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SHORT COMMUNICATION

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ABSTRACT

Scientific research is often targeted towards predicting broad-scale patterns in biophysical variables, with spatial data traditionally communicated using static figures and written descriptions in scientific journals and reports. However, inaccessibility and lack of flexibility mean that these communication methods have often hindered research uptake by resource managers and decision-makers. We used *R shiny* to develop an interactive webtool that maps estimates of 109 biophysical variables, including hydrology, ecology and water quality metrics across the New Zealand digital river network. *NZ River Maps* is freely available online and can be used to visualise regional patterns, identify site-specific characteristics and overlay regional planning layers. Interactive webtools improve on traditional communication methods by allowing inspection of predictions for selected sites and plotting of spatial patterns. The ability to quickly visualise and quantify relevant spatial data has enabled better communication of research outputs to provide robust and transparent inputs into environmental management.

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Introduction

The availability of large-scale spatially-explicit environmental data and advances in predictive modelling techniques have allowed researchers to generate predictions of biophysical variables over large spatial areas. For example, New Zealand's digital river network has been used to generate national-scale predictions for a variety of variables, including hydrological indices (McMillan et al. 2016), wetted width (Booker 2010), invertebrate communities (Booker et al. 2015), periphyton cover (Snelder et al. 2014), physical habitat for fish (Booker 2016), and the probability of occurrence of various fish species (Leathwick et al. 2008). However, these predictions have typically been presented as static figures within published papers (Figure 1). This form of communication means that such figures, and the data used to construct them, cannot easily be accessed or used by other researchers, decision-makers or local practitioners, such as river managers. This inaccessibility is particularly problematic where legislation calls for community participation within the environmental planning framework (e.g. Ministry for the Environment 2014). Previous options for data provision included making raw datasets available for download and

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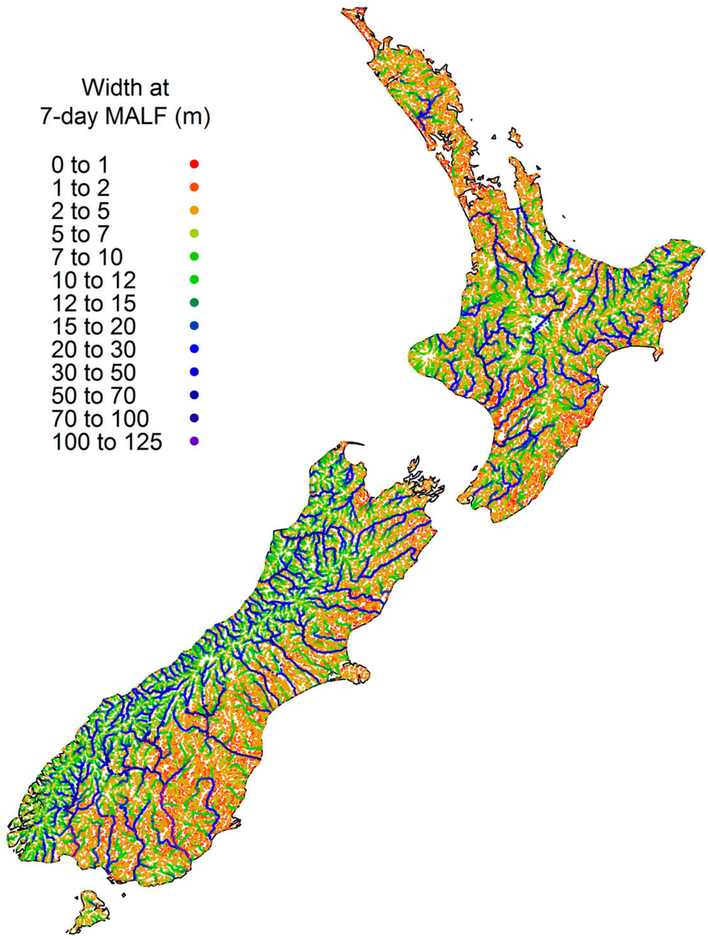

Figure 1. Typical static image of spatial data published in papers and reports, showing estimates of wetted width at 7-day MALF (mean annual low flow) at stream reaches of Strahler order 3 and above (Booker, 2015). While readers can view national and regional patterns, it is not possible to interrogate estimates at the local scale or access individual data values.

developing specialised software applications to visualise results (Table 1). However, these options are not without their limitations. Datasets may be of limited value if potential users are not sufficiently skilled to use them appropriately. Additionally, researchers may lack the time or skills to develop specialised software to display their findings, whilst outsourcing this work may result in a product that is not easily updated when scientific knowledge advances. Therefore, improved communication of environmental data is required to improve the democratisation of data and inform decision-making (Sawicki and Craig 1996).

