Objective

The objective of the work was to assess the potential for the 'floating apples' approach to estimate volume flux in the Churn downstream of Gloucester St Sluice. If viable this may have offered a method of estimating the volume flux entering BMP as the difference between the EA gauged flow upstream of Gloucester St and the estimated flow downstream of Gloucester St sluices.

Context

A 'floating apples' approach to estimating flow in BMP at BMP footbridge had been attempted as part of the July low flow trial. This had proved unsuccessful for the following reasons:

- The near surface velocity associated with the BMP through-flow was so low that, even in the light wind conditions occurring in the trial, near surface flow was clearly wind-affected, often with upstream surface flow occurring. It was evident that this affected apple movement thus creating considerable uncertainty and variability in the near surface velocity estimates
- There is uncertainty in the depth profile at BMP footbridge as measured by a dipstick. Bed visibility is often poor depending on the lighting conditions. There is considerable vegetation at some locations along the bed at the bridge. There is a considerable layer of soft sediment (e.g. 53cm at the 2m across bridge location) occurring making it difficult to locate the local bed using a dipstick with any confidence.
- There is the usual uncertainty in choice of 'velocity-factor' to infer local depth-averaged velocity from estimated near surface velocity (e.g. typically taken as 0.8 with range 0.7-0.9).

The above factors were evident in early analysis of the low flow findings. Subsequently, the possibility that flows at BMP footbridge may not be representative of flows entering BMP at Gloucester St emerged i.e. there may be complex dynamics governing flows into Lower BMP and out of lower BMP through the leaking BM Sluice Gates meaning the flow under Gloucester St bridge at a given time may be very different to that occurring at BMP footbridge at that time.

Site Description

The work was undertaken on the morning of 25th July 2025 0900-1030 BST. The weather was dry and bright with light wind (Met Office suggesting 3-6 mph gusting 9-15 mph) from the west. The study location is well sheltered from westerly winds and there was no evidence of wind effects observable in the movement of surface borne river debris (e.g. leaves, twigs etc). Gloucester St sluices were set with the large gate closed and both small gates open leading to the typical character of low flows immediately upstream of the sluices, the 'take off' to BMP being well defined and likely to be of order 10% of the Churn flow (as judged by eye based on proportion of cross section diverted, depths of diverted and river flow, velocity etc.).

Environment Agency River Churn Data (Hydrology Data Explorer accessed 31 July 2025) is as follows (Table 1).

Date	Daily mean flow m3/s	15 min level at 10:00
24th	0.107	0.138
25th	0.097	0.137
26th	0.097	0.133

Table 1 Environment Agency R Churn upstream data (Hydrology Data Explorer)

It would therefore be expected that the Churn flow at Gooseacre would be about 0.09 m3/s, adjusting for an assumed BMP take off of about 10% of the Churn flow upstream of Gloucester St sluices.

The Churn upstream of Gooseacre Lane bridge is straight and of uniform width of approximately 4m with a stone wall on the west bank and a heavily vegetated east bank for which the wetted flow boundary was difficult to locate (Figure 2).

Above the wall on the west bank there is a footpath offering ease of safe movement. The bed appeared of relatively uniform profile along this part of the river being formed of a variety of small stone sizes with occasional large stones, and light in stream vegetation (Figure 1). Disturbance of the bed created small silt clouds, showing some silt was present between stones. Depth was typically around 10-15cm in mid-stream though the large stones were such as to reach near to or to the water surface. The water surface was far from smooth and reflected the small-scale variability of the bed. Thus, although the velocity was evidently predominantly horizontal and aligned with the banks, it was likely that there was considerable structure in the vertical and much horizontal eddy formation which would lead to dispersion and variability in along stream velocity inferred from float-tracking.

