# 02 - A PASSIVE PROPORTIONAL SAMPLER TO MONITOR OVERLAND FLOW

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**Abstract**

Traditionally overland flow (OLF) measurements were taken using large fixed installations with tanks and flow meters. This meant that measurements were confined to research centres where equipment could be maintained and data downloaded easily. Also this equipment could not be moved easily so generally only one field was tested. However to resolve the issues of expense and fixed position, we need to develop small light mobile instruments which will allow us to go onto farms and show how the problems of flooding, pollution and saturation of fields apply at farm level. We may need to investigate the relationship between OLF and landform, soil type or farm management style. All these investigations require measurements on a wide scale.

## 1. INTRODUCTION

Traditional equipment to measure Overland flow (OLF) were large and fixed in position. They could not be moved easily from one site to another. This approach was appropriate for developing an understanding of OLF but was not the best option to solve the problem of OLF meaning pollution of surface water, flooding of land, roads and houses, water logged land. Overland flow occurs on fields where there is heavy soil, undulating landscape or where soil has been mismanaged allowing poaching or plough pan leading to free surface water. What are needed are movable stand-alone monitors that can be placed anywhere for extended periods. These can be used to identify the likelihood of any field being polluted in the period January to March when fields are wet and farmers are encouraged to spread slurry on wet land in Ireland (DAFF, 2010).

Water quality is still not what it should be with 30% of river channel polluted to some degree and approximately 15% of channel subject to pollution from diffuse sources (land and septic tanks) (EPA 2010). Improvements may include alterations to streams, farm management and wastewater treatment (Cooksley *et al.* 2011). Septic tank pollution is relatively easy to identify from the location of the house and where the pollution starts and continues indefinitely. On the other hand, agricultural pollution on the surface of a field may look clean 350 days in the year. It is only on days with heavy rain that it offends (Clothier *et al.*, 2011). This is where monitoring equipment is useful which is set in the field recording day and night for three to six months everything that occurs, from a surface water point of view, and identifying offending fields.

Soil and subsoil classification systems such as the Teagasc/EPA (2009) system in Ireland, and the so-called Hydrology of Soil Types system in the UK go a long way to address the problem. However they will not address management effects such as poaching, plough pan and other damage by machinery. It would require a revision of the entire soil survey. Field instruments can play an important role.

There are a range of instruments in the scientific literature of the type in question here. Some are expensive and fixed in nature. But others are low cost, mobile and of simple construction (Harmel *et al*. 2006). A number of devices have been developed in the USA to measure and/or sample OLF, but only three of these provide sampling. The Percent Discharge Meter, which consists of a rectangular flat plate with lines of 10 divisions in two successive groups, takes a 10% sample and a 1% sample (Franklin *et al*. 2001). Malone *et al*. (2003) describe a drop former and rotating slot sampler for low discharges, between 0.5 and 200 ml $min^{-1}$. The sampler as investigated by Bonta and Goyal (2000)

uses a drip former over a bucket wheel. None of the above met our design criteria and we determined to develop our own small sampler.

There is evidence to suggest that remote sensing from satellite using radar may have something to offer in this regard (F. Cawkwell, private communication). These machines can gather information from the entire earth in a matter of weeks. They use spectrometers that can absorb radiation over a wide band. Once calibrated a satellite could record soil moisture.

Based on the need for improved sampling suitable for research needs, the object of the project was to:
(a) To develop a sampler, which is inexpensive and portable,
(b) To collect samples and record total discharge
(c) To provide sampling proportional to discharge, and,
(d) To take samples with a volume of approximately 0.1% of discharge.

## 2. MATERIALS AND METHOD

### 2.1 Design Criteria

The design criteria were that the sampling should be proportional to flow and that the sample should be small in keeping with the standard of small samples used in laboratories i.e. to be about 0.1% or 1/1000 of discharge through the weir.

### 2.2 Design Options

The sampling equipment will be attached to an aluminium dam equipped with a weir to control flow. The sampler is attached to the dam close to the weir. There should be a logger which records start and stop time of flow. Design options relate to the slope of the ground, type of weir, the location of the sampler attached to the dam and the detail of the sampler tube (number and type of nozzles, air vent, and length and slope of sampling tube).

