



## Salmon Habitat Restoration Center of Expertise Technical Bulletin Vol. 1

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# Estimating Surface Flow Velocity in River Channels Using High Resolution Drone Videos: Large-Scale Particle Image Velocimetry (LSPIV)

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## SHR-COE Technical Bulletins

Technical Bulletins are published by the Salmon Habitat Restoration Center of Expertise (SHR-COE) in Pacific Region as a means of disseminating technical information, guidelines, workflows and instructions relevant to restoration practitioners.

This Technical Bulletin is for SHR-CoE staff and external restoration practitioners describing how to (a) collect videos of river channels in the field using drones and (b) process the videos with third-party software to obtain estimates of surface flow velocity using Large Scale Particle Image Velocimetry (LSPIV). Herein, data processing is described using RIVeR software (Rectification of Image Velocity Results); however, the procedure can be generalized for other software applications.

## Introduction

Surface flow velocity is a key variable in many habitat restoration projects [1,2] despite many operational challenges to acquiring reliable field data. The recent development of particle tracking and image analysis techniques such as Particle Image Velocimetry (PIV), together with the widespread use of UAVs (Unmanned Aerial Vehicles, i.e., drones) to collect high-resolution images and videos, has made it possible to readily obtain estimates of surface flow velocity in river channels [3,4]. The combined application of particle tracking and image analysis with UAV imagery





## Salmon Habitat Restoration Technical Bulletin Series

is referred to as LSPIV. It applies the same principles developed for PIV in controlled laboratory settings to larger field sites in fluvial environments where velocity measurements are needed.

In simple terms, image analysis techniques such as PIV identify patterns such as turbulent eddies, floating woody debris, or foam from turbulent flow over ripples and rapids, and track them in subsequent frames extracted from a video. These patterns act as “tracers”, whose movements are used to reconstruct a displacement field for each pair of subsequent frames in the video.

Displacement fields for all pairs are then averaged to obtain a mean displacement field for the entire video. Finally, the mean displacement field can be converted into a velocity field using either ground control points (GCPs) to rectify the images, or a scale conversion factor in meters per pixel, the latter being the easiest method for drone-acquired videos. This conversion factor is inferred from the known distance between two points in the frames (or the dimensions of a known feature). Once image rectification is complete, the surface velocity field is generated. LSPIV software has been developed in the last decade and is easily accessible. Most LSPIV software also performs pre- and post-processing of the video footage. In the case of UAV footage acquired perpendicular to the flow, the only two things needed are high resolution video (see **Data Collection**) and the scale conversion factor in m/pixel.

### Applications and Limitations

LSPIV can be used to obtain estimates of surface flow velocity for most rivers. As such, it has many potential applications for salmon habitat-related projects, including:

- a) Identifying areas where fish passage and migration may be problematic;
- b) Locating suitable habitats for resting and spawning (coupled with data on species-specific habitat suitability indices, river bed grain-size, and water depth);
- c) Geomorphic analyses such as estimating shear stress, sediment mobility and transport capacity; and
- d) Calibration and validation of hydraulic models.

Since velocity estimations obtained with this methodology have inherent uncertainty, they should be used cautiously when more precise data and/or 3D velocities are necessary. Common examples of such tasks are infrastructure design (e.g., culverts, side channel intakes) and discharge measurements, which require velocity profiles through the water column. In such cases, direct measurement techniques using an instrument such as an Acoustic Doppler Current Profiler (ADCP) are preferred.



## Salmon Habitat Restoration Technical Bulletin Series

# Data Collection

## Equipment and Software

The two basic requirements to obtain surface velocity estimates with LSPIV are (1) a video camera and (2) video processing software to produce surface velocity maps. The former is most often a drone and all commercial drones produced since the late 2000s (e.g., the DJI commercial fleet including the DJI Mini) have cameras with adequate resolution for LSPIV application. Videos also can be collected with a regular HD camera (even from a smartphone) and processed for LSPIV purposes, as long as the conditions described in **Technical Requirements** are satisfied.

