River discharge from surface velocity measurements

A field guide for selecting alpha

Envirolink Advice Report

June 2021

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Citation:

Biggs, H., Smart, G., Holwerda, N., Doyle, M., McDonald, M. & Ede, M. (2021). River discharge from surface velocity measurements - A field guide for selecting alpha. Envirolink Advice Report. Christchurch, New Zealand.

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NIWA CLIENT REPORT No: 2021196CH

Report date: June 2021
NIWA Project: ELF20508

Revision	Description	Date
Version 1.0	Draft Report	31 May 2021
Version 1.1	Draft Report	3 June 2021
Version 1.2	Draft Report	29 June 2021
Version 1.3	Final Report	30 June 2021

Quality Assurance Statement		
	Externally Reviewed by:	Graeme Horrell (Graeme Horrell Consultancy Ltd)
	Internally Reviewed by:	Graeme Smart
	Formatting checked by:	Rachel Wright
	Approved for release by:	Helen Rouse

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Executive summary

This Envirolink funded advice document provides practical methods for converting from surface velocity to depth averaged velocity using 'alpha' (which is the ratio of depth averaged velocity to surface velocity). The accuracy of discharge measurements derived from surface velocities are highly dependent on the selection of an appropriate alpha value. To identify the best methods for estimating alpha we undertook a literature review, theoretical analysis, field experiments and data analysis. There are six methods recommended for estimating alpha that are both practical and based on sound physical principles. The method that should be selected will depend on the site being gauged (i.e. routine monitoring site, or one-off flood flow measurement) and the supplementary information that can be obtained. A workflow for selecting the appropriate method for estimating alpha is provided in the appendices of this document. The most promising method is to generate a site-specific alpha coefficient based on reliable discharge and surface velocimetry measurements (Method 1b). Ideally this will be undertaken at a range of flows (i.e. stage levels) to generate a site-specific stage-alpha rating curve. This method is preferred because no inherent assumptions about velocity profile shape are required, and this method can be used even when velocity profiles differ from conventional log law (Method 2a) or power law (Method 2b) profiles. Method 1b also does not require extrapolation of ADCP data to the water's surface to predict surface velocities but measures them directly. Other methods such as site specific 'local alpha' values were also assessed. With this approach each vertical is assigned an individual alpha coefficient. While this method may better match a single ADCP gauging, it will not extrapolate well across a wide range of discharges and is not practical to implement. In most situations a single alpha coefficient for a site is recommended, with the exception being flood flows in compound channels where the 'Divided Channel Method' is recommended.

The effects of wind were also investigated both analytically and experimentally. Wind effects are very complicated to address analytically as impacts on the water surface velocity depend on: wind shear stress (e.g. wind velocity profiles and turbulence); fetch; surface roughness (which has a feedback loop with wind generated surface waves); surface tracer types (i.e. surface particles such as wood shavings, or surface features such as boils and eddies); and even the turbulent mixing characteristics of the channel itself (i.e. vertical mixing of wind disturbed surface water). Measurements of wind also pose their own practical challenges, such as: obtaining measurements above the water surface rather than the bank; and obtaining measurements that are spatially representative of average wind at the cross section. Due to the heterogeneity of most gauging sites (i.e. banks, riparian vegetation, local terrain etc), it is very difficult to accurately quantify average wind, let alone surface shear stress due to wind. The practical recommendation of this document is to not perform surface image velocimetry if there are visible wind effects on the water surface (i.e. wind generated surface waves, ripples, or visible motion of tracer particles). It is recommended that field staff bring a wind anemometer whenever performing surface image velocimetry so they can record wind velocities at a location that is 'representative' of wind at the study site. For fixed camera sites it is recommended to install an anemometer or weather station to log time series of wind velocities. This information can then be used to identify anomalous data points in surface velocity discharge records or could be used to attach Quality Codes (QC) based on site specific wind thresholds. Wind effects should be assessed on a site by site basis and it would be imprudent for us to recommend any blanket wind limits. For example, there will be significant differences between a slow flowing lowland river where wind creates substantial surface velocity variability, or a high velocity high gradient highly turbulent upland river where surface velocity discrepancies due to wind effects are rapidly mixed throughout the water column.

1 Introduction

Accurate quantification of discharge is critical for engineers, river users, managers, and policy makers. Councils around New Zealand are currently developing fixed camera flow measurement sites (based on surface velocimetry techniques), which provide several advantages over standard gauging sites. Gaugings from fixed cameras can be triggered remotely, allowing more frequent measurements to update stage discharge-relationships. This enables better capture of peak and low flows, which can be challenging (or dangerous) for field teams to measure. Cameras can quickly capture flow information at a site, which is useful in rapidly changing conditions (Le Coz et al. 2010; Al-Mamari et al. 2019), or when loop ratings exist (Muste et al. 2011). Fixed cameras can provide evidence of geomorphic change and enable rating curves to be reconstructed more rapidly after cross section geometry is resurveyed. The use of drones to deploy cameras is also growing and provides a convenient way to measure flow in challenging locations (i.e. flood flows), or to survey physical habitat (spatial velocity distributions). Although the use of cameras for flow measurement provides multiple advantages, there are still challenges to overcome to make discharge from surface velocimetry accurate and reliable. A major source of uncertainty is how best to convert from surface velocity to depth averaged velocity (Dramais et al. 2011) and the effect of wind on the water's surface.

The challenges of converting from surface velocity to depth averaged velocity apply regardless of the hardware used, for example: fixed cameras (Le Coz et al. 2010); drones based cameras (Detert et al. 2017); or Surface Velocity Radar (SVR) (Welber et al. 2016). Likewise this problem exists regardless of the method used for calculating surface velocities from imagery, for example: Space Time Image Velocimetry [STIV] (Fujita et al. 2019), Large Scale Particle Image Velocimetry [LSPIV] (Muste et al. 2008; Le Coz et al. 2014), Particle Tracking Velocimetry [PTV] (Patalano et al. 2017), or Feature Tracking Velocimetry (Cao et al. 2020). Conversions from surface velocity to depth averaged velocity are parameterised by an α (alpha) coefficient, which is the ratio of depth averaged velocity to surface velocity (U/u_s). The standard value assumed for α is 0.85 or 0.86 (Rantz, 1982), which originates from velocity profiles that follow a $1/6^{th}$ power law (Smart and Biggs, 2020a). This standard value is acceptable when no other site-specific information is available and is valid in many flow situations (i.e. flows in wide rectangular channels where depth is much larger than roughness heights). However, in practice there is significant natural variation in α, due to variations in site geometry, flow conditions and wind effects on the water's surface. For example, common ranges reported for α are 0.84 to 0.90 (Turnipseed and Sauer, 2010), or 0.7 to 0.9 (Hauet et al. 2018), with some extreme values reported (e.g. >1.1) due to irregular velocity profiles, or wind effects. Generally small rivers with rough beds, exhibit lower α values, whereas concrete lined artificial channel are higher (Fujita, 2018). Variability in α can be reduced by careful selection of measurement sites, for example avoiding sites with submerged vegetation, wake effects, changing geometry (i.e. when flow is not uniform longitudinally, which commonly occurs due to channel constrictions, such as a bridge, sill, or weir) and strong winds (Randall, 2021). To improve the accuracy of flow measurement from surface velocimetry clear guidance on the selection of alpha coefficients is needed.

This Envirolink funded advice document provides recommended techniques for estimating alpha (Sections 2,3,4), with a discussion of other methods for estimating and applying alpha in Section 5. Wind effects are discussed in Section 6, along with recommendations for wind quantification for quality control. Challenges of surface image velocimetry and recommendations for improving the quality of input data are covered in Section 7. Conclusions and future recommendations are covered in Section 8. A map of fieldwork sites is provided in Appendix A. The derivation of equations for alpha from log law velocity profiles is provided in Appendix B. A summary of results from fieldwork is provided in Appendix C. An explanation of the 'Divided Channel Method' is provided in Appendix D. A workflow for selecting an appropriate α method based on available input data is provided in Appendix

E. The recommendations in this advice document are based on a literature review of existing techniques, theoretical analysis of velocity profile equations, and field measurements to provide validation data. This document focuses on selection of α, with guidelines for setting up camera flow measurement sites and surface velocimetry in general provided by Fujita (2018), Engel et al. (2021), Randall (2021), Hydro Technology Institute Ltd (2021), and others.

2 Method 1: Alpha from site calibration data

2.1 Method 1a: Site alpha from extrapolated ADCP velocity data

An average alpha value for a study site ('global' alpha) can be easily estimated from ADCP velocity data using the software QRev (Randall, 2020). First, open the measurement in QRev, then click 'Extrapolation', then choose 'Velocity' (Figure 2-1). Choose the extrapolation that best fits the data (for example a power law). The data will be displayed as normalised elevation $\frac{z}{H}$ on the y axis vs normalised velocity $\frac{u}{U}$ on the x axis. Set the subsection to 20%:80% to only use data from the central part of the channel. Click the 'Data cursor' button and select the top of the profile where it reaches the water's surface. The 'X value' is the average surface velocity divided by the depth averaged velocity $\frac{u_s}{U}$. Site alpha is then obtained as $\alpha = \frac{1}{\text{'X value'}} = \frac{U}{u_s}$ (Hauet et al. 2018). Site alpha values can be recorded at a range of flows and plotted against stage to provide a site-specific 'stage-alpha rating curve'[1] (Figure 2-2). Site-specific alpha values for extreme flows (floods) can then be estimated by extrapolation of the stage-alpha rating curve.