### 2.3 Test apparatus

The laboratory apparatus is illustrated in Fig 3. It consists of a shallow triangular tank (1.6m wide and 1.2m from front to back) and shaped like an overland flow instrument (OFI) in a full scale model. It is made of a water-proof plywood base and aluminium walls with the front corner flattened to accommodate a weir. The tank is set at an angle to represent slope in the field and this angle is adjustable. Water supply comes from a pipe perforated over its length at the back of the tank and water exits the tank through the weir. Two types of weirs were used during trials, a V-weir and a Sutro or proportional weir. The sampler is attached to the tank at the front end and extends to the sample bottle on a scale (with a capacity of 3100g and a precision of 1.2g). The sampler tube is flexible and can assume a range of shapes. Discharge through the shallow tank flows to a tank on a scale (capacity150kg precision 0.02kg) and is recorded.

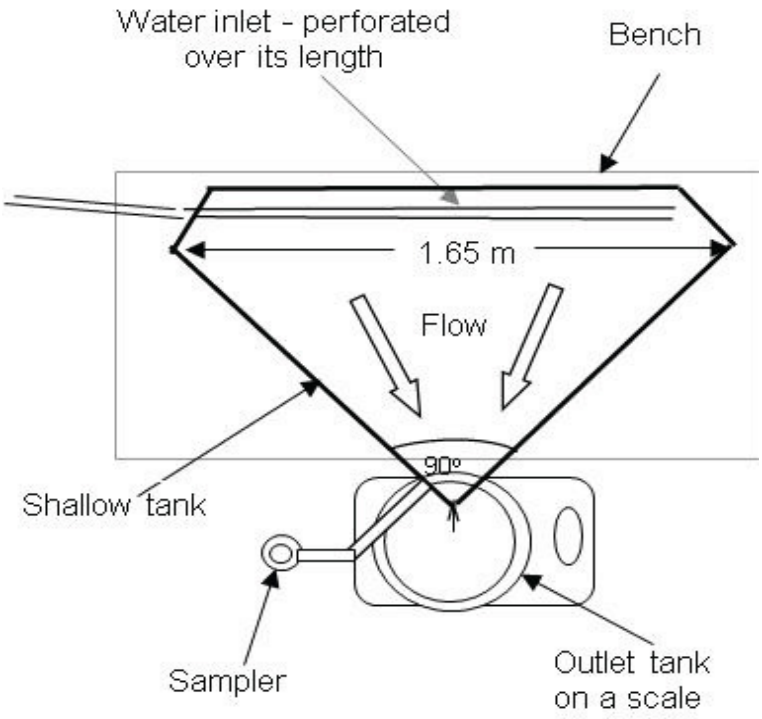


***Figure 3:*** *Test rig used to develop the sampler in the laboratory.*

***Table 1.*** *Test parameters and values used with the OFI laboratory rig.*

| **Test Parameters**[1,2] | **Test Values**[1,2] **(unless stated otherwise)** |
|---|---|
| Sampler 1 | |
| Sampler 1 Pipe dia. | Weir type; V-weir |
| Sampling Ratio | Sample tube; 3mm ID plastic |
| Sampler slope | Nozzle dia.; 0.7, 1.0mm |
| Sampler position | Sample tube slope; 21% |
| Water discharge rate | Port position |
| Tank slope | Inlet flow: 15lit.min-1; 2 |
| Sampling ratio | |
| Sampler 2 | |
| Water discharge rate | Weir type; Sutro weir |
| Sampling ratio | Sample tube; 10mm ID rubber |
| P/V characteristic | Nozzle dia.; 0.7, 1.0 , 2.0mm |
| | Inlet flow: 15lit.min-1 |
| Sampler 3 | |
| P/V characteristic | Weir type; Sutro weir |
| Start/Stop | Sample tube; 10mm ID rubber |
| Water discharge rate | Nozzle dia.; 1.0mm |
| Nozzles in the sampler | Sample tube slope; N.A. |
| Air bleed | Port positions; 4 and 5 |
| Sampling ratio precision | Inlet flow: 15lit.min-1 |