Several software applications are available to perform LSPIV analyses. Most are based on routines developed for programming languages like Matlab (i.e., PIVlab<sup>1</sup>) or Python (i.e., OpenPIV<sup>2</sup>). Some common ones that are freely available online include RIVeR [5], Fudaa-LSPIV [6] and KLT-IV [7]. This technical bulletin describes the workflow for LSPIV analysis using RIVeR. Its software package and User Manual can be found here: <https://riverdischarge.blogspot.com/p/download-river.html>.

The RIVeR software itself does not need to be installed, but it does require a specific Matlab compiler (M2020b, v. 9.9) that can be downloaded from the MathWorks webpage (<https://www.mathworks.com/products/compiler/matlab-runtime.html>). The compiler requires administrator privileges for installation on a government laptop; therefore, it is necessary to submit an IT ticket, attaching form FP\_5165, to request the software installation. Once the Matlab compiler is installed, RIVeR is launched by opening the *RIVeR\_GUI.exe* file.

## Technical Requirements

To produce reliable surface velocity maps with LSPIV, several technical requirements must be met:

- The video must be at least 30 seconds in length; 40-45 seconds is good practice. Longer videos can be trimmed, while a video that is too short may produce unreliable results.
- The video resolution must be at least 720 HD; it is best to collect videos at the highest resolution available.

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<sup>1</sup> PIV tool with GUI, V 3.01, <https://www.mathworks.com/matlabcentral/fileexchange/27659-pivlab-particle-image-velocimetry-piv-tool-with-gui/>

<sup>2</sup> <http://www.openpiv.net/index.html>



## Salmon Habitat Restoration Technical Bulletin Series

- The frames per second (fps) ratio should be at least 20 fps and ~30 fps is ideal. If videos are recorded at >60 fps, they may be too large for processing and require compression.
- The video should be taken at a vertical angle above the water surface (i.e., NADIR angle). While it is possible to process oblique angled videos, processing is more difficult and requires exact GPS coordinates of 6-10 GCPs located in proximity of the water on both banks.
- The drone (or camera) should be as stable as possible. While most LSPIV software can stabilize the frames during pre-processing, it is good practice to only collect footage when the drone is stable. If the operator can visually detect consistent shaking when viewing the video from the drone controller, the footage is likely not useful for LSPIV. This can happen in cases of intense wind or when the camera is attached to a “fixed” point (e.g., bridge) subject to vibrations.
- The flow area should be centered on the screen and occupy 50-70% of the image, with each bank occupying ~15-25% of the screen (Figure 1).
- Partial shading due to clouds or vegetation should be avoided as it can impact the quality of the velocity measurements, although it is still possible to partially correct for such effects.

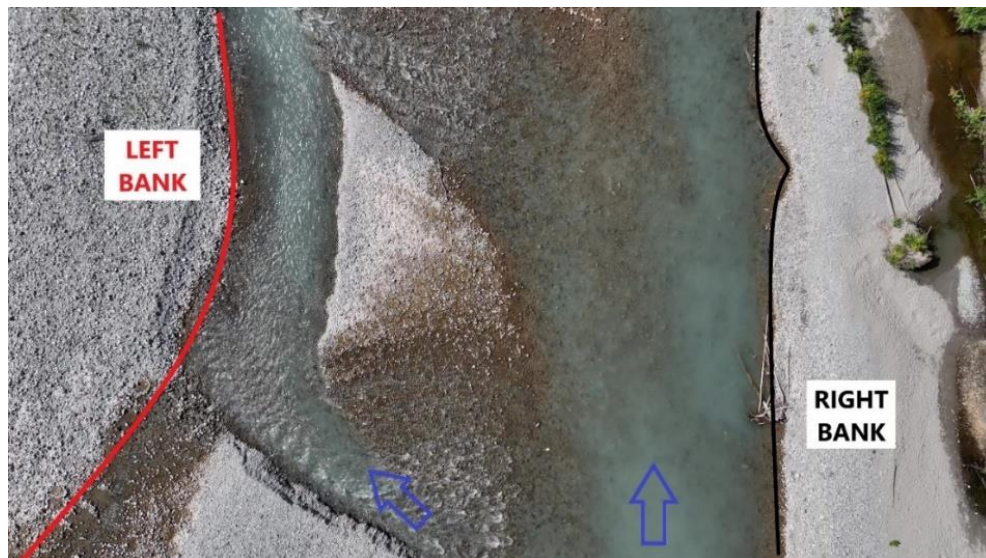


Figure 1. Frame extracted from a video recorded with a DJI Mavic 3E on the Mamquam River in Squamish, September 2023. Water flow is from bottom to top in the image. The river channel occupies ~50% of the frame, with the remaining frame occupied by the left and right banks.