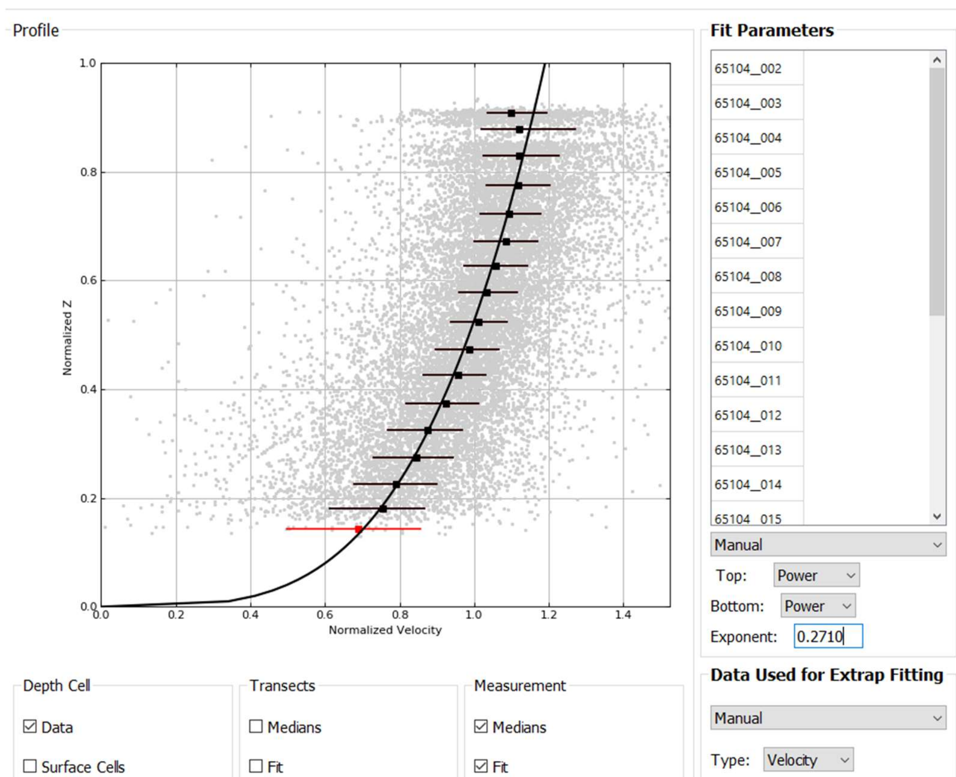

Figure 2-1: Velocity profile extrapolation in QRev for estimation of alpha.

[1] The development of stage-alpha rating curves first appeared in French hydrometry reports in the early 1900s.

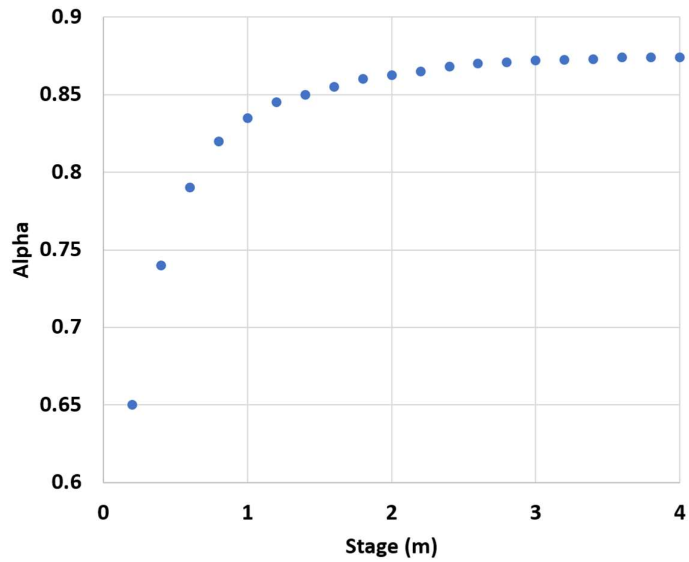

Figure 2-2: Example of a site-specific stage-alpha rating curve.

While this method is convenient and practical for use by field hydrologists, it does suffer from uncertainties in extrapolation to the water's surface. There can be substantial changes in velocity between the measured data and the water's surface (e.g. due to wind, secondary currents etc) and the most suitable extrapolation method may vary by deployment and site.

2.2 Method 1b: Site alpha from accurate reference discharge and discharge from surface velocimetry with α=1

Another method for determining site average alpha is to use the ratio of reference discharge Q_{Ref} from velocity measurements (i.e. ADCP, POEM, current meter) to that calculated from surface velocimetry Q_S using an initial alpha value of 1.

$$\alpha = \frac{Q_{Ref}}{Q_{S,\alpha=1}}$$

This equation originates from the relationship that the measured reference discharge (e.g. ADCP) and discharge from surface velocimetry will be the same if an appropriate alpha value is selected:

$$Q = \sum_{n=1}^{N} \alpha * \mathrm{u}_{s,n} * dA_n = \sum_{m=1}^{M} \mathrm{U}_{Ref,m} * dA_m$$

$$\alpha \sum_{n=1}^{N} 1 * \mathrm{u}_{s,n} * dA_n = \sum_{m=1}^{M} \mathrm{U}_{Ref,m} * dA_m$$

$$\alpha = \frac{\sum_{m=1}^{M} \mathrm{U}_{Ref,m} * dA_m}{\sum_{n=1}^{N} 1 * \mathrm{u}_{s,n} * dA_n} \qquad \alpha = \frac{Q_{Ref}}{Q_{S,\alpha=1}}$$

Where, there are N surface velocimetry sections, with indices from $n = 1$ to $n = N$, average surface velocity at section n is $\mathrm{u}_{s,n}$ and surface velocimetry section area is dA_n. Then there are M sections for the reference discharge measurement, with indices from $m = 1$ to $m = M$, depth averaged velocity at section m is $\mathrm{U}_{Ref,m}$ and the reference discharge section area is dA_m.

In practice Q_{Ref} will usually be found by using an ADCP with either a section by section method (i.e. using the software SxS Pro), or with a moving boat gauging (which is essentially a very large number of small sections). $Q_{S,\alpha=1}$ can be found in an appropriate STIV or LSPIV software (i.e. HydroSTIV or FUDAA LSPIV) by computing discharge at the cross section with an alpha value of 1 (Figure 2-3).

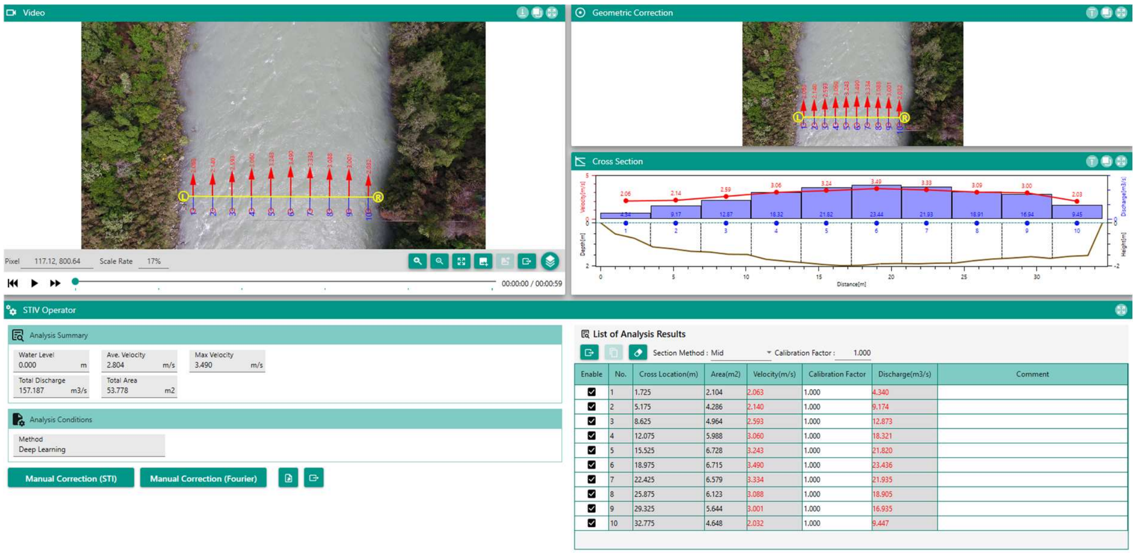

Figure 2-3: Discharge from surface image velocimetry in HydroSTIV, with an initial value of α=1, to obtain Q(S,α=1) (Hurunui River, New Zealand).

This approach has multiple advantages because surface velocities are measured directly, rather than being extrapolated from in situ velocity measurements (i.e. from ADCPs), which have significant near surface uncertainty due to blanking distances, wind effects and secondary currents. By repeating this approach at multiple discharges (or stage levels) a site-specific stage-alpha rating curve could be constructed. At some sites this would provide little benefit compared to a traditional stage-discharge curve for low to medium flow, but has significant benefits for extrapolating rating curves beyond what can be measured with in situ equipment, or at sites with loop ratings, tidal effects, or flashy flows where discharge is hard to measure.

Method 1b has been formulated around the use of in situ velocity measurements (e.g. ADCP) for reference discharge, and surface image velocimetry for surface velocities since these are the most common techniques currently in use. However, this method is equally applicable for use with other measurement techniques, such as:

- Surface velocities from Surface Velocity Radar (SVR).
- Surface velocities at (or just below) the water's surface using a propeller current meter (or similar). For example, during large floods where measurements deeper in the water column are not possible [NEMS Open Channel Flow Measurement 2.8.1.6 Surface One-Point Measurement].
- The reference discharge Q_{Ref} could also be measured using methods such as salt dilution.
- A stage-discharge relationship that is accurate at low-medium flows could also be used to generate a stage-alpha rating curve (i.e. with surface velocity data at a range of flows). This rating curve could then be extrapolated to predict site alpha at high (or extreme) flows. Surface velocimetry could then be used to capture flood peaks beyond the functional range of the original stage-discharge relationship.

For floods in compound channels, the ‘Divided Channel Method’ can be used for improved accuracy (Appendix D). With a stage-alpha rating curve from Method 1b used to estimate alpha in the main channel section, and other methods used to estimate alpha for sections outside of the main channel.

3 Method 2: Alpha based on velocity profile equations and site physics

Best estimates of alpha values are also important for sites without calibration data, or during extreme conditions such as floods, when other measurements are not safe/feasible. Any estimates of alpha are based on inherent assumptions about the shape of velocity profiles.