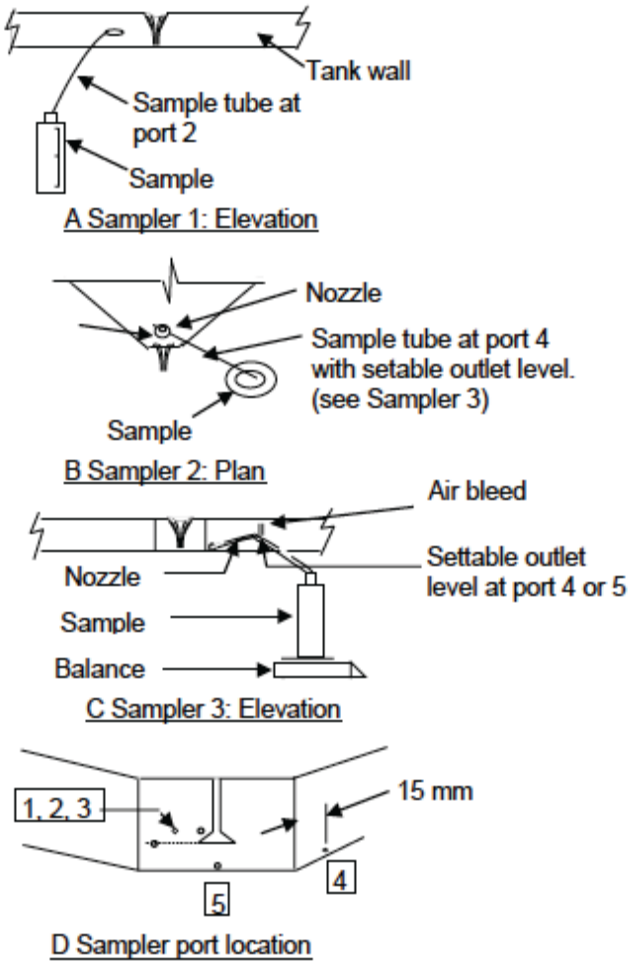


***Figure 4***: *The three sampler designs*

Approximately 80 tests were performed. The data were divided into three sampler designs, Samplers 1, 2 and 3. These are described in Table 1. In Fig. 4. Sampler 1 used a V-weir and had a steep slope on the sampler tube. This could apply suction to the sample tube inlet and increase the flow. The sampler tube was plastic and had rubber connections to the shallow tank and to the sample bottle which has markings to indicate volume. Four plastic pipes (3, 4.2, 5.25, and 5.5 mm I. D.) connecting the sample bottle to the test apparatus were used with this sampler and two plastic restrictor nozzles (1.0 and 0.7mm I.D.) at the connection point of the tube to the test apparatus wall. Other parameters were tested using the 3mm ID tube in the sampler. These included sampler pipe slope, sampler outlet position, discharge rate and tank slope.

Sampler 2 used three nozzles one of which was 2.0mm ID and a Sutro weir. The Sutro weir, otherwise known as the proportional weir, gave a straight line graph between hydraulic head and discharge, whereas the characteristic of the V-weir used in Sampler 1 was curvilinear. The nozzles were placed in the tube where it connected to the wall of the tank. Flow would start and stop precisely without a lot of dribbles. To this end the sampling tube was made to pass a high point on a level with weir. This reduced the tendency for dribbling.

Sampler 3 used one, two or three nozzles and an air-bleed. The nozzles were placed in the intake to the sampler, on the upstream side of the T-piece that formed the air bleed and on the downstream side of the T-piece. This last nozzle was often not submerged and could be surrounded by air. On such occasions a meniscus would form giving rise to increased resistance. The other nozzles were

completely immersed in water and had no meniscus. The air bleed formed by the T-piece prevented suction from the lower end of the sampling tube from affecting flow in the sampling tube.