## Salmon Habitat Restoration Technical Bulletin Series

If the Area of Interest (Aoi) cannot be captured in a single video, multiple videos can be recorded provided there is ~10% overlap between them. It is good practice to exclude the area close to the edges of overlap from analysis in order to avoid camera distortion effects (see **Data Processing** section).

An essential parameter needed for reliable surface velocity maps is the scale conversion factor (meters/pixel). Most LSPIV software can calculate the scale conversion factor once the user inputs the distance between two points in the frame. If an orthophoto of the Aoi is available, it can be imported in Google Earth Pro (or any GIS software) to calculate the distance between two points. This is the best way of orthorectifying the image, whose accuracy is in the same order as the orthophoto (a few cm in most cases). In a similar way, any visible object of known dimensions (i.e., a target, the drone case, a field notebook) can be placed close to one of the banks while recording the video to calculate the scale conversion factor with the LSPIV software. Alternatively, one can use Google Earth Pro (or similar software) to measure the distance between clearly distinguishable, fixed reference points such as stable vegetated bars, man-made structures or large rock outcrops. This method is least preferred and its accuracy depends on the chosen object (i.e., the error can be in the order of meters). If none of these options is available, the user should collect coordinates of a few reference points included in the video and calculate the distance between them as a desktop exercise, or measure the distance in the field if safe to do so. The accuracy of this method is associated with the accuracy of the point measurements (i.e., error can be in the order of cm to m).

### Data Collection Workflow

The following workflow is recommended when collecting data for LSPIV purposes:

1. Before data collection, identify the Aoi where surface velocities are needed (e.g., delineate the area by drawing a polygon in Google Earth Pro or similar software).
2. Check that the drone is functioning properly (i.e., enough memory to record multiple videos, charged batteries, etc.).
3. Verify that it is possible to obtain the scale conversion factor, either from an orthophoto of the Aoi, or by placing a visible object of known dimensions in the frame while recording the videos (see **Technical Requirements**).
4. When on site, record videos according to the criteria in the **Technical Requirements**. If the Aoi is too large for a single video, multiple videos should be collected making sure that (a) there is



## Salmon Habitat Restoration Technical Bulletin Series

at least ~10% overlap between videos and (b) the flight elevation varies by less than 5 m between flights.

5. If the drone flight elevation varies by more than 5 m between multiple videos, a different scale conversion factor is needed. If using an object, it should be moved to ensure it is visible in each video if the elevation changes. If an orthophoto is available for the Aoi, the flight elevation can be changed without issue.

## Data Processing

This section describes the basic procedure to obtain surface velocity maps with LSPIV using RIVeR software. RIVeR has the advantages of being free, user-friendly, easy to install and operate, and with a User Manual that is helpful in guiding the analysis. For more info about the software, refer to [5]. Alternative LSPIV software options are available (see **Equipment and Software**) and the user should feel free to use whichever one best meets their purpose.

After downloading and installing the software, the steps of analysis are as follows (refer to the RIVeR User Manual for more details):

1. **Frame Extraction:** First, select the video file and specify how many frames to include and the length of video to analyze (Figure 2). All frames should be analyzed, the duration should be ~30 seconds, and the number of extracted frames should be ~900. It is best to select the “Grayscale” option to save time and memory, since the PIV analyses are conducted in grayscale regardless. After pressing “Extract XXX frames,” RIVeR will extract the frames from the video and store them in a folder located in the same directory as the video.