3.1 Method 2a: Alpha from log law profiles

For logarithmic velocity profiles $\alpha = \frac{H}{H-Z_0} - \left[ln\left(\frac{H}{Z_0}\right)\right]^{-1}$ (Le Coz et al. 2010; Welber et al. 2016; Fujita, 2018; Smart and Biggs, 2020a), where H is flow depth and Z_0 is the roughness coefficient from the log law velocity profile. Under the assumption that $H \gg Z_0$ and $u_* = \sqrt{gHS}$ this equation simplifies to:

$$\alpha = 1 - \frac{\sqrt{gHS}}{\kappa \mathrm{u}_s}$$

where g is gravitational acceleration, S is slope, κ is the Von Kármán constant (~0.40), and u_s is the time averaged surface velocity (Smart and Biggs, 2020a).

To estimate alpha at a gauging site, parameters that are averaged in both time and space are needed. Cross sectional mean depth H is found as:

$$H = \frac{A}{b}$$

where A is cross sectional area and b is cross-sectional width (i.e. top width).

Care should be taken when estimating u_s for a whole gauging site rather than a single vertical $\mathrm{u}_{s,n}$. Taking the 'average' surface velocity from a software such as HydroSTIV, provides the arithmetic mean of the surface velocity sections (i.e. $\frac{1}{N}\sum_{n=1}^{N} \mathrm{u}_{s,n}$) which assigns equal weighting to each surface velocity measurement. This is a problem, because it doesn't account for changes in channel cross sectional area (i.e. more flow in the centre of the channel where it is deeper and faster) but treats near bank surface velocities with equal importance. To account for this difference, it is recommended to compute an area weighted cross section averaged surface velocity:

$$\mathrm{u}_s = \frac{1}{A}\sum_{n=1}^{N} \mathrm{u}_{s,n} * dA_n$$

where $\mathrm{u}_{s,n}$ is the time averaged surface velocity in section n, and dA_n is the area of section n.

This equation can be further simplified for convenience, since the area weighted surface velocity summation $\sum_{n=1}^{N} \mathrm{u}_{s,n} * dA_n$ is simply discharge with $\alpha = 1$, which is $Q_{S,\alpha=1}$:

$$Q_{S,\alpha=1} = \sum_{n=1}^{N} 1 * \mathrm{u}_{s,n} * dA_n$$

Using software such as HydroSTIV and setting $\alpha = 1$ it is very easy to evaluate $Q_{S,\alpha=1}$ (Section 2.2). Thus u_s becomes:

$$\mathrm{u}_s = \frac{Q_{S,\alpha=1}}{A}$$

and the equation for alpha simplifies to:

$$\alpha = 1 - \frac{A\sqrt{gHS}}{\kappa Q_{S,\alpha=1}}$$

The equations $\alpha = 1 - \frac{\sqrt{gHS}}{\kappa \mathrm{u}_s}$ and $\alpha = 1 - \frac{A\sqrt{gHS}}{\kappa Q_{S,\alpha=1}}$ are based on the assumption that $H \gg Z_0$ which may not be valid for some rough bed open channel flows. In these cases, more complicated equations that account for higher relative roughness may be needed (Smart and Biggs, 2020b). However, under the assumption that $u_* = \sqrt{gHS}$, the original equation $\alpha = \frac{H}{H-Z_0} - \left[ln\left(\frac{H}{Z_0}\right)\right]^{-1}$ can be expressed in terms of quantities readily available from remote sensing data (Appendix B):

$$\alpha = \frac{U}{\mathrm{u}_s} = \frac{1}{1 - e^{-\left(\frac{\mathrm{u}_s \kappa}{\sqrt{gHS}}\right)}} - \frac{\sqrt{gHS}}{\kappa \mathrm{u}_s}$$

$$\alpha = \frac{1}{1 - e^{-\left(\frac{Q_{S,\alpha=1}\kappa}{A\sqrt{gHS}}\right)}} - \frac{A\sqrt{gHS}}{\kappa Q_{S,\alpha=1}}$$

As can be seen in the results from fieldwork (Appendix C), this equation slightly improves the prediction of alpha compared to $\alpha = 1 - \frac{A\sqrt{gHS}}{\kappa Q_{S,\alpha=1}}$ (for some of the sites). However, at other sites there is little difference between the methods (i.e. Wairau Creek which is concrete lined [smooth walled] and relatively swiftly flowing, such that H>>Z_0).

Predicting alpha from the log law provides a practical way to estimate alpha when no velocity profile information is known. This may be useful for situations where only remote sensing data can be obtained, for example: slope from a Digital Elevation Model (DEM) of the gauging reach, depth and area from a cross section with aerial ground penetrating radar, and surface velocities from a drone. This may be particularly useful for extremely large floods where it is not possible to deploy in channel equipment, or in remote locations with difficult access. There are downsides to this approach however, since slope can be hard to measure accurately (particularly in low gradient rivers). This approach also assumes that $u_* = \sqrt{gHS}$ which may not be accurate in some cases (Smart and Biggs, 2020b). The approach also assumes that log profiles extend to the water's surface, which deviates from reality in many cases due to surface wind effects and secondary currents.

3.2 Method 2b: Alpha from power law profiles

For velocity profiles parameterised by a power law (Smart and Biggs, 2020a; Randall, 2021), alpha can be estimated from the power law exponent M as:

$$\alpha = \frac{1}{M+1}$$

With the following derivation (Smart and Biggs, 2020a):

$\frac{\bar{u}}{u_*} = a\left(\frac{z}{d}\right)^M$	where d is roughness scale, M is power law exponent	(1)
$\overline{u_s} = au_*\left(\frac{H}{d}\right)^M$	$\overline{u_s}$ is mean surface velocity at $z = H$	(2)
$U = \frac{au_*}{(\mathrm{M}+1)}\left(\frac{H}{d}\right)^M$	average (1) from $z = 0$ to H	(3)
$\alpha = \frac{U}{\overline{u_s}} = \frac{1}{M+1}$	(3) / (2)	(4)

Care should be taken when using equation 4, since power laws are also commonly expressed in the form:

$$\frac{\bar{u}}{u_*} = a\left(\frac{z}{d}\right)^{\frac{1}{m}} \qquad \text{where } \frac{1}{m} \text{ is the power law exponent} \qquad (5)$$

Expressing the equation for α using a power law in the form of equation 5 yields:

$$\alpha = \frac{1}{M+1} = \frac{1}{\frac{1}{m}+1} = \frac{m}{m+1}$$

The use of a $\frac{1}{m}$ power law exponent is the form provided by ISO 748, Welber et al. (2016), Johnson and Cowen (2017), Fujita (2018) and others. While results are equivalent whether using M or $\frac{1}{m}$, caution should be taken to understand the difference. When reading the power law 'exponent' in QRev, it is provided as M, which is convenient to use in the equation $\alpha = \frac{1}{M+1}$.

The practical method for estimating the power law exponent M in QRev is similar to that used in Section 2.1. Open the ADCP measurement in QRev, click 'Extrapolation', then choose 'Velocity' (Figure 3-1). Set the subsection to 20%:80% to use data from the central part of the channel (i.e. avoid near bank regions). The data will be displayed as normalised elevation $\frac{z}{H}$ on the y axis vs normalised velocity $\frac{u}{U}$ on the x axis. Choose the 'power' extrapolation for the 'top' and 'bottom' of the ADCP data. Sometimes the power law is automatically fitted to the data, other times it should be manually adjusted to fit the data (the reason for this anomaly is unknown). The power law exponent M can then be recorded and used to estimate alpha from the equation $\alpha = \frac{1}{M+1}$.

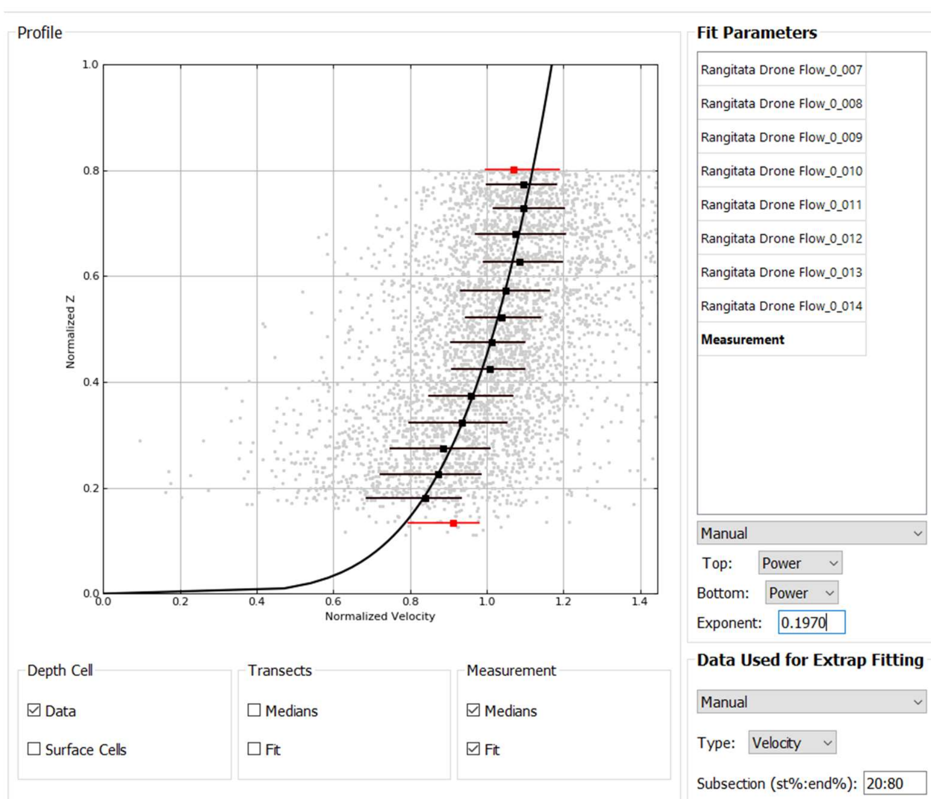

Figure 3-1: Power law velocity profile in QRev (Rangitata River, New Zealand).