It is difficult to match conditions in the field with a simple laboratory rig. Maximum flow values in the field are so large and minimum values are so small. We examined flow data from three experimental field sites including area of 0.46ha and a 1.45ha neighbouring our research centre and a 1.0ha site at our own centre. Maximum flow rates for the three sites were 16.4, 9.86, and 2.8 lit.min$^{-1}$. The lowest Quartile at the 0.46ha site was 0.03 lit.min$^{-1}$ to yield the following test data (0.42, 1.0, 6.0 and 15.0 lit.min$^{-1}$). The test data value of 15 lit.min$^{-1}$ is close to the maximum value in the field. However the value of 0.42 lit.min$^{-1}$ which is the lowest rate of discharge the laboratory equipment can reach and is many times larger than the minimum flow in the field. The mid test data values of 1.0 and 6.0 lit.min$^{-1}$ are empirical and simply fill a gap in the test data.

## 3. RESULTS AND DISCUSSION

The results below give the volume of sampling and the uniformity of the process under a typical range of conditions. The sampler design is novel and does not appear in the literature. They are constructed from plastic and rubber materials and are light and easy to carry to the field. Setting up an OFI can be a little difficult on account of the need to have the high point of the sampler and the low point of the logger on the same level as the base of the weir.

Measurements with the V-weir are summarised in Figs 5.1 to 5.6. The V-weir has a curved characteristic against pressure (ILRI, 1978) but still it was possible to get a proportional relationship between sample and flow (Fig 5.2). This was with a 3mm pipe and it is possible to configure a sampler that would give a proportional sample with a V-weir. In this case it happened by mere chance. The Sutro weir is more reliable as it always gives a linear relationship between pressures and flow, hence, if the system is proportional then sampling is proportional.

Continuing with the same sampler, pipe diameter is plotted against sampling ratio (sample divided by discharge) that gives a non-linear relationship (Fig. 5.3). Pipe diameter sizes are between 0.77mm to 5.5mm, and sampling ratio increases with pipe size. The effect of port position (Fig. 4) on sampling ratio is given in Fig. 5.4. In this diagram it is evident that port position can have an influence on sampling ratio and port 2 gave a 20% higher flow than the other two ports. It is not clear how this would affect a sampler but for design purposes it was kept in mind. The effect of ground slope on sample ratio is illustrated in Fig. 5.5. The data show a little scatter but a good regression value was given ($R^2$ = 0.98). It shows a range of values that amounts to a variation between trials of approximately 10%. It is to be expected that sampler slope would affect discharge. In Fig 5.6 sampling ratio (sample size to corresponding discharge volume) increased steadily with slope, in an almost proportional relationship. In the laboratory every effort was made to eliminate the effect of sampler slope as in the field it could have almost any value. Sampler 1 indicated the parameters, which should be chosen for the other two samplers.

