	0.707	0.825	0.330	0.065
5	154	109	106									108	1	1.381	1.499	0.599	0.119
6	154	71	70	70								70	1	0.899	1.017	0.407	0.080
7	154	88										88	0	1.130	1.248	0.499	0.099
8	168	45	38	38	38	37						38	8	0.447	0.565	0.226	0.045
9	164	36	33	35								35	4	0.422	0.540	0.216	0.043
10	386	48	47									48	1	0.243	0.361	0.144	0.029
11	168	32	33	31	35	26						32	9	0.376	0.494	0.198	0.039
12	170	28	27	21	33	21						27	17	0.314	0.432	0.173	0.034
13	170	22	26	29	29	27						27	10	0.314	0.432	0.173	0.034
Totals																**3.543**	**0.701**

Figure 6-25: Manually-calculated result from trial 7 at Halswell.

6.7.4 Conclusion

The RBM process is repeatable and accurate. The next stage will be to deploy it at a suitable site within ECan's territory and carry out longer-term trials.

7 Hawke's Bay trials

7.1 Trial 8 – Karamu Stream (12 March 2019)

7.1.1 Aim

To set up the equipment and ensure that everything was working properly before visiting other sites. Although the 10-metre-wide Karamu Stream was not typical of the type of stream we were targeting for trials, it had a flat concrete area where we could set up and make sure the equipment was working (Figures 7-1) before deploying it in the stream.

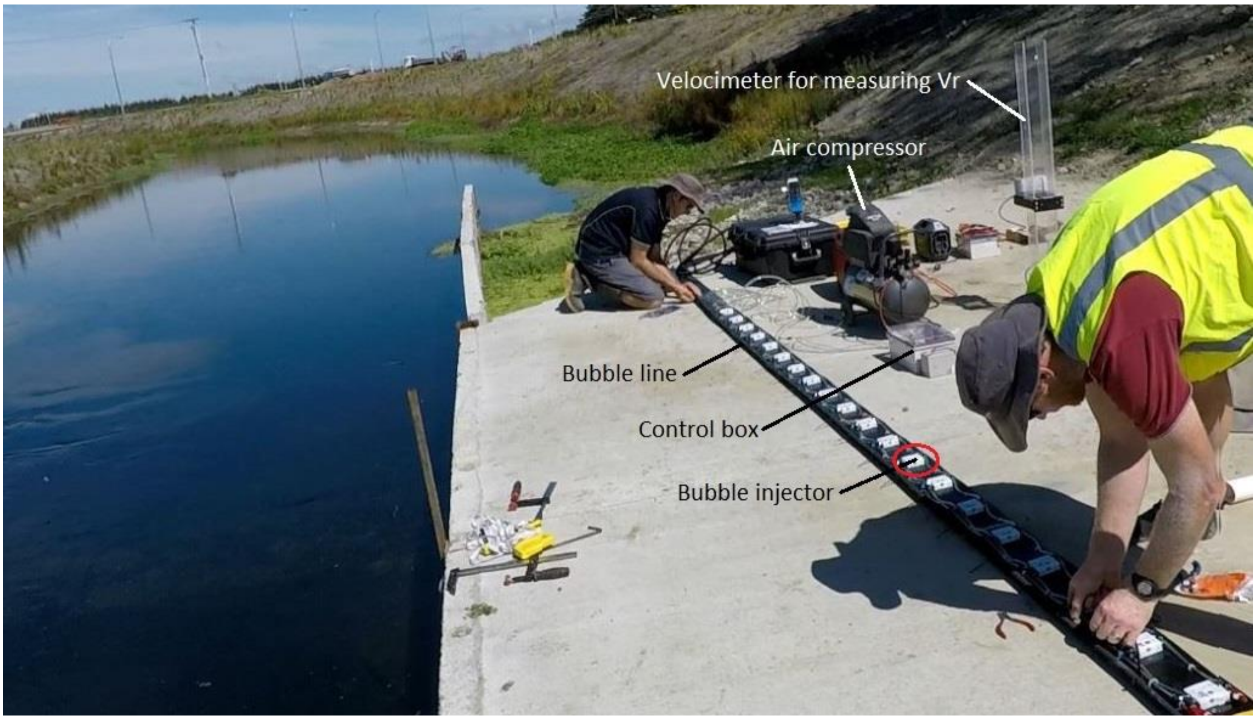


Figure 7-1: Setting up the equipment.

7.1.2 Method

We installed two taglines across the 10-metre-wide stream, laid the bubble line and aligned the rubber edge with the upstream tagline using a T-square with levels (Figure 7-2). We also fitted nozzles and a 'soak-hose' bought from a local hardware store to see if they might give some useful indication of flow. We used HBRC's petrol driven air compressor and flew a drone with a video camera over the laid-out area.

Figure 7-2: Aligning the bubble line with the tagline, using a T-square with levels.

7.1.3 Result

After resolving initial problems with the air compressor, the equipment worked correctly. The output of the soak-hose was a 'fizz' of bubbles of all sizes. While it looked spectacular, it covered such a large area it did not produce much useful displacement information. However it did indicate a 'rough' flow profile across the stream. It used a lot of air and the bubble output was not consistent along the length of the soak hose. The output of the nozzles was better, but uncontrolled, so spread out over too great an area to provide accurate displacement information. The RBM performed consistently and we were able to locate the bubble surfacing location by eye. With just the RBM running, it was interesting to see how a shoal of yellow-eyed mullet in the stream interacted with the bubble line (Figures 7-3 and 7-4). We were releasing a shot of bubbles every 1.7 seconds. Holding the camera underwater showed the mullet doing a 'U-turn' at the bubbles, or perhaps at the 'click' of the bobbin valves.

Figure 7-3: A shoal of Mullet do a 'U-turn' right at the bubble line.

Figure 7-4: The activity above the water surface was equally dramatic.

7.1.4 Conclusion

We verified that the soak hose and nozzle methods were not viable for accurate measurement of flow but could give an approximate indication of how flow was distributed across a stream. Unlike RBM, these required an excessive amount of compressed air. It was also another useful RBM familiarisation exercise.

7.2 Trial 9 – Tutaekuri-Waimate Stream @ Goods Bridge (13 March 2019)

In the Goods Bridge region, the Tutaekuri-Waimate Stream flows through vineyards (Figure 7-5). When we arrived, there appeared to be a lot of fast-moving water.

7.2.1 Aim

To obtain an accurate RBM Total Discharge measurement that compared favourably with an ADCP stationary gauging.

7.2.2 Method

We set the reference taglines in place (Figure 7-6), 1.6 metres apart, laid the bubble line across the stream and aligned the rubber edge with the upstream tagline. Because of the strong flow, we placed a mallet on the rubber at the centre to prevent any tendency for the bubble line to shift in the water current. We measured V_r in the Velocimeter.

Figure 7-5: Drone shot of Tutaekuri-Waimate Stream at Goods Bridge, looking downstream.

An ADCP gauging was carried out by HBRC field staff on the downstream side of the bridge (Figure 7-5), as a routine monthly measurement. We carried out a stationary ADCP reference gauging at the RBM site (Figure 7-7).

Figure 7-6: View from left bank. Thomas flying the drone to obtain aerial video.

Figure 7-7: View from right bank. Deploying the ADCP boat (the reference) between the two taglines.

7.2.3 Result

We were only able to detect bubbles at eight points initially/manually, but further analysis may yield all 20 of them given enough access to the Matlab frame stepping software. As an approximation, we took an average of the six 'non-edge' points and fitted the missing points with these average values. While approximate, this approach was reasonable given that the bed was quite flat. The way it was configured, the bubble line was about half a metre short, so did not cover the edges completely. Our stationary ADCP Q reference measurement (between the taglines) was 2.320 m^3/s, the RBM estimate (Figure 7-8) was 2.282 m^3/s and the ADCP measurement downstream of the bridge was 2.123 m^3/s.

	A	B	D	E	F	G	I	J	K	L	N	O	P	Q
1	**Rising Bubble flow measurement at Tutaekuri-Waimate Stream, Hawkes Bay**													
2														
3	*Jeremy Bulleid, Thomas Wilding, Phil Hall*													
4	**Date**	13 March 2019	~ 1200 - 1300 NZST											
5	**Q, ADCP boat between taglines**		2.320	Cumec		Stationary method								
6	**Q, ADCP boat, DS side of bridge**		2.123											
7	**Q from RBM**		2.282	cumecs		Approximation								
8	**WTemp**		16.2	degC										
9	**Bubble spacing**		0.2	m		20 injectors								
10	**Video ref**	Gopro	GPPR1443		frame number reference given in cell comment									
11	**Vr**		0.2095	m/s	measured in small velocimeter on bank									
12	**Distance between taglines**		1600 mm Left bank, 1650mm right bank											
13	**Edge /tag to nozzle offset**		-60	mm										
14														
15	**Manual on-screen measurements from the 8 points I was able to see and inferred the rest from the *average (0.122)* of the non edge values**													
16	*These measurements done from video measuring displacement on screen and scaling*													
17	**#**	**True tagL sep'n (mm)**	**Seq 1**				**Seq 2**				**composite**			
18			Screen	offs	p Area	q	Screen	offs	p Area	q	Screen	offs	p Area	q
19	**Right bank**													
20	1	1650.0					864	804	0.1609	0.034	864	804	0.1609	0.034
21	2	1647.4												*0.122*
22	3	1644.7												*0.122*
23	4	1642.1	3664	3604	0.7208	0.151					3664	3604	0.7208	0.151
24	5	1639.5												*0.122*
25	6	1636.9												*0.122*
26	7	1634.2												*0.122*
27	8	1631.6												*0.122*
28	9	1629.0												*0.122*
29	10	1626.3					2790	2730	0.5460	0.114	2790	2730	0.5460	0.114
30	11	1623.7												0.1217
31	12	1621.1												*0.122*
32	13	1618.4	3146	3086	0.6173	0.129					3146	3086	0.6173	0.129
33	14	1615.8												*0.122*
34	15	1613.2												*0.122*
35	16	1610.6												*0.122*
36	17	1607.9	2623	2563	0.5126	0.107					2623	2563	0.5126	0.107
37	18	1605.3	2738	2678	0.5357	0.112					2738	2678	0.5357	0.112
38	19	1602.7	2824	2764	0.5527	0.116					2824	2764	0.5527	0.116
39	20	1600.0	1439	1379	0.2758	0.058					1439	1379	0.2758	0.058
40	**Left bank**													
41	**Discharge (cumecs)**					**0.673**				**0.148**				**2.282**
42						6 points				2 points				

Figure 7-8: Partial result from Tutaekuri-Waimate Stream.

7.2.4 Conclusion

The RBM approximation (see line 15 on Figure 7-8 for explanation) was 2.282 m^3/s, the HBRC FlowTracker reference gauging, carried out between the taglines, was 2.320 m^3/s. There are more video recordings taken from different aspects, but these are yet to be processed. Because we were able to calculate partial discharges at the stream edges and in the middle, it seems likely that we could yet get a more complete result. Because of the missing points we did not attempt to calculate the RBM measurement uncertainty. The taglines might have been better-placed three metres apart as we later discovered the bubbles were being displaced further than 1.6 metres.

7.3 Trial 10 – Raupare Stream @ Ormond Road (14 March 2019)

Raupare Stream is in the lower Karamu catchment. It originates from groundwater springs adjacent to the Ngaruroro River near Twyford, and flows for approximately 7.5 km to the southeast, converging with the Karamu Stream.

7.3.1 Aim

To carry out RBM Q measurements in Raupare Stream to test for repeatability, and accuracy against a reference FlowTracker gauging. We also wanted to see if we could successfully obtain instantaneous snapshots of Q.

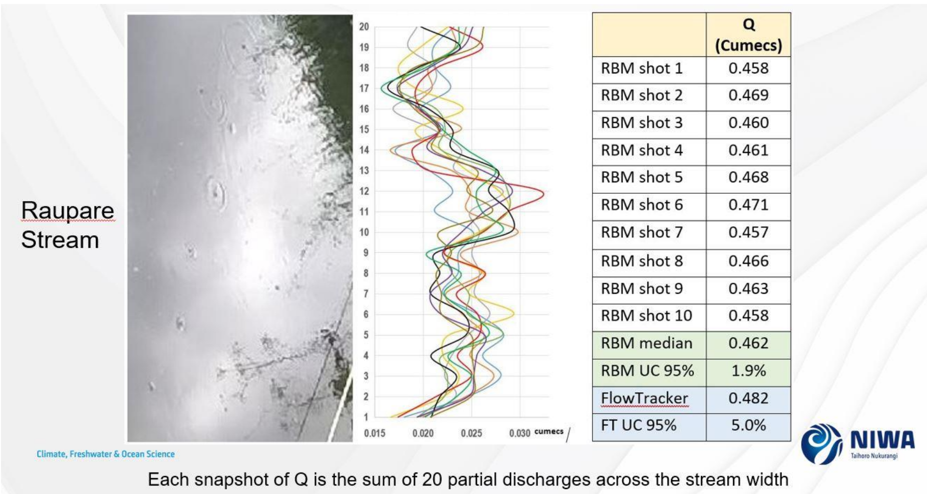
7.3.2 Method

This site is kept clear of weed to enable regular FlowTracker measurements for verification of the water-level-to-flow rating, so minimal weeding was needed. We laid out the site in the usual way with taglines 1.230 metres apart (Figure 7-9).

Figure 7-9: A drone's-eye view of the Raupare monitoring site. The whitish object near the middle of the downstream tagline is an ADCP with a stilling well water-level monitoring station on the right.

7.3.3 Result

The result we obtained from calculating 10 'Q snapshots' is shown in Figure 7-10.



	Q (Cumecs)
RBM shot 1	0.458
RBM shot 2	0.469
RBM shot 3	0.460
RBM shot 4	0.461
RBM shot 5	0.468
RBM shot 6	0.471
RBM shot 7	0.457
RBM shot 8	0.466
RBM shot 9	0.463
RBM shot 10	0.458
RBM median	0.462
RBM UC 95%	1.9%
FlowTracker	0.482
FT UC 95%	5.0%

Figure 7-10: Ten instantaneous snapshots of Q.

The results were calculated, by single-stepping through frames of video taken from the stilling well tower platform. We were able to get 10 very repeatable, instantaneous values of Q (Figure 7-10) from manual calculations taking ~30 minutes each. The results compared very favourably with our three-point (0.2, 0.6, 0.8 of depth) FlowTracker reference. While the FlowTracker gauging took over an hour, the video used for the 10 consecutive RBM calculations only lasted 17 seconds.

7.3.4 Conclusion

This has shown that Q snapshots are viable. This has positive implications for the compressed air and/or power budgets for a solar-powered monitoring station. A single shot of air, injected across a stream, can give a Q data point, without the need for averaging. This minimises the amount of compressed air required. The 20 partial discharges appear quite variable, but the sum of these, from each shot, is the same within the calculated uncertainty.

7.4 Trial 11 – Paritua Stream (15 March 2019)

The Paritua/Karewarewa Stream is a tributary of the Karamu Stream. The channel of the Paritua/Karewarewa Stream flows through areas of unconfined and confined aquifers, and in some reaches, loses water to the unconfined aquifer. The Napier earthquake of 1931 altered land levels resulting in the joining of the Paritua and Karewarewa streams.

7.4.1 Aim

To obtain an accurate RBM Total Discharge measurement that compares favourably with a FlowTracker gauging in this very weedy stream.

7.4.2 Method

To clear enough weed to enable the FlowTracker to carry out a reference gauging, set up the taglines and bubble line and measure V_r in the Velocimeter.

7.4.3 Result

Rise velocity V_r was 0.2075 ± 0.0004 m/s (at the 95% confidence level). The measurements started at 10:30 NZST. Water temperature was 19.7 degrees Celsius. While setting up at Paritua, the level/flow started increasing alarmingly (Figure 7-8), with a lot of detached algae and weed floating downstream. This turned out to be a flow release from a reservoir upstream. At 10:09 NZST the staff gauge read 0.384 m and at 10:51 read 0.428 m.

Figure 7-8: The Paritua Stream was choked with weed.

7.4.4 Conclusion

We could not get any meaningful results from either method, but other than the conditions at the time we visited, there is nothing that indicates we could not get a result here under baseflow conditions. The FlowTracker gave unstable readings and needed to be de-weeded every half minute. The RBT was good until the flow became so high the bubble line started to shift. We then moved to Karewarewa Stream @ Rosser Road.

7.5 Trial 12 – Karewarewa Stream @ Rosser Road (15 March 2019)

The Karewarewa stream is frequently subject to abstraction bans during any low flow season. When we arrived, it appeared unaffected by the flow changes we experienced at Paritua Stream. We went to the Rosser Road site where FlowTracker gaugings are routinely carried out. This part of the stream is kept clear of weed to enable acceptable FlowTracker measurements (Figures 7-9 - 7-12).

7.5.1 Aim

To obtain an accurate RBM Total Discharge measurement that compared favourably with a three-point (0.2, 0.6, 0.8 of depth) FlowTracker reference gauging in a shallow, slow-moving stream.

Figure 7-9: Setting up the bubble line in the Karewarewa Stream was straightforward.