This method is convenient and useful at many gauging sites. However, it suffers from the same limitations as Method 2a, because it assumes that the vertical distribution of velocities follows a well-defined equation. This can differ from reality at sites with accelerating flows, surface wind, secondary currents, bridge piers, bed wakes, bars, debris and other sources of flow resistance near the water surface, such as submerged riparian vegetation or aquatic vegetation (Smart, 1999; Biggs et al. 2019). At sites with these characteristics (Figure 3-2), Methods 2a and 2b are unsuitable.

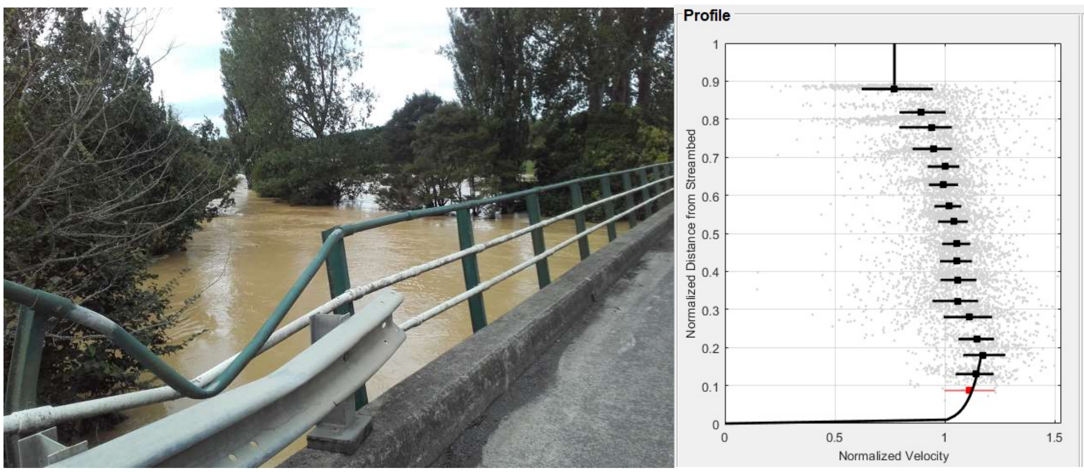

Figure 3-2: Flooded river where flow resistance higher in the water column (trees, bridge piers etc) cause irregular velocity profiles. Resulting in the site being unsuitable for alpha methods that assume an underlying velocity profile shape.

4 Method 3: Alpha estimates without input data

4.1 Method 3a: Default alpha value

The traditional method is to assume alpha has a constant value of 0.85 or 0.86 (Rantz, 1982). This originates from integration of a 1/6th power law velocity profile to give 0.857 (Smart and Biggs, 2020a). This alpha value is assumed to apply to all velocity profiles across a cross section, so is used as a 'global' alpha value. This approach doesn't consider any site-specific characteristics or flow physics, and it can be considered as a 'default value' when no further information is available. For deep, hydrodynamically smooth channels (i.e. low relative roughness) the default alpha value is suitable if no other information is known (Welber et al. 2016). However, as relative roughness increases (i.e. shallow and rough bed flows) then alpha will deviate from the default value, resulting in larger errors (Welber et al. 2016).

4.2 Method 3b: Alpha estimation from site characteristics

A slight improvement over using Method 3a is to select a site-specific coefficient based on a visual assessment of the site characteristics. Although highly subjective, this is likely more accurate than assuming a default value of α=0.857. There is some variation in advice for selection of alpha, so the opinions of selected experts are provided below:

Turnipseed and Sauer (2010) recommend selecting values of alpha between 0.84 and 0.90, where lower values are assigned to irregular streambeds, while higher values are used for smooth beds (such as concrete lined channels).

Hauet et al. (2018) looked at empirical data from 3611 gaugings over 176 sites and found that α generally increases with depth, but they could not find a clear relationship between α and the bed roughness or relative roughness. Their general 'rule of thumb' recommendations are:

"For natural rivers:

- For water depth less than 2 meters: consider using α = 0.8 with an uncertainty of about +/- 15% at 90% confidence level.
- For greater water depth, consider using α = 0.9 with an uncertainty of about +/- 15% at 90% confidence level.

For artificial concrete channels:

- Consider using α = 0.9 with an uncertainty of about +/- 15 % at 90% confidence level. For water depth less than 2 meters: consider using α = 0.8 with an uncertainty of about +/- 15% at 90% confidence level."

We generally do not recommend following this rule of thumb advice for natural rivers, as it has a large discontinuity in the value of alpha (i.e. jumping from 0.8 to 0.9) at the somewhat arbitrary cut-off of 2 m depth. However, we do recommend using α = 0.9 for artificial concrete channels.

Le Coz et al. (2011) and Fujita, (2018) suggest using a default value of α = 0.85, or to select α based on site roughness and estimates of what power law exponent would likely apply (Table 4-1).

Table 4-1: Estimating α based on site roughness and expected power law profile exponents (Le Coz et al. 2011; Fujita, 2018), where the power law exponent is represented as 1/m or M (see Section 3.2).

	normal	smooth	rough	very rough	extreme cases
m	6-7	10	4	2-3	
M	0.143-0.167	0.1	0.25	0.333-0.5	
α	0.86-0.87	0.91	0.8	0.67-0.75	0.6-1.2

Hauet et al. (2018) and Welber et al. (2016) investigated the prediction of α from relative roughness (defined in terms of d_{50} and depth) but did not find a clear relationship. However, Smart (2021b) found a general relationship between α and relative roughness or relative depth (defined in terms of depth and d_{84}) using the Hicks and Mason (1991) dataset from over 100 New Zealand rivers. Although the data presented by Smart (2021b) showed substantial scatter, there were clearly defined trends (Table 4-2) which may provide a useful rule of thumb for estimating alpha in shallow rough bed rivers.

Table 4-2: From Smart (2021b) relative depth, power law exponent M and alpha. Based on the Hicks and Mason (1991) dataset from over 100 New Zealand rivers, with alpha calculated from 1/(M+1).

H/d_{84}	M	α
>30	0.16	0.86
10 - 30	0.19	0.84
2 - 10	0.58	0.63
< 2	1.59	0.37

While none of these methods are ideal (compared to collecting data at the gauging site from which to estimate alpha using Methods 1a, 1b, 2a, 2b), we would recommend following the advice of Le Coz et al. (2011), Fujita (2018) and Smart (2021b). The field data analysed as part of the preparation of this advice document (Table C-1) indicate that a user 'best judgement' estimate of alpha based on (Table 4-1) will provide a more accurate estimate of α, than simply selecting the default value of α = 0.857.

5 Discussion of other methods for estimating and applying alpha

There are several other possible methods for estimating and applying alpha values. The development of a 'Reference book of river types and alpha values' is not recommended, nor is the application of 'Individual alpha values for each surface velocimetry section'. However, for flood flows in compound channels the use of the 'Divided channel method' is recommended.

5.1 Reference book of river types and alpha values

One possible option is to develop a reference book of alpha values for different channel and flow characteristics, similar to the manual "Roughness Characteristics of NZ Rivers" by Hicks and Mason (1991). This could be a workable approach, however the experimental variables required quickly multiply until it becomes impractical. For example: (A) channel materials (i.e. range of roughness from smooth concrete to boulder lined), (B) channel geometry (rectangular, trapezoidal, channel sinuosity, constrictions etc), (C) slopes, (D) depths (i.e. relative submergence, and floods overtopping banks), (E) surface winds, (F) other in channel resistance (aquatic vegetation, riparian vegetation, bridge piers etc). Due to the large number of potential options (A×B×C×D×E×F), we recommend avoiding this method and instead performing individual site calibrations to create a site-specific 'stage-alpha rating curve'. A reference book could be useful for one off measurements at remote locations, however for routine gauging sites the 'predicted' alpha value would need to be checked, and if measurements were undertaken to check the value, then these may as well be used to create a site alpha value.

5.2 Individual alpha values for each surface velocimetry section

For this approach, a separate alpha value is applied to each surface velocimetry section. In this case an ADCP is used to record section by section data (i.e. SxS Pro) at verticals across a river channel, which are used to analyse individual alpha values for each surface velocimetry section. These individual alpha values can then be input into software such as HydroSTIV or Fudaa-LSPIV. Doing this will produce an excellent match between the ADCP gauging and the surface velocimetry gauging, since both data sets are being so closely fit to each other. However, outside of this reference gauging, the relationship will rapidly deteriorate. For example, as discharge changes so will the alpha values for each of the verticals. Then as the river level increases previously dry banks for which there was no data collected will become inundated, generating ambiguity/uncertainty around what value of alpha to apply to these sections. For this method to work, a 'local stage-alpha rating curve' would be needed for each section. This would be very impractical for field hydrologists to implement, and would need to be updated as channel geometry and cross sections change. There would also be further challenges recording suitable data for each section during large floods. For these reasons, and inherent variability in alpha values between sections (Welber et al. 2016), the use of individual alpha values for each surface velocimetry section is not generally recommended.

An alternative variant of this method (instead of measuring alpha for each section) is to predict alpha for each section based on the local flow physics. While this is a possible approach, it is largely impractical for field hydrologists to implement. As discussed in the sections on Method 2a and 2b, there are also situations where velocity profiles do not follow conventional log law or power law profiles. In these cases, the method would be both impractical and inaccurate. A site averaged alpha value at a range of flows is therefore preferred for practical flow measurement. The exception to the rule is for flood flows in compound channels, where the 'divided channel method' is recommended.

5.3 Divided channel method

For flood flows in compound channels the 'divided channel method' (Appendix D) is recommended. With this method surface velocimetry sections in the main channel are assigned an alpha value based on extrapolation from known alpha values for the main channel (i.e. Method 1b), while surface velocimetry sections covering flow outside the main channel (i.e. over flood plains) are assigned an alpha value based on Method 2a, 2b, 3a or 3b. With the appropriate method dependent on channel characteristics and available data. This method provides a good balance between accounting for site geometry and flow heterogeneity (2-3 alpha coefficients applied), yet is far more practical than applying different alpha coefficients for every surface velocimetry section.