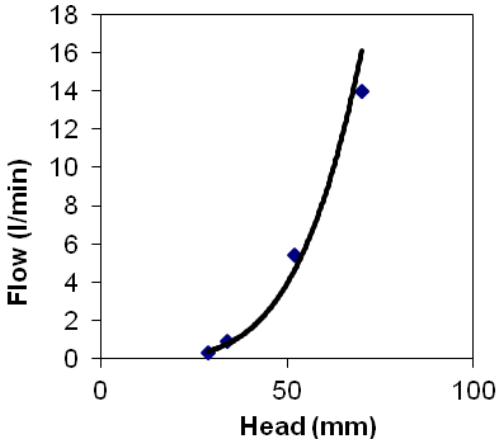


*Figure 5.1: Characteristic curve for a V-notch weir ($R^2$ = 0.99)*

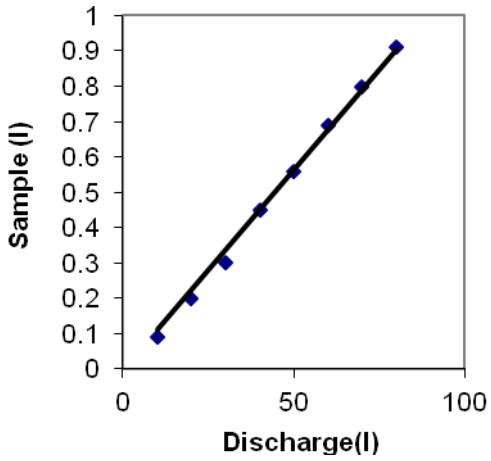


*Figure 5.2: Sample volume plotted against flow ($R^2$ = 0.99) 3mm pipe.*

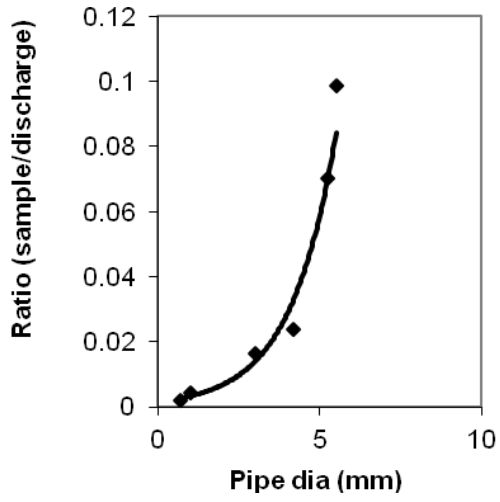


*Figure 5.3: Effect of pipe size*

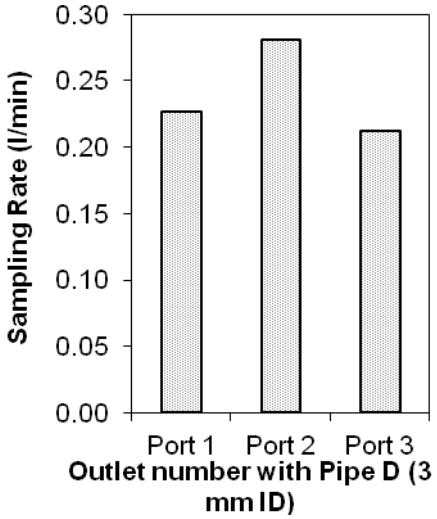


*Figure 5.4: Effect of port number on sampling rate*

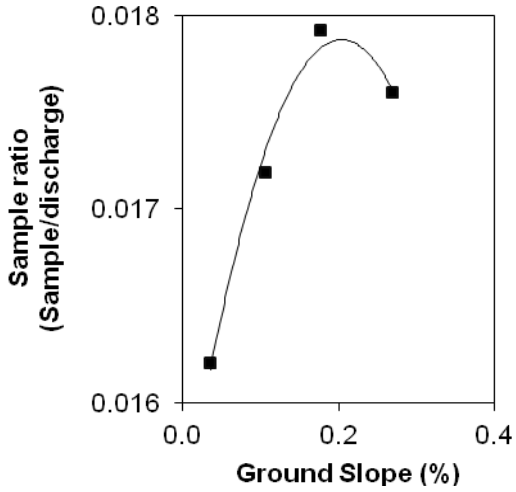


*Figure 5.5: Effect of ground slope on sample rate*

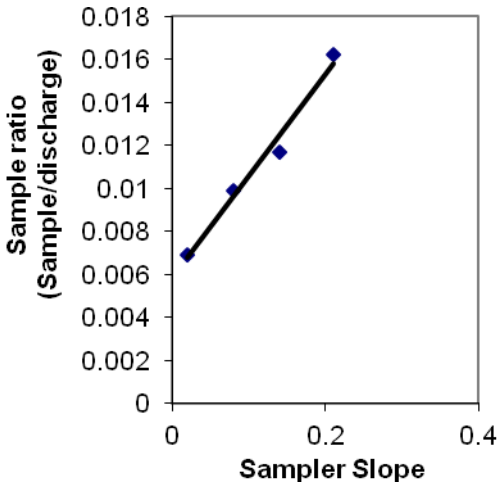


*Figure 5.6: Effect of sampler slope, $R^2$ =0.98*

***Figure 5:*** *Measurements with the V-notch weir (Sampler 1)*

The V-notch weir did not have a proportional characteristic as shown in Fig.5.1 and in the equation of the curve (ILRI 1978). It was considered responsible for the lack of linearity in sampling. Therefore the Sutro weir with its proportional characteristic (Fig. 6) was chosen and incorporated into the laboratory test rig. Sampling became linear after that. The Sutro weir is not entirely linear as like most weirs there is a small curve at the base of the characteristic but it was not expected to seriously affect sampling. There were 43 measurements with the Sutro weir and these suggested an 8 mm cut-off as did the textbook the design was obtained from (ILRI, 1978). This applies to most weirs but where the level and flow are measured the values obtained are true. Thus the cut-off does not apply to the Sutro weir in this paper.