The rapid and recent development of the *shiny* package (Chang et al. 2016) in the R Statistical Environment (R Core Team 2017) provides an opportunity for researchers to create interactive methods of visualising data and research results for sharing with potential users. In this paper, we outline the benefits of applying interactive methods using examples from an interactive webtool we developed. This webtool allows non-specialist

Table 1. Comparison of traditional options for sharing research outputs with readers and potential end-users for inclusion in decision-making processes.

Research outputs	Advantages	Disadvantages
Static image in paper or report	• Easy to produce using standard graphics packages • Detailed data methodology and limitations can be provided	• Typically shows data at coarse scales with no option for interrogating data at different spatial or temporal scales • Journal articles and reports not always accessible
Oral presentation	• Methods and limitations can be provided • Targeted to specific audiences • Users can ask specific questions	• Available to a limited audience
Provision of data	• Users can visualise and interrogate data as required • Digital repositories available for storing data online	• Researcher may get many data requests • Potential copyright & intellectual property issues • Requires user skill to interpret and visualise data appropriately
Equation describing relationship	• Can be applied to other datasets	• Requires user skill to interpret and visualise equations appropriately • Requires users to have data
R package	• Can share data and analytical methods	• Requires users skilled in R Statistical Environment
Geographic Information System	• Provides a method for spatial mapping and geoprocessing of new or existing datasets	• Requires users skilled in GIS software
Specialised software development	• Provide interactive options for users to interrogate data • Can be customised to be fit-for-purpose	• May be difficult for researchers to develop, distribute and maintain software files • Requires specialist software developers • May require administrative rights to install software • May result in expensive proprietary software

users to visualise data that previously resided in multiple journal articles and technical reports. We anticipate that interactive displays of data previously unavailable to resource managers will bridge a communication gap by making scientific research output more accessible and understandable. In this paper we highlight how researchers can create interactive webtools using the R Statistical Environment to communicate spatial information and discuss the advantages of using such a platform.

Methods

We developed an interactive webtool, *NZ River Maps* (https://shiny.niwa.co.nz/nzrivermaps), that allows users to display and interrogate national-scale estimates of biophysical variables predicted across the entire New Zealand river network (Booker and Whitehead 2017). This section describes the data displayed by the webtool, webtool development, and the utility of the webtool.

Modelled data

We collated a database of 109 national-scale estimates of biophysical variables predicted across the entire New Zealand river network (Table 2). These data had previously been displayed as equations (e.g. Booker 2010) or figures (e.g. Booker and Woods 2014) in 15 journal articles and technical reports. In some cases, the data were also downloadable from online data portals (e.g. https://data.mfe.govt.nz/). We wished to make them publicly available in a user-friendly format, thereby facilitating their use and application.

The estimates were generated using the New Zealand digital river network (Version 1): a representation of 576,277 reaches (a section of river between two confluences) that describe the spatial configuration and characteristics of New Zealand's rivers (Snelder and Biggs 2002). While the national estimates were predicted using different statistical methods and predictive variables, all studies used a similar general approach (Figure 2). First, field

Table 2. National-scale estimates of biophysical variables available for users to interactively map and interrogate within NZ River Maps.