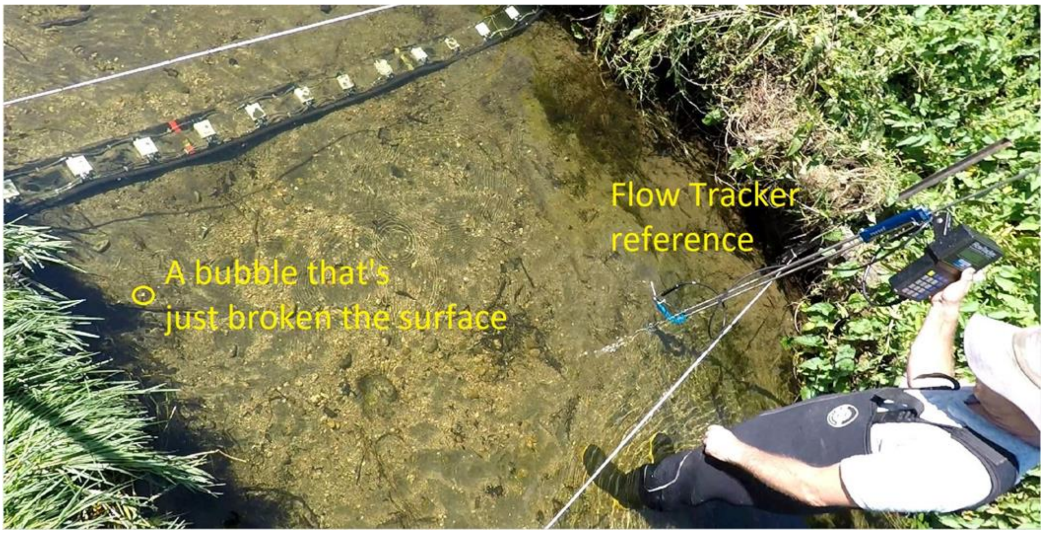


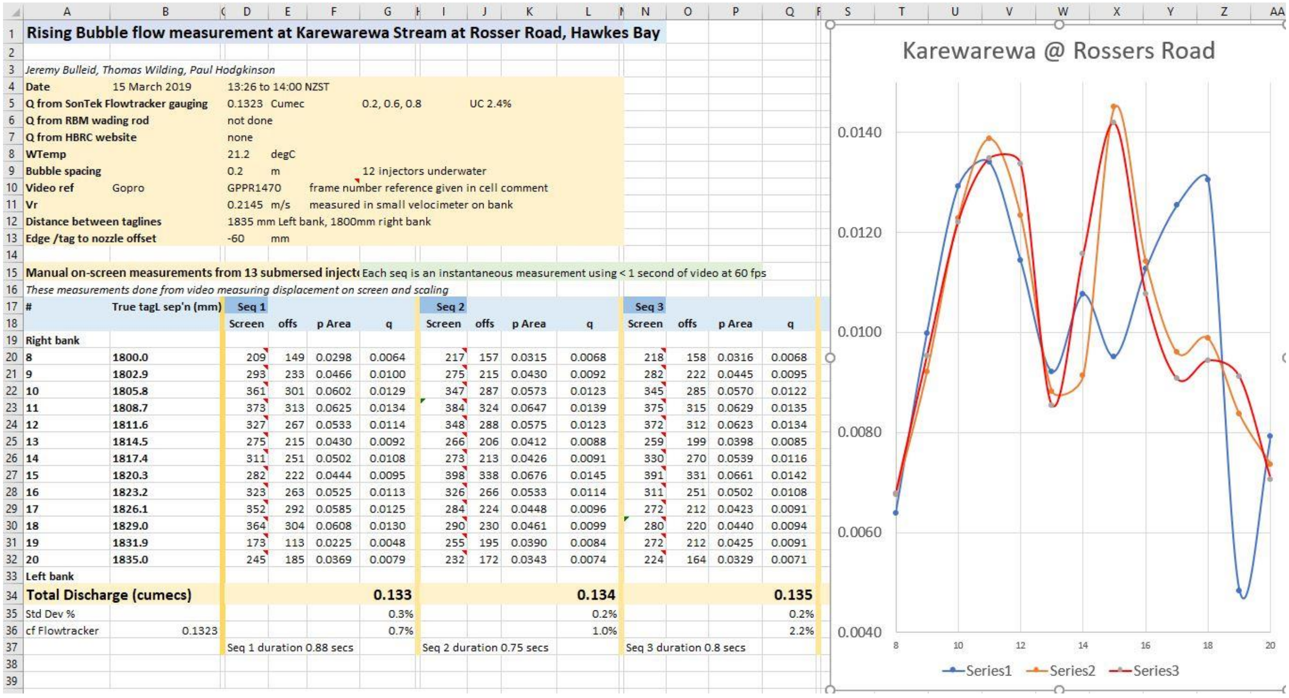
Figure 7-10: Weed had been cleared earlier for the benefit of the FlowTracker. This exposed a pumicy bed.

7.5.2 Method

The stream had already been cleared of weed for the benefit of three-point FlowTracker gauging. We set up the taglines and bubble line in the usual way (Figure 7-9). The stream was about 2.5 metres wide, so we could only submerge 12 of the available 20 injectors. We set up the Velocimeter to measure the bubble rise time while the FlowTracker gauging (Figure 7-10) was being carried out.

7.5.3 Result

The median rise velocity (V_r) from 30 bubbles was 0.2145 ± 0.0004 m/s (68% confidence). When back in Christchurch the flow rate was manually calculated from about five seconds of video taken while on site. Three 'shots' of bubbles, 1.7 seconds apart yielded three Q datapoints (Fig 7-11).



Rising Bubble flow measurement at Karewarewa Stream at Rosser Road, Hawkes Bay

Jeremy Bulleid, Thomas Wilding, Paul Hodgkinson

Date	15 March 2019	13:26 to 14:00 NZST
Q from SonTek Flowtracker gauging		0.1323 Cumec 0.2, 0.6, 0.8 UC 2.4%
Q from RBM wading rod		not done
Q from HBRC website		none
WTemp		21.2 degC
Bubble spacing		0.2 m 12 injectors underwater
Video ref	Gopro	GPPR1470 frame number reference given in cell comment
Vr		0.2145 m/s measured in small velocimeter on bank
Distance between taglines		1835 mm Left bank, 1800mm right bank
Edge /tag to nozzle offset		-60 mm

Manual on-screen measurements from 13 submersed inject Each seq is an instantaneous measurement using < 1 second of video at 60 fps

These measurements done from video measuring displacement on screen and scaling

#	True tagL sep'n (mm)	Seq 1				Seq 2				Seq 3			
		Screen	offs	p Area	q	Screen	offs	p Area	q	Screen	offs	p Area	q
Right bank													
8	1800.0	209	149	0.0298	0.0064	217	157	0.0315	0.0068	218	158	0.0316	0.0068
9	1802.9	293	233	0.0466	0.0100	275	215	0.0430	0.0092	282	222	0.0445	0.0095
10	1805.8	361	301	0.0602	0.0129	347	287	0.0573	0.0123	345	285	0.0570	0.0122
11	1808.7	373	313	0.0625	0.0134	384	324	0.0647	0.0139	375	315	0.0629	0.0135
12	1811.6	327	267	0.0533	0.0114	348	288	0.0575	0.0123	372	312	0.0623	0.0134
13	1814.5	275	215	0.0430	0.0092	266	206	0.0412	0.0088	259	199	0.0398	0.0085
14	1817.4	311	251	0.0502	0.0108	273	213	0.0426	0.0091	330	270	0.0539	0.0116
15	1820.3	282	222	0.0444	0.0095	398	338	0.0676	0.0145	391	331	0.0661	0.0142
16	1823.2	323	263	0.0525	0.0113	326	266	0.0533	0.0114	311	251	0.0502	0.0108
17	1826.1	352	292	0.0585	0.0125	284	224	0.0448	0.0096	272	212	0.0423	0.0091
18	1829.0	364	304	0.0608	0.0130	290	230	0.0461	0.0099	280	220	0.0440	0.0094
19	1831.9	173	113	0.0225	0.0048	255	195	0.0390	0.0084	272	212	0.0425	0.0091
20	1835.0	245	185	0.0369	0.0079	232	172	0.0343	0.0074	224	164	0.0329	0.0071
Left bank													
Total Discharge (cumecs)					**0.133**				**0.134**				**0.135**
Std Dev %					0.3%				0.2%				0.2%
cf Flowtracker	0.1323				0.7%				1.0%				2.2%
		Seq 1 duration 0.88 secs				Seq 2 duration 0.75 secs				Seq 3 duration 0.8 secs			

Figure 7-11: Instantaneous discharge results from three shots of bubbles 1.7 seconds apart.

The instantaneous partial discharge of each 'slice' varied significantly but the Total Discharge (the sum of the partial discharges) remained the same. We obtained consistent results that compared favourably with the reference FlowTracker (Figure 7-12).

	Q (Cumecs)
RBM seq 1	0.133
RBM seq 2	0.134
RBM seq 3	0.135
RBM median	0.134
FlowTracker	0.1323

Figure 7-12: Left - An Eel came to check out the bubble line. Right – Result summary; RBM vs FlowTracker.

7.5.4 Conclusion

The RBM worked well in this slow-moving (mean velocity 0.1404 m/s), shallow water (mean depth 0.401 metres). The FlowTracker ISO discharge uncertainty was 2.4%; filename 23427.WAD.

7.6 Overview of trial results

Figure 7-13 shows how RBM rated against the available references from 0.132 to 2.320 m^3/s. For details, refer to sections 6 and 7. These results have been manually calculated by stepping through video recordings (frame-by-frame), measuring on-screen displacements and scaling to true size.

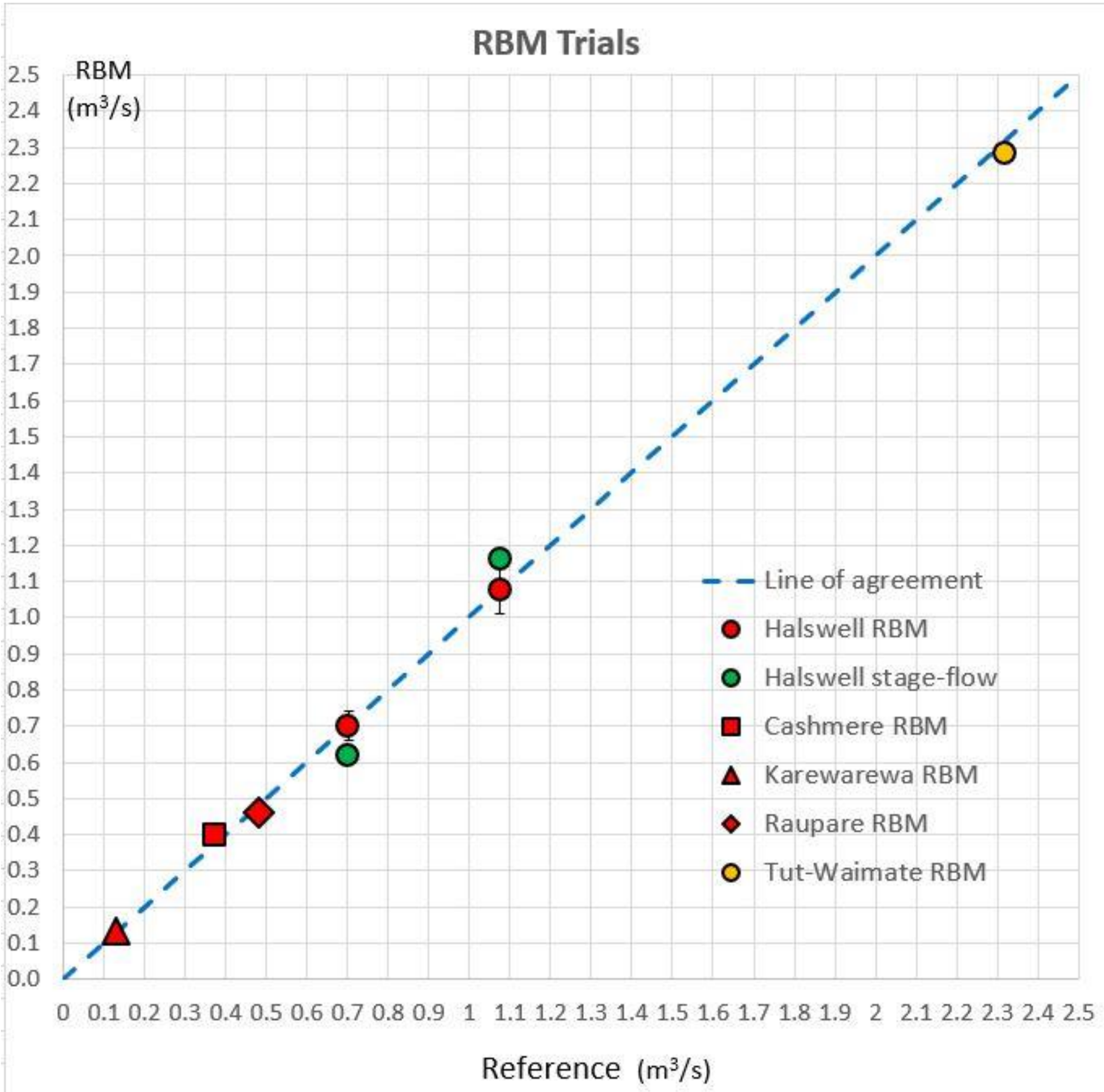


Figure 7-11: Graph of RBM vs Reference Q, from the trials.

8 Manual and automated video processing options

8.1 The process

Total discharge (Q) is calculated using

$Q = V_r * A$,

where V_r is the bubble rise velocity (measured in the Velocimeter) and A is the displacement area on the water surface.

To determine area, we identify the *surfacing location* of each bubble. From this we measure the downstream displacement of each surfacing location, from its origin, and calculate the total displacement area defined by multiple injectors.

8.1.1 Capturing the images

To capture images we have developed a controller that initiates a 300-frame video take, operates the air-valve that simultaneously fires each of the bubble injectors on the stream bed and stops the video after five seconds.

The video clip may be telemetered, from a remote site to the office, for manual processing or for QA verification. Alternatively, it may be processed automatically (Figure 8-1), on site, to output and log the results of successive Q measurements. Onsite automation minimises the amount of data (per measurement) that would need to be transferred – one Q value vs 300 0.3 MB image files.

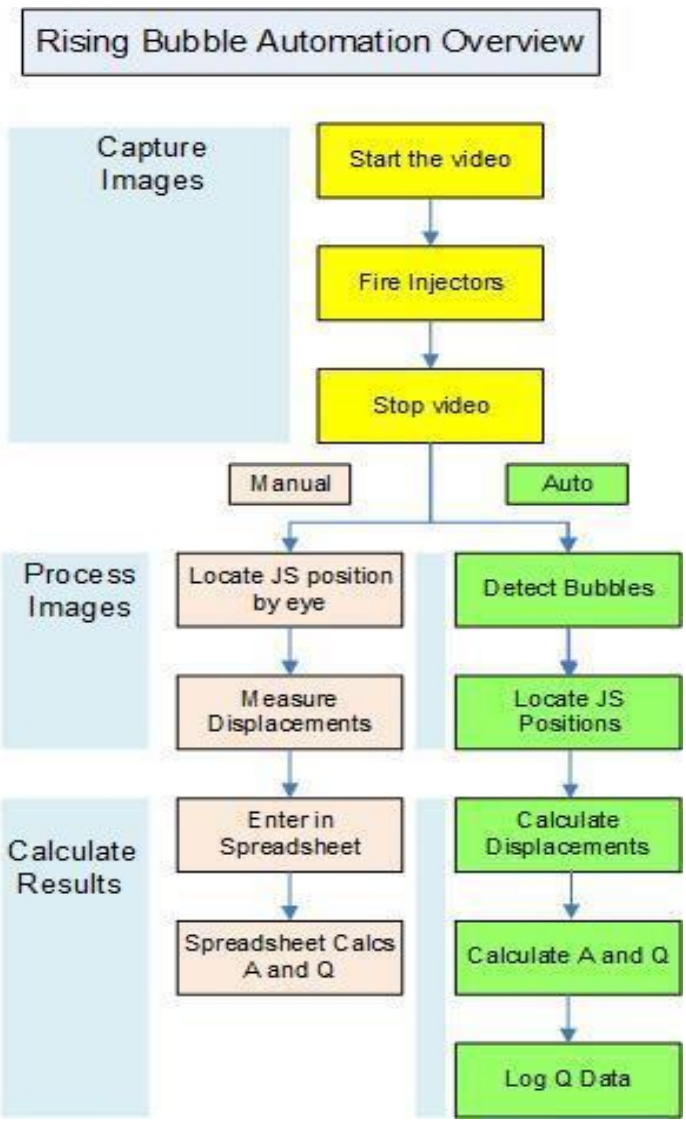


Figure 8-1: RBM video processing options.

8.1.2 Processing the images manually

This describes the 'Manual' path (orange) in Figure 8-1.

Use a video player that can single-step, frame-by-frame, to precisely locate the position of the just surfaced bubble. Locate the two reference lines. These will not be the exact visual location of the taglines (if these are used), the best location is the mid-point between the tagline and its reflection (Figure 8-3). The reflection is a virtual image that is apparently projected below the water surface the same distance as the tagline sits above it (like looking in a mirror). This midpoint is the reference at the water surface.

8.1.3 Processing the images automatically using Artificial Intelligence

This describes the ‘Auto’ path (green) in Figure 8-1.

We have developed a reliable bubble detector by creating a multi-layered Artificially-Intelligent Neural Network (NN) that detects surfaced bubbles. We chose Deep Learning (DL), a machine learning technique that does what comes naturally to humans - it learns by example. So, with DL we do not need to understand which features best represent the bubbles we are trying to detect – DL uses training images to extract these features for us. But this process requires literally hundreds of training and verification images. Here, video comes to the rescue, as it is easy to derive lots of labelled data from video taken of the water surface at bubble rise time.

Another reason for using DL is that, unlike conventional Machine Learning (ML) where features are manually extracted, if necessary, we can keep training with more, and more-diverse images. This strategy can facilitate development of a detector that is more robust and can give better results over a wider range of natural conditions. In contrast, where DL can go on learning indefinitely, ML (with manual feature extraction), will require a lot of human input and approach a precision ‘ceiling’.

There are three stages in the AI process: creating the NN, training the NN to detect bubbles and creating/using the bubble detector. Because of the need for large training datasets, and hence long training times, we needed to exploit the power of a High-Performance Computing Facility (HPCF). Even with this extended capability it took over seven days to train the neural network used to obtain the results in Figure 8-5.

Once trained, the detector software can be compiled into a relatively compact ‘Q measurement’ firmware application (app) and embedded into a small processor to enable ‘stream-side’ processing. In comparison to the long training process, the detector portion of the firmware works very fast (minutes), as it uses just enough features to uniquely identify its target.

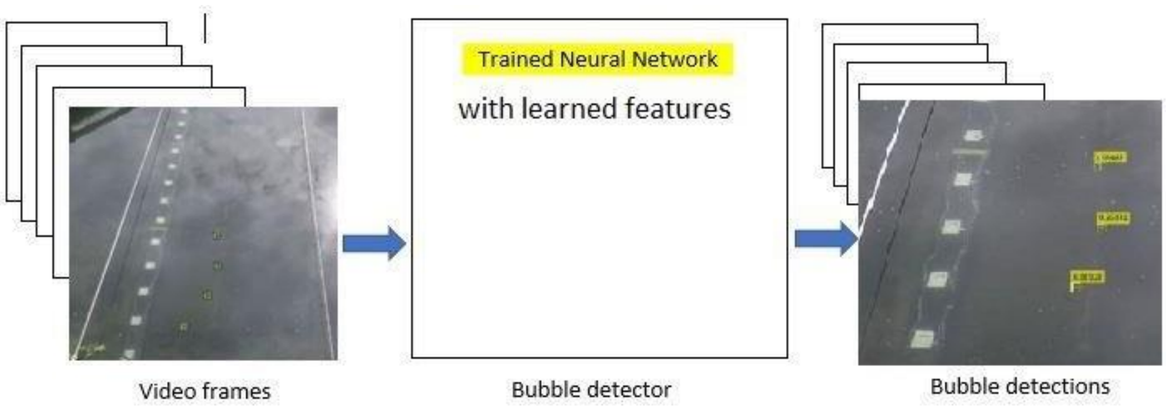


Figure 8-2: Bubble detection using trained neural network analysis of video frames.

8.1.4 Rectifying the reference lines

For practical reasons, especially for longer-term monitoring, the camera may need to be aimed end-on to the bubble line. In the example, to enable automation, <u>the computer programme needs six pieces of information (R1, R2, R3, R4, r3, r4)</u> to inform it about the specific site geometry. Figure 8-3 shows the camera field-of-view, from up on the Raupare Stream stilling well tower, overlaid with a geometrical construction that has been built into the computer programme.

This is a one-off exercise at a new site, for longer-term deployments, or until the camera is moved. When the camera has been installed, use a video frame from it (initially with the tagline in the image) to define the four reference points, and r3 and r4's <u>proportions</u> of line length (xR4-xR3). In this case r3 is 0.409(xR4-xR3) and r4 is 0.144(xR4-xR3). These can be measured on screen with a distance-line tool (for 'pixel accuracy') or a ruler.

All measurements are done relative to the plane of the water surface. The injector images are refracted by the water and cannot be used for reference. The references will need to track water level and more work needs to be done in this area.