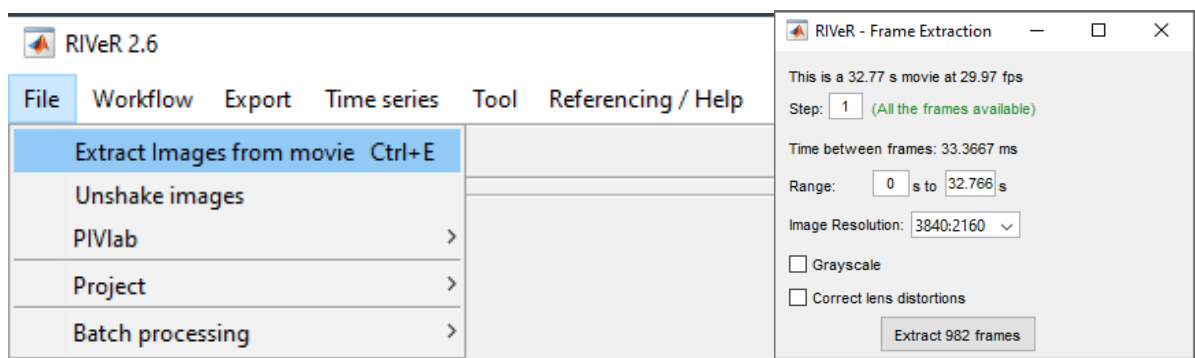


Figure 2. Frame Extraction panel in RIVeR.



## Salmon Habitat Restoration Technical Bulletin Series

2. **Unshake Images:** This is an important step to correct shaking due to camera vibration. After clicking “Unshake images” (Figure 2, left panel), the user will select all the frames that were just extracted and a new window will appear showing the first frame (Figure 3). The user will be asked to draw a mask contouring the area covered by flowing water, and then click “Unshake.” RIVeR will generate a series of unshaken frames and store them in a new sub-folder located in the folder with the original frames. This step of the analysis is usually time consuming, lasting between 20 and 90 minutes depending on the frame number and resolution.

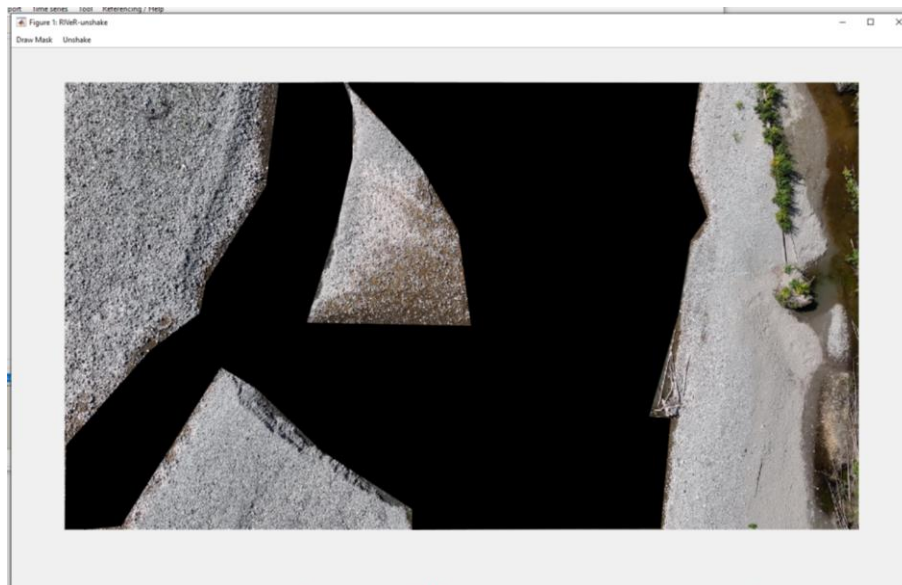


Figure 3. Unshaking frames in RIVeR. The black area is the mask covering the water surface.