6 Wind effects and measurements

Surface wind is a significant problem for surface velocimetry methods (Hauet et al. 2018; Peña-Haro et al. 2020). Wind blowing upstream will slow surface velocities and increase alpha values (Figure 6-1), while wind blowing downstream will increase surface velocities and decrease alpha values.

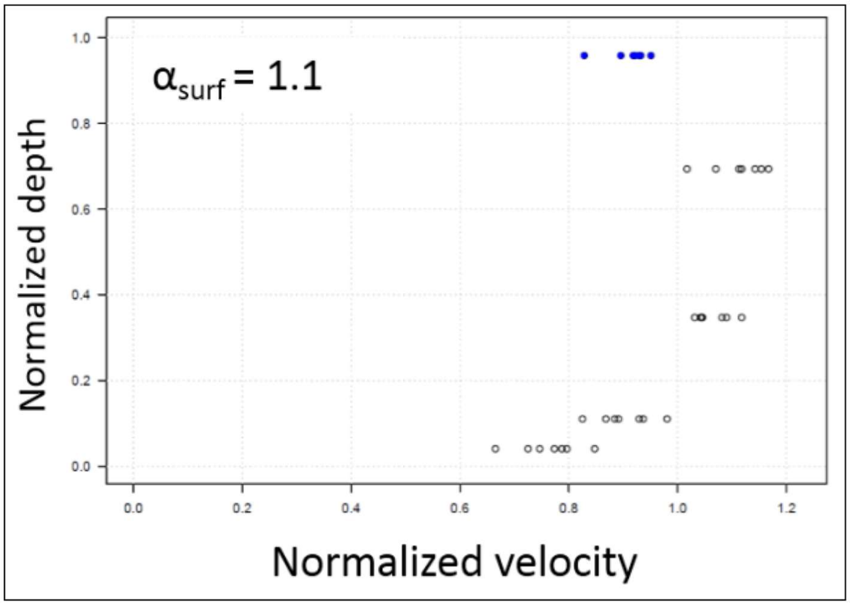

Figure 6-1: Velocity profiles with upstream wind slowing surface velocities (Hauet et al. 2018).

Wind effects are very complicated to address analytically (Smart, 2021a,b) as impacts on the water surface velocity depend on: wind shear stress (e.g. wind velocity profiles and turbulence); fetch; surface roughness (which has a feedback loop with wind generated surface waves); surface tracer types (i.e. surface particles such as wood shavings, or surface features such as boils and eddies); and the turbulent mixing characteristics of the channel itself (i.e. vertical mixing of wind disturbed surface water). For example, during fieldwork for this project (Appendix C) surface wind was observed to significantly affect the Tekapo Canal (Figure 6-2:Left), which was deep (~3.5 m), had large surface area (~33 m wide), large fetch (straight channel multiple kms long) and relatively low cross sectional mean velocities of (0.4 to 0.55 m/s). However, there were far less noticeable effects in the Hurunui River (Figure 6-2:Centre), and Rangitata River (Figure 6-2:Right), although wind conditions were similar. It is possible that turbulent mixing in these steeper, rougher and higher velocity channels lessens the effect of surface wind, as wind affected surface water is quickly mixed throughout the water column.

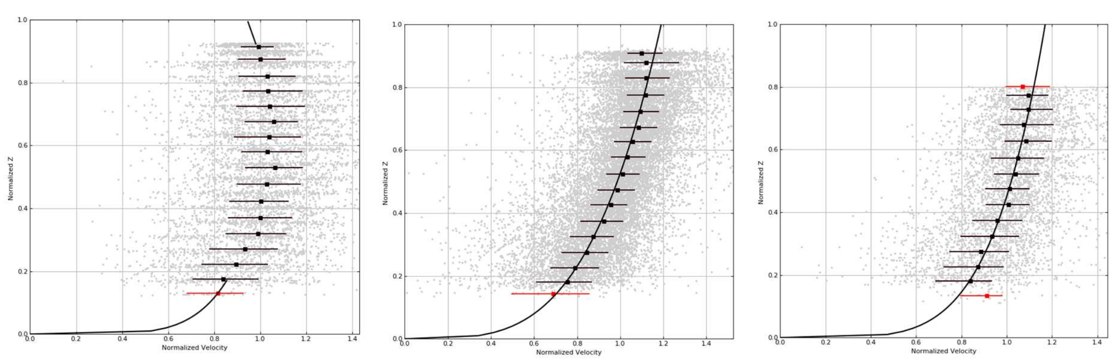

Figure 6-2: Left: Tekapo Canal, Centre: Hurunui River, Right: Rangitata River, New Zealand.

If the effects of wind on surface velocities (and alpha coefficients) cannot be directly predicted, there should at least be measurements of wind to characterise any potential impacts on the flow gauging. This could then be used to assign QC codes to the recorded data. Unfortunately, measurements of wind also pose their own practical challenges, such as: obtaining measurements above the water surface rather than the bank; and obtaining measurements that are spatially representative of average wind at the cross section. Due to the heterogeneity of most gauging sites (i.e. banks, riparian vegetation, local terrain etc), it is very difficult to accurately quantify average wind, let alone surface shear stress due to wind. The practical recommendation of this document is to not perform surface image velocimetry if there are visible wind effects on the water surface (i.e. wind generated surface waves, ripples, or visible wind induced motion of tracer particles) (Randall, 2021). It is also recommended that field staff bring a wind anemometer whenever performing surface image velocimetry so they can record wind velocities at a location that is 'representative' of wind at the gauging site. Handheld anemometers such as the ProTech QM1646 (Figure 6-3: Right) are relatively inexpensive, easy to operate, can record time averaged velocities and have the windvane separated from the electronics module (enabling it to be attached to a staff for measurements at different heights). These basic anemometers are effective for characterising wind speed, but care must be taken to also record wind direction (i.e. for wind velocity). This can be achieved by first deploying the anemometer parallel to the channel and recording mean wind speed (i.e. 2 minute average), then record whether the wind was blowing from upstream to downstream (or vice versa). Next, deploy the anemometer perpendicular to the channel and recording mean wind speed (i.e. 2 minute average), then record whether the wind was blowing from the true left bank to true right bank (or vice versa). If time allows, also make measurements at multiple elevations (i.e. 1 m, 2 m, and 3 m). Ideally measurements will be made above the water's surface, as close to the gauging cross section as possible (with measurement elevation above the water's surface recorded), however there are many situations where this is simply not possible (or safe), such as during flood gaugings. In these cases, record measurements from a safe location on the bank, then record the approximate location of the wind measurement relative to the gauging cross section (i.e. drawing a rough map with the estimated distances and elevation to characterise the measurement location).

For fixed camera sites it is recommended to install a directional anemometer or weather station to log a time series of wind velocities. For scientific studies, advanced wind measurement equipment capable of recording vertical profiles of 3-axis wind velocities and turbulence can be installed (Figure 6-3:Left), however for routine gauging a climate station capable of measuring 2-axis wind velocities is suitable (Figure 6-3:Centre). The anemometer or weather station location should be oriented to true North (i.e. including magnetic declination) and surveyed with RTK GPS. This wind velocity record can then be used to identify anomalous data points in surface velocity records, or could be used to attach QC codes based on site specific wind thresholds. Wind effects should be assessed on a site by site basis and it would be imprudent for us to recommend any blanket wind limits. For example, there will be significant differences between a slow flowing lowland river where wind creates substantial surface velocity discrepancies, or a high velocity, high gradient, highly turbulent upland river where surface velocity discrepancies due to wind effects are rapidly mixed throughout the water column.

By logging wind data along with surface velocities and discharge (i.e. for ongoing gauging sites) it may also be possible to identify data points with wind bias in the stage-alpha rating curve (i.e. from Method 1b), then determine empirical corrections for future measurements with those wind conditions.

Figure 6-3: Left: Wind tower with three Campbell Scientific CSAT3B sonic anemometers. Centre: Vaisala WXT536 climate station. Right: ProTech QM1646 handheld anemometer.

7 Challenges of surface image velocimetry and recommendations for improving the quality of input data

Surface image velocimetry is a powerful tool for flow measurement, however the inherent uncertainties of flow measurement from surface velocities must be understood. The relationship between surface velocity and depth averaged velocity (α) is only one potential source of uncertainty, and there can be significant challenges in accurately measuring surface velocities. More extensive recommendations can be found from sources such as Fujita (2018), Engel et al. (2021) and Randall (2020; 2021). Here, a few recommendations are provided to improve the quality of input surface velocity data.

- Cameras must record videos with a consistent frame rate. Most cameras do this (i.e. DSLR, drone cameras, phone cameras etc), however avoid any IP cameras that only record 'changes in motion' where frame rate is inconsistent to minimise data storage or transmission (e.g. security cameras).
- Use cameras with rectilinear lenses where possible (i.e. not fisheye) to reduce errors associated with image correction.
- For fixed camera stations on channel banks mount cameras as high as possible to maximise the angular field of view (i.e. looking down on the channel), also try to include the full flow extent of large floods in the field of view.
- For fixed camera stations try to choose straight reaches with consistent geometry (i.e. a long run).
- Try to select sites where high flows are contained, rather than spilling out onto a flood plain.
- Select a measurement location with a stable cross section (if one exists).
- Try to avoid sites where distributed flow resistance throughout the water column creates irregular velocity profiles, for example: submerged aquatic vegetation, upstream bridge piers, and flood flows through riparian vegetation (Figure 3-2).
- For fixed camera stations place cameras on the bank that is facing away from the prevailing sun direction (i.e. cameras facing south in the southern hemisphere) to minimise surface reflections.
- For fixed camera stations a stable camera tower (i.e. pole or mast) is needed to minimise imagery vibration. Camera covers, wipers and heaters may be needed to remove rain drops and lens fog.
- For fixed camera stations install and survey more ground control points than are needed for orthorectification (i.e. more than 10) and distribute them widely around the site to fill as much of the image field of view as possible. This will help with image rectification and calculation of any lens distortion. It will also provide redundancy in case any ground control points are lost, obscured, mis-surveyed, or bumped/moved.
- Tracer particles are extremely important. For most routine gauging (outside of large floods) there will likely be insufficient tracer particles to use LSPIV for image processing. For sparse tracer particles STIV is recommended (or potentially PTV or FTV).
  - If necessary tracer particles can be added to a river from an upstream location, or using a drone mounted distribution system (Figure 7-1).