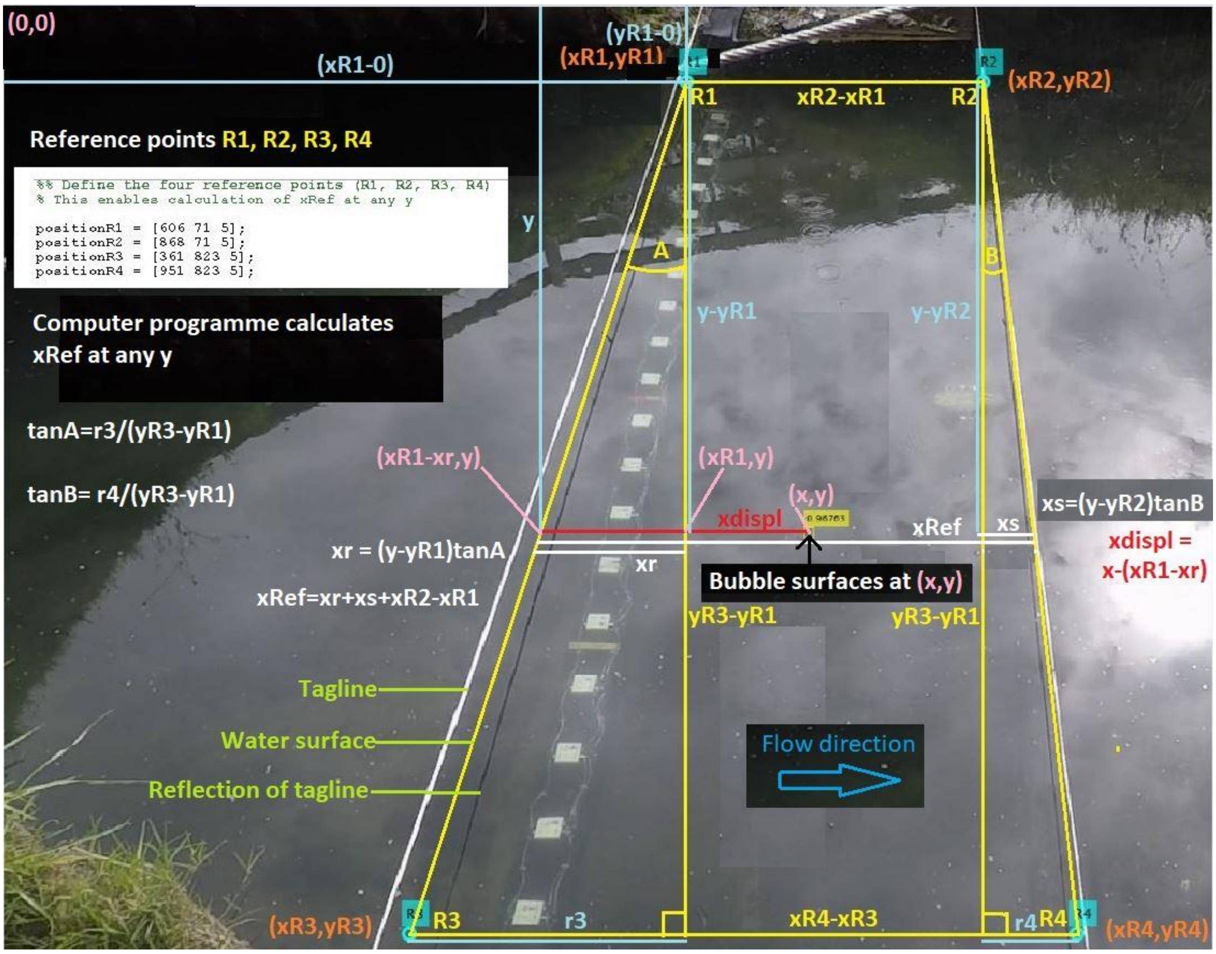


Figure 8-3: Rectifying the image perspective from the Raupare stilling well tower.

8.1.5 Calculating the results

We looked in detail at the results from flow measurements carried out at Raupare Stream in Hawkes Bay. We calculated these manually, by stepping through video frames, measuring bubble surfacing positions on-screen with a ruler and inserting these measurements into a processing spreadsheet. We now use these manual results to compare the automation results against. Figure 8-4 shows 'surfaced bubble' detections, in a single frame of video. The inset bubble image is an actual training image and exemplifies how little resolution is required to obtain valid detections.

8.2 Bubble detection software applied – Raupare Stream

Raupare Stream; view from the Stilling-well Tower and is the location of the video shoot. This shows the detections obtained from a single frame of video. Each annotated bubble shows the detector's confidence in having achieved a correct detection (Figures 8-4 to 8-6).

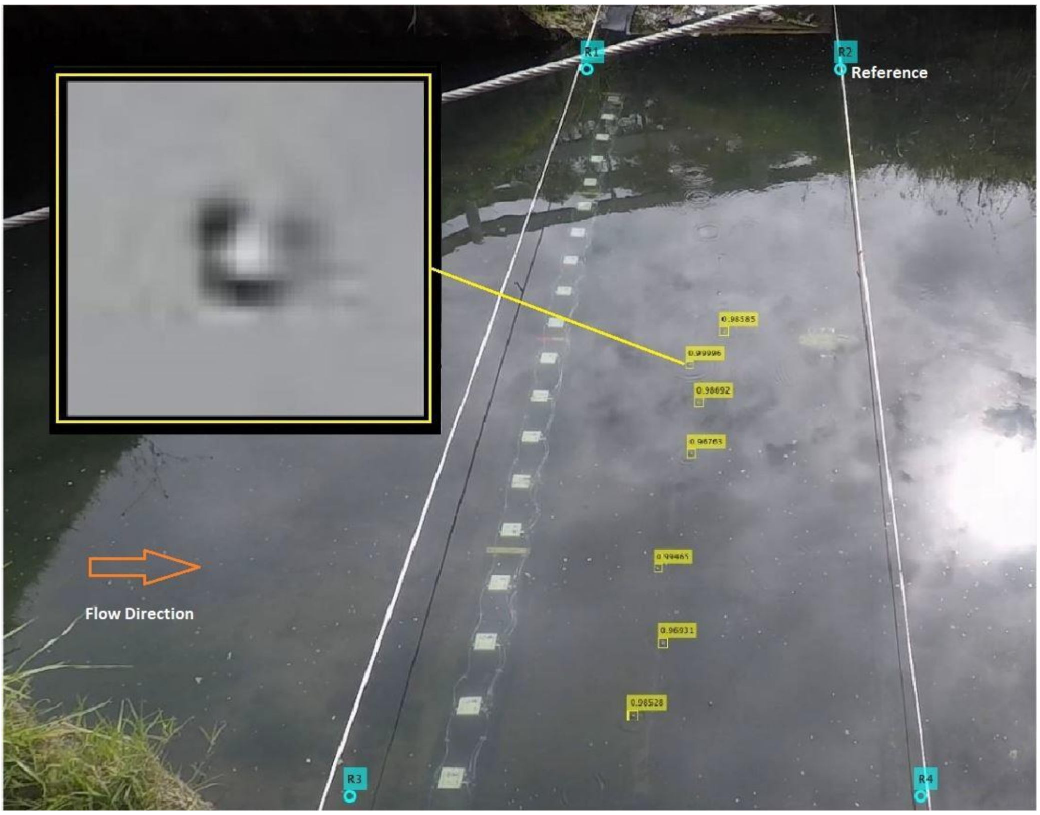


Figure 8-4: Figure 8-4: Artificially Intelligent bubble detector being tested on video recorded at Raupare.

The hardest detections are those furthest from the camera, as is the case where the GoPro is mounted at the stilling well on the right bank (for practical reasons) and 'looks' across the entire width of the stream. The images in Figure 8-5 show detections at the far side of the stream, an approximate distance of five metres line-of-sight. The training to achieve this took seven days and there is still more training needed.

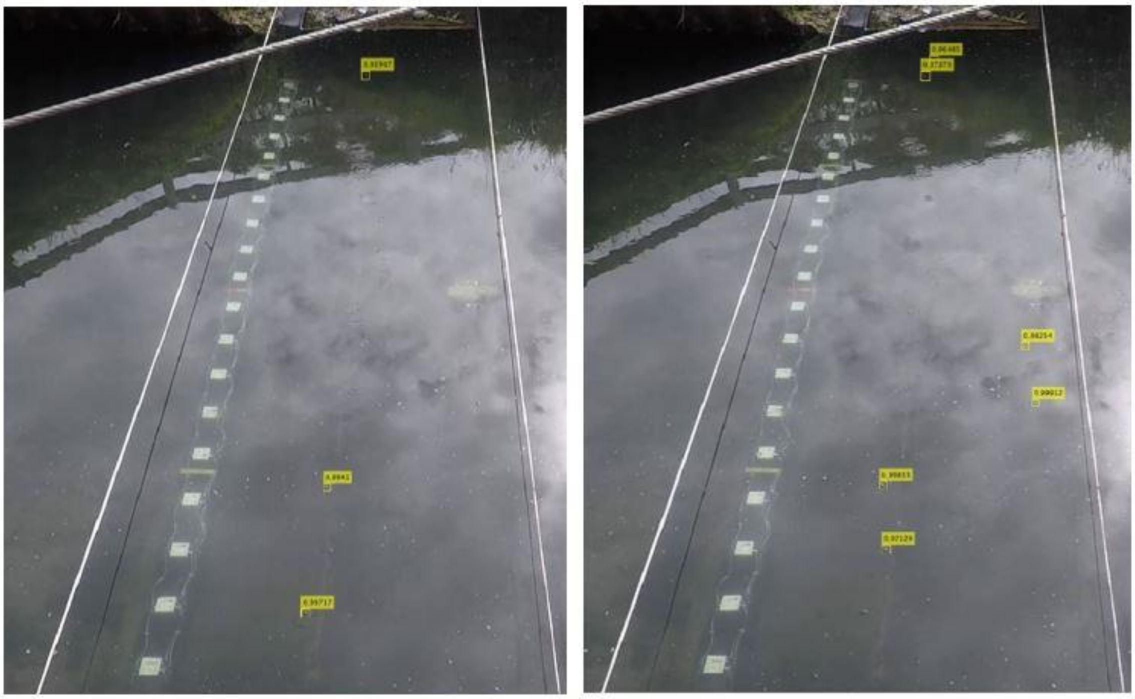


Figure 8-5: The AI bubble detector can now detect bubbles from the farthest injectors at the left bank.

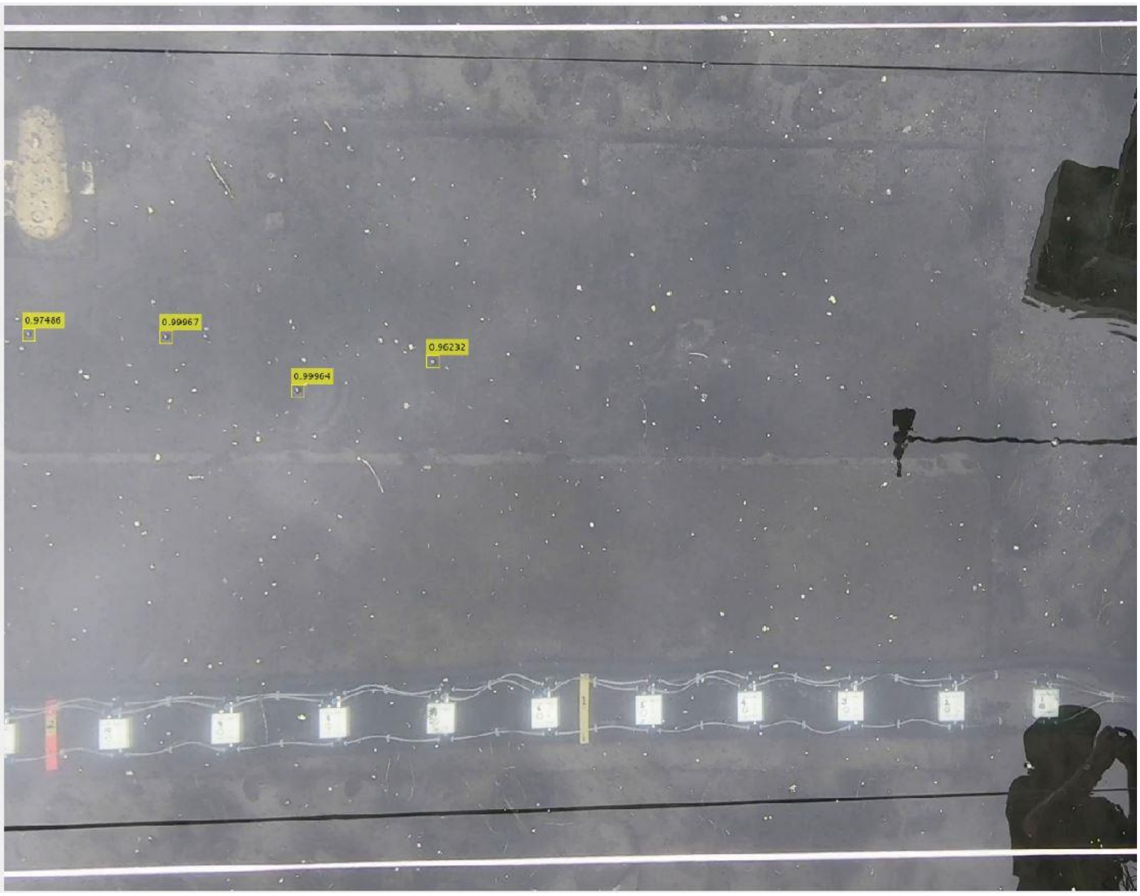


Figure 8-6: Raupare Stream: Just-surfaced bubbles from a different aspect.

8.2.1 From images to numbers

From the bubble surfacing displacements, the app calculates the ‘just-surfaced’ image position (in pixels) relative to the reference (SDR), converts it to true displacement (in metres) and calculates the partial area (pA) and partial discharge (q) contributed by each injector (Figure 8-7). We limited this example to nine injectors and were able to get only six of the nine detections.

dischargeStruct

1x9 struct with 4 fields

Fields	SDR	TrueDispl	pA	q
1	[]	[]	[]	[]
2	0.3985	0.4901	0.0980	0.0215
3	0.4295	0.5283	0.1057	0.0232
4	0.4108	0.5053	0.1011	0.0222
5	[]	[]	[]	[]
6	0.5558	0.6836	0.1367	0.0300
7	0.4672	0.5747	0.1149	0.0252
8	0.5035	0.6193	0.1239	0.0272
9	[]	[]	[]	[]

Figure 8-7: Example of the software structure we use to assemble and store the data used to calculate Q .

8.2.2 Verifying the automated result

Figure 8-8 shows the partial discharge calculated at injector positions one to nine. The results from the automatic calculations (green bars) are shown beside the manually calculated values (orange bars). We carried out a ‘three-point’ FlowTracker gauging (0.482 m^3/s). This took over an hour. The manual RBM calculation was 0.462 m^3/s, taken from a series of 10 ‘shots’ at 1.7 second intervals.

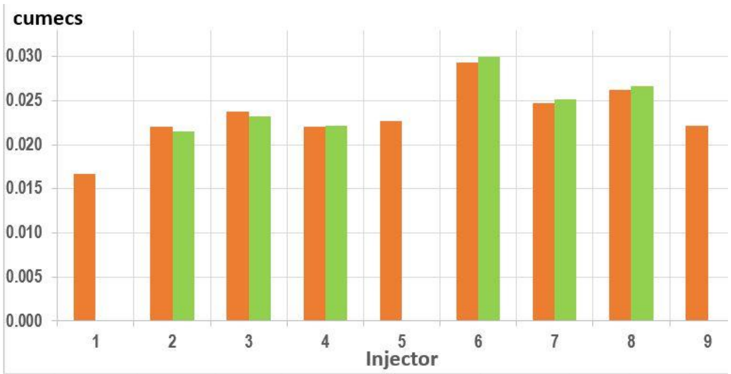


Figure 8-8: An example showing how automatic processing stacks up against manual processing.

8.2.3 Conclusion

Summing the partial discharge values gave manual 0.149 m^3/s, and automatic 0.148 m^3/s. A good first result. This can be improved on with more training.

9 Retrieving a video recording

Captured video images can be retrieved by either direct camera download using a USB cable or by remote download to a Dropbox account – its address needs to be set up in the NUC.

9.1 Remote Video Module (RVM)

The video module (Figure 9-1) enables the capture of five-second video clips, and can be initiated by:

- Remote command via Smartphone;
- Sample period programmed into Neon logger;
- Event programmed into Neon logger.

This module is used for both partial-automation, where video is telemetered and Q calculated manually from the frames, or full-automation, where the NUC computer is configured with the automation software (Matlab code compiled to C++ and embedded in the NUC).

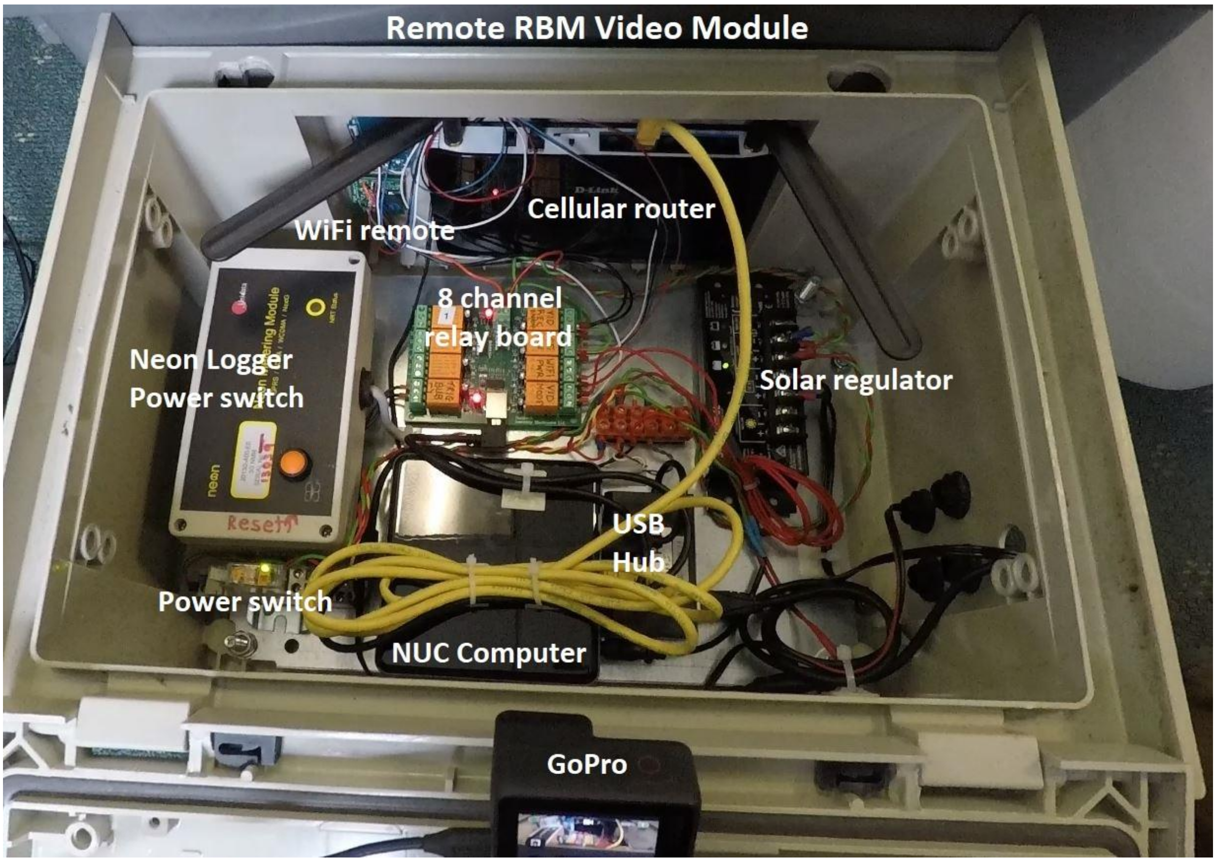


Figure 9-1: The remote video module, showing the locations of the electronic hardware.

