

Do we still need a human? Geomorphic analysis and interpretation of river systems in an age of emerging technology and big data.

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Key Points

- Emerging technologies and big data open up opportunities for landscape and river analysis like never before.
- Emerging technologies and big data open up opportunities for landscape and river analysis like never before. It is therefore timely to reflect on whether a human is still needed to undertake such analyses? The answer is yes!
- We still need humans to:
 1. have the conceptual grounding and training to ask significant scientific and management questions
 2. select the right tool for the job
 3. collect the right data using the technology available (or decide to use traditional methods)
 4. interrogate and interpret the output
 5. verify the output in the field (make sure it's real)
 6. make well-informed river management decisions that are place-based
- We use the case study of the River Styles Framework to discuss where opportunities lie for emerging technology and tools to be 'plugged in' to the process

Abstract

The era of big-data acquisition and semi-automation of geomorphic river surveys is transforming how we see and analyse riverscapes. It is therefore timely to consider how to better integrate these analyses into existing and widely used conceptual frameworks and consider to what extent a human is still needed in the process. We demonstrate how the River Styles Framework, which entails identification and interpretation of river character and behaviour, condition and recovery, can be used as a 'powerboard' into which available, developing and future semi-automated tools and workflows can be plugged (or unplugged). Prospectively, such approaches will increase the efficiency and scope of analyses. We appraise the role of human decision-making in conducting expert-manual analyses and interpretations. Luckily, humans are not yet redundant! We are needed to choose the right tools for the job, interrogate and validate output(s) in the field, and make geomorphic and management interpretations. Genuine integration of big-data analytics, remote-sensing based tools for semi-automated river analysis with expert-manual interpretations including field insights, will be an essential ingredient to advance our understanding of rivers, to translate information into knowledge, and raise the standards of practice in river science and management.

Keywords

Big data, remote sensing, interpretation, reading the landscape, River Styles

Introduction

Geomorphology is an interpretative science, for which abductive reasoning underpins many analyses (Brierley et al., *subm*). But, there are many different ways of reading and interpreting the landscape. In geomorphic terms, simple differentiation can be made between remotely-sensed and field-based approaches. Both approaches are vital; indeed, they are complementary. If we care about the health and status of our rivers, we need a full toolbox of understandings to help guide management and planning, particularly in the 21st Century.

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In recent decades there has been an increasing reliance on remote sensing datasets and geographical information systems (GIS) to inform the geomorphic analysis of river systems as the discipline transitions towards an era of big-data generation (Piégay et al., 2020). Since the advent of Google Earth (GE) in particular, and the provision of geospatial data by national environmental bodies for public use, the availability of free or low-cost remote sensing data has increased exponentially. Data derived from satellites, drones, and on-ground scanners and sensors are transforming not only our ability to analyse and quantify landscape characteristics, but to view landscapes in dimensions and detail like never before. Our capacity to work across scales is now unprecedented, making catchment-scale analyses of river systems (and associated management) a more tractable task.

In parallel, recent decades have also seen the emergence of a number of riverscape interpretation frameworks; that document the geomorphic (or hydromorphic) context of a river system. These include classification and characterisation frameworks, nested hierarchical frameworks, and habitat assessment frameworks (Belletti et al., 2015; Brierley & Fryirs, 2005; Kasprak et al., 2016; Rinaldi et al., 2015). Typically these frameworks have, at their core, a conceptual structure and sequence of activities/steps that scaffold and build layers of evidence, analysis and interpretation about riverscape form, process, condition and trajectory. In many parts of the world, river management agencies have adopted such frameworks to aid in prioritisation, decision-making and on-ground conservation, restoration or rehabilitation activities (e.g. Fryirs et al., 2021). Tools and workflows can be plugged-in to these frameworks to help increase the efficiency and accuracy of geomorphic analysis of river systems (Fryirs et al., 2019).

This paper asks the reader to take time to reflect on these rapidly developing practices, to consider the effectiveness and efficiency with which emerging technologies and tools can (or cannot) be used to semi-automate the geomorphic analysis of rivers while also considering the fundamental need for reality checking, verification in the field and human interpretation skills to ensure the outputs make sense on-the-ground. This is even more important in an era where singular ‘black box’ answers are desired by authorities because they appear to be more robust and where the excess of data problem can blind users or send them down alley ways from which they cannot escape (topics for another paper!). We ask the reader to also pause and consider how a balance can be struck between automation and human skill, particularly in a post-COVID era where fieldwork budgets are cut, remote and virtual work escalates, and connection to place, people and culture arguably wanes.