   - For imagery with dappled sun glint (such as shallow flows with surface waves) tracer particles can be colour red using non-toxic biodegradable dye, then imagery can be thresholded in the HSV colour space prior to image processing to extract tracer particles (Biggs et al. 2021).
   - Surface waves can also cause problems and errors for surface image velocimetry, as specular reflection from waves can be interpreted as bright tracer particles that are moving (Benetazzo et al. 2017). The use of contrasting tracer particles (e.g. black particles on a bright background, or coloured particles for image thresholding) is recommended. The use of larger tracer particles (e.g. clumps of grass or vegetation thrown into the flow upstream) can also help to address this problem. Imagery with specular reflection from surface waves is generally easier to process using STIV software such as Hydro-STIV or RIVeR-STIV, since manually defined gradient lines can be used to trace the passage of tracer particles and distinguish them from moving surface wave reflections.

- Aerial imagery processing is not trivial and often requires user judgement. The software Hydro-STIV is very user friendly, however in many situations the use of manually defined gradient lines in the STIV images is needed. This is particularly true for imagery with sparse tracer particles. All videos processed for this report required manually defined gradient lines, or at least the user to manually check gradient lines automatically found with HydroSTIV's deep learning mode.

- Drone imagery may need to be stabilised before processing with surface velocimetry software. Matlab code to do this based on feature tracking is available from the lead author of this advice document upon request. A future release of HydroSTIV will also include this capability. This capability is already available in Fudaa-LSPIV, and will be available in the FlowPic smartphone app.

- To obtain imagery with the best distribution of tracer particles, it is recommended to record longer videos (e.g. 5 minutes), then cut them to a suitable length for analysis (e.g. 1 minute). There are many ways to cut and edit videos, however a convenient method is to view the video in VLC media player, then 'Record' the best 1 minute section, which will export it as a separate video file (saved in the 'Videos' folder by default).

- In addition to wind measurements, it is also recommended to record additional meta data about the channel characteristics and gauging (e.g. substrate, site geometry [i.e. straight run, with a deep pool and bend 100 m downstream], rising/falling limb, aquatic vegetation, moving bed material, turbulence, waves etc). This information can be useful for categorising the site/gauging.

- Discharge gauging from surface image velocimetry is non-trivial, and user-related errors are common (Detert, 2020). It is recommended for staff to attend training sessions and workshops prior to undertaking this work (where possible). The learning process can also be simplified by collecting easy to process input data. For example, well seeded (lots of tracer particles), rectilinear (not fisheye), orthorectified (down looking) and stabilised (not shakey, rotating, or drifting) drone footage, can be easily processed in software such as HydroSTIV (Hydro Technology Institute Ltd, 2021), where scaling is derived from cross section width, and user judgement is only needed for drawing gradient lines in the space-time images to get surface velocities. Recording imagery that is already orthorectified also removes multiple sources of uncertainty (Le Coz et al. 2021) and simplifies error analysis calculations.

Figure 7-1: NIWA environmental monitoring technician Hamish Sutton flying a tracer particle distribution system in the Tekapo Canal (left) and Rangitata River (right).

8 Conclusions and future recommendations

The accuracy of discharge measurements derived from surface velocities are highly dependent on the selection of an appropriate alpha value. The method that should be selected will depend on the site being gauged (i.e. routine monitoring site, or one-off flood flow measurement) and the supplementary information that can be obtained. Where possible we recommend using Method 1b and generating a site-specific alpha coefficient. Ideally this will be undertaken at a range of flows (or stage levels) to generate a site-specific stage-alpha rating curve. This method is preferred because no inherent assumptions about velocity profile shape are required, and this method can be used even when velocity profiles differ from conventional log law (Method 2a) or power law (Method 2b) profiles. Method 1b also does not require extrapolation of ADCP data to the water's surface to predict surface velocities but measures them directly. The extrapolation required for Method 1a, or the curve fitting required for Method 2b, can introduce additional sources of uncertainty. For sites where surface velocities, cross sections and slope are known accurately, but there are no ADCP velocity profiles or reference discharge measurements, then Method 2a can be used to estimate alpha. Likely Method 2a would be appropriate for one-off measurements of flood flows in remote locations where all input data are derived from remote sensing measurements (i.e. surface velocities from drone imagery, cross sections from drone mounted Ground Penetrating Radar (GPR), and slope from a DEM derived from aerial imagery). If no input data are available, then Method 3b is recommended, where alpha is estimated from site characteristics. The use of 'local' alpha values is not recommended, due to both practical implementation, and problems with extrapolation beyond the measurements from which they were determined (i.e. changing local alpha values at higher flows and changing wetted perimeter of the channel resulting in flow cover previously dry sections without any local alpha values).

Wind effects are very complicated to address analytically as impacts on the water surface velocity depend on: wind shear stress (e.g. wind velocity profiles and turbulence); fetch; surface roughness (which has a feedback loop with wind generated surface waves); surface tracer types (i.e. surface particles such as wood shavings, or surface features such as boils and eddies); and even the turbulent mixing characteristics of the channel itself (i.e. vertical mixing of wind disturbed surface water). Measurements of wind also pose their own practical challenges, such as: obtaining measurements above the water surface rather than the bank; and obtaining measurements that are spatially representative of average wind at the cross section. Due to the heterogeneity of most gauging sites (i.e. banks, riparian vegetation, local terrain etc), it is very difficult to accurately quantify average wind, let alone surface shear stress due to wind. The practical recommendation of this document is to not perform surface image velocimetry if there are visible wind effects on the water surface (i.e. wind generated surface waves, ripples, or visible motion of tracer particles). It is recommended that field staff bring a wind anemometer whenever performing surface image velocimetry so they can record wind velocities at a location that is 'representative' of wind at the study site. For fixed camera sites it is recommended to install an anemometer or weather station to log time series of wind velocities. This information can then be used to identify anomalous data points in surface velocity discharge records, or could be used to attach QC codes based on site specific wind thresholds. Wind effects should be assessed on a site by site basis and it would be imprudent for us to recommend any blanket wind limits. For example, there will be significant differences between a slow flowing lowland river where wind creates substantial surface velocity discrepancies, or a high velocity, high gradient, highly turbulent upland river where surface velocity discrepancies due to wind effects are rapidly mixed throughout the water column.

Care should also be taken when recording input data for surface image velocimetry, since the accurate determination of mean surface velocities provides another significant source of uncertainty in addition to uncertainties in alpha. Where necessary, additional tracer particles should be added to flows to improve the accuracy of surface velocity measurements. At some locations (such as the Tekapo Canal site used in this advice document) surface velocimetry was not possible without added tracer particles.

Future work on the effect of wind on different tracer particle types (i.e. particles with different surface area and submergence) and how turbulent mixing impacts surface wind effects is recommended. The development of a dedicated application for processing ADCP data to extract cross sections and perform more detailed analysis of velocity profile data is also recommended. While this analysis can be performed in MATLAB, it would be beneficial for a user-friendly package with a GUI (such as QRev or QRevInt) to be developed that is accessible for field hydrologists. Alternatively, features dedicated to pre-processing ADCP data for surface velocimetry could be added to QRev, which would be extremely beneficial for field hydrologists globally. Future work to reprocess the data of Welber et al. (2016) and Hauet et al. (2018) to further test the equations of Section 3.1 (Method 2a) is also recommended. The original analysis of Welber et al. (2016) and Hauet et al. (2018) did not take into account the slope of the channels, but focused on empirical relative roughness metrics (i.e. d_{50}/depth) rather than Z_0 (the roughness coefficient from a log law velocity profile) which incorporates the effects of both bed roughness and flow physics (Appendix B).

9 Acknowledgements

The authors would like to thank Hamish Sutton, Hayden McDermott, Duncan Macpherson, David Plew, Jo Bind, and Jess Kerr for help with fieldwork during the project. The authors would also like to thank Jérôme Le Coz, Martin Detert, Alexandre Hauet and Mark Randall for valuable discussions and reviews during the project. The authors would like to thank Hydro Technology Institute Ltd (the developers of HydroSTIV) for collaborating on the project. The lead author of this advice document would like to acknowledge the contributions of the project team and attribute credit for conceptualisation of Method 1b and the divided channel method to co-authors Martin Doyle and Nicholas Holwerda. The work was funded by the Ministry of Business Innovation and Employment (MBIE) under Envirolink Advice Contracts [C01X1936 2066-TSDC169 and C01X2008 2115-TSDC176], the support of which is gratefully acknowledged. The authors would also like to acknowledge the valuable contributions made by the related projects C01X1812 'Drone Flow' and eFlows FWWA2103 'Velocity Profiles'. Without the equipment, methods, software and theoretical analysis developed by those projects this advice document would not have been possible.