Category	Variables	Source
River Environment Classification	Classes within the River Environment Classification that describe climate, topography, geology, land cover, network position, valley landform. Also includes distance to the sea, stream order, upstream catchment area, catchment name	(Soil Conservation & River Control Council 1956; Snelder and Biggs 2002)
Hydrology	Metrics describing the hydrological regime, including one in five-year low flow, mean annual low flow, median flow, mean flow, proportion of flow in February, FRE3 (average number of events per year that exceed three times the median flow), month with the lowest mean flow	(Booker and Woods 2012, 2014; Booker 2013)
River width	Wetted width across the river channel (m) at different flow statistics, including mean annual low flow, mean flow, median flow, one in five-year low flow	(Booker 2010)
Bed sediment cover	Proportion of river bed area predicted to be covered by different sediment classes, including mud and vegetation, sand, fine gravel, coarse gravel, cobble, boulder, bedrock	(Haddadchi et al. 2018)
Sediment load	Suspended sediment load	(Hicks et al., 2011)
Water chemistry	Median predictions of water chemistry variables, including total nitrogen, clarity, total suspended solids, turbidity, water temperature, dissolved oxygen, E. coli, ammonium nitrogen, nitrate nitrogen, dissolved reactive phosphorus, total phosphorus	(ANZECC & ARMCANZ 2000; Unwin and Larned 2013)
Macroinvertebrates	Median predictions of macroinvertebrate health indices, including taxon richness, Macroinvertebrate Community Index (MCI), EPT taxon richness, % EPT	(Unwin and Larned 2013; Booker et al., 2015)
Fish presence-absence	Predicted presence or absence of a given fish species, including alpine galaxias, banded kokopu, bignose galaxias, black flounder, bluegill bully, brook char, brown trout, Canterbury galaxias, chinook salmon, Clutha flathead galaxias, common bully, common smelt, Crans bully, dwarf galaxias, flathead galaxias, gambusia, giant bully, giant kokopu, goldfish, Gollum galaxias, inanga, koaro, lamprey, longfin eel, northern flathead galaxias, rainbow trout, redfin bully, roundhead galaxias, shortfin eel, shortjaw kokopu, torrentfish, upland bully, upland longjaw galaxias	(Crow, Booker, Sykes, Unwin, and Shankar 2014)
Fish habitat	Availability of suitable physical habitat (m) according to the suitability criteria of Jowett and Richardson (2008) for a given fish species at the mean annual low flow and relative to the mean wetted width. Species include brown trout, koaro, longfin eel, shortfin eel, smelt, torrentfish	(Booker, 2016)
Bird habitat	Predicted habitat suitability for whio (blue duck)	(Whitehead 2009)
Resource use	Consented water abstraction	(Booker et al. 2016)

measurements of the response variable were collated and assigned to reaches on the digital river network. Then a statistical model was used to determine the relationship between the response variable and relevant available landscape- and reach-scale variables. Finally, the derived relationships were used to predict the response variable across the river network. A list of response variables and references to the original studies can be found in Table 2.

Webtool development

Our priority was to create a webtool that easily conveyed complex spatial information to non-specialist users, as well being easy to maintain and update without the need for specialist software designers. We chose to use the *shiny* package available for the R Statistical Environment (Chang et al. 2016; R Core Team, 2017). *Shiny* builds on the functionality and flexibility of the R Statistical Environment without requiring developers to be fluent in web-specific programming languages, such as HTML, CSS or Java, and provides tools for creating interactive web content that responds to user-inputs.

We used the *shiny* package to create complex layouts and add functionality like mapping (using the *leaflet* package, Cheng et al. 2017) and graphics that are dependent on a user's choices (Figure 3). For example, users can zoom into a map to interrogate data or use dropdown boxes to change the mapped variables. We used this functionality to create two main panels: a main map panel and a side panel (Figure 3).

The Map Panel allows users to visualise a range of spatial data, including NIWA's national estimates, some publicly available Regional Council layers and a simplified version of the river network. These data can be turned on and off using checkboxes in the top right of the map panel. Estimates are mapped at the reach-scale, where circles represent the centre of a reach and the size indicates the stream order. Each circle is coloured by the estimated value of the selected variable. Users can click on individual circles to view the estimated value in a popup box (Figure 3c).

The Side Panel contains tabs that allow users to adjust how data are displayed. Users can select the *Options* tab to switch between variables, transform the data to allow