3. **PIVlab Analysis:** At this point, the user can choose either to have the frames processed automatically (“PIVlab automatic”), or open the Matlab routine and have direct control of the processing parameters (“PIVlab GUI”). Herein, we describe the former option and the RIVeR User Manual provides details for the latter “PIVlab GUI” option, which allows for several pre- and post-processing techniques. After selecting the frames to be processed, the user draws a rectangle by holding and dragging the pointer to delineate the processing area (Figure 4). Since there are distortion effects associated with the drone camera, it is best to exclude the portion close to the edges (i.e., ~5-10%) from analysis. The software then asks the user to draw masks around features to be excluded from analysis (e.g., gravel bars, immobile large woody debris, bridges). After drawing one mask, the procedure can be repeated until the user is satisfied with the area to be processed. Next, when RIVeR asks, “Do you want to draw another mask?”, the



## Salmon Habitat Restoration Technical Bulletin Series

user selects “No” (Figure 4). Selecting “No” automatically initiates PIV processing and progress can be tracked in real-time as a percentage shown in the upper part of the screen. This step can take from ~20 mins to >1 hour, depending on the number and quality of frames, the extent of the area processed, and the computing power of the machine.

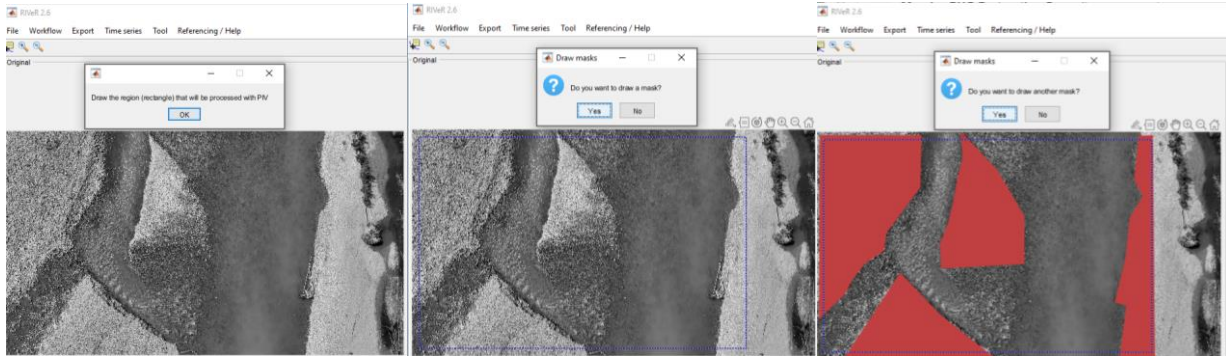


Figure 4. PIVlab in RIVeR. The blue dashed rectangle in the middle panel delineates the area for velocity analysis and the red polygons in the right panel represent the masked areas excluded from analysis.

4. **Image Rectification:** After obtaining the median displacement field (pixels/sec) from PIVlab, the mean velocity field (m/s) is derived by rectifying the images (i.e., providing a scale conversion factor). The user should follow all menu options in sequential order under the “Workflow” tab. Once the steps have been completed, they are highlighted in green (Figure 5).

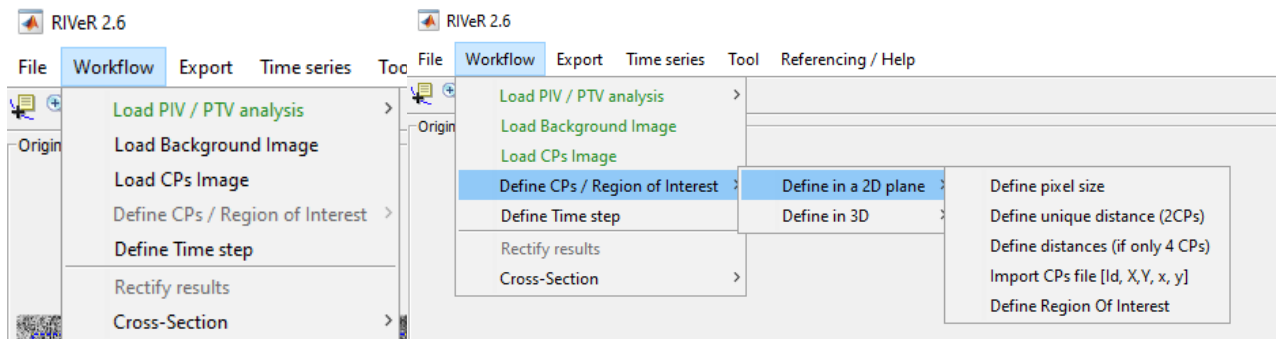


Figure 5. RIVeR Workflow to extract velocity fields from displacement fields.