As a river management profession and industry we need to ensure that these checks and balances are continually put in place and suitably qualified practitioners are undertaking the analyses, the QA/QC checks and implementation with stakeholders in-place. This is particularly important when such analyses and outputs are increasingly used in river management and restoration practice.

As a demonstration in this paper, we use the River Styles Framework, to highlight which parts of this analysis can (and cannot yet) be semi-automated. We outline some of the tools and workflows that are available to semi-automate analyses. Using the analogy of a powerboard, we demonstrate the need for a more integrated approach to analysis of rivers and provide a perspective on the importance of situating the River Styles Framework (and others like it) in an age of big-data. Balancing this, however, we also call for the ‘baby not to be thrown out with the bathwater’. Human skills at reading and interpreting the output and reading and interpreting landscape in the field are still fundamental to the process.

The powerboard and its tools: How much geomorphic analysis can be automated?

Here we use the River Styles Framework as our demonstration. The Framework has four stages; 1) catchment-wide baseline survey of river character, behaviour, patterns and controls, 2) catchment-framed assessment of river evolution and geomorphic river condition, 3) assessment of future trajectory of adjustment and geomorphic river recovery potential, and 4) catchment-framed vision building, and prioritisation of management efforts.

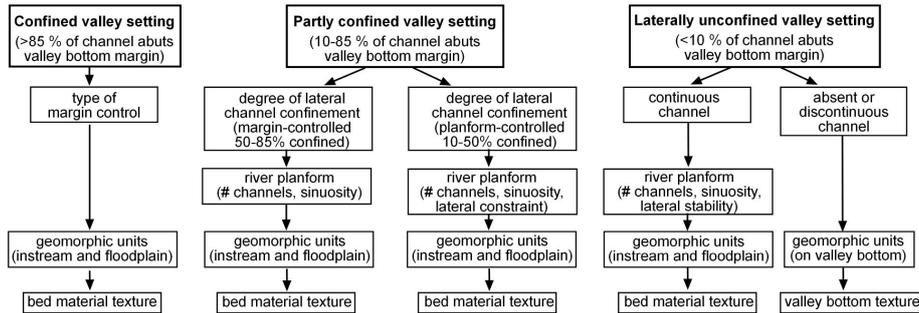
Analysing and interpreting river character

Stage 1 of the River Styles Framework is used to identify, characterise and interpret the behaviour of river types across the spectrum of river diversity. Four measures are used, set within a hierarchical approach to

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analysis (Figure 1A); valley setting, river planform, geomorphic units and bed material texture (Brierley & Fryirs, 2005).

(A) The powerboard - Stage 1, Step 1 River Styles procedural tree



(B) Available tools and workflows to plug-in to the powerboard

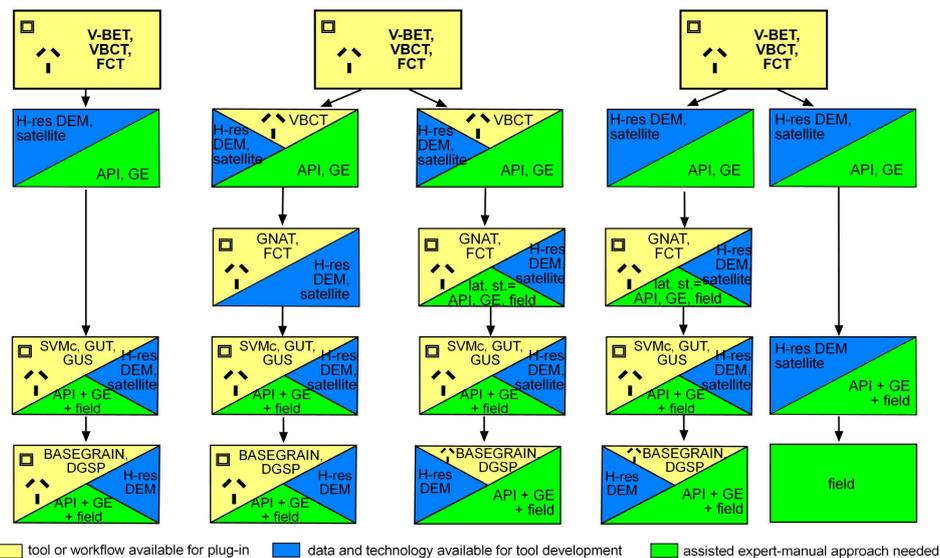


Figure 1. The Stage 1 River Styles procedural tree and powerboard depicting the range of tools that are available for semi-automation and where tools are not yet available and a human is still needed. Source Fryirs et al. (2019).