10 Glossary of abbreviations and terms

ADCP	Acoustic Doppler Current Profiler
FTV	Feature Tracking Velocimetry
FUDAA LSPIV	Software for processing surface velocimetry videos using LSPIV
GCP	Ground Control Point
GPR	Ground Penetrating Radar
GUI	Graphical User Interface
HSV	Hue Saturation Value (an alternative colour space to RGB)
HydroSTIV	Software for processing surface velocimetry videos using STIV or PTV
LSPIV	Large Scale Particle Image Velocimetry
POEM	Pressure Operated Electronic Meter
PTV	Particle Tracking Velocimetry
QC	Quality Control
QRev	Software for processing ADCP discharge data
ROI	Region of Interest
STIV	Space Time Image Velocimetry
SVR	Surface Velocity Radar
SxS Pro	Section by Section Pro is a software for measuring discharge with Teledyne RDI ADCPs using sections and is commonly used for flood gauging with moving bed

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Appendix A Fieldwork sites

To provide data for this advice document fieldwork was undertaken at: Wairau Creek (Auckland Council), Hurunui River (NIWA), Rangitata River (NIWA), Tekapo Canal (NIWA), and Makerewa River (Environment Southland).

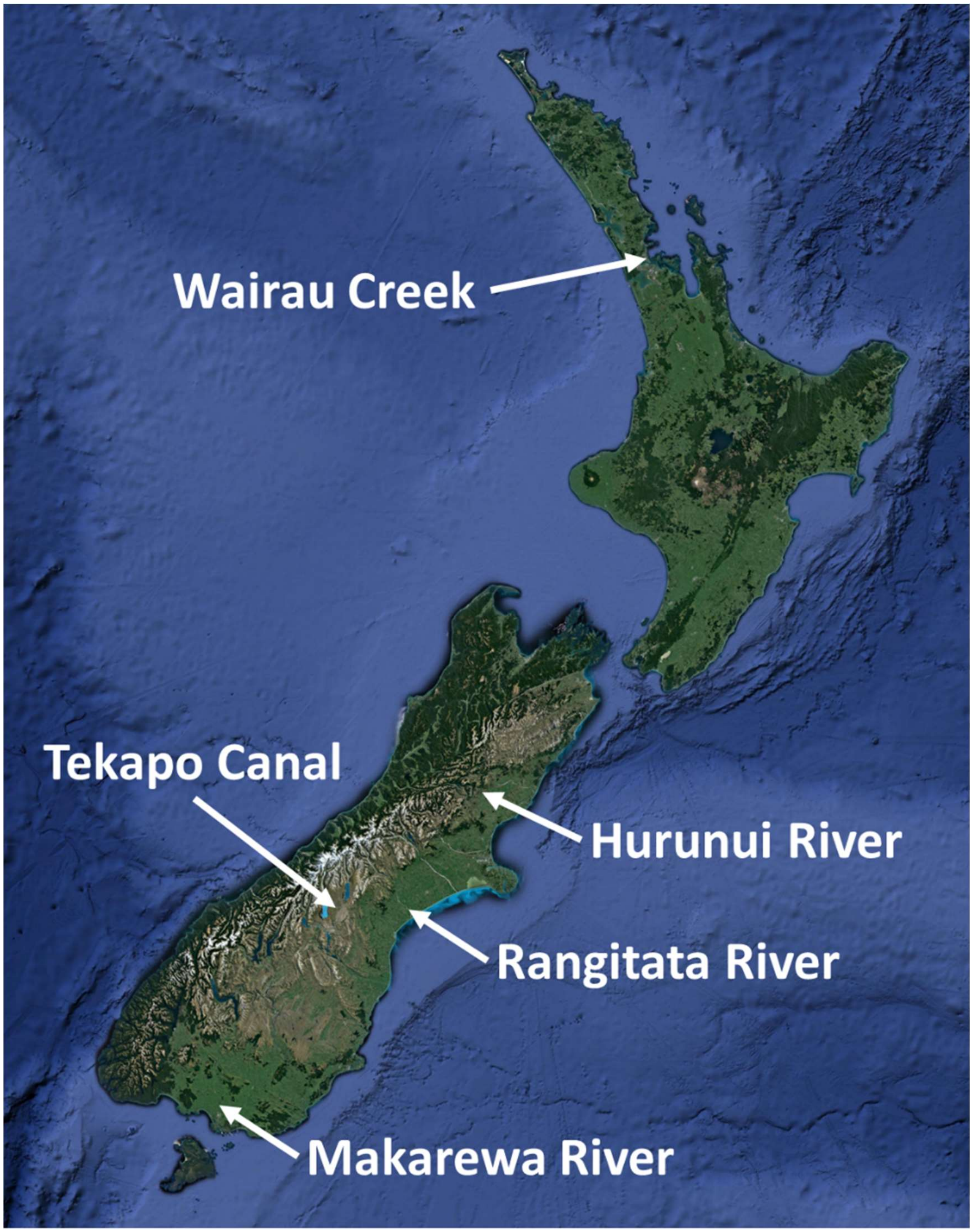

Figure A-1: Fieldwork locations in New Zealand where data were collected for this report.

Appendix B Derivation of equations for alpha from log law profiles

From Smart and Biggs (2020a).

With no flow acceleration, secondary flow or surface wind drag, a logarithmic velocity profile (Keulegan, 1938) can be assumed to extend to the surface. The depth averaged velocity is then related to mean surface velocity $\overline{u_s}$ and friction velocity u_* as follows:

$\frac{\bar{u}}{u_*} = \frac{1}{\kappa} \ln\left(\frac{z}{Z_0}\right)$	$\kappa \approx 0.4, \bar{u} = 0$ at $z = Z_0$ (roughness scale)	(1)
$\overline{u_s} = \frac{u_*}{\kappa} \ln\left(\frac{H}{Z_0}\right)$	surface velocity $\overline{u_s}$ at $z = H$	(2)
$U = \frac{1}{H-Z_0} \int_{z=Z_0}^{z=H} \frac{u_*}{\kappa} \ln\left(\frac{z}{Z_0}\right) dz$	average (1) from $z = Z_0$ to $z = H$	(3)
$U = \frac{u_*}{\kappa}\left(\frac{H}{H-Z_0} \ln\left(\frac{H}{Z_0}\right) - 1\right)$	evaluate (3)	(4)
$\frac{U}{\overline{u_s}} = \frac{H}{H-Z_0} - \frac{1}{\ln\left(\frac{H}{Z_0}\right)}$	(4) / (2)	(5)
$\frac{U}{\overline{u_s}} = \frac{H}{H-Z_0} - \frac{u_*}{\kappa \overline{u_s}}$	substitute in $\frac{1}{\ln\left(\frac{H}{Z_0}\right)} = \frac{u_*}{\kappa \overline{u_s}}$ from (2)	(6)
$\frac{U}{\overline{u_s}} = 1 - \frac{u_*}{\kappa \overline{u_s}}$	for cases where $H \gg Z_0$	(7)
$\frac{U}{\overline{u_s}} = 1 - \frac{\sqrt{gHS}}{\kappa \overline{u_s}}$	assuming $u_* = \sqrt{gHS}$ substitute into (7)	(8)

where $\bar{u}$ is the time averaged streamwise velocity at elevation z above the log profile zero plane, U is the depth average of $\bar{u}$, κ is the Von Kármán constant, Z_0 is the log law roughness scale, H is flow depth above the log law origin, g is gravitational acceleration, S is slope, and α is the velocity index.

In most cases $H \gg Z_0$, however for flows with higher relative roughness equation (6) can be improved by substituting in $Z_0 = \frac{H}{e^{\left(\frac{\overline{u_s}\kappa}{u_*}\right)}}$ with the following derivation:

$\frac{\overline{u_s}\kappa}{u_*} = \ln\left(\frac{H}{Z_0}\right)$	rearrange (2)	(2a)
$e^{\left(\frac{\overline{u_s}\kappa}{u_*}\right)} = \frac{H}{Z_0}$	rearrange (2a)	(2b)
$Z_0 = \frac{H}{e^{\left(\frac{\overline{u_s}\kappa}{u_*}\right)}}$	rearrange (2b)	(2c)
$\frac{U}{\overline{u_s}} = \frac{H}{H - \frac{H}{e^{\left(\frac{\overline{u_s}\kappa}{u_*}\right)}}} - \frac{u_*}{\kappa \overline{u_s}}$	substitute (2c) into (6)	(9)
$\frac{U}{\overline{u_s}} = \frac{1}{1 - e^{-\left(\frac{\overline{u_s}\kappa}{u_*}\right)}} - \frac{u_*}{\kappa \overline{u_s}}$	simplify (9)	(10)
$\frac{U}{\overline{u_s}} = \frac{1}{1 - e^{-\left(\frac{\overline{u_s}\kappa}{\sqrt{gHS}}\right)}} - \frac{\sqrt{gHS}}{\kappa \overline{u_s}}$	assuming $u_* = \sqrt{gHS}$ substitute into (10)	(11)

Appendix C Results from fieldwork

Fieldwork results are summarised in Table C-1. ADCP discharges are the average of at least four moving boat cross sections, or were measured using SxS Pro (Hurunui River).