Graphs were plotted of water discharge against sampling rate using 3 different sized nozzles each located at the inlet to the sampler (Fig. 7, Table 1: Sampler 2). The data fit well with $R^2$ values of 0.83, 0.92 and 0.88 for nozzles of 0.7, 1.0 and 2.0mm respectively (Fig. 7). As indicated the discharge through the 2mm tube nozzle is much larger than that through the smaller nozzles.

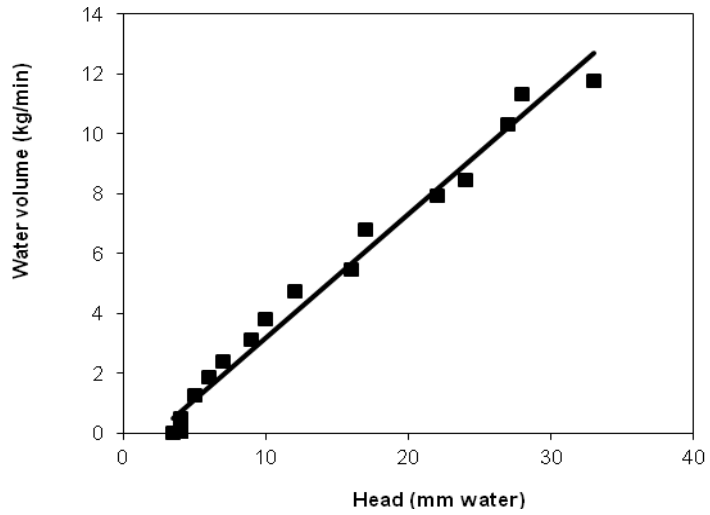


***Figure 6**: Head/volume flow curve for the Sutro weir ($R^2$ = 0.98) (Sampler 2)*

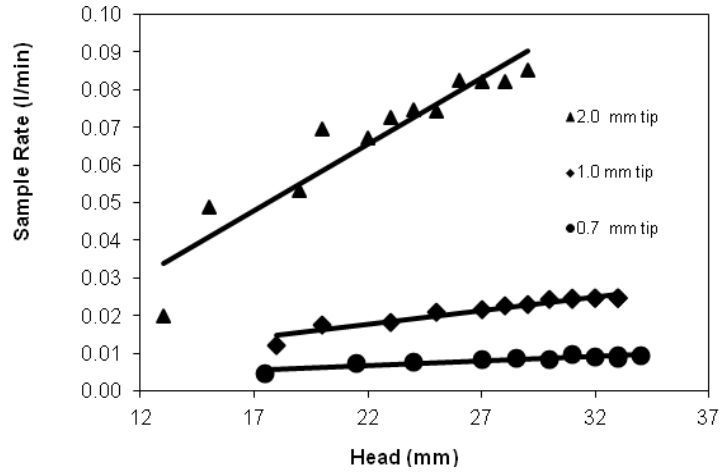


***Figure 7:** Sample rate vs. head using nozzles 0.7, 1.0 and 2.0 mm with $R^2$ values of 0.83, 0.92 and 0.88 respectively (Sampler 3).*

Sample volume is directly proportional to discharge through the weir as shown on Fig. 8. All three nozzles affected discharge and the effect is significant (Table 2). The sampling rate is evident from

these plots with the three nozzles giving a sample ratio of 0.0024, 0.0018 and 0.0011 respectively. These values are consistent over the range described in the graph. The lowest value will collect a sample of less than 1.0lit in a typical OLF event. However with extreme events sample volumes could be larger so a larger receptacle may be required. Sampler 2 revealed the sample size available with each nozzle.