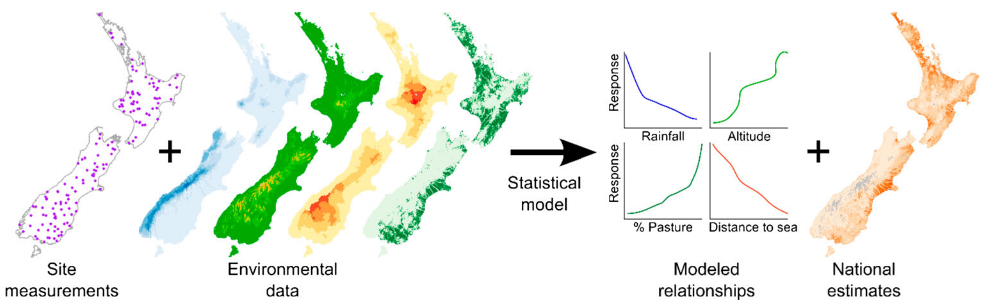

Figure 2. Schematic diagram showing the modelling process used to generate the national-scale estimates of environmental and ecological variables across the New Zealand river network. Site measurements of each response variable were combined with environmental data in a machine-learning model (typically random forest or boosted regression tree models) to identify the relationship between each response variable and the environment. These relationships were then applied to all reaches of a national digital river network to make predictions of the response variable. Details about each modelled response variable are described in the references contained in Table 2.

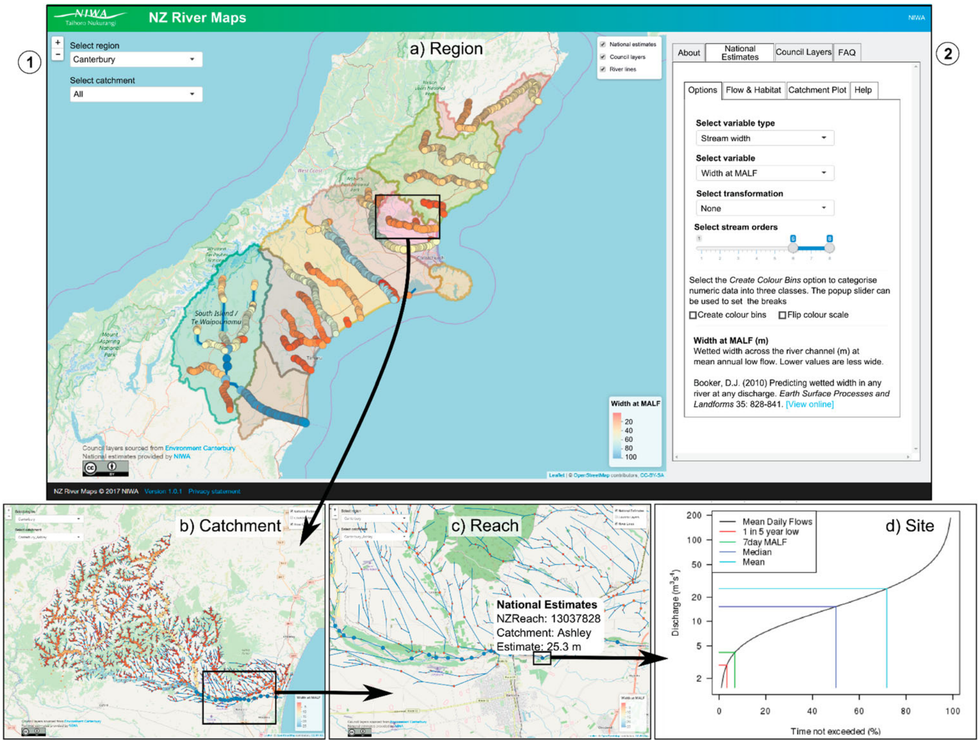

Figure 3. NZ River Maps (https://shiny.niwa.co.nz/nzrivermaps) is an interactive webtool that allows users to map and interrogate many biophysical variables estimated on the New Zealand digital river network. Users can choose how variables are shown on the map panel (1) by using dropdown boxes and slider bars on the side panel (2), zoom to individual a) regions, b) catchments or c) reaches, and interrogate and produce plots of d) site-specific data. Information about each variable, including a reference to the original data source, is provided in the side panel (2).

better differentiation between sites, and change the number and size of reaches that are plotted using the stream order slider. This tab also provides a description of the selected variable and the reference (and link where available) of the original publication for more information about how the biophysical variables were calculated. Users can click on individual reaches to access their estimated flow duration curve and weighted usable width for several fish species under the *Flow and Habitat* tab, while the *Catchment Plots* tab lets users graph estimates of two estimated variables upstream and downstream of a selected reach.