The hierarchical structure of the Step 1 River Styles procedural tree means that as tools and workflows are developed or improved they can be plugged-in at a level to match the resolution of the data being used and the scale at which the analysis is being conducted (Figure 1B). Conversely, if a tool or workflow becomes obsolete, superseded or no longer fit for purpose it can be unplugged or replaced in the approach. Additionally, if a tool is not yet available (or has been unplugged) then it is obvious to a user that the expert-manual approach to analysis is needed that employs traditional methods. This highlights the importance of having a conceptual framework and approach to analysis in place that can act as the ‘powerboard’ to underpin the geomorphic analysis of rivers.

Figure 1 maps some of the tools and approaches that are already available, those that will come soon, and where a human is still needed for the foreseeable future. In Figure 1B, each box matches a box in Figure 1A. For links to the available tools please refer to Table 1 in Fryirs et al. (2019). Yellow shading represents a socket where a tool or approach is currently available to undertake analysis. Blue shading is used where the data and technology are available for tool development. Green shading is used where an expert-manual approach to analysis is still required. What Figure 1B shows is that it is possible to get some ways into the geomorphic analysis of river type using existing tools and workflows, particularly at coarser scales and at higher levels in the hierarchy (i.e. valley confinement). The further into the tree and analysis one goes, the greater the reliance on the more traditional expert-manual approach. However, even in instances where a tool exists, they occur on a gradient from conceptual prototypes (only deployable or able to be plugged-in by the programmer who developed it) to operational research-grade tools (which work but require expertise to run), to more polished

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production-grade professional software (e.g. Geomorphic Change Detection (GCD)). **Figure 3** shows some of the possible outputs from use of these tools.

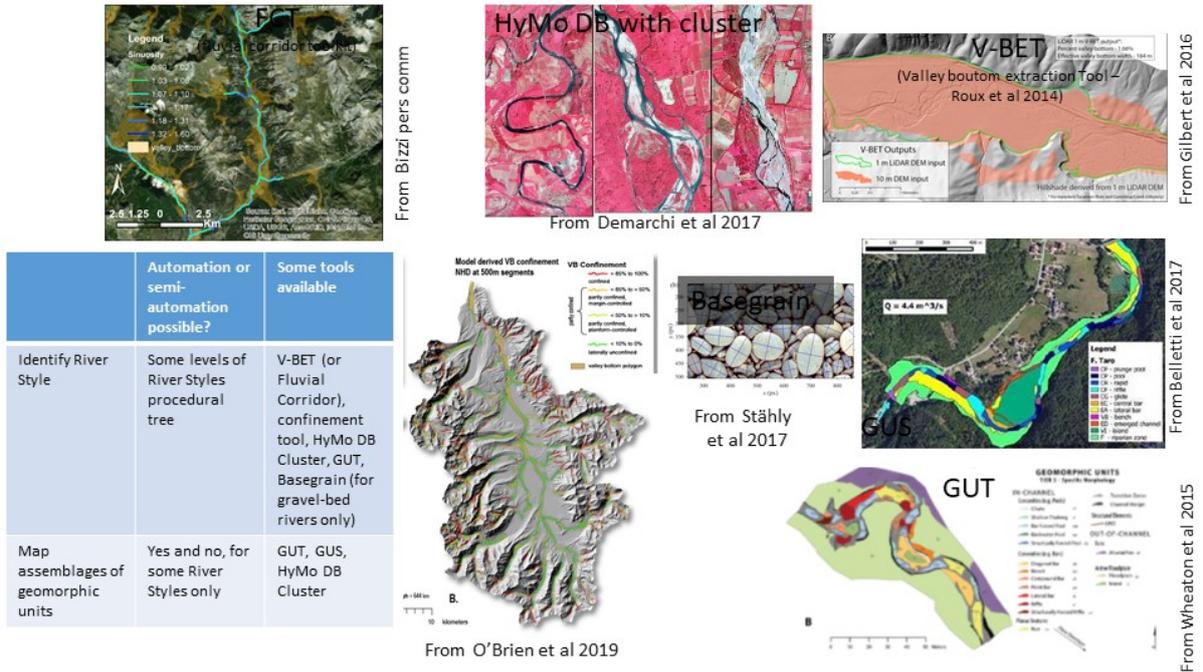


Figure 2. Extent of possible automation and examples of outputs for analysing river character, for example, valley confinement and setting, channel planform, geomorphic units and bed material texture.

