

## ***Interactive comment on “Fluorescent particle tracers for surface flow measurements: a proof of in a semi-natural hillslope” by F. Tauro et al.***

**F. Tauro et al.**

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We would like to thank the Editor and the three anonymous Reviewers for their accurate comments on our paper that will greatly help us to improve on the presentation of our work. We are glad that Reviewers have positively received the objective of our work, that is, introducing a new experimental approach for conducting observations in surface hydrology. We are also very pleased that they have deemed our technology to be original and potentially useful for improving the current understanding of rainfall-runoff phenomena. As rightfully emphasized by the Reviewers, understanding surface flow propagation and developing effective flow measurement systems are important issues in contemporary hydrology. In this context, Dr. Grimaldi has fostered and promoted

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scientific debates in the new IAHS Decade Initiative (<http://distart119.ing.unibo.it/iahs/>). We are also pleased that Reviewer 1 has considered our work to be a significant, new contribution in the area of hydrology and has recommended the manuscript for publication after moderate revision and that Reviewer 3 has defined the manuscript as well documented and has suggested it for publication after minor revisions.

We generally concur with the Reviewers' constructive comments and will revise the manuscript according to their suggestions. In the following, the main points raised by the Reviewers are reported and accompanied with our responses.

REVIEWER 1 "A moderate revision is needed to provide a more concise contribution focusing on motivations, strengths and weaknesses of the proposed measurement technique, as well as directions for future research." And "I feel, however, that the largest audience would be rather captured by a more concise discussion written along the following lines:

- These are the strengths of the proposed technique.
- These are, at present, the weaknesses of the proposed technique.
- These are the directions to overcome the problems in future research."

We thank Reviewer 1 for the suggestion. For the proposed instrumentation, we will provide a more concise and sharp explanation of its design rationale, its novelty and benefits with respect to traditional methods, and its weaknesses, while identifying future research directions for possible ameliorations .

REVIEWER 1 "The authors may want to provide a more concise introduction section by highlighting the methods currently in use for the determination of overland flow velocity and the potential strengths of the proposed measurement technique over these methods."

We thank Reviewer 1 for the suggestion. We will include a thorough review of currently used overland flow observation techniques comprising major strengths and drawbacks

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along with an effective explanation of the potential benefits offered by our methodology.

REVIEWER 2 " The setup of the paper would be enhanced if the reader understood more fully how the present work relates to these other studies. To the casual reader, a 4th proof-of-concept study may suggest a tough concept to prove?" And " why is a separate proof-of-concept required for small streams (i.e. rills)? What differentiates such flow measurement challenges from the stream-based work? What specifically cannot be quantified currently vis-à-vis overland flow currently and how does the fluorescent tracer approach overcome these limitations? Better development of this line of questioning would help greatly in the Introduction of the paper. At present, there is a glaring absence of key papers from the overland flow literature that might help place this work in some process context. There appears to be no reference whatsoever in the Discussion section to any overland flow studies, leaving the reader questioning if in fact, in the end, there is any qualitative advancement from the work (that can be applied to overland understanding)?"

We thank Reviewer 2 for the suggestions. We will include a comprehensive explanation of the motivations for conducting a spectrum of proof-of-concept experiments for the proposed instrumentation, that is, the analysis of stream and overland flows. In particular, we will address challenges and technical difficulties associated to both types of measurements to properly motivate the need for two separate analyses. Furthermore, we will provide a complete review of commonly used overland flow monitoring systems and highlight the possible improvements offered by our methodology.

GENERAL COMMENTS In the following, we briefly elaborate on the comments of the Reviewers to elucidate on the changes that will be included in the manuscript during this round of revisions.

The main contribution of the proposed approach is to provide a potentially automatic, continuous, low-cost, environmental friendly, and nonintrusive measurement system for surface flow observations. Indeed, the use of fluorescent particles as flow tracers

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presents remarkable advantages: 1) the beads are commercially available at competitive prices; 2) they can be designed to be biocompatible and, therefore, they can be deployed in the environment in relatively large batches; 3) they are insoluble and, therefore, smaller amounts can be used to trace flows as compared to liquid dyes and chemicals such as salt; 4) they are buoyant so that they can be detected using automated recording systems.

The major advantages of the proposed methodology against currently available approaches are: 1) a relatively small amount of fluorescent particles can be deployed in the environment to provide reliable measurements and 2) observations are nonintrusively performed without the need of probes. These features enable the methodology to be applied in adverse conditions, such as heavy floods and inundations. Traditional approaches, such dye and salt tracing, can provide reliable results only at smaller spatial scales. In addition, they can be harmful for the environment, if deployed in large quantities, and cannot be easily detected during floods and severe weather conditions.

Given the great potential of fluorescent particles, we have addressed and verified their visibility and detection in both controlled laboratory conditions and natural settings. Specifically, the first two papers (Tauro et al., 2010, 2011b) are devoted to basic laboratory tests to verify the bead visibility and their accuracy in tracing different flow regimes. We have also developed detection and tracking procedures and have validated them through laboratory analysis.

We have then resorted to field studies and designed two proof-of-concept experiments for validating the proposed approach in relevant and complementary hydrologic conditions. Indeed, stream and overland flows present inherently different flow characteristics and widely varying practical problems. In particular, stream flows are typically characterized by considerably higher flow velocities than overland flows. Stream flows are not generally affected by the presence of vegetation and turbidity therein is lower than natural rills. Challenges in detecting the particles in such conditions are mainly due to: 1) high velocity regimes; 2) presence of foam; and 3) light reflections. Particles

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of diameters up to a few millimeters can be deployed in stream flows to compensate for such high flow rates. On the other hand, the detection of particles in overland flows is mainly affected by: 1) presence of vegetation; 2) high turbidity loads; 3) interaction of the particles with soil sediments; and 4) interaction of rain drops with the flow. Such challenges posit the use of the smallest beads that can be detected by the camera.

Therefore, the main objectives of the present paper are to assess the visibility of fluorescent particles of different diameters and to understand the weaknesses of the procedure to provide guidelines for future research. From our investigation, we have found that the main weaknesses of the methodology are:

- illumination conditions;
- quantity of particles to deploy;
- environmental impact of the particles.

Conversely, our methodology has demonstrated the following advantages:

- ability to observe particles as small as  $70\mu\text{m}$  in diameter;
- flow estimates obtained through the use of the largest fluorescent particles are comparable to results with Rhodamine dye.

Future and ongoing research will address many of the raised problems. Specifically, the following directions are currently being pursued:

- new bio-compatible, bio-degradable, and low cost fluorescent particles are being fabricated and laboratory and field tests are currently in progress. This will allow to deploy larger quantities of particles in the environment at lower costs;
- miniature cameras are being tested to mitigate the illumination problem. Specifically, cameras will be located below the lamp unit in the experimental apparatus, thus reducing confounds from light reflections;

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- different fluorophores excited in a broad range of wavelengths are being tested. This amelioration will allow for using more portable lamps and reducing the total cost.
- an extensive field campaign is being planned to quantify the uncertainty of the observations and to automate the procedure.

We hope that the detailed reply to each of the Reviewer's comments and the above statements have provided more details to the reader on our methodology and have shed light on the modifications that will be addressed to the manuscript.

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