9.1.1 Operating the Remote Video Module

The following instructions are for retrieving video using a Smartphone:

1. Configure the GoPro Hero 7 Black: on, video, resolution 2.7k, FOV linear, 60 fps, WiFi ON/2.4GHz

2. Connect the GoPro to the video module via the USB cable.

3. Connect the solar panel and 12V battery.

4. Reset the Neon logger - press the orange button. Green power indicator is off. The Neon (ID 4680, Serial Number 13039) can be monitored on the server (Test Area\AndrewS\Remote Bubbler).

5. Verify that the Neon starts up properly – red NRT Status indicator on steady (indicates logger and Neon Server are communicating) then after a while starts flashing (logger and server are now incommunicado for another five minutes (as currently programmed).

6. On the Smartphone, open the 'Stardroid' app (Figure 9-2)

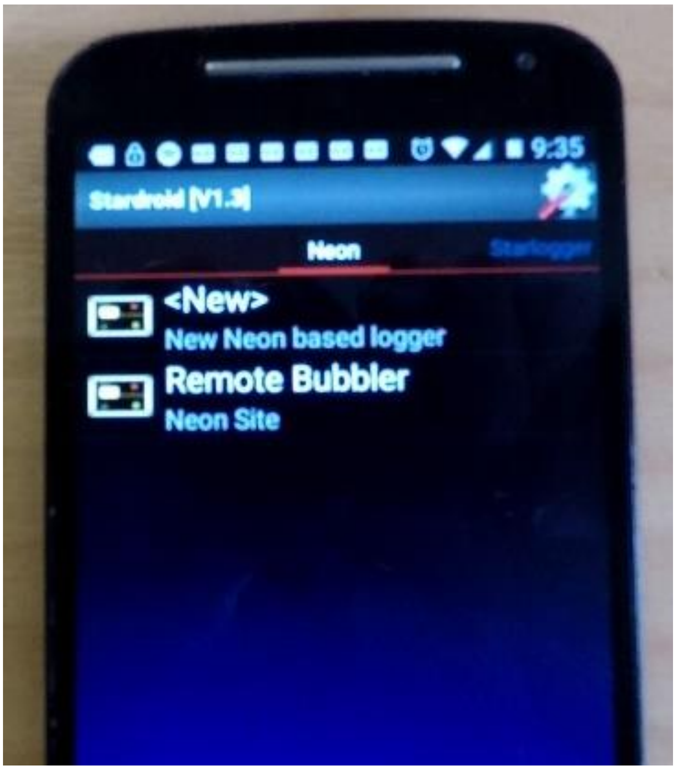


Figure 9-2: NIWA's Stardroid app.

7. Select the 'Remote Bubbler' app from the menu.

8. Select 'Actions', 'ON', then 'Set channel ON' (Figure 9-3).

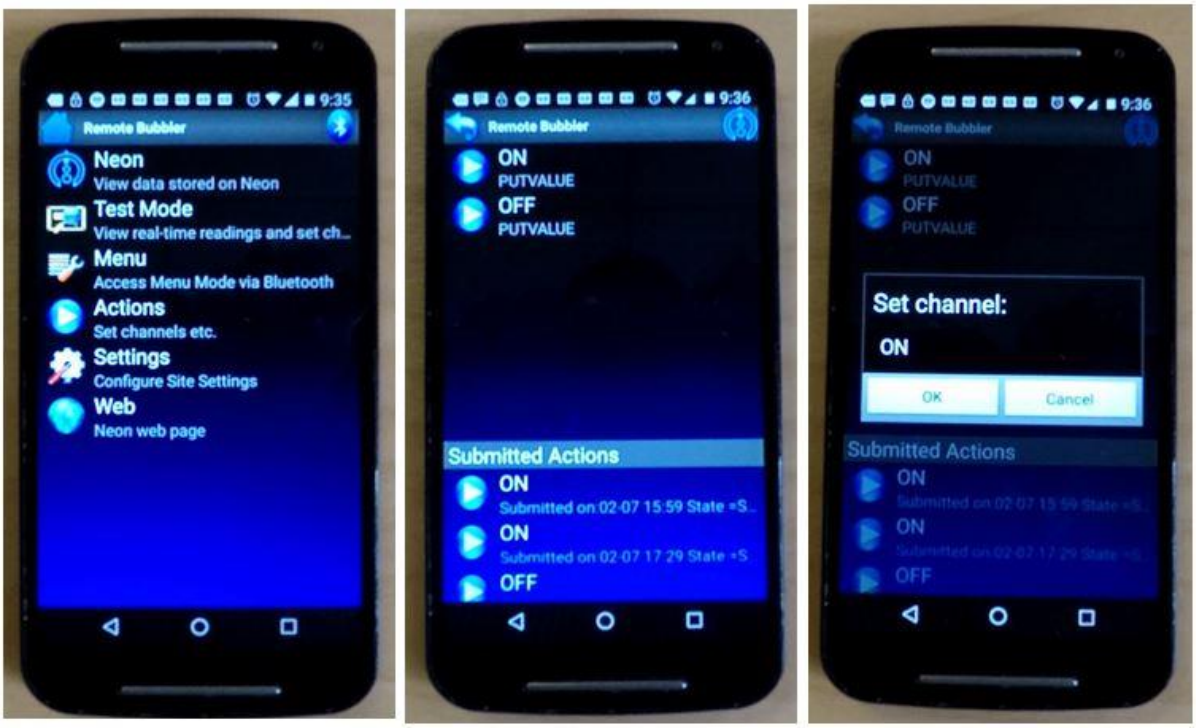


Figure 9-3: NIWA's Remote Bubbler screen.

9. When the Neon Server communicates (currently programmed for every five minutes) with the Neon logger (red indicator steady) the server sends the ON command to the logger. Power relay 'clicks', green indicator comes on, red power indicator on 8 channel relay board turns on.

10. The relays on the 8-channel relay board (each with its own green status indicator) are controlled by the Intel NUC Core-i7 PC. At power-up, the NUC boots up and runs a script file which does the following…

11. Relay 5 is turned on to switch the camera to video mode;

12. Relay 6 is turned on to connect power to the WiFi remote;

13. Relay 7 is pulsed to switch on the WiFi remote;

14. Relay 8 (wired to remote REC button) is pulsed to start the recording (GoPro beeps);

15. Relay 4 is pulsed to trigger the bubble line;

16. After a five second delay, relay 8 is pulsed to stop recording (GoPro beeps);

17. Relay 6 is turned off to power down the WiFi remote;

18. Relay 5 is turned off to switch GoPro back to USB/charge mode;

19. Once the camera is back in USB/Charge mode, it is mapped to a virtual drive via the MTPDrive software. The video file is copied over to a nominated Dropbox cloud service directory on NUC.

20. The Dropbox directory is synchronised via the cellular router. The file then becomes available to other PCs connected to the Dropbox account after about 10 minutes.

21. Once the transfer is complete and the operator can view the new video file, a command to deactivate the main power relay should be sent to the NMM. This powers down the NUC and the cellular router, leaving only the NMM, the relay power LED and GoPro-charging as loads on the system battery.

22. In manual mode, the delivered video clip is analysed and Q is calculated (off-site) by doing on-screen measurements. This takes about half an hour.

23. In partial-automation mode, the delivered video file can be processed by running it through the processing software (off-site) which contains the trained detector function.

24. In full-automation mode, Q is calculated (on-site) and sent to the Neon Server where it is stored and accessible to the client via any authorised Internet-connected device.

9.1.2 Component list

Here is a list of the major components (and suppliers) used in the construction of the RVM:

- Neon Data Logger – Unidata Pty, Perth, Australia;
- NUC Core i7 PC – Intel, with NIWA script file;
- USB 8-relay module – Denkovi;
- GoPro Hero 7 Black video camera and WiFi Remote Control – GoPro;
- Cellular Router – D-Link DWR-921;
- USB hub – provides USB connection to GoPro which doesn't work with native NUC USB ports
- Solar regulator – Sunsaver-6L
- Power switch – Omron DIN-mounting relay with indicator.

10 Overview of the developed tool

The RBM Tool is a system (Figure 10-1) that, to a datalogger, 'looks like' a sensor.

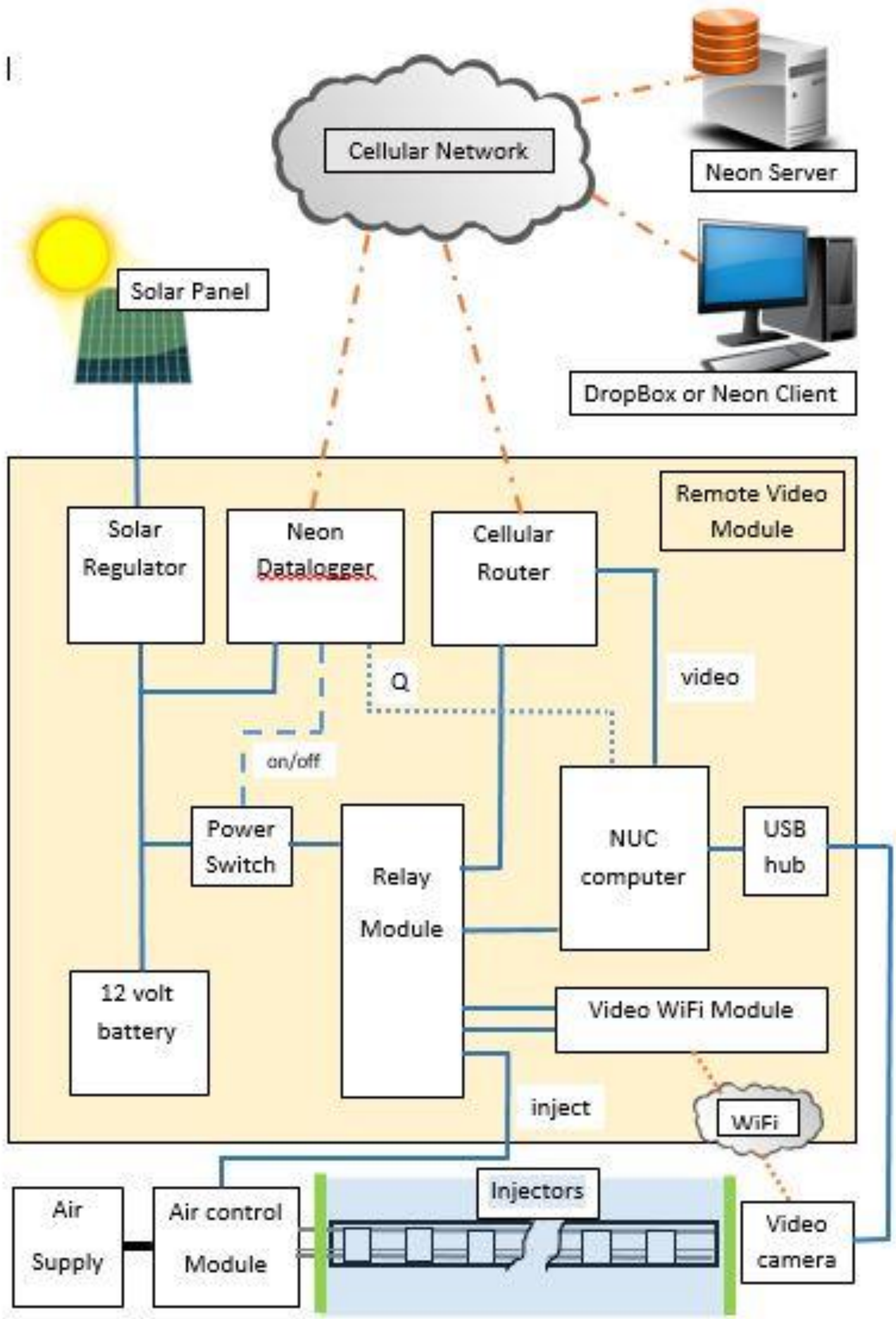


Figure 10-1: An overview of the system.

The system is normally powered by a solar-charged 12-volt battery. A Q measurement, or video file request, is initiated by the Neon datalogger, either by remote command, or programmed into the Neon. The Neon then powers-up the system and the NUC-PC begins running a script which carries out the sequence of events detailed in section 9.1.1. The camera is activated via the WiFi module. The air box then switches compressed air to the bubbler line. This injects one or more shots of bubbles. The video records the surfacing bubbles The NUC PC then retrieves the five-second video from the camera and, what it does next depends on which automation mode has been configured – partial or full automation.

In partial automation the video recording is sent to the cellular router and is transmitted, via the cellular network, to a nominated Dropbox account holder for processing.

In full automation the video recording is processed by the detector software in the NUC PC. This calculates Q and sends it to the Neon datalogger for storage. The Neon Server retrieves these data and they can be viewed or downloaded by connecting any Internet-capable device to the Neon Server.

10.1 From prototype to production

While the prototype Tool does function end-to-end, it will require significant work to take it from ‘functioning prototype’ status to ‘production-ready’ status.

Here are some discussion points:

10.1.1 Velocimeter

The Velocimeter could be significantly reduced in size from its present 130x130 mm, to as little as 50x50 mm, without the rise velocity of the 6 mm diameter bubble being slowed by ‘wall effect’. The Velocimeter may also be reduced in height (perhaps by 40%) but this needs to be related to stream depth.

10.1.2 Bubble line

In its present transportable configuration, one idea to improve the bubble line may be to attach a second layer of rubber on top of the injectors, via the existing screw, creating a ‘sandwich’. A clearance hole would allow the bubble to ascend. A gap at the upstream edge could be closed. This could prevent weed catching on the air tubes, protect the fittings and allow occasional cleaning with a brush.

10.1.3 Injectors

These are currently machined but could be made from injection-moulded plastic. This would lower the cost of manufacture, especially if tube fittings could be built into the moulding process. It could also give more control over the space that defines the bubble volume. Another option for driving the injector bobbin is to use an electric solenoid in each injector.

10.1.4 Software

More training of the AI model is required to make the detector robust. We should also attempt to achieve a generic detector that isn’t site-specific. This might be best achieved by first setting up several sites in partial automation mode and extracting the video images to train the detector under more-diverse conditions.

While we have not tested this yet, in addition to calculating discharge, we could also calculate average depth-integrated velocity and surface velocity (while the bubbles remain on the surface) using the displacements and the time derived from the camera's frame count at 60 frames per second.

10.1.5 Rectifying the reference line

Most of the uncertainty in Q comes from A (area). In Figure 6-15 we have assumed that the uncertainty in the origin of each of the 13 injectors is 5 mm. But if we double this and assume the uncertainty is now 10 mm, the standard uncertainty increases from 2.7% to 5.0%. Therefore, a key aim, going forward, is to refine and develop the means to locate the bubble line accurately and know this location. Replacing a tagline with a laser beam may help align the bubble line more accurately.

11 Acknowledgements

The following are thanked for their contributions to the Rising Bubble Method and to this report:

- MBIE for Envirolink Tool funding (MBIE Contract No. C01X1802) and NIWA for additional financial support;
- Regional Council tool 'champion' Thomas Wilding (HBRC) for significant input into the project and the wider Environmental Data SIG for their support of this Tool project;
- Hawke's Bay Regional Council (HBRC) and Environment Canterbury (ECan), including –
  - Steve Grant, Phil Hall, Paul Hodgkinson, Tom Edwards and other HBRC staff for assistance during field trials; and
  - Bruce Digby, Martin Webb, Phil Downes (ECan) for assistance during field trials;
- Andrew Starr, Brendon Smith (NIWA) for assistance with equipment design;
- Grant Thyne (NIWA) for assistance with velocity rating car experiments; and
- Steve de Lima (NIWA) for the Smartphone app.

12 Glossary of abbreviations and terms

AI	Artificial Intelligence as used for bubble detection
CNN	Convolutional Neural Network; an Artificial Intelligence model
fps	Video frames per second
LED	Light Emitting Diode
NUC	The Intel computer module used in the Remote Video Module (RVM)
Q	Symbol for Total Discharge
rating tank	NIWA's facility for rating (calibrating) current meters at reference velocities
RBM	Rising Bubble Method
shot	Simultaneous injection of a single bubble from each injector on the bubble line
Stardroid	NIWA's mobile application software for Smartphones

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Other supporting literature:

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Clift, R., Grace, J.R., Weber, M.E. (1978) Bubbles, drops and particles. *Academic Press*

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Appendix A Outcomes of Envirolink Tool contract objectives

The contracted objectives

The MBIE contracted Envirolink Tool objectives are shown in Figure A-1.

Technical Objective	*ID*	*Task Name*
1 – Identify 'just-surfaced' bubbles	1	Build a preliminary RB image dataset
	2	Create and train a classification model
	3	Obtain more video of rising bubbles
	4	Retrain model with 2000 images/state
	5	Repeat and iterate 3 and 4
2 – Find displacement of bubble	6	Track sequence by state frame by frame
	7	Identify relative location of just-surfaced
	8	Identify real location of just-surfaced
3 – Calculate Total Discharge	9	Calculate total displacement area
	10	Calculate total discharge Q
4 – Complete and test system software	11	Write software to control injection, video
	12	Begin end to end testing operation
5 – Carry out flume tests	13	Characterize the system, eg. uncertainties
	14	Test in flume 5 to 31 litres per second
6 – Build equipment and do field trials	15	Build and install HBRC RBM station
	16	Begin HBRC field trials
	17	Build and install Ecan RBM station
	18	Begin Ecan field trials
	19	Analyse preliminary results
7 – Enable uptake of Tool by councils	20	Prepare report on field trials
	21	Prepare a paper on the technology
	22	Prepare info for technology transfer

Figure A-1: The technical objectives and milestones proposed in PROP-57832-ENVTOOLS-NIW.

Outcome of each objective

Objective 1 – Identify 'just-surfaced' bubbles

A classification model (Convolutional Neural Network (CNN) and image dataset of different bubble classes (just surfaced, on surface, burst) was built and tested. An accuracy of 100% was achieved (Figures A-2, A-3).