## Salmon Habitat Restoration Technical Bulletin Series

These steps are:

- a) *Load PIV / PTV Analysis.* This is only necessary if the PIVlab analysis is run manually through GUI. If automatic processing is selected, then the session is already loaded into RIVeR.
  - b) *Load Background Image.* Select “Automatic” or pick any of the extracted images.
  - c) *Load CPs Image.* Choose any of the extracted images in which you can identify the object/distance used to calculate the scale conversion factor.
  - d) *Define CPs / Region of Interest.* Select “Define in a 2D plane”. If you already know the pixel size (in meters), select “Define pixel size” and input the scale conversion factor. Otherwise, select the option “Define unique distance (2CPs)”. At this point the user needs to select two points in the image and input their known distance in meters (follow the instructions on screen to zoom in and select the points with more accuracy). Finally, the region of interest to be rectified needs to be delineated with a polygon. Since no distortion is involved with this procedure, it is best to draw a rectangle around the entire frame for simplicity.
  - e) *Define Time step.* The user needs to input the time step between frames (in milliseconds, ms); usually RIVeR shows the correct value by default but it should be confirmed. For example, if the drone camera recorded a video at 30 fps, the time step in milliseconds is obtained by dividing 1000 (milliseconds in one second) by 30 fps:  $\text{Time Step} = 1000/30 = 33.33 \text{ ms}$ .
  - f) *Rectify results.* After selecting “Rectify results,” RIVeR proceeds to transform the displacement fields into velocity fields. The results are shown on the right side of the screen, and they can be manipulated and exported easily (see next step).
5. *Results Visualization and Export.* Results are visualized on the right panel of the window (Figure 6) either in terms of “Vectors” or “Vectors and Magnitudes” (often referred to as heat maps). RIVeR automatically shows the median velocity field (i.e., the frame with the highest number, highlighted in green in Figure 6), but the user can move the progress bar to the left and visualize any of the analyzed frames. Plot settings can be changed in “Tool Plot settings” in the bottom right corner to change vector color and size, mesh dimension, colormap, etc. The mesh dimension option (“m” and “n” in Figure 6) is particularly useful because it allows the velocity vectors to be displayed at different scales. If a finer resolution is needed, the values of “m” and “n” should be increased. Results can be exported either as images (“Export Images”) or as \*.csv files (“Export Current Velocity Fields”) with coordinates (X and Y) and both planar components of surface velocity (U for the longitudinal and V for the transversal component). Export examples of Vectors and Vectors and Magnitudes are shown in Figure 7.