Figure 1 Bed of Churn at Gooseacre

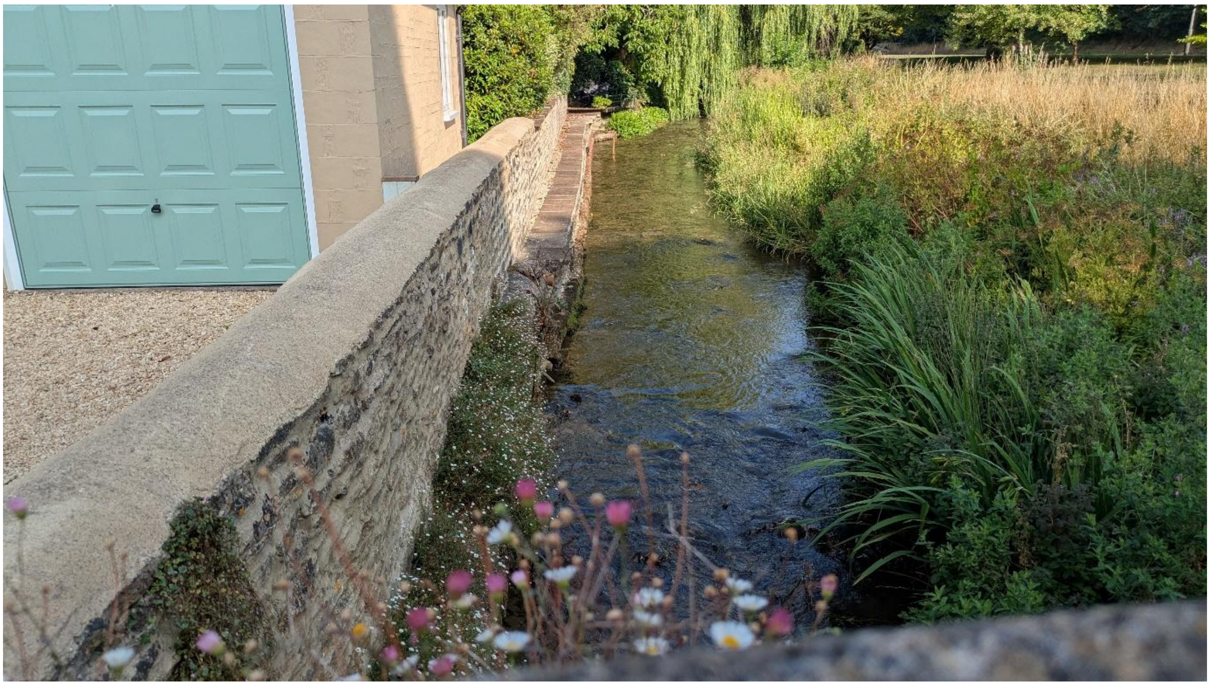

Figure 2 Churn looking upstream from Gooseacre Lane bridge

A few metres downstream of Gooseacre Lane Bridge there is an informal leaky stone dam (Figure 3) constructed by members of the public creating a deeper backwater of some 30+cm which likely affects the Gooseacre Lane level board.