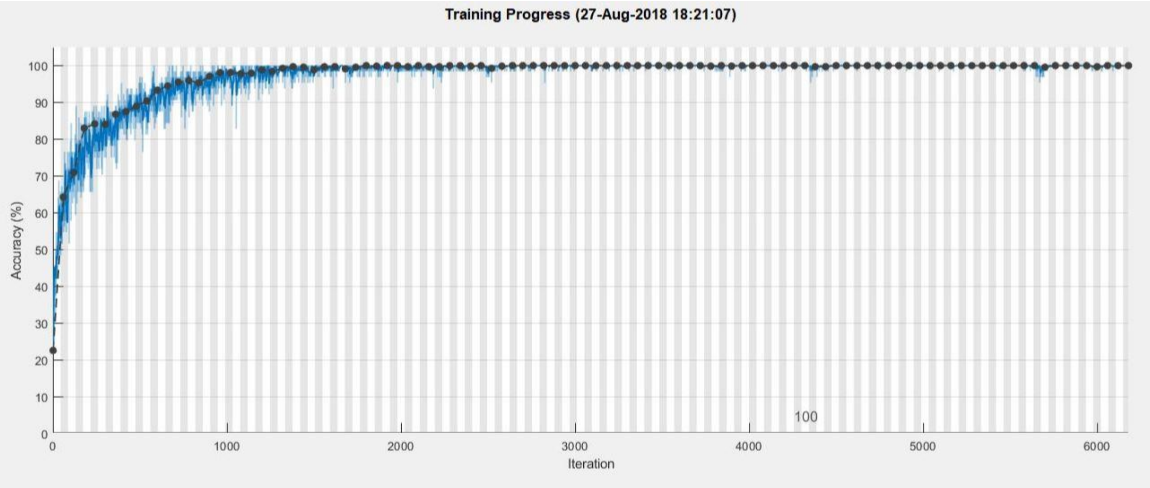

Figure A-2: Training the CNN classification model - as training progresses (blue trace) the model learns by iteratively checking its predictions against 'blind test' images (black trace).

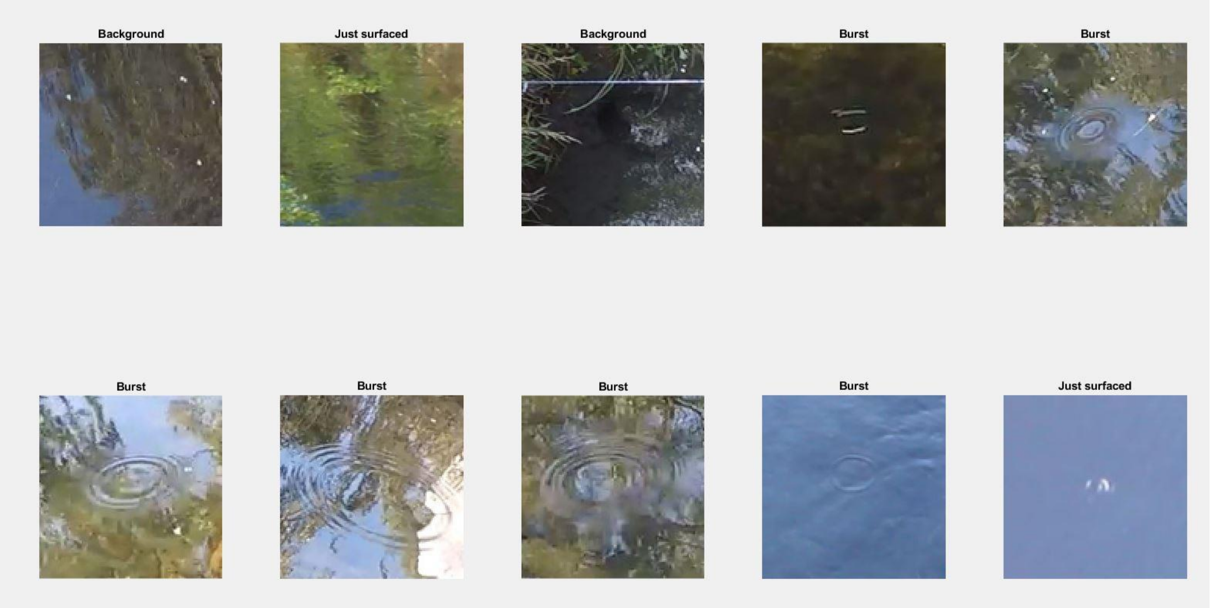

Figure A-3: Examples of the predicted classes of images never 'seen' by the model.

As the AI detection software was developed, a second (Regional) neural network was needed. A Regional CNN model was developed. In addition to classifying the bubbles, this 'located' them.

Objective 2 – Find displacement of bubble

There was some early success with the RCNN AI model, but it was limited by the low resolution of the images. Figure A-4 shows an accurate RCNN detection, but to achieve this the camera had to be closer to the water surface (so doesn't take in the whole scene) and the surfaced bubble a bit larger (just-surfaced + 5 frames to increase resolution for training).

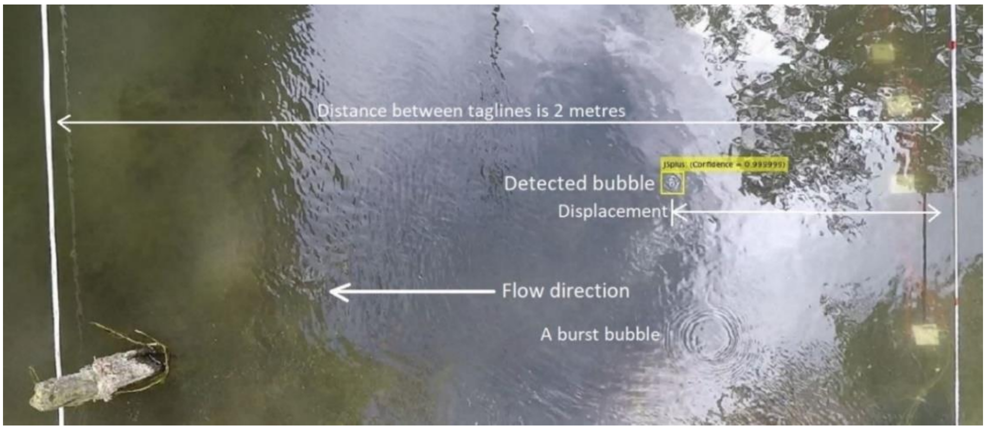

Figure A-4: The method behind using AI to locate a surfacing bubble.

Further AI research and development resulted in the application of a Faster RCNN model. Together with Matlab's introduction of a new algorithm for capturing and labelling training images more quickly, this greatly improved the detection capability of the AI model. Figure A-5 shows the improvement as applied to Raupare Stream where the farthest bubbles can now be detected.

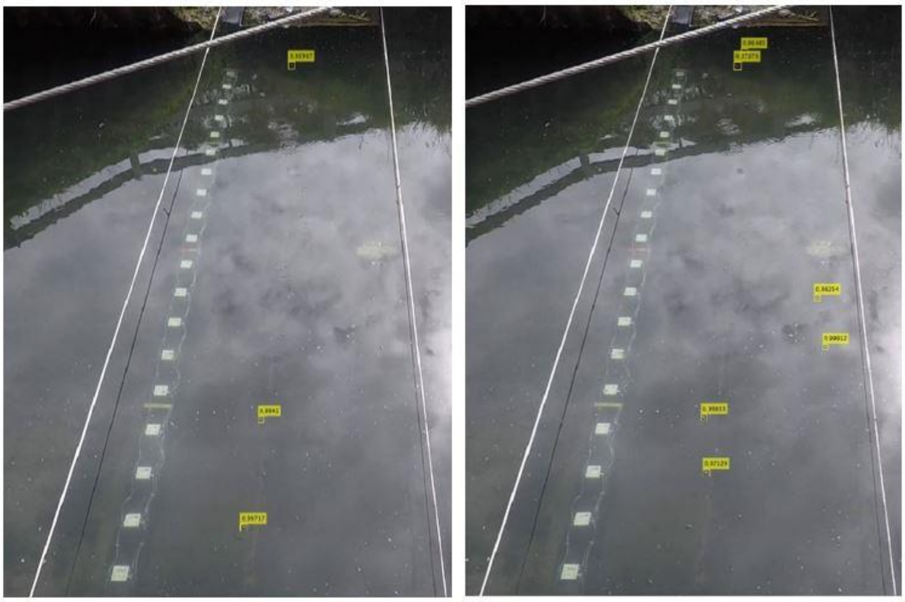

Figure A-5: With Faster RCNN, bubbles can be detected across the full stream width with one camera.

Objective 3 – Calculate Total Discharge

This can be achieved (Figure A-6) with partial automation, where the video can be taken remotely and telemetered to the office where it may be processed manually (this takes half an hour per Q measurement, and therefore half the time it takes for a three-point FlowTracker measurement and doesn't require the travel).

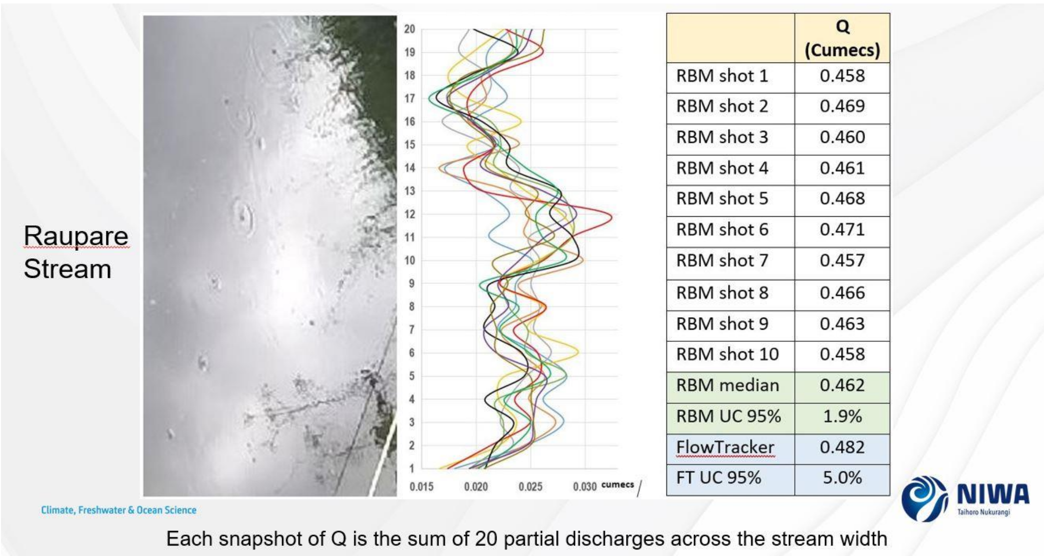

Figure A-6: Calculation of Total Discharge in Raupare Stream.

The uncertainty in the table is for a single shot but this can be reduced by taking more samples ('shots'). Getting the system software to do the heavy lifting (Figure A-7) is working, but the model requires more, and more diverse training as there are <u>a few gaps</u>. This currently takes a week.

dischargeStruct

1x20 struct with 4 fields

Fields	SDR	TrueDispl	pA	q
1	0.9318	1.1461	0.2292	0.0503
2	0.4012	0.4935	0.0987	0.0217
3	0.4324	0.5319	0.1064	0.0233
4	0.4108	0.5053	0.1011	0.0222
5	[]	[]	[]	[]
6	0.3169	0.3898	0.0780	0.0171
7	0.4690	0.5768	0.1154	0.0253
8	[]	[]	[]	[]
9	0.5045	0.6206	0.1241	0.0272
10	[]	[]	[]	[]
11	[]	[]	[]	[]
12	[]	[]	[]	[]
13	[]	[]	[]	[]
14	[]	[]	[]	[]
15	[]	[]	[]	[]
16	[]	[]	[]	[]
17	[]	[]	[]	[]
18	1.3090	1.6100	0.3220	0.0706
19	0.4340	0.5339	0.1068	0.0234
20	0.4687	0.5765	0.1153	0.0253

Figure A-7: The software has generated this output by automatically analysing video, frame by frame. It shows the partial discharge (q) contributed by each of the 20 injectors across the stream. Q = ∑q

Objective 4 – Complete and test system software

This is working (Table A-1), but the model needs much more training (a lengthy process) to make detection more robust.

The development has been done using Matlab (Figure A-8). This will be compiled into computer code that can be embedded into the NUC Intel computer board in the Remote Video Model (Figure A-9).

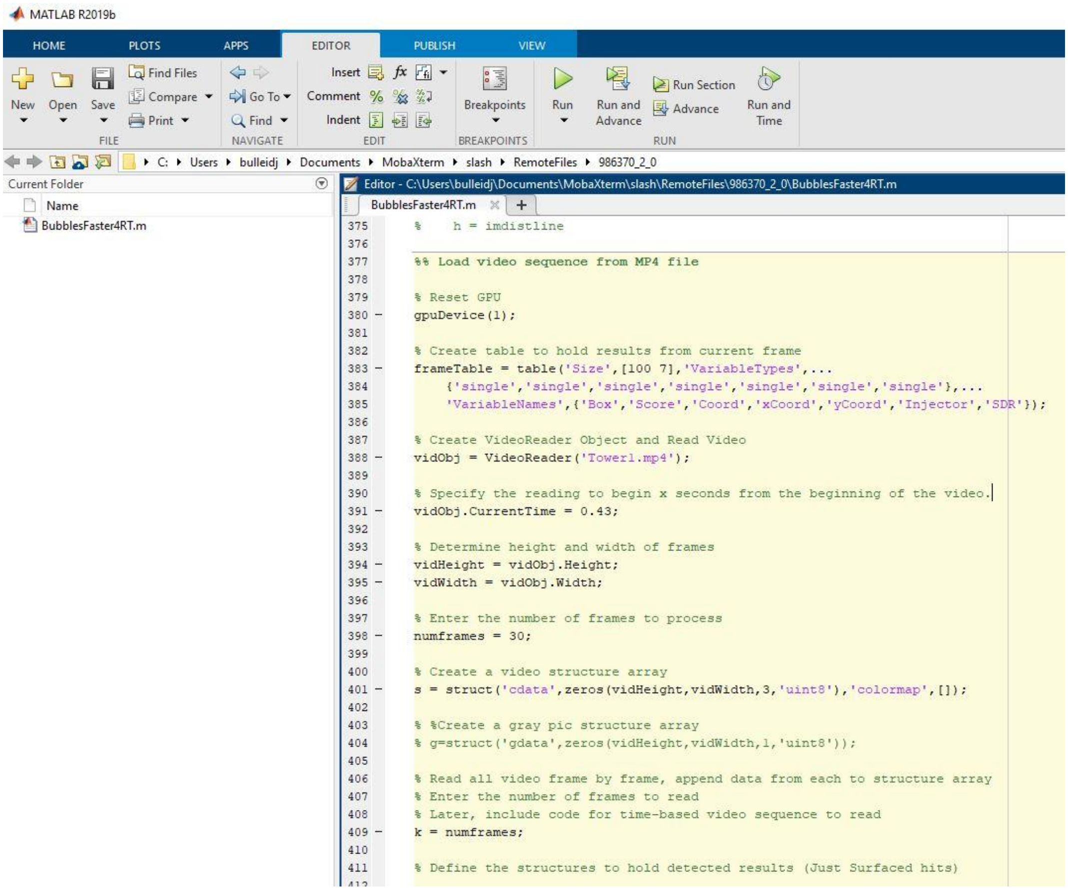

Figure A-8: A snippet of the system programme (BubblesFaster4RT.m) within the Matlab environment.

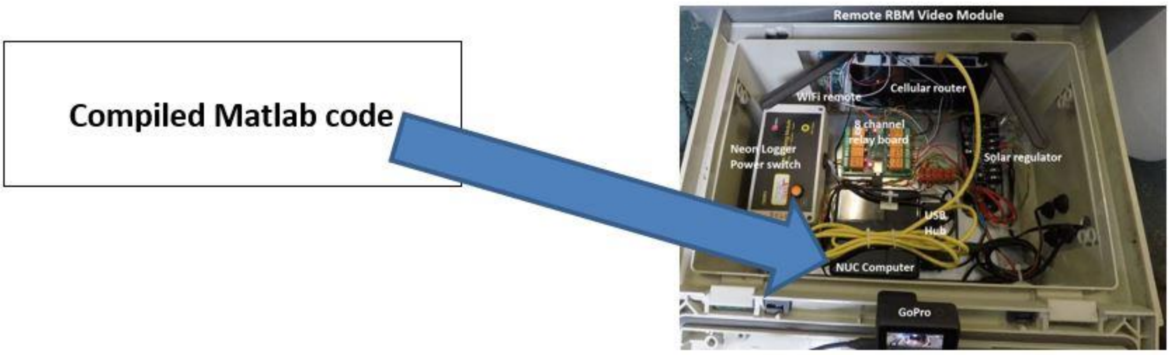

Figure A-9: The software ends up in here.

Objective 5 – Carry out flume tests

Tests were carried out in NIWA's six-metre recirculating flume. A sliding table was set up over the flume to provide a reference to the 'just-surfaced' bubble displacements (Figure A-10).

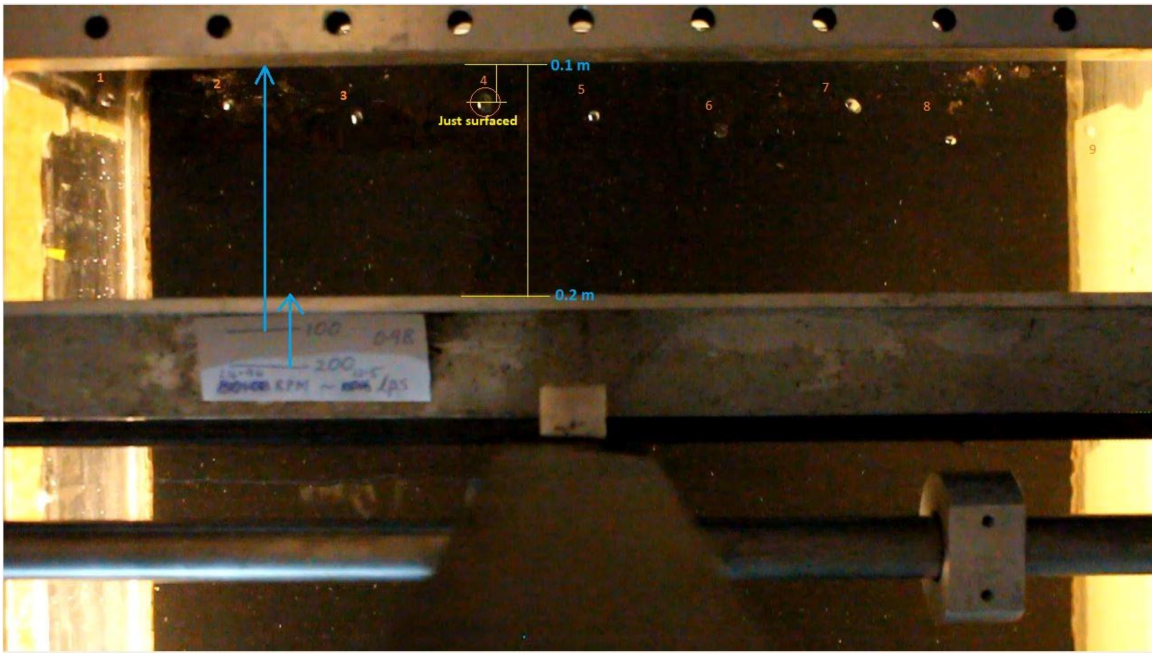

Figure A-10: An example of preliminary tests carried out in NIWA's six metre recirculating flume showing bubble just surfacing location. This was tracked by eye frame by frame.

The displacements in Figure A-11 were calculated manually from video record. Some turbulence was caused around the air tubes at the point they entered the water.