## Salmon Habitat Restoration Technical Bulletin Series

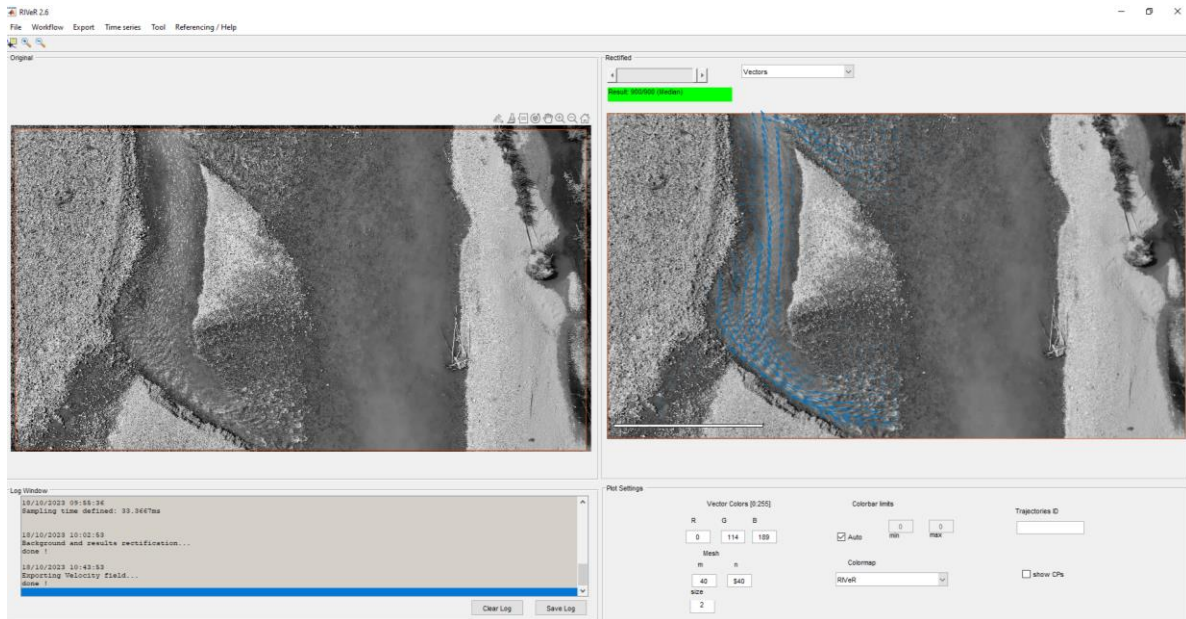


Figure 6. RIVeR Plot Settings window.

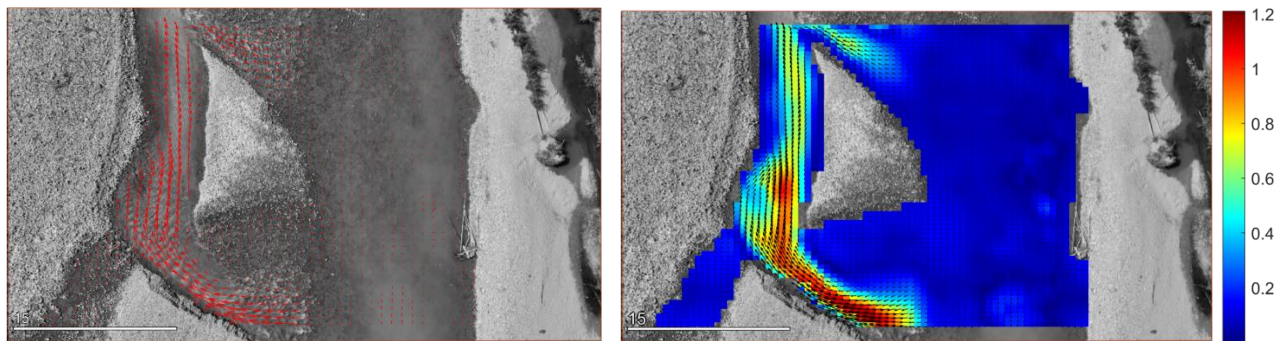


Figure 7. Output of RIVeR surface velocity vectors, which indicate direction of flow (left panel), and output of surface velocity maps (right panel). Velocity is expressed in m/s and warmer colors indicate faster flow.

## Concluding Remarks

This technical bulletin provides background information and a workflow to obtain estimates of river water surface velocity from drone videos using Large Scale Particle Image Velocimetry. LSPIV has become an effective tool for estimating surface velocity thanks to ease of recording aerial videos by drone, and the development of free, user-friendly software for processing the videos. Its range of applications includes hydraulic modelling, geomorphic assessment, fish migration and passage



## Salmon Habitat Restoration Technical Bulletin Series

assessment, and habitat suitability analysis. While limitations related to both resolution and field of application should be taken into account (see **Applications and Limitations**), LSPIV is a robust and reliable tool to obtain information on surface flow structure, especially in situations where other technologies are impractical [8]. As image recognition software continues to improve, together with advancements in the power and resolution of drone cameras, the use of LSPIV is expected to become more common in fish habitat projects requiring hydraulic data.

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### Salmon Habitat Restoration Technical Bulletin Series

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## Acronyms and Glossary

Aoi	Area of Interest
CP	Control Point
fps	Frames per Second
GCP	Ground Control Point
LSPIV	Large Scale Particle Image Velocimetry
PIV	Particle Image Velocimetry
PIVlab automatic	Automated Image Processing in RIVeR
PIVlab GUI	Manual Image Processing in RIVeR
RIVeR	Rectification of Image Velocity Results
SHR-CoE	Salmon Habitat Restoration - Center of Expertise
UAV	Unmanned Aerial Vehicle

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