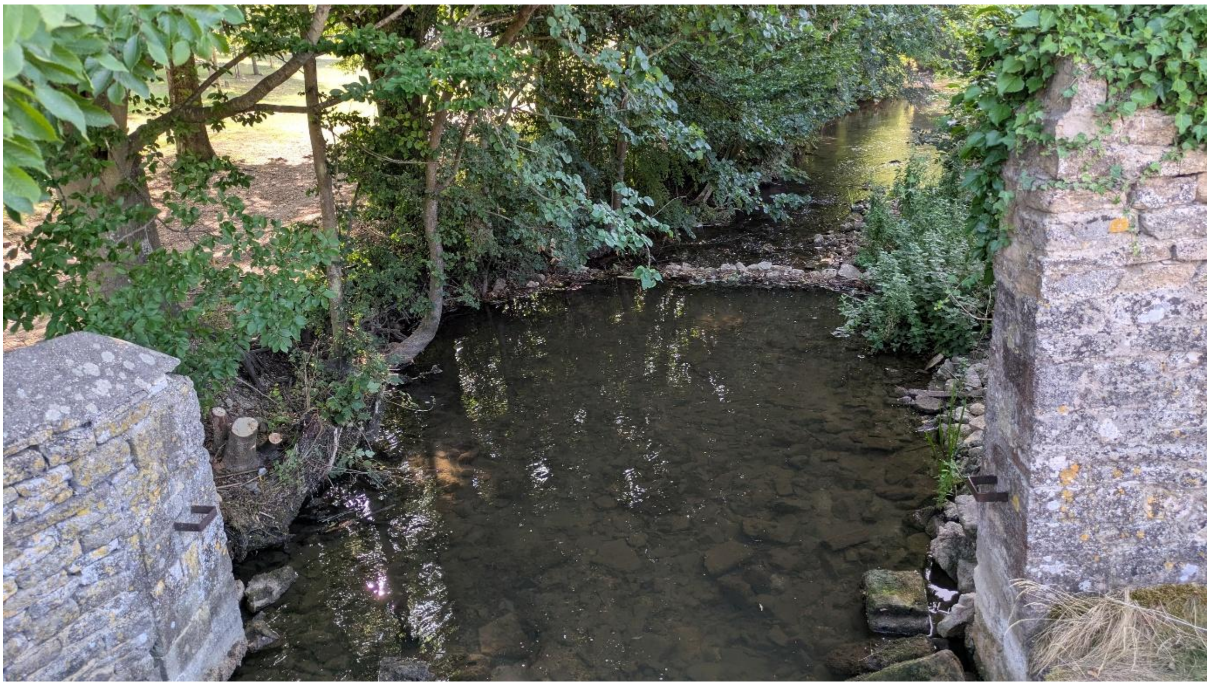

Figure 3 Leaky Dam from Gooseacre Lane Bridge looking downstream

Figure 4 Gooesacre Lane Level Board – taken as 0.18m above board datum

It was decided to undertake the apple releases at the section through the camera post already located in the river and time them over a measured 5m downstream. It was established that one person could release the apples and walk instream to capture them using a net while a second person could video the apples for timing purposes either from the footpath or instream.

Method

The Churn was divided into 9 logical sub sections as shown in Table 2. Bed depths at the centre of each of 7 internal subsections and at the bank were measured to the nearest cm at every half metre across the chosen section using a metal rule. Although there was variability in the bed profiles because of the location of larger stones, no section in the test 5m appeared significantly different to any other in character and only the one section depth profile was taken.

Apples of approximate diameter 5cm and individualised by attached coloured tape were released in clusters of 4 sequentially at half metre intervals across the river. Each release was videoed and the time taken for each individual apple to transit the 5m test reach was taken from the video (to the nearest 1s). An example frame of an apple release from a central subsection is shown in Figure 5.

Figure 5 Example Frame from Shortly After a Cluster of Apples Were Released from a Central Subsection of the Stream. Some Longitudinal and Lateral Dispersion is Already Evident only a Few Seconds after Release.

The sequence of releases took approximately half an hour, and it is unlikely that river conditions changed materially during this time. No evident change was noted at the time of the fieldwork.

On occasions one or more of the released apples either grounded for a period before being freed or grounded permanently. Such appeals were excluded from subsequent analysis.

The average transit time for each cluster was calculated and used to provide a near surface velocity estimate for each of the half metre subsections. The sub-section depth-average velocity was inferred from the sub-section near surface velocity using a velocity ratio factor.

A velocity ratio of 0.857 is suggested by USGS, which originates from the assumption of a power law vertical profile of horizontal velocity. The literature suggests a typical range 0.7-0.9[1] for shallow streams though a wider range can occur in unusual conditions such as heavy vegetation.

Care needs to be taken in the transferability of velocity ratio based on reported literature values. Some reviews of velocity ratio are focused on ‘skin’ velocity observations (such as those obtained through remote sensing) whereas the apples used in this study floated with perhaps 3cm immersed. For flow depths of around 10cm, the apples are therefore responding to flows in the upper third of the water column and therefore the appropriate velocity ratio to adjust to depth-average velocity (expected to occur at approximately 6cm below surface) would be expected to be rather smaller than that required for correction of near surface ‘skin’ velocity measurements.

The total volume flux (Q, m^3/s) is estimated as the sum of the estimated individual subsection volume fluxes i.e.

$$Q = \Sigma_i (\alpha_i * u_i * d_i * w_i)$$

where,

α_i is the assumed velocity ratio for subsection i

u_i is the calculated near surface velocity for subsection i

d_i is the measured depth for subsection i

and

w_i is the width of subsection i.

The choice of appropriate velocity ratio is a key uncertainty in this study, the consequences of which are indicated in the results section. Although there is some literature which seeks to relate the appropriate velocity ratio to observable aspects of the river such as bed material and form, slope, depth, occurrence of vegetation, wind etc, none of this work is compelling and in practice the appropriate choice of velocity ratio for a given site and set of conditions could only be established through calibration against a comprehensive volume flux assessment (e.g. through flume, weir, ADCP etc). In principle, the velocity ratio could vary between subsections (e.g. as a result of the

[1] Eg as reviewed by Perplexity AI July 2025 (referenced sources inspected).

occurrence of vegetation, bed form, bed material or simply depth), but in this assessment it is taken as the same for each subsection.