RBM Flume calculation

	A	B	C	D	E	F	G	H	I
1	RBM Flume calculation								
2									
3		*Vr*	*0.2*		*Flume flow*	*0.0125*	*Cumecs*		
4									
5	Inj	Frame	Rel posn	Scale1	Offset	Scale2	Displ	pA	q
6	1	51	9	70	0.1000	0.1000	0.1129	0.0073	0.0015
7	2	52	12	70	0.1000	0.1000	0.1171	0.0076	0.0015
8	3	48	8	70	0.1000	0.1000	0.1114	0.0072	0.0014
9	4	52	12	70	0.1000	0.1000	0.1171	0.0076	0.0015
10	5	56	18	70	0.1000	0.1000	0.1257	0.0082	0.0016
11	6	52	23	70	0.1000	0.1000	0.1329	0.0086	0.0017
12	7	53	18	70	0.1000	0.1000	0.1257	0.0082	0.0016
13	8	56	31	70	0.1000	0.1000	0.1443	0.0094	0.0019
14	9	46	10	70	0.1000	0.1000	0.1143	0.0074	0.0015
15									
16									**0.0143**
17	There was some turbulence caused by the air tubes entering the water								
18	Depth ~0.3 m								
19	Est uncertainty <5%								
20	Used typical Vr though not measured at the time								
21									

Figure A-11: One example of a calculation carried out by basic on-screen measurement, using nine injectors 0.065 m apart. The flume flow was set very low, at 0.0125 m^3/s, the RBM calculation 0.0143 m^3/s.

Figure A-12 shows that, within experimental uncertainty, the displacements (judged by eye) were linearly proportional to flow rate in the range 5 to 30 litres per second.

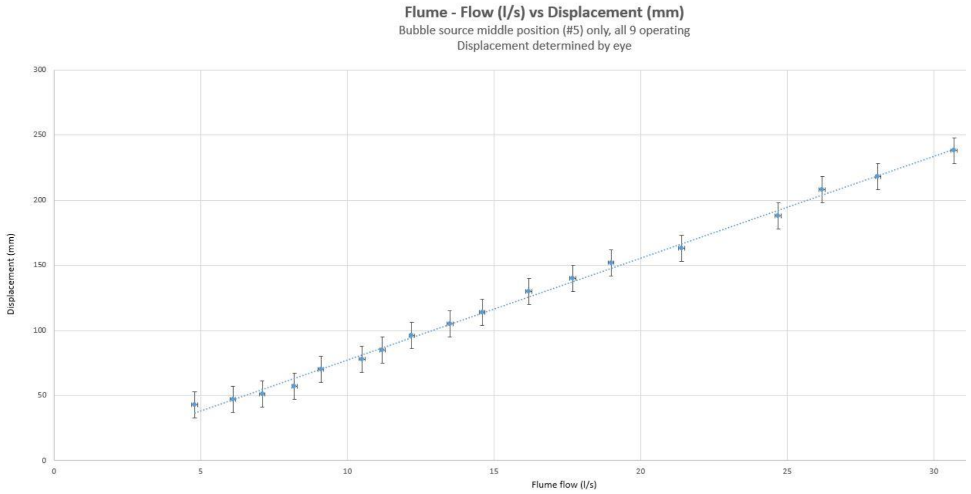

Figure A-12: Checking shallow, low-flow linearity, by eye, in NIWA's 6 metres flume.

Objective 6 – Build equipment and do field trials

Two portable RBM stations were assembled and used to carry out field trials with council staff as described in section 6 (Canterbury Trials, at Halswell River) and in section 7 (Hawke's Bay Trials at Karamu, Tutaekuri-Waimate, Paritua, Kawerawera and Raupare Streams) with HBRC staff during a week-long visit to Napier.

Objective 7 – Enable uptake of tools by councils

In order to familiarise councils with RBM to encourage early uptake of the tool, progress has been consistently reported over the duration of the development. An in-depth record of the development is covered in this report. A significant amount of other material, such as videos, is archived in NIWA's P:\PRODUCT\NIWA_PRODUCTS\Stream Discharge Measurement with Bubbles. Presentations and publications are shown in Table A-1.

Table A-1: Formal presentations and publications to keep councils progressively informed.

RBM oral presentations		
NIWA Field Team Leaders	Nov-18	Jeremy Bulleid
ED SIG workshop	Nov-18	Jochen Schmidt
Combined NZHS/NZMS conference	Dec-18	Jeremy Bulleid
NZHS workshop	Mar-19	Jeremy Bulleid
RBM publications		
NZHS Current Newsletter #54	Nov-18	Jeremy Bulleid, Thomas Wilding
NZHS Current Newsletter #55	May-19	Jeremy Bulleid, Thomas Wilding
NZHS Current Newsletter #56	Nov-19	Jeremy Bulleid

Appendix B Compressed air supplies

Figures B-1 – B-3 show the dive tank regulator (from Dive HQ Chch) we used with a diver’s air tank to supply compressed air to drive the bobbin valve and, after further regulation in the control box, supply air at a pressure of 0.9 Bar to create the bubble. This apparatus has an overpressure release valve for safety. This primary regulator has been set below the specified maximum input pressure of the regulator in the control box.

Figure B-1: The diver regulator we connected to the compressed air tank we used in early tests.

Figure B-2: Mains-powered compressor used at Halswell River where mains power is available.

Figure B-3: This 12V DC battery (or 230V) powered compressor can pump up to 120 PSI but at low flow, so needs an external reservoir tank. We used a modified BBQ LPG tank. Being small and light

This area would benefit from further development and testing.

Appendix C Bubble Injector Manufacturing Drawings

Drawings for the Bubble Injector are given in Figures C-1 – C-4 and a photo of the injector, opened up, in Figure C-5.

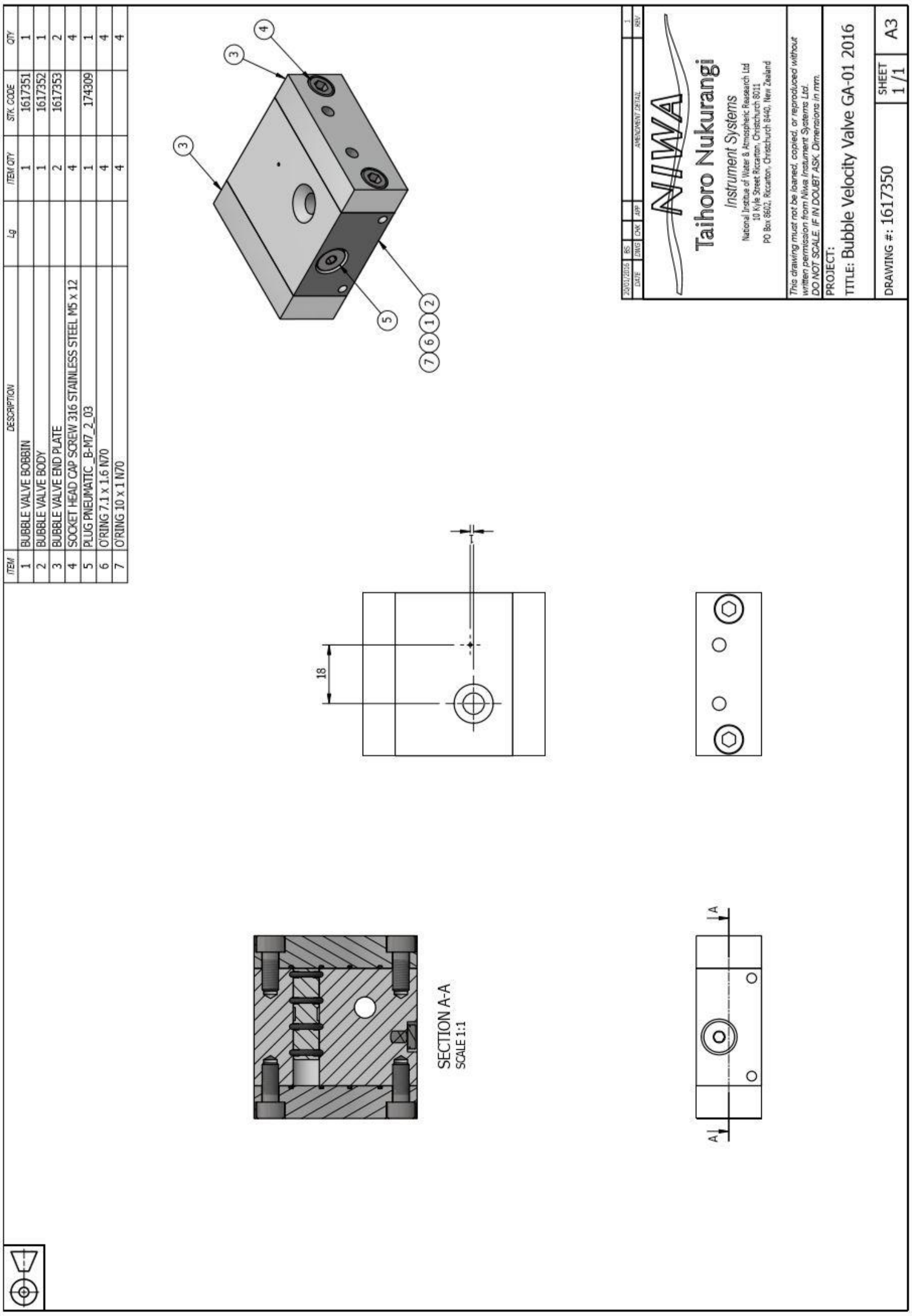

Figure C-1: Injector manufacture.

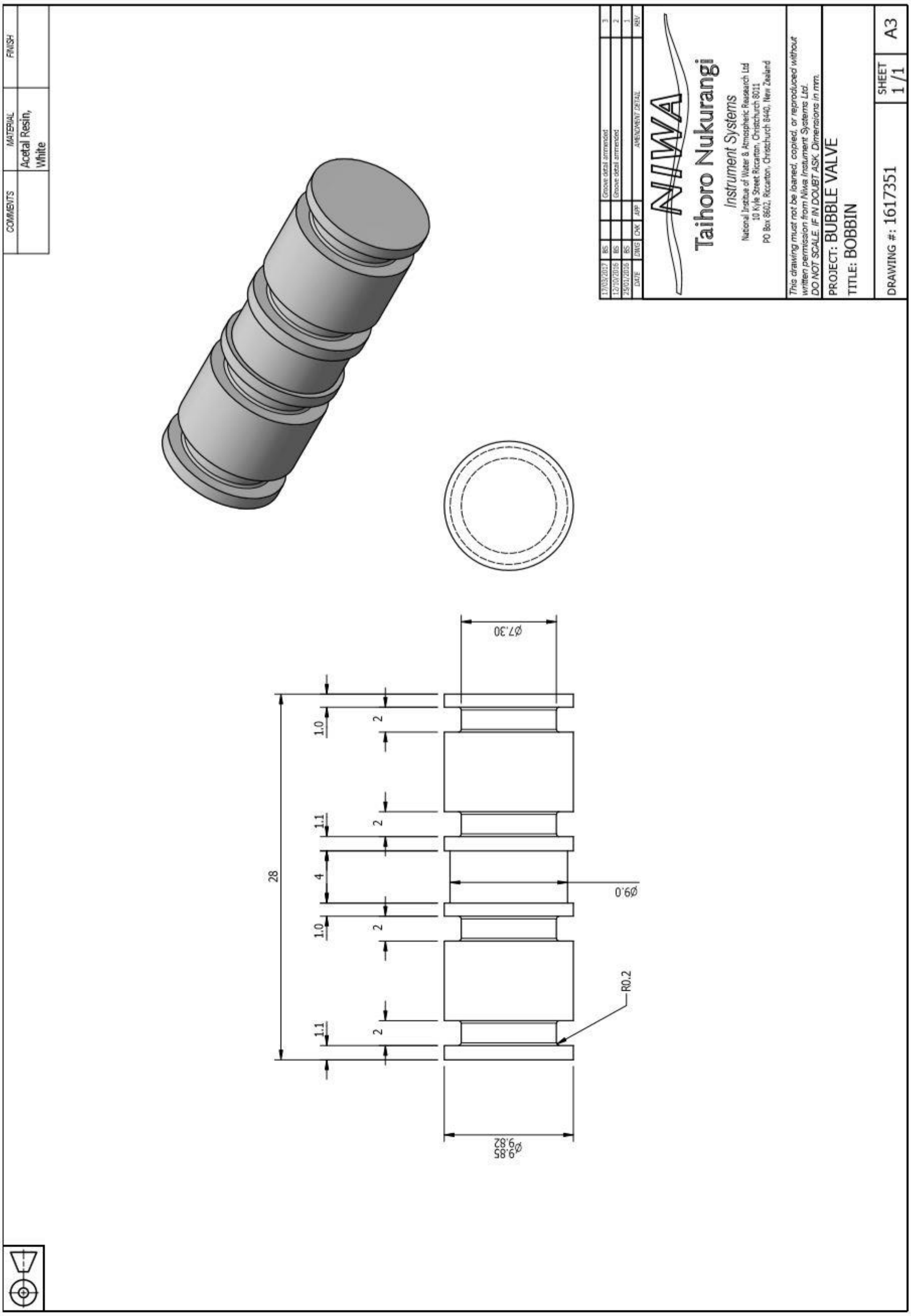

Figure C-2: Injector Bobbin manufacture.

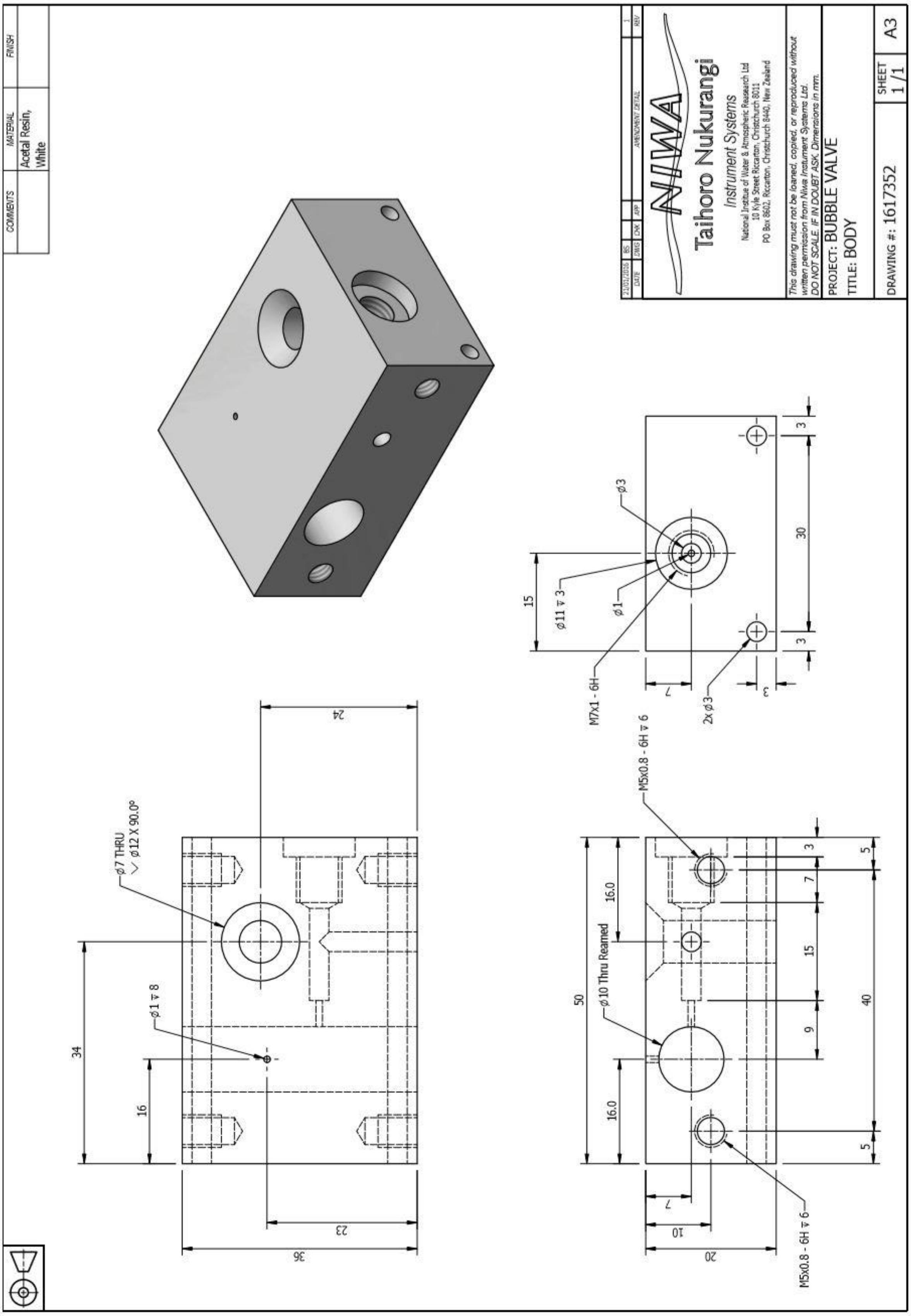

Figure C-3: Injector Body manufacture.

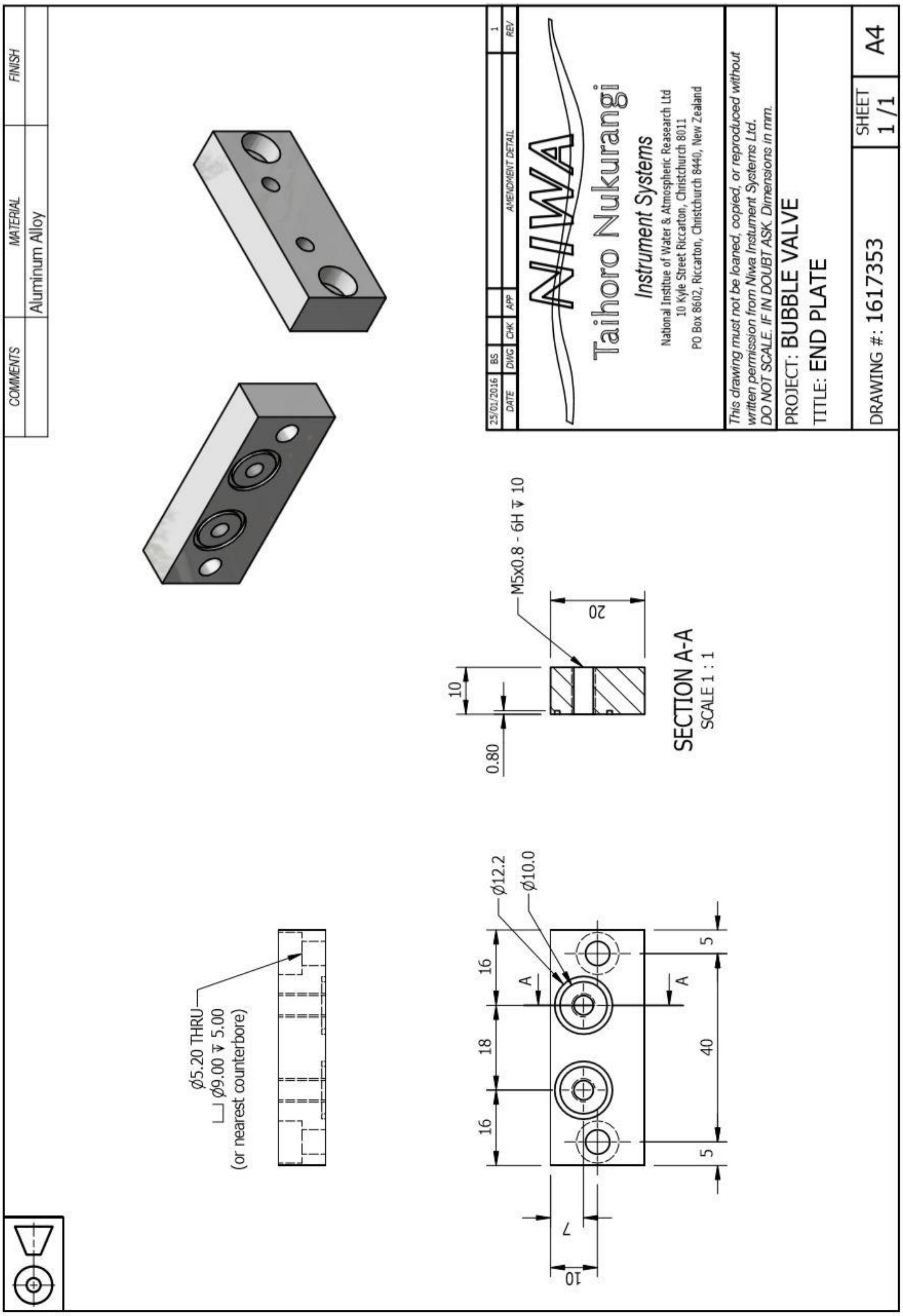

Figure C-4: Injector End Plate manufacture.