Analysing and interpreting river behaviour

For analysis and interpretation of process and river behaviour another set of tools and skill-sets are required. To date, this step is at the forefront of remote sensing applied to river geomorphic analysis (Marcus & Fonstad, 2010; Guillon et al., 2020) and semi- or full-automation procedures are being explored (Figure 3).

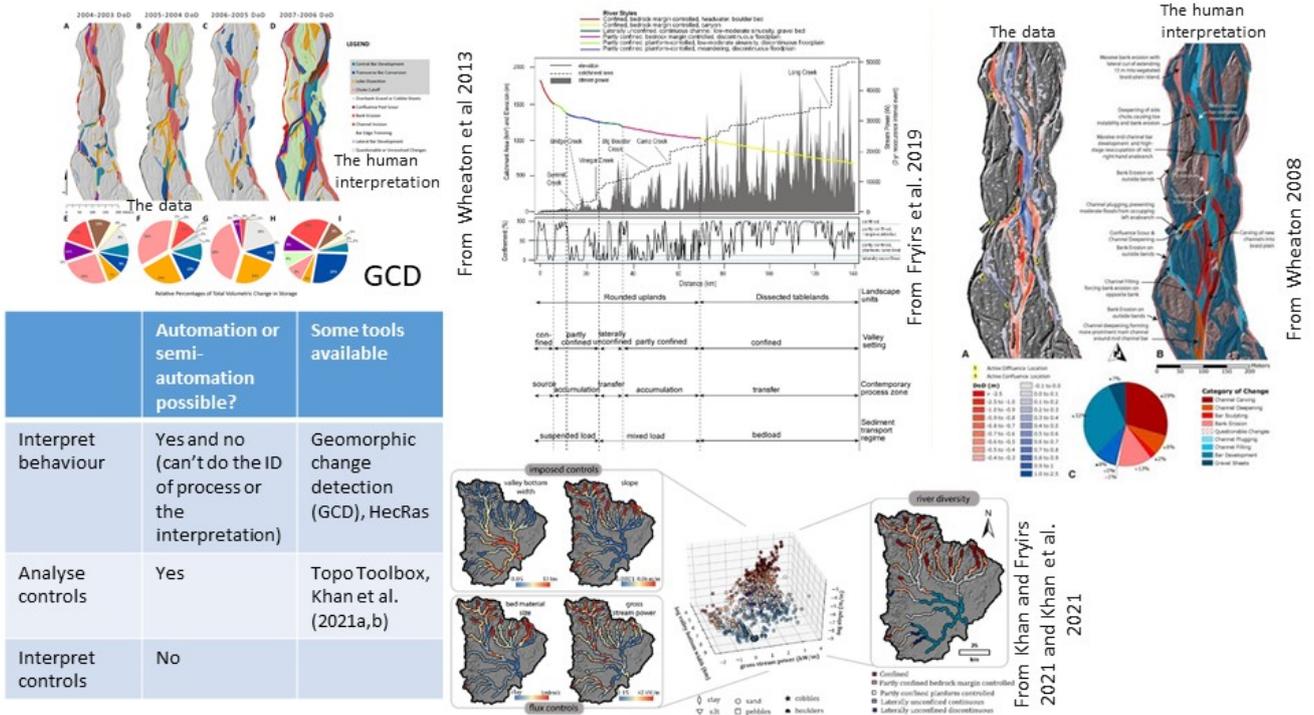


Figure 3. Extent of possible automation and examples of outputs for analysing river behaviour, patterns and controls, for example, analysis of erosion-deposition processes, producing stacked longitudinal profiles and quantifying controls on river diversity.

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For example, multi-temporal aerial photography and satellite imagery are available to undertake analysis of lateral channel dynamics for rivers with notable geomorphic adjustments. Horizontal scales of detection are a function of imagery resolution; for example, LANDSAT, Sentinel-2, PlanetScope and Worldview3 satellites have resolutions of 30, 10, 3-4 and 0.31 m respectively. The unprecedented frequency of data acquisitions mean there is potential to track geomorphic adjustments daily or sub-weekly. Google Earth Engine (Gorelick et al., 2017; Boothroyd et al., 2021) is likely to enable spatial and temporal upscaling of existing tools.