NZ River Maps also provides some publicly available regional council layers relevant to freshwater management, including regional planning data and areas of natural, recreational or ecological importance. These spatial data are represented on the map as polygons, lines or points depending on the underlying data type. Each feature (e.g. an individual point or polygon) is coloured by the metadata provided in the layer, as indicated by the map legend. Users can map these data and produce summary plots of the selected national estimate, both within a selected feature and within all features in the selected spatial layer.

We also embedded Google Analytics into the webtool. This functionality allows us to measure user dynamics, including how many users visit the site, where they come from and how long each visit lasts. Users can provide feedback via a dedicated email address, with early comments leading to design changes that improved functionality.

Results

NZ River Maps has had steady visitor traffic since its launch, with over 3,559 users from 55 countries at the time of writing. Most users are from New Zealand and typically visit for 6.8 ± 8.3 (mean ± standard deviation) minutes, although some stay for up to 70 minutes. Most users accessed NZ River Maps using a Windows-based desktop, with Google Chrome being the most popular internet browser.

Discussion

Providing interactive methods for visualising spatial data offers an opportunity for expert and non-expert audiences to gain better insights into the patterns and complexity of the data that cannot be accessed from static images (Valero-Mora and Ledesma 2014; Ellis and Merdian 2015). These advantages, and the availability and ease of use of the *shiny* package, have resulted in the development of several interactive webtools within New Zealand, including tools to interrogate economic and social data at different spatial scales (MBIE and MfE 2018; The Treasury & Stats NZ 2018; MBIE 2018a, 2018b) and calculate ecological health indices (Zeldis, Plew, et al. 2017; Zeldis, Storey, et al. 2017; Zeldis, Whitehead, et al. 2017).

The development of NZ River Maps has enabled public access to a large and complex dataset that was previously only available as static images and descriptions in published papers and technical reports. When we designed NZ River Maps, we were interested in providing public access to national estimates of biophysical data predicted onto the New Zealand digital river network, with the hope that this availability might increase use of the data. Feedback from users indicates that, to date, NZ River Maps has been used for a wide range of purposes, including

- comparing estimated naturalised flow statistics (7-day mean annual low flow and 1 in 5-year low flow) with observed flow statistics to demonstrate the possible long-term effects of flow alteration (Jackson & Mager, 2017),
- screening of consent applications to abstract water from rivers by comparing the order of magnitude of maximum consented rate of take with flow regime characteristics such as mean flow,
- describing how patterns in the probability of occurrence of native fish species might relate to cultural values while talking with local indigenous communities,
- comparing estimated conditions (e.g. catchment area and wetted width) across a catchment when selecting field sites for research,
- querying estimated sediment loads into lakes,
- investigating bioremediation strategies,
- helping design field research campaigns, and
- inspecting whether a location is estimated to have stable substrate (gravels or cobble) versus soft substrate (silt or sand) and, therefore, could develop nuisance periphyton growth.

These application examples suggest that the availability of these data has informed scientific research, in addition to fulfilling our aim for the datasets to be easily used to inform environmental management. NZ River Maps is contributing to the democratisation of data by enabling users to easily access environmental data that would otherwise be unavailable to non-specialist audiences (Sawicki and Craig 1996).

Development and maintenance of NZ River Maps is funded through NIWA's Sustainable Water Allocation Programme as a method of communicating research results to a wider audience. In theory, a webtool does not require any maintenance after it has been uploaded. However, in practice, some on-going maintenance is needed in response to updates from web browsing software; a problem when sustained funding is not guaranteed. We plan to add new features and predictions as they become available, with all changes to the webtool described in a downloadable version control document. This documentation will ensure that users understand the potential implications of data updates, particularly important if data are being used in decision-making processes. In addition, we plan to continue surveying users to better understand their requirements, both with respect to data availability and the user interface of the webtool.

Conclusion

Providing easily accessible and interactive ways of visualising data online has the potential to enhance the use of scientific research by the public and resource managers, particularly when data are spatially distributed, complex and multi-faceted or inaccessible to many potential users. Recent technological advances enable researchers with some familiarity of the R Statistical Environment to quickly develop interactive applications that allow users to interrogate and visualise data in new ways. In turn, the accessibility of these online applications suggests that they are likely to be used by a broader audience than traditional forms of science communication, such as scientific papers and reports. These aspects have the potential to benefit researchers by increasing dissemination, understanding and application of their research findings by the wider academic community, resource managers and interested members of the public.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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