An additional benefit from the sampler is that it can be used to measure total discharge using Fig 8. If the volume of the sample is measured then entering this value on the y-axis of Fig. 8 will give a value for discharge on the x-axis. This results from the fact that the sample is proportional to flow.

Sampler 3 works well over the operating range of the samplers. With three 1mm diameter nozzles installed in series in the sampler a discharge as low as 0.8 lit.min$^{-1}$ was achieved. This would amount to 1lit in a typical OLF event. The maximum discharge measured through the laboratory rig was 14 lit.min$^{-1}$ and this is close to maximum flow by the 2m wide field instrument 16.1 lit min$^{-1}$.

Table 3 shows the start and stop times for Sampler 3. Some of these data were recorded with nozzles discharging to open air in the sampler. Others were recorded discharging to water. The meniscus in the former nozzles increased the difference in time between start and stop. The difference due to meniscus was significant. For accurate sampling the head across the sampler should be close to zero at start and stop. Therefore all three nozzles should be under water at start and stop.

The effect of aspiration is shown in Fig. 9. The sampler with a sealed vent provided 15% more sample than an aspirated sampler due to suction in the downward part of the sampling tube. Fig. 9 does not support the expectation of reduced scatter due to aspiration as there is a similar lack of scatter whether the sampler is aspirated or not. Aspiration is justified when the sampling tube varies in length or slope. This will be the usual case with the field instrument.

***Table 2**: Analysis of variance for key design parameters of the proportional samplers.*

| **Parameter** | **Source** | **N**[1] | **F crit** | **F** | **P-value** [2] | **Signific**[3] |
|---|---|---|---|---|---|---|
| Sutro straight/curve | Fig. 6 | 31 | 4.00 | 9.84 | 0.0026 | S** |
| Nozzle size | Fig. 7 | 4 | 19.00 | 887.00 | 0.0011 | S*** |
| Number of nozzles | Fig. 8 | 3 | 6.94 | 45.5 | 0.0018 | S** |
| Start/stop: nozzle in air/water | Table 3 | 4 | 5.98 | 30.1 | 0.0015 | S** |
| Aspiration/Not | Fig. 9 | 3 | 18.50 | 19.7 | 0.0472 | S* |

[1] Number of values, [2] Probability,.[3]Significance: *, ** and *** indicates degree of significance

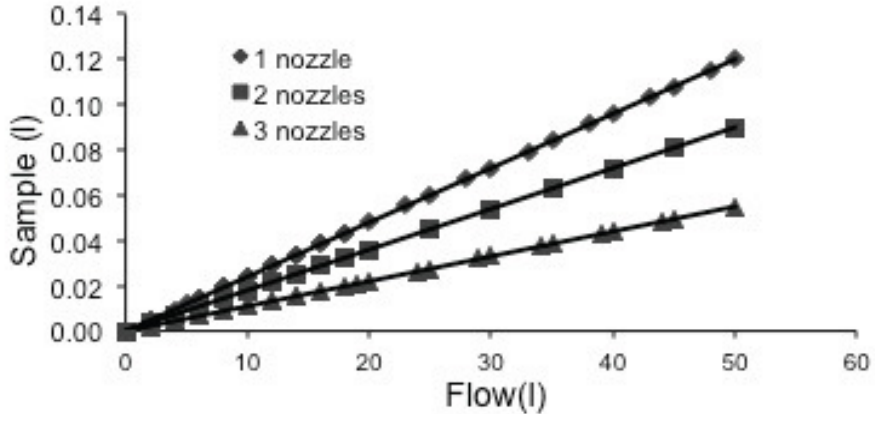


***Figure 8**: Regression lines for sample volume plotted against discharge for 1, 2 or 3 nozzles of 1.0mm diameter and 1 bend in the sampler. $R^2$ values are 0.99, 0.89 and 0.99 with respect to nozzles. (Sampler 3).*