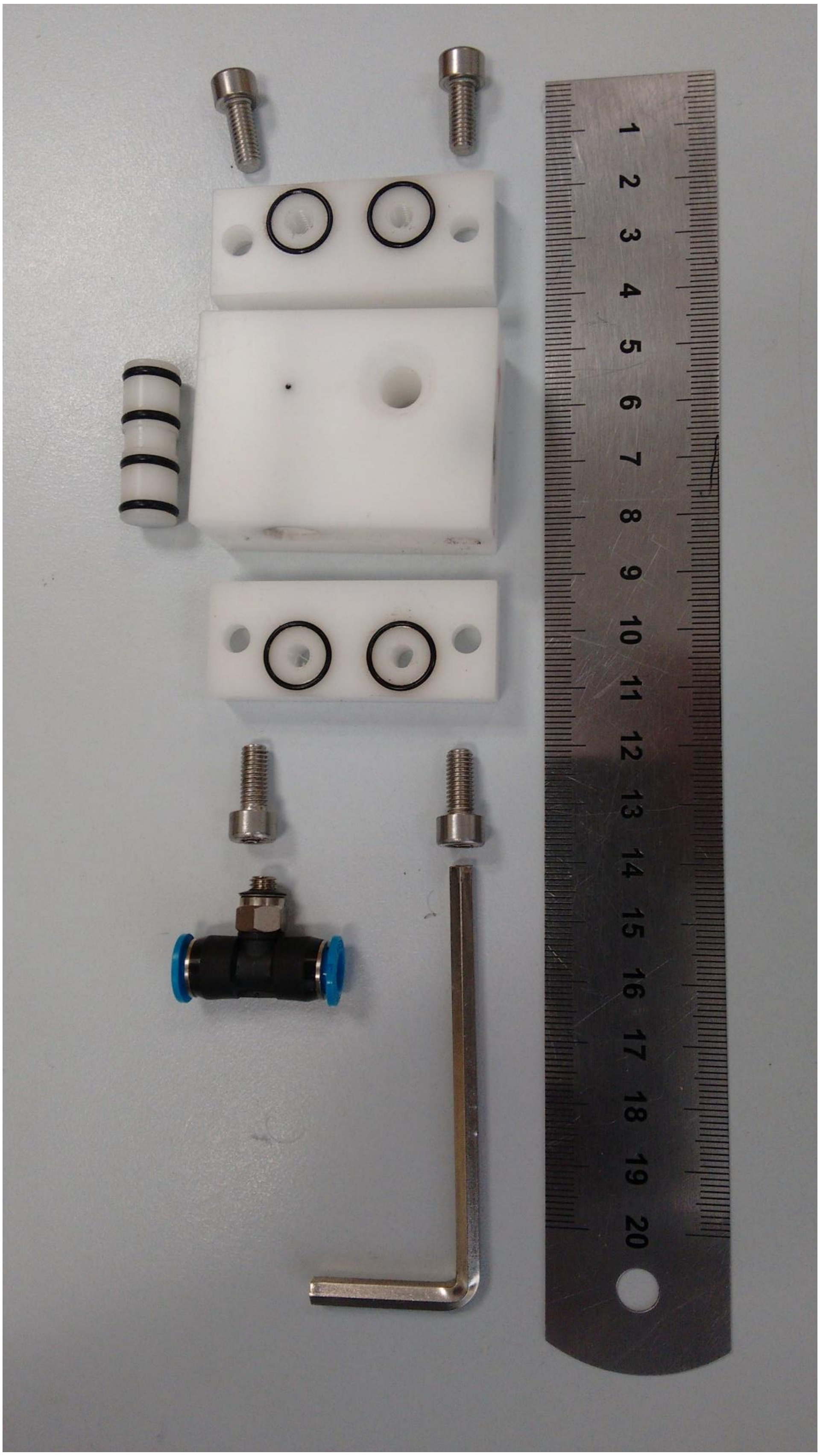

Figure C-5: The injector opened up.

Appendix D The Velocimeter

Overview

Here we describe the electronics and operation of the Version 1 Velocimeter (Figure D-1) used in the Hawke's Bay trials in March 2019, and the transition to the Version 2 Velocimeter with which HBRC is currently (December 2019) obtaining data from different streams to investigate variability in rise velocity.

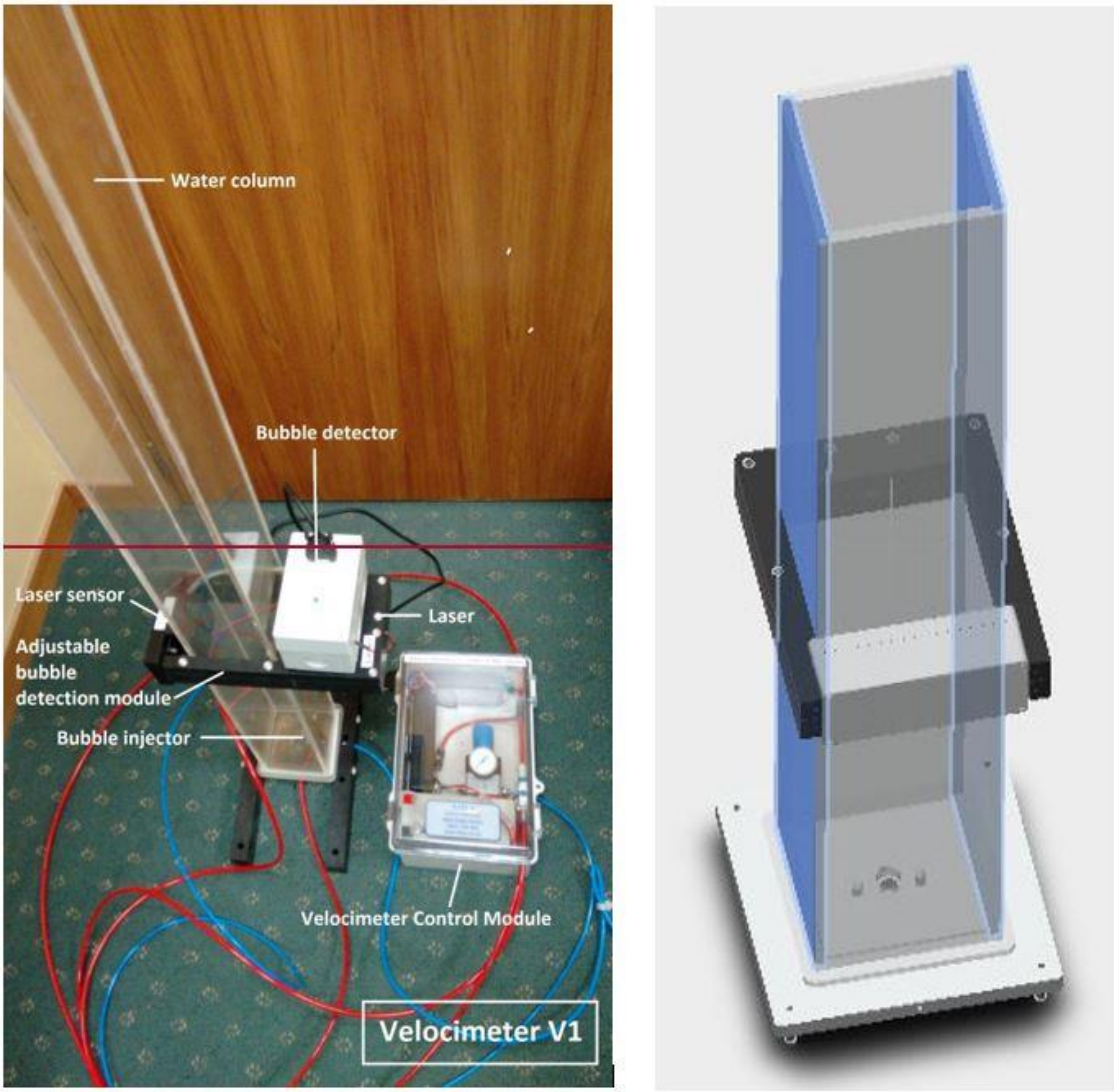

Figure D-1: Left; the version 1 velocimeter and control box. Right; a Computer-Aided Design (CAD) model of the Velocimeter

Figure D-2 outlines the Velocimeter construction along with its component parts.

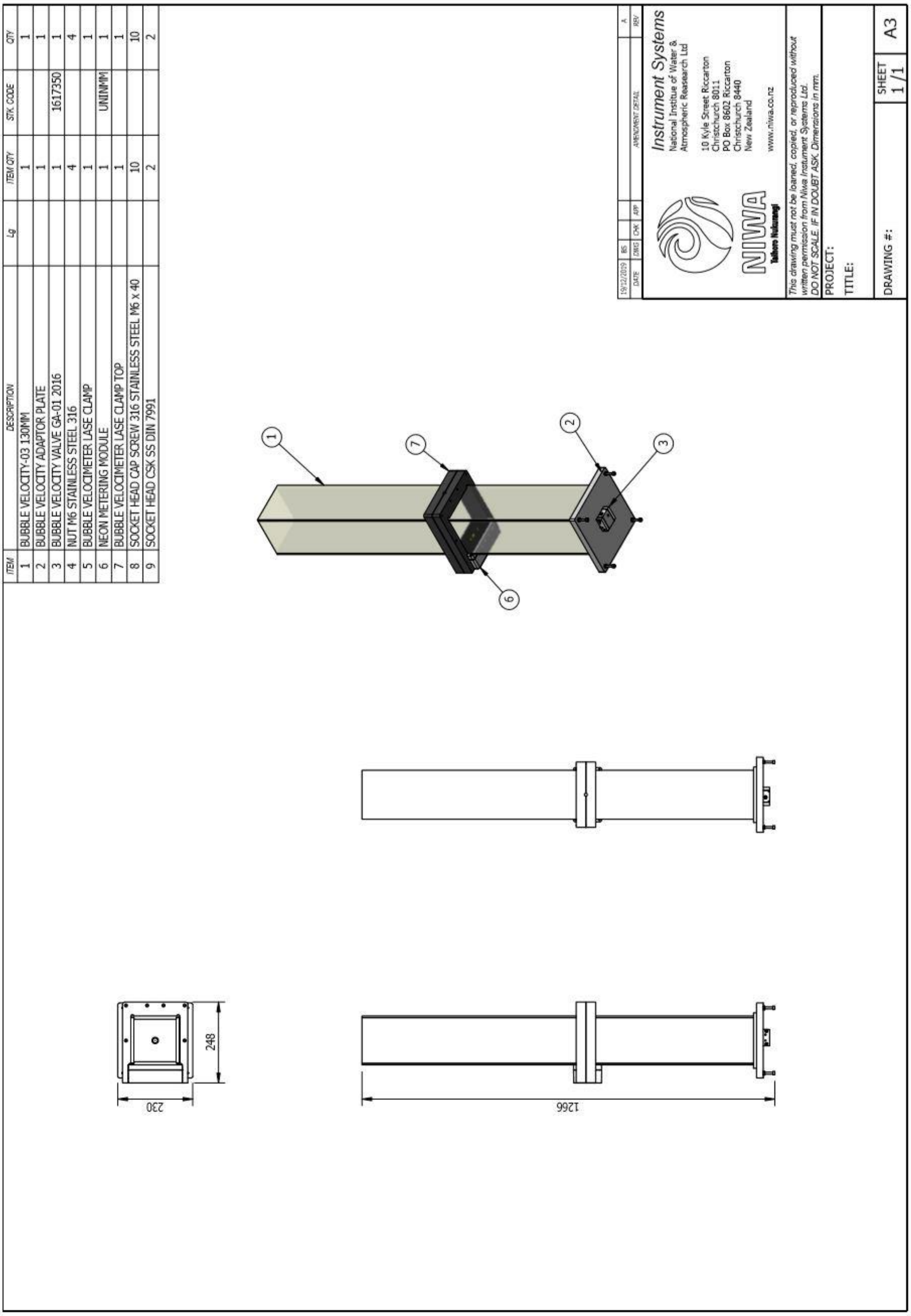

Figure D-2: Velocimeter manufacture. The inside dimension of the column is 130 mm

Control module

We have developed two versions of the control module. The main difference between the Version 1 (Figure D-3) and Version 2 modules is that Version 2 does not have a Smart Interface. This functionality has been integrated into the Version 2 bubble detector (Figure D-4).

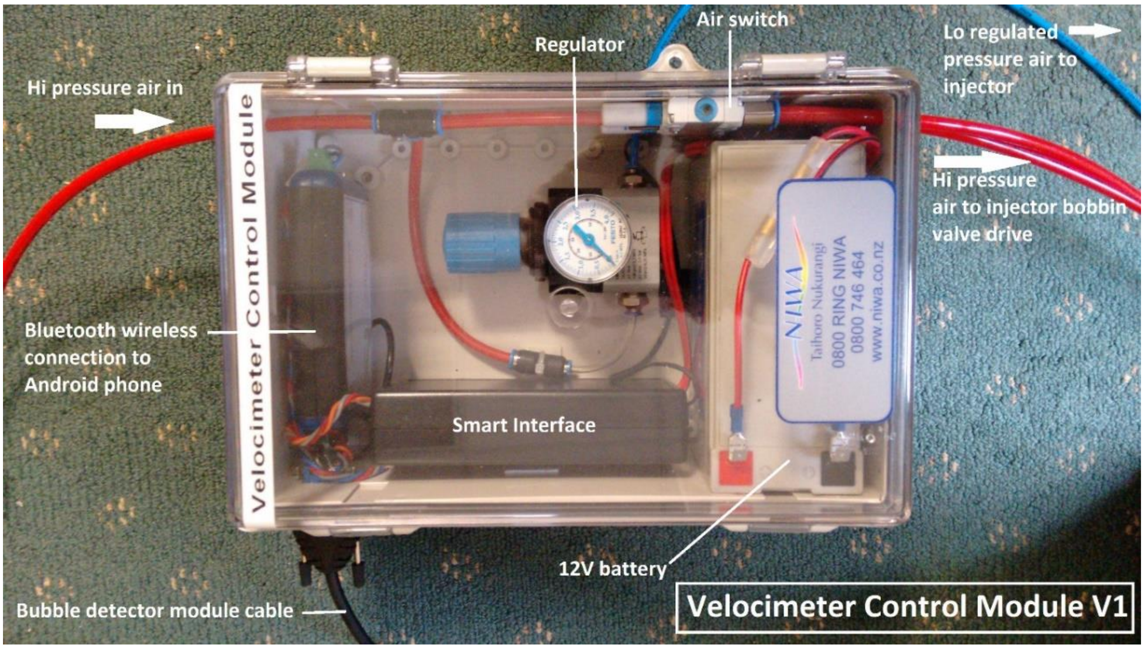

Figure D-3: Version 1 control module.

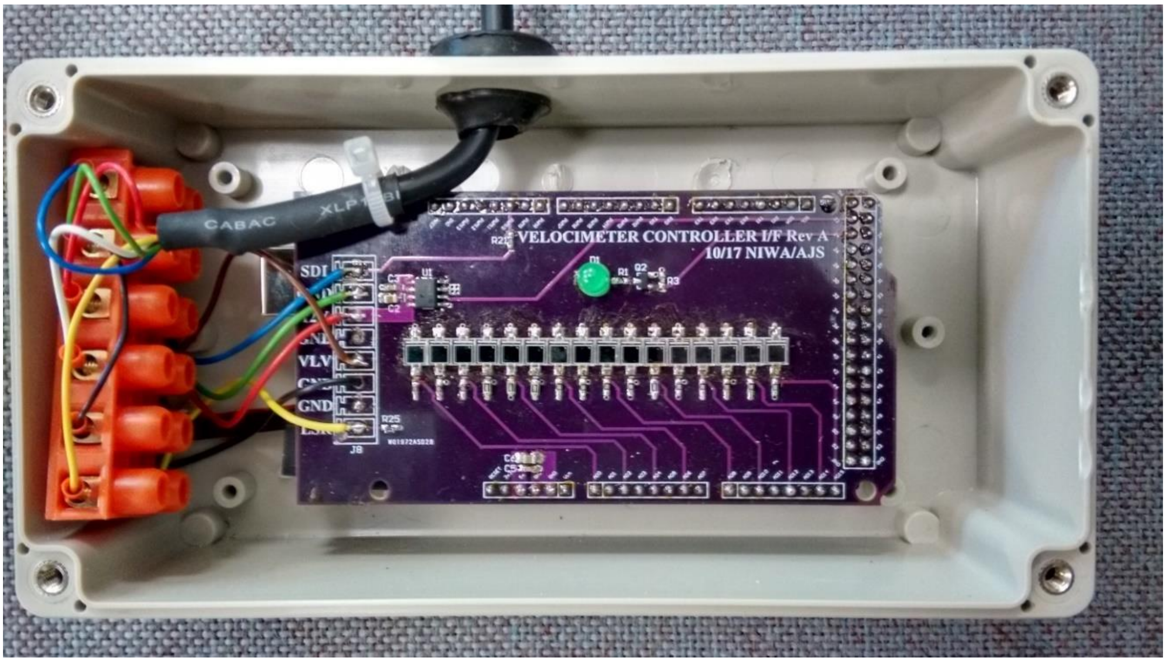

Figure D-4: The Version 2 bubble detector electronics showing the array of 16 laser light sensors. The green light has now been moved to the outside of the enclosure and flashes when a bubble is detected.

Bubble detection

The bubble detector has been implemented as a movable ‘collar’ that can be slid up and down the water column to allow a choice of vertical path length (Figure D-5).