Observations

In the central and western part of the river the apples followed a near linear trajectory and were well clustered. Apples released on the eastern part of the river, particularly the margin, tended to drift towards the central part of the river where the flow was evidently faster with notably greater variability in trajectory. Thus, transit times for the eastern part of the river derived were rather faster than would be associated with the 'true' river velocity on the east side. To correct for this the velocity inferred for the 3.5m release was taken as half that resulting from the raw transit time, this approach being 'validated' by inspection of the first few seconds of the release before drift towards the central part of the stream occurred.

Results

The results are shown in Figure 6 and in Table 2. Velocity measurements for the close to margin sections were not taken in the field because of grounding and wall interference. The results for these subsections are arbitrarily taken as half that of the adjacent measured section.

The variability of individual apple velocity in each release cluster was relatively small with standard deviation of individual apple velocities being typically 10cm/s for a velocity of 40 cm/s in the central and west part of the river which was the dominant contribution to total section volume flux. However, the uncertainty in the release average near surface velocity is therefore likely order 10%.

Depths are quoted to the nearest centimetre so the error in subsection depth is perhaps order 5%.

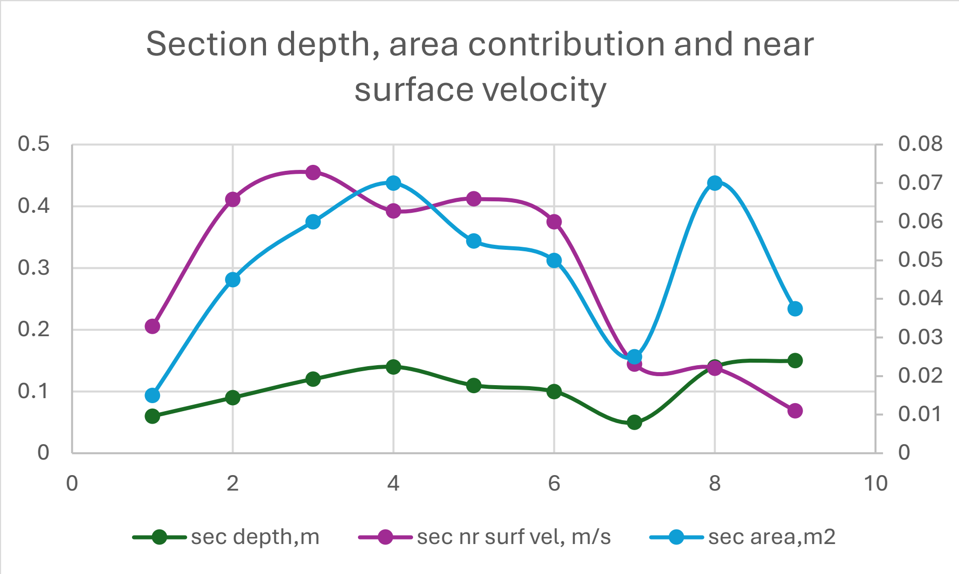

Figure 6 Field Results - Section Chainage is Shown from the Right (Wall) Bank Looking Downstream. Section Depth and Velocity ae Shown on the Left Vertical Axis and Subsection Area on the Right Vertical Axis.

The reduction in bed depth at section 7 was due to the presence of a large stone typical of this part of the river.

section	A	B	C	D	E	F	G	H	I
chain min,m	0	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75
chain max,m	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4
chain mid,m	0.125	0.5	1	1.5	2	2.5	3	3.5	3.875
sec width,m	0.25	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.25
sec depth,m	0.06	0.09	0.12	0.14	0.11	0.1	0.05	0.14	0.15
sec area,m2	0.015	0.045	0.06	0.07	0.055	0.05	0.025	0.07	0.0375
sec nr surf vel, m/s	0.205628	0.411255	0.455006	0.392628205	0.412085	0.375	0.144579	0.137747	0.068873
depth av vel cor factor	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
section volume flux m3/s	0.002622	0.015731	0.023205	0.023361378	0.019265	0.015938	0.003072	0.008196	0.002195