For the analysis of morphologic change, Geomorphic Change Detection (GCD) already provides a helpful tool/workflow to aid interpretations (Wheaton et al., 2010, 2013, Williams et al., 2020; **Figure 3**). However, as **Figure 3** highlights, an expert-manual approach is still needed to translate erosion-deposition dynamics and match this with the geomorphic units that are being formed and reworked to then categorise the processes (and by extension, behaviour) and map areas of adjustment or change (Wheaton et al., 2013; Williams et al., 2015).

Analysing downstream patterns and controls

Any analysis of river character and behaviour should be placed within a catchment-scale context. Knowing the position of a reach within its catchment and the pattern of reaches that occur along longitudinal profiles sets context, and aids interpretation of why that type of river occurs where it does (Brierley & Fryirs, 2005). Some parts of this analysis can already be fully automated (**Figure 3**). For example, longitudinal profile generation can be automated using the MATLAB program Topo Toolbox or using ArcMap stacked profile tool as examples. However, once produced, the interpretation of the plots still needs to be undertaken using the expert-manual approach.

Potential extensions into analysis of geomorphic condition and recovery potential

In the River Styles Framework, catchment-wide appraisals of river character, behaviour and pattern conducted in Stage 1 provide the foundations for systematic analyses of geomorphic river condition and recovery potential in Stages 2 and 3, prior to considering management applications in Stage 4 (Fryirs, 2015; Fryirs & Brierley, 2016). Methods for undertaking high level automation of some geomorphic condition metrics is emerging in industry (e.g. Vietz, this volume). However, it still requires significant human intervention to establish ‘what is good’, what to measure and how to make the interpretation. Recovery analysis that builds upon catchment-wide analysis of river evolution and changing connectivity relationships is maturing (Fryirs, 2013). With rapidly emerging datasets, analytical and modelling approaches, such analyses can be integrated with, and build upon, historical (decadal) studies of channel adjustment (Bizzi et al., 2018). These appraisals are readily facilitated by analysis of satellite imagery and derived quantitative assessment of the pattern/extent of channel adjustment on the one hand, or using geomorphic change detection (GCD) techniques on the other (**Figure 4**). Moreover, if historic aerial images are of sufficient image resolution and overlap, quantitative three-dimensional analyses of river geomorphic adjustment and condition are achievable. When combined with insight from spatially distributed observations and numerical predictions of sediment transport rates and volumes the analysis of fluvial morphodynamics and can inform river management decision making (Schmitt et al. 2016; Frings and Ten Brinke, 2018). Such work is now directly utilised in analysis of flood risk and forecasting where delineation of areas of floodplain inundation and erosion hotspots are used to define ‘erodible corridors’, ‘space to move’ and ‘event-scale morphodynamic corridors’ (Piégay et al., 2005; Rinaldi et al., 2015; Czuba et al. 2015).

Is a human still needed to undertake geomorphic analysis of riverscapes?

The geomorphic analysis of rivers will never be fully-automated. While significant progress has been made to develop tools and workflows that can help make the process more efficient, scaleable and less-qualitative, much of what has been developed to date can only assist an expert to undertake analyses and interpretations and has occurred independent of an integrating platform or framework to plug into. In 2021, we suggest that the field is still situated in an expert-manual approach for the analysis of riverscapes.

We recognise that some of the tools noted in this paper will not yet perform well in some settings, largely due to insufficient data resolution, or the need for a new tool to be developed (e.g. high-energy mountain streams or lower order confined rivers). However, in coming years it is highly likely that as emerging technologies and

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data resolution improve, and processing speeds increase, much of the initial, baseline survey of rivers will become semi- or fully-automated, and new plug-in tools will be available to undertake, at least, a first filter of the types, distribution and behavioural attributes of rivers we see in our landscapes. The potential roll out of such tools across networks (and regions) is a partial reality.