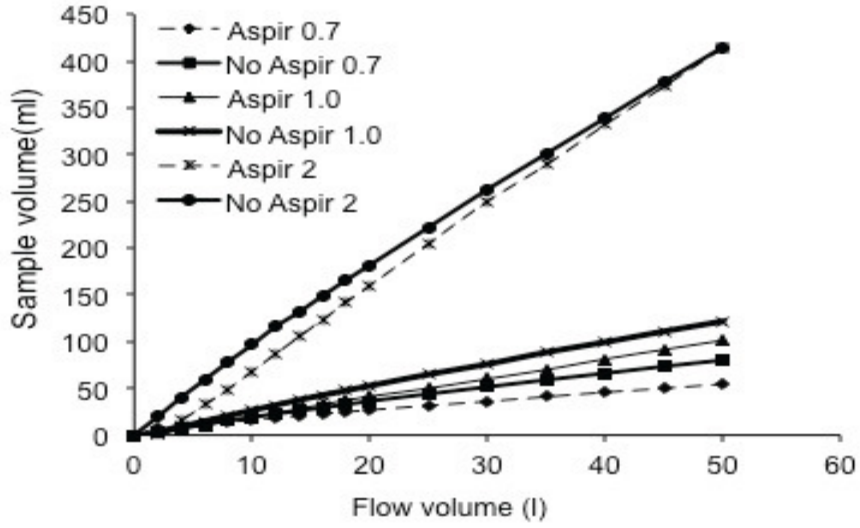


***Figure 9**: Effect of aspiration on sample volume for nozzles in Sampler 3: 0.7 mm, 1.0 mm and 2 mm.*

***Table 3**. Start and stop times for the sampler (Sampler 3) with nozzles in air or in water.*

| Sample | Nozzle in air | Nozzle in water | Mean |
|---|---|---|---|
| Start | 153 155 149 149 | 139 139 139 139 | 145.25 |
| Stop | 143 146 140 140 | 137 140 140 140 | 140.75 |
| Difference | 10 9 9 9 | 2 1 1 1 | 5.25 |
| Average | 9.25 | 1.25 | |

The Passive proportional sampler can be connected just below the weir of a 2m wide dam with Sutro weir of a field instrument. A bottle of 1 lit or more depending on requirements can be attached to the sampler. The sampler can quantify discharge or additional equipment to measure discharge can be installed with the sampler. The assembly of instruments can be used singly or in groups to monitor small or large areas. Protection of the instruments against livestock or machinery may be necessary.

## 4. CONCLUSION

Sampler 1 determined the parameters for Sampler 2, and Sampler 2 identified the parameters for Sampler3. The findings with all three samplers are listed below.

The achievement of samples proportional to discharge means that Sampler 3 with a plastic tube and one to three plastic nozzles of 1.0mm internal diameter within the tube to control sampling rate provides proportional samples of water and no mechanical device is required. Three nozzles are best as they provide the target-sampling rate. This could have a substantial impact on surface water studies worldwide. Loads of any chemicals dissolved or suspended in the water sample can be calculated. The sampler uses only difference in water level to initiate and terminate sampling flow and the components used are inexpensive. The main conclusions are summarized below.

(a) Sampler 3 with fine bore inlets (0.7, 1.0 and 2.0mm) generates discharge that is proportional to discharge through the Sutro weir.

(b) Sample size as low as 0.1% of total discharge is available.
(c) Samples up to 1litre can be obtained under moderate conditions.
(d) A larger sample can be obtained under very wet conditions
(e) Total discharge can be calculated from sample volume.
(f) Arrangement of three, two and one nozzle offer sampling rates of 0.11%, 0.18% and 0.24% of the main discharge. Three nozzles are best as this arrangement satisfies sampling objectives.
(g) Aspiration of the sampling tube reduces sample size
(h) Aspiration did not affect uniformity of sampling.

(i) Sampler 2 gave sampling rate with different size nozzles.
(j) With sampler 1 ground slope was shown to affect discharge by 10%.
(k) Sample rate is proportional to sampler slope.
(l) Pipe diameter has a large effect on sample volume.
(m) Outlet location has a small effect on sampling rate.
(n) In one experiment, sampler characteristics matched those of the V-shaped weir to produce proportional sampling.
(o) The sampler is made from inexpensive plastic and rubber components.

The conclusions listed here satisfy the objectives of a proportional passive sampler gathering samples down to 0.1% of discharge.

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