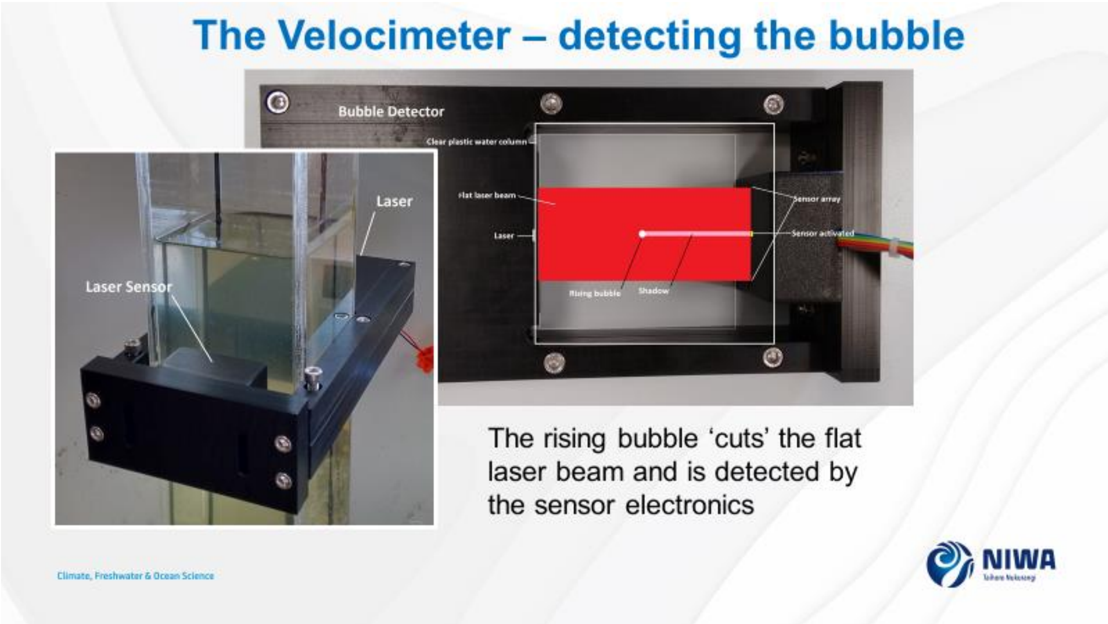

Figure D-5: The Version 1 bubble detector on the Velocimeter used in the Hawke's Bay trials, March 2019.

We have used two ways to trigger a bubble rise time measurement: a datalogger for long-term experimental measurements and a more practical method, using a Smartphone app when in the field or office. When a bubble is injected at the bottom of the water column a timer is started. When the rising bubble passes through the flat, red laser beam, its shadow is detected by a line of laser light sensors (Figures D-5 and D-6).

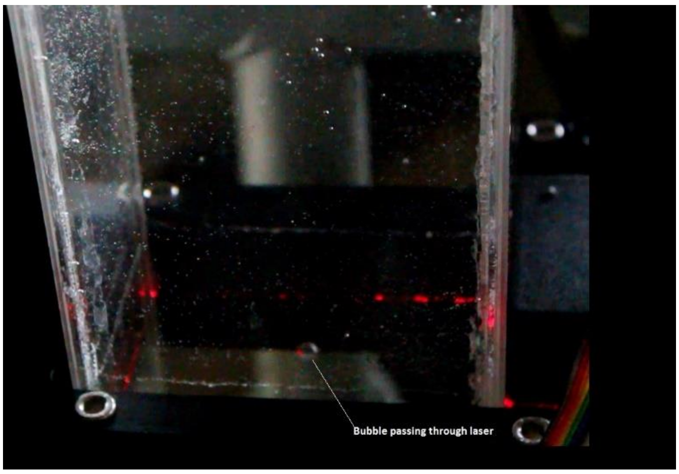

Figure D-6: The flat laser beam, incident on the array of light sensors, is eclipsed by the rising bubble.

This stops the timer and the time taken for the bubble to rise from injector to detection, through a vertical path of known length, is output on the Smartphone app. Typically we release 30 bubbles, record the 30 rise times and calculate the median rise velocity from path length/median rise time.

Appendix E Experiments with an RBM wading rod

We built and trialled two prototype RBM wading rods.

Raupare Stream, Hawke's Bay, NZ (14 March 2019)

We carried out a wading gauging with a prototype single-point RBM wading rod. While not carried out at the same time, it's interesting to compare the results (Figure. Bubbles located by eye.

Table E-1: Comparison of the three methods at the site on the same day.

Method	Q	UC at 95% CL	Duration
FlowTracker Reference (0.2, 0.6, 0.8)	0.482	5.0%	~ 1 hour
RBM Wading Rod – 1 injector	0.448	3.3% *	~ 0.5 hour
RBM Bubble Line - 20 injectors	0.462	<2%	~ 17 seconds

* 95% of 100 resample replicates fell within 3.3% of the mean. Displacement was estimated by eye and measured by laser distance measurement tool.

Pretty River, Ontario, Canada (30 May 2019)

North American Stream Hydrographers (NASH) share similar discharge measurement limitations in their prairie streams and have taken an active interest in our development. In this demonstration, bubbles were located using a GoPro to record their release at each vertical (Figures E-1 and E-2).

Figure E-1: Experimenting with an RBM wading rod and nitrogen bubbles in Pretty River, Ontario, Canada.

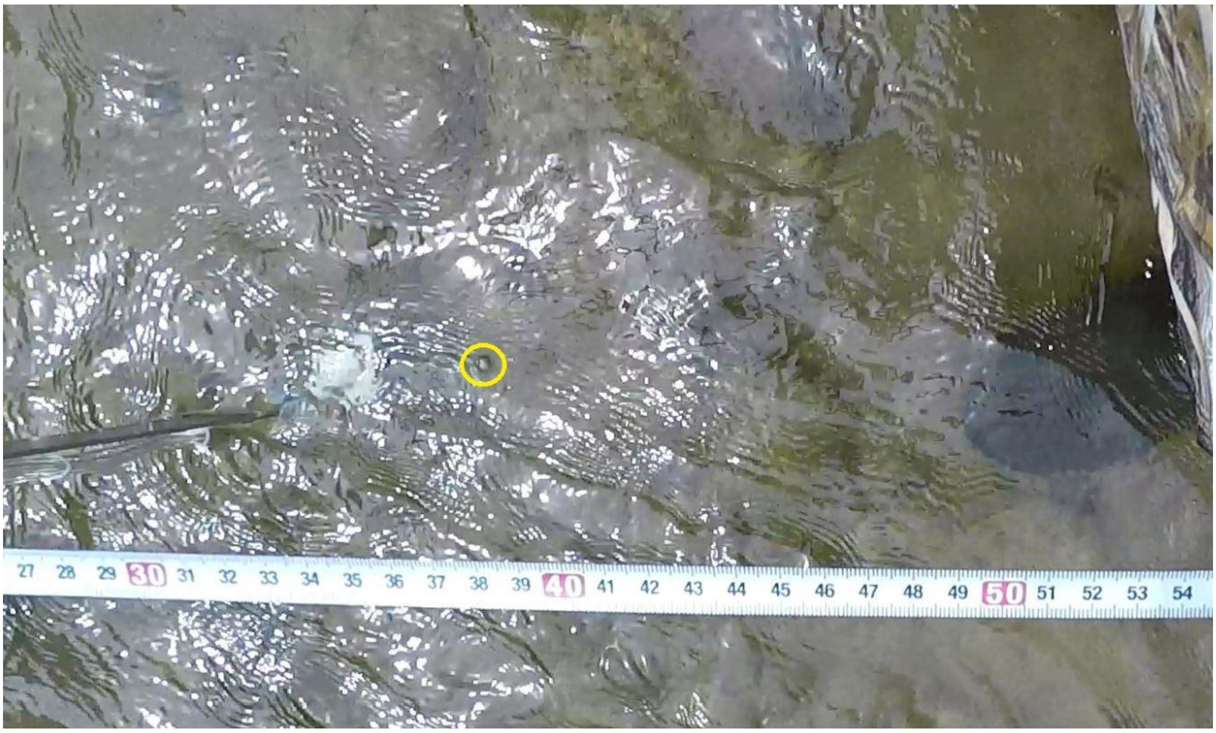

Figure E-2: The video frame in which a nitrogen bubble injected from the river bed just surfaces (annotated with yellow circle) - what the GoPro video camera saw. The measuring tape (used to measure displacement of the bubble) should have been closer to the water but the slider had jammed.

While we could detect bubbles close to the edges, the water was too fast to see them all. They would move out of the GoPro's field of view. In the middle of the stream, the bubbles were being affected by turbulence around the legs of the person doing the gauging.

Conclusion

While wading gauging with bubbles works, it can only be used in very slow (<0.2 m/s), shallow (<1.0 m) streams.

Appendix F Time to reach terminal rise velocity (V_r) test

Since it takes a finite time for a bubble to accelerate from zero velocity to terminal velocity, we needed to measure this (Figure F-1) to see how significant it was.

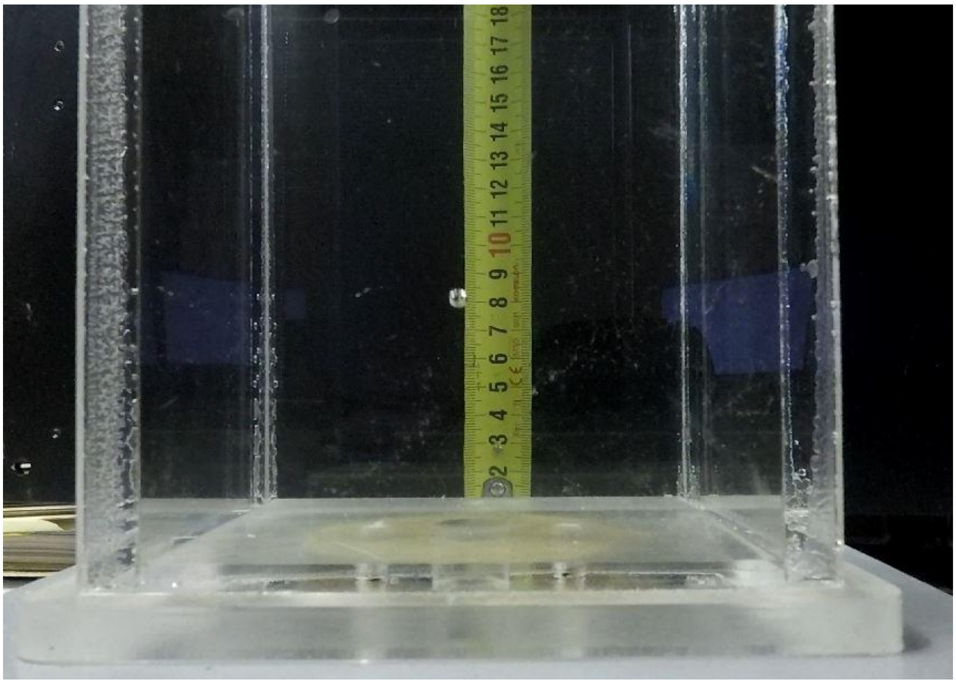

Figure F-1: Experiment to measure the time it takes an injected bubble to get to terminal velocity V_r.

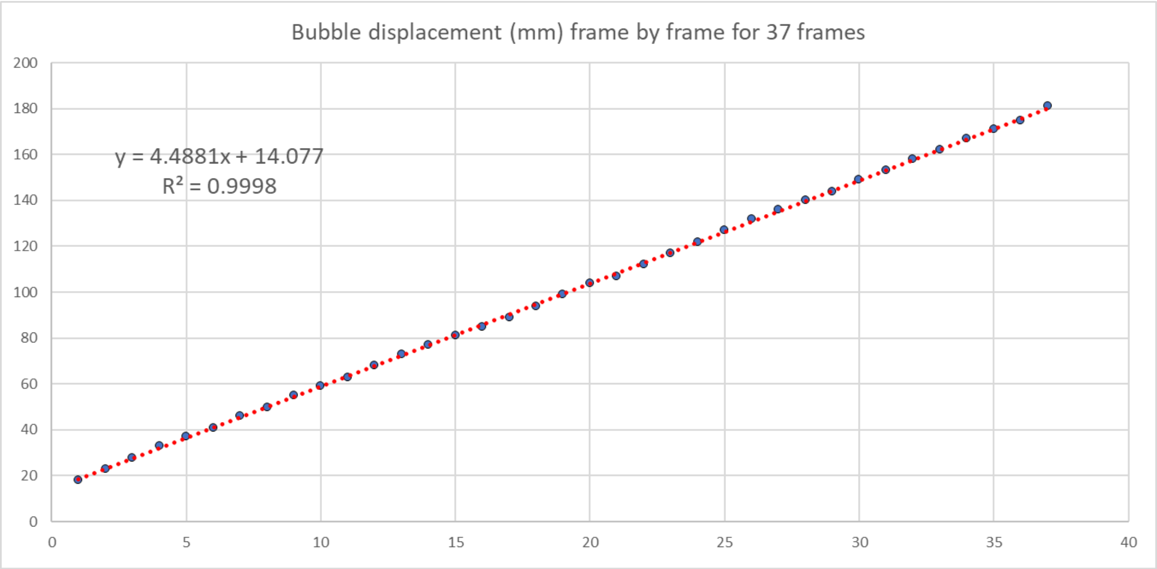

Figure F-2: Bubble position was recorded every video frame (0.01666 seconds) from 18 mm above the injector.

Conclusion

The straight line suggests that the bubble has reached terminal velocity (V_r) within a few mm. Hence there appears to be little need to make a correction to the Velocimeter rise time for shallow water.

Appendix G RBM tests in the rating tank

We carried out preliminary tests by towing an array of nine injectors behind the velocity rating car (Figure G-1) at NIWA's Kainga current meter calibration facility. We were able to test down to 1.5 metres, limited by the tank's maximum depth.

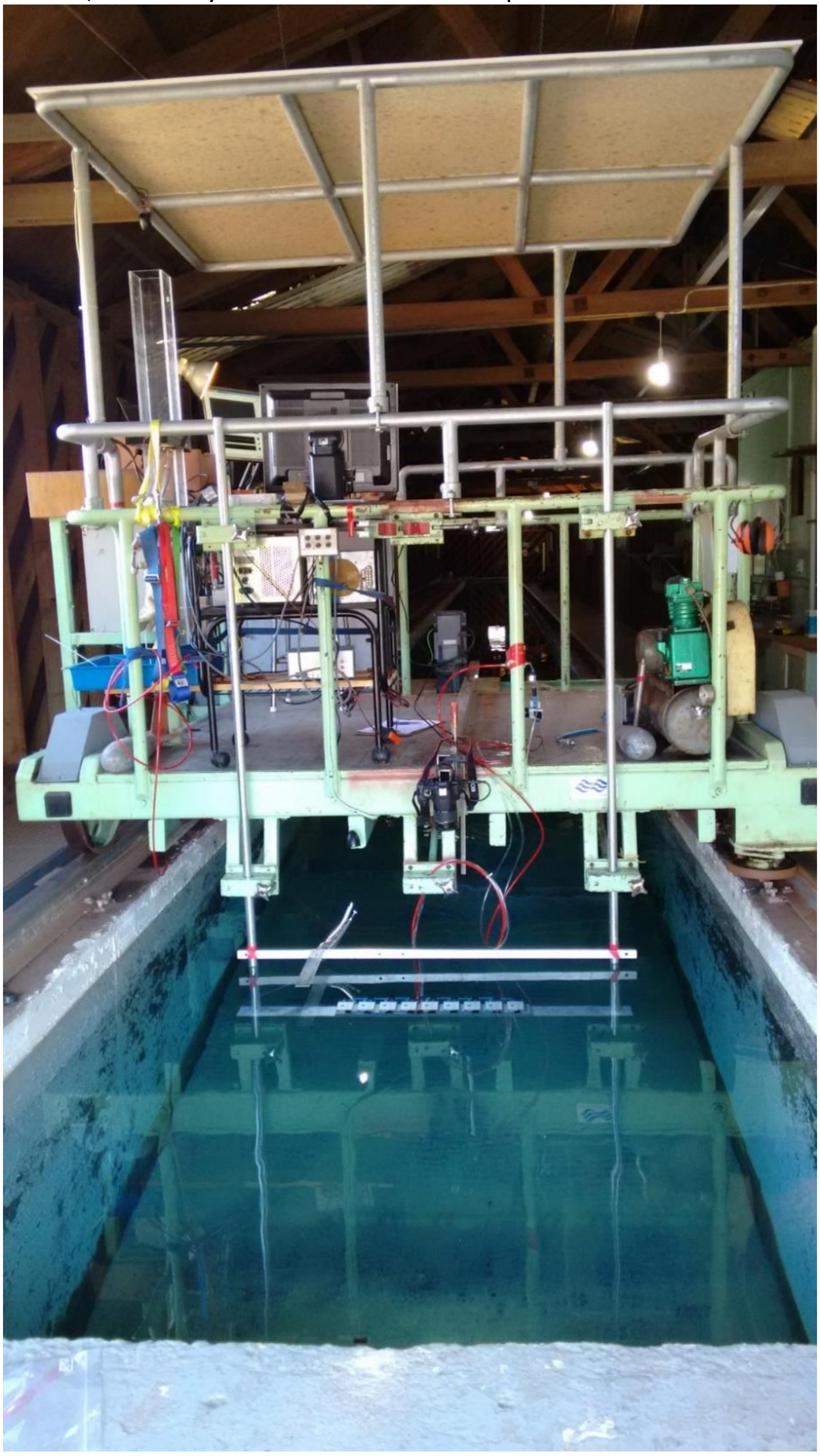

Figure G-1: Towing the injectors through still water at known velocities.

Appendix H Equipment configuration and site preparation

The equipment may be configured to suit the monitoring site. While this is the responsibility of the end-user, here we discuss some of the more important aspects.

Preparing the injectors

The injector modules may be mounted on a rubber strip (e.g., 150 wide x 6 mm thick and long enough to span the stream with some extra length for mounting) or other suitable substrate with injector spacing appropriate to the stream width and bed contour. Thicker and stiffer rubber help correct alignment of the origin (thick edge to locate T-square against, stiffer to minimise lateral movement so keep it as straight as possible), but there needs to be enough flexibility to follow the contour of the stream bed. While the injectors will typically be equi-spaced, if there is a section of the stream that has higher flow, then it may improve accuracy to add an extra injector(s) at this point. In longer-term installations, consider 'pinning' the substrate to the bed. In any event, it is advisable to accurately populate the substrate to facilitate accurate location of the origin.

Preparing reference benchmarks

Four reference benchmarks are required. These enable the software to convert from image scale (pixels) to true dimensions (metres). All distance measurements are done, or translated, to the water surface. Initially this may be done by inserting four tagline stakes where the taglines are typically spaced two metres apart. Tagline separation should be greater than the bubble displacement.

Preparing the streambed

Because the bubbles must be able to rise to the surface unimpeded, it is necessary to carry out some basic preparation: establish the approximate location for the bubble line, clear any major stones or other obstacles to enable the line to follow the contour of the bed, clear any weed from a two-metre wide swathe of stream bed - this depends on how far the bubbles are displaced downstream (depends on depth and flow-rate).

Locating the air supply

The compressed air supply may be located some distance from the bubble line. The reasons for this are: there is very little air flow in the separate regulated 0.9 Bar bubble air supply line, therefore negligible pressure drop that might otherwise reduce bubble size. The tubes themselves form a small local reservoir at each injector; the bobbin-valve drive (~2 Bar) has no effect on the bubble size other than to be the bobbin-driving force to inject the bubbles.

Camera

This is an area where experimentation will pay off. Showing that the 'end-on' field of view at Raupare was do-able was not an easy exercise. The reason for attempting this was for the benefit of practicality. We wanted to know whether videoing from the Raupare tower (as in a permanent installation) was going to be a 'showstopper' if we only used a single readily-available video camera. The resolution of the farthest bubble we would have to detect was less than 30 pixels using a GoPro Hero 7 Black with a 'line-of-site' of about five metres. The Faster RCNN model took a long time to train – seven days on only 104 training images. However, it has shown that it can be done and so can be improved on, with more images. While technically possible, a second camera would cause extra expense and practical difficulties (e.g., connection), as would a higher-resolution camera with zoom lens. A camera at each end of a stream would however, provide visual diversity and possibly make detection more robust