Table 2 Results Collation (Shown for Assumed Velocity Ratio 0.85) Indicating the Contribution of Each Subsection to the Overall Section Volume Flux

The inferred section total volume flux is sensitive to the choice of velocity ratio, the two varying in proportion. For the above data it is found as shown in Figure 7

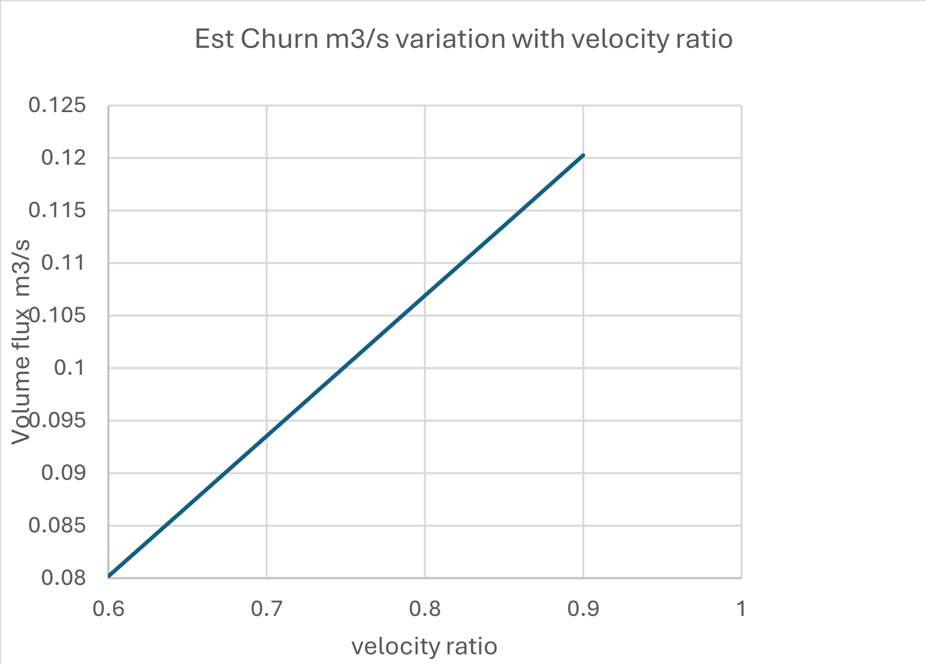

Figure 7 Variation in Estimated Churn Volume Flux with Choice of Velocity Ratio

For a reasonable a priori central estimate of velocity ratio of 0.8, the central estimate of total volume flux is 0.107 m3/s.

Discussion

The uncertainty in the estimated volume flux needs to be considered.

Using a relatively low but credible velocity ratio of 0.7, perhaps motivated by the dimension of the apples relative to the depth of flow, leads to an estimate of 0.093 m3/s. A lower ratio still might be justifiable because of the roughness of the bed and the shallowness of the stream. A value of 0.6 would lead to an estimated volume flux of 0.08 m3/s.

Hundt & Blasch (2019) offer an empirical relationship between velocity ratio (α) and water depth for shallow streams with rough beds as

$$\alpha=0.00628*d = 0.465$$

where d is measured in cm. Taking d=10cm would lead to a velocity ratio of 0.53 corresponding to a volume flux estimate of only 0.071 m3/s.

Consideration of the uncertainty in inferred average velocity and depth leads to an additional uncertainty of perhaps 15%.

Conclusion

Although the volume flux estimation methodology used for the Churn at Gooseacre has been shown to be capable of leading to a credible volume flux estimate, the uncertainty in the resulting value of perhaps 20-30%, corresponding to an uncertainty in estimated volume flux of order 0.02-0.03 m3/s, renders the technique of no practical value in inferring the flow into BMP in low flow conditions when used in combination with upstream EA gauged data since the uncertainty in resulting inferred BMP flow is considerably greater than the likely BMP flow occurring (expected order 0.01 m3/s).

The choice of velocity ratio could be calibrated against authoritative volume flux measurement, but that calibration would only be valid in a restricted set of conditions (of water depth, vegetation occurrence) and is therefore likely to have little practical value.

Reference

Hundt S, Blasch K (2019) Laboratory assessment of alternative stream velocity measurement methods. PLoS ONE 14(9): e0222263. https://doi.org/10.1371/journal.pone.0222263