	Top Width (m)	Cross Section Area (m^2)	Mean Depth (m)	Slope	Discharge from ADCP (m^3/s) [Q_{ADCP}]	Discharge Hydro STIV (m^3/s) [$Q_{H,\alpha=0.857}$]	Discharge Hydro STIV (m^3/s) [$Q_{H,\alpha=1}$]	Alpha from Hydro STIV $Q_{ADCP}/Q_{H,\alpha=1}$	Alpha from QRev profiles Top: Constant Bottom: No Slip	Alpha from QRev profiles Top: Power Bottom: Power	Power law exponent (M)	Alpha from power law exponent 1/(M+1)	Alpha from site physics (log profiles $H>>Z_0$)	Alpha from site physics (log profiles)	Alpha from site roughness estimate	Mean wind speed (m/s)†
Wairau Creek #1	4.796	2.227	0.464	0.0004004	1.948	1.710	1.996	0.921	0.941	0.881	0.113	0.897	0.881	0.881	0.91	-3.930
Wairau Creek #3	6.182	4.234	0.685	0.0004004	6.838	6.488	7.571	0.902	0.953	0.929	0.105	0.905	0.928	0.928	0.91	-5.507
Hurunui River	34.500	53.783	1.559	0.0040600	120.744	134.709	157.187	0.768	0.911	0.840	0.265	0.791	0.787	0.796	0.8	-2.443
Rangitata River	27.199	21.133	0.777	0.0026640	33.368	37.723	44.017	0.758	0.913	0.855	0.197	0.835	0.829	0.832	0.8	-4.633
Tekapo Canal #1	33.510	116.750	3.484	0.0001125	49.890	43.450	50.701	0.984	1.008	0.912	0.135	0.881	0.643	0.708	0.857	-2.361
Tekapo Canal #2	33.364	116.010	3.477	0.0001125	51.672	49.377	57.616	0.897	0.959	0.929	0.116	0.896	0.688	0.730	0.857	-1.320
Tekapo Canal #3	33.217	113.910	3.429	0.0001125	62.084	54.340	63.407	0.979	0.993	0.920	0.125	0.889	0.724	0.751	0.857	-0.978
Makerewa River #1	23.797	16.070	0.675	0.00127	10.996	10.427	12.167	0.904	0.933	0.877	0.143	0.875	0.713	0.744	0.857	-1.973
Makerewa River #2a	23.157	8.911	0.385	0.00127	3.755	4.406	5.141	0.730	0.920	0.813	0.173	0.853	0.700	0.737	0.8	+1.701
Makerewa River #2b	23.157	8.911	0.385	0.00127	3.755	4.126	4.815	0.780	0.920	0.813	0.173	0.853	0.680	0.726	0.8	+1.701

Table C-1: Summary of results from fieldwork. Makerewa River #2a was with oblique imagery from the river bank, while #2b was from a drone, both were low flow conditions.

† Wind direction downstream is positive, and upstream negative.

Appendix D Divided channel method for compound channels and flood flows

In some situations, the use of a single alpha value for the entire channel may be inappropriate. This may occur during large floods when flows overtop the banks of the main channel and inundate surrounding areas. In this case the alpha value used for the central part of the channel may not be suitable for flow in the shallow and relatively rough surrounding areas (i.e. flood plains). Figure D-1 shows the recommended methods for selecting alpha for flows with different channel geometries.

In Figure D-1(c), a stage-alpha rating curve using method 1b may have been established for the main channel, however during large floods flow overtops the banks of the main channel and inundates areas without existing data or stage-alpha ratings. In this case it is suggested to compute discharge in the main channel using alpha values extrapolated from an existing rating curve using Method 1b, then select alpha values for the unknown flood plain areas using either Method 2a, 2b, 3a, or 3b. The selection of which method is appropriate will depend on channel characteristics and what data is available.

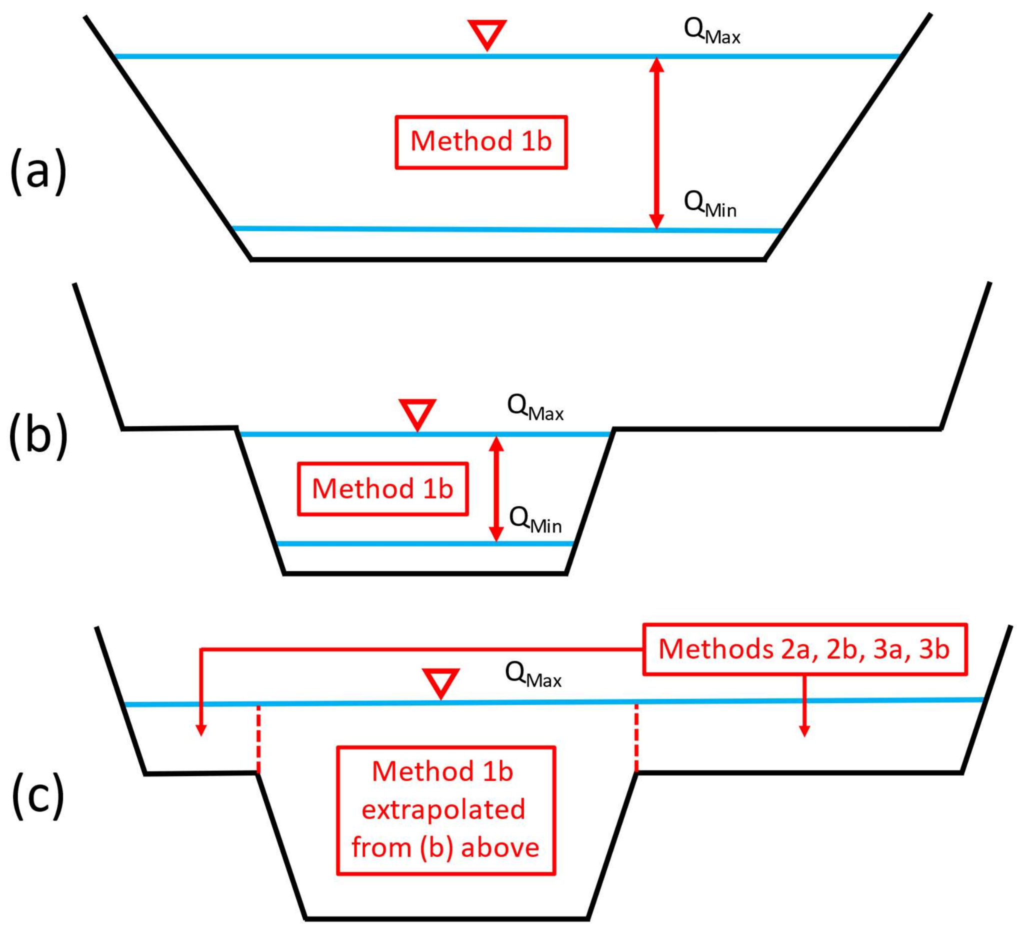

Figure D-1: Alpha methods for different channel geometries: (a) flow contained within regular channel geometry at all discharges; (b) compound channel where flow is usually contained within main channel; (c) compound channel during a large flood where flow spills out of main channel.

Appendix E Workflow diagram for selecting the alpha method

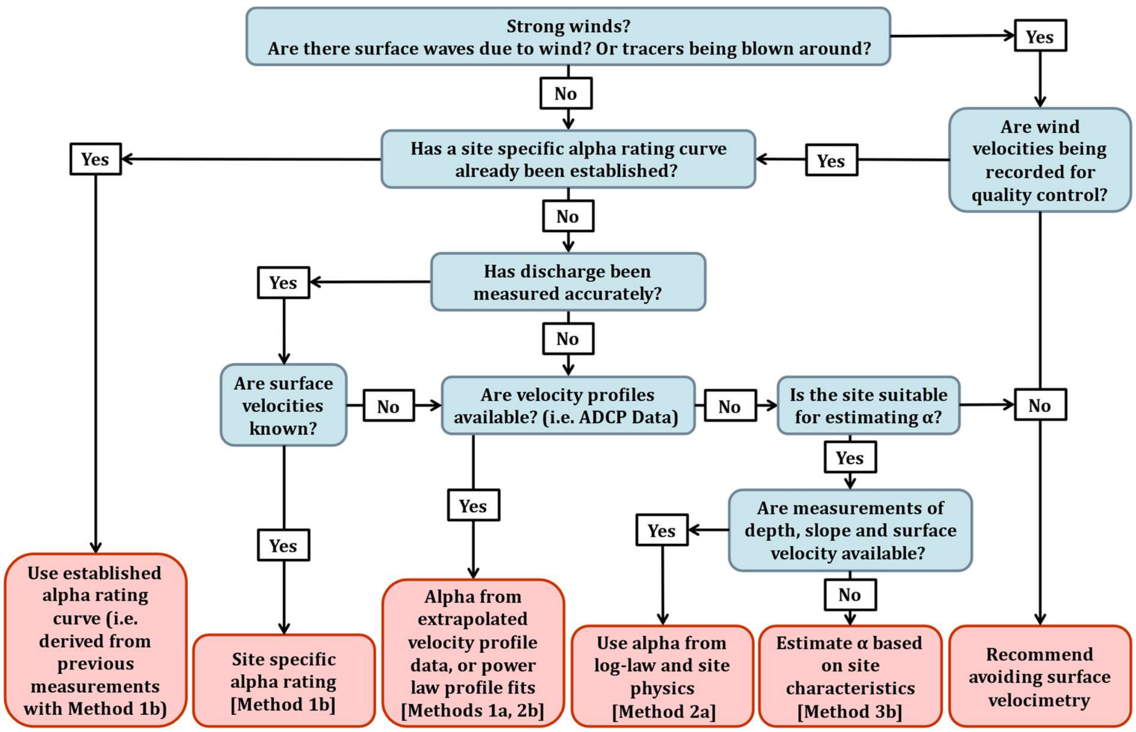

Figure E-1: Workflow diagram for selecting the alpha estimation method.

Explanation of the case 'Is the site suitable for estimating α?'

If there is no input data from which to derive α (i.e. no velocity profiles or reference discharge measurements), then α will need to be estimated. This will be ok at most sites; however, the accuracy will be dependent on how well flow characteristics at the site match conventional log law or power law velocity profiles. Variability in α can be reduced by careful selection of the measurement site, for example avoiding sites with submerged vegetation, wake effects and changing geometry (i.e. when flow is not uniform longitudinally, which commonly occurs due to channel constriction, such as a bridge, sill, or weir). Some sites, such as those with dense submerged vegetation throughout the water column should be avoided entirely. At other marginal sites the measurement should proceed, but add as much meta data about the site characteristics as possible (to help inform quality control), then return to the site in the future if possible to measure α and reprocess the gauging.

Alternatives for the case 'Recommend avoiding surface velocimetry'

If there are strong winds and they are not being recorded for quality control, then it is generally recommended to avoid discharge gauging from surface velocimetry methods and use other techniques (e.g. POEM). However, where no other techniques are available and a gauging is still required (such as during extreme floods), then proceed with surface velocimetry measurements, but make a note of the reduced confidence in the accuracy of the gauging. For deep flood flows with high winds (i.e. tracers being blown around on the water surface), it may also be possible to measure 'surface' velocities with contact current meters (e.g. propeller meters) a small distance below the water surface, where the effects of surface wind are reduced.