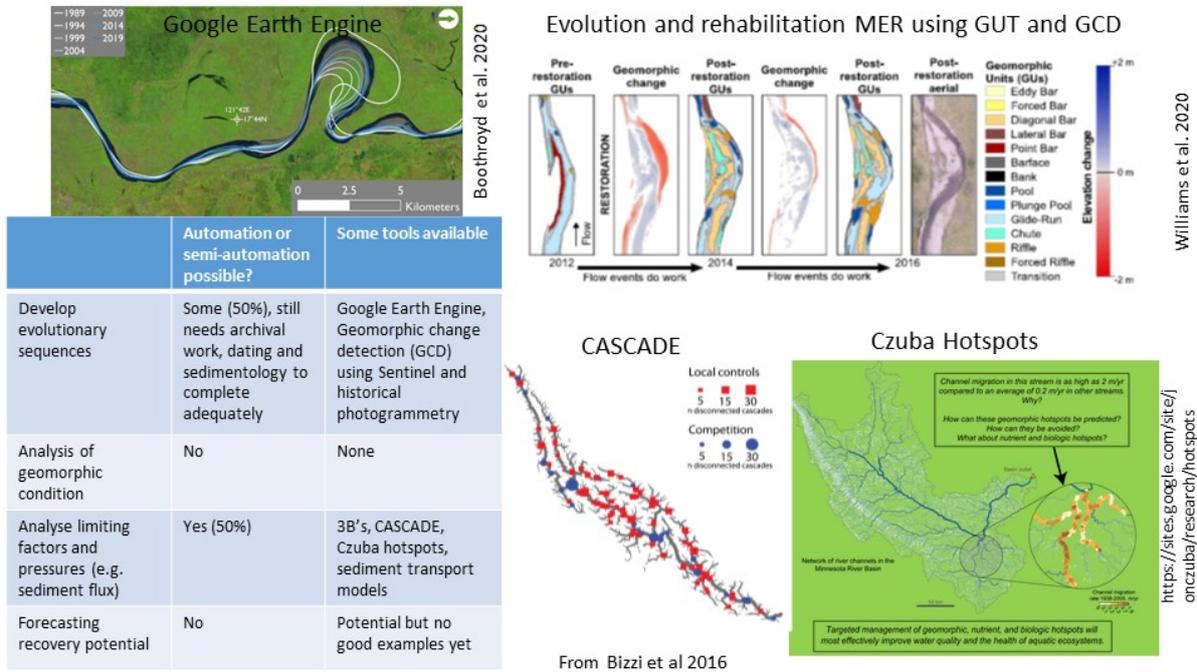


Figure 4. Extent of possible automation and examples of outputs for analysing river evolution, condition and recovery potential.

Currently, to take the next step and analyse process and behaviour, an expert is required to interpret erosion-deposition or change detection outputs and to place this analysis in a spatial and temporal context. It is likely that in the coming years remote sensing derived products, tools, analysis procedures will be used not only in Stage 1 but also Stages 2 and 3 of the River Styles Framework allowing the characterisation of historical condition and trajectories, and the prediction of future ones for use in analysis of river condition and recovery.

There will always be a fundamental need for the results of such work to be contextualised and interpreted by an expert. In many cases, there will also be a need for experts to field-verify and validate the approximations derived using such models. A geomorphologist is required to check that what is produced through the semi- or fully-automated process makes sense on-the-ground. This is particularly important when outputs are used by environmental management agencies and local communities to make decisions about prioritisation, resourcing and on-ground rehabilitation activities. If the output does not make sense in their ‘place’ then the likely uptake and utility of such products will be limited to the academic arena.

A human is still needed in many parts of the process and this will continue to be the case into the foreseeable future. Humans are still needed to:

- continue to develop new tools and approaches to analysis of big data;
- carefully choose a coherent, scaffolded framework or approach to plug the tool into;
- have the conceptual grounding and training to ask the right questions;
- collect the right data, measure the right things, at the right spatial and temporal scales to answer the questions;
- choose the right tool or workflow for the job;
- carefully consider whether current data and tools are ‘good enough’ for some analyses (or choose to use traditional methods);
- interrogate and interpret the output (check its validity in the field);
- manage datasets and their storage;
- make resourcing and conservation or rehabilitation decisions;

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- set the appropriate project or rehabilitation objectives; and
- undertake place-based, community integrated, river management on-the-ground.

Conclusions

A delicate balance needs to be struck in moving the geomorphic analysis of rivers forward in light of the technology and big-data revolution. As a discipline we cannot allow the technology to drive the questions and outputs, but we do need to use the latest technology and big-data to answer questions of significance, whether scientific or managerial. We call on the geomorphology community to carefully consider how we might work more collaboratively to share tools and findings to support the democratisation of knowledge.

The River Styles Framework is one of several frameworks to analysis and interpretation of rivers into which the right tools can be plugged to automate the process. Our capacity to develop and integrate such tools into this (and other) frameworks as part of collaborative research and development, as well as on-ground application of findings is an exciting challenge for the fluvial geomorphology and river management community going forward into the 21st Century.

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