Making the invisible visible: the impact of federating groundwater data in Victoria, Australia

Peter Dahlhaus, Angela Murphy, Andrew MacLeod, Helen Thompson, Kirsten McKenna and Alison Ollerenshaw

ABSTRACT

The Visualising Victoria's Groundwater (VVG) web portal federates groundwater data for the State of Victoria, Australia, thus making legacy data, government datasets, research data and community-sourced data and observations visible to the public. The portal is innovative because it was developed outside of the government and offers real-time access to remote authoritative databases by integrating the interoperable web services they each provide. It includes tools for data querying and 3D visualisations that were designed to meet end-user needs and educate the broader community about a normally invisible resource. The social impact of the web portal was measured using multidisciplinary research that employed survey instruments, expert reference groups, and internet analytics to explore the extent to which the web portal has supported decision making by governments, industry, researchers and the community. The research found that single access, multiple data set web portals enhance capacity by providing timely, informed and accurate responses to answer queries and increase productivity by saving time. The provision of multiple datasets from disparate sources within a single portal has changed practices in the Victorian groundwater industry.

Key words | data interoperability, groundwater, social impact, spatial information systems

Peter Dahlhaus (corresponding author)
Angela Murphy
Andrew MacLeod
Helen Thompson
Kirsten McKenna
Alison Ollerenshaw
Centre for eResearch and Digital Innovation,
Federation University Australia,
University Drive,
Mt Helen,
Victoria 3350,
Australia
E-mail: *p.dahlhaus@federation.edu.au*

INTRODUCTION

Groundwater is a precious resource, however because it is hidden from view, the nature of groundwater can be misunderstood by non-scientists and is often the subject of myths (Price 1996). Globally, the expanding demand for groundwater to supply human consumption, energy and food production has led to groundwater resource overexploitation (Gorelick & Zheng 2015) with corresponding threats to environmental and ecological values (e.g. Nevill *et al.* 2010) and the sustainability of food production (e.g. Scanlon *et al.* 2012). As a result, groundwater exploitation in many countries is regulated by statutory requirements that increasingly consider the competing economic, social and environmental needs (e.g. Holman & Trawick 2011; AWA 2012; Fernandez *et al.* 2014; Gill *et al.* 2014).

Referred to as the New Digital Age (Schmidt & Cohen 2013), or era of Big Data (e.g. Boyd & Crawford 2012; Mayer-Schonberger & Cukier 2013) the present time period provides unprecedented opportunities for a deeper understanding and appreciation of our global environments, including hydrogeological environments. The volume of digital data on natural environments has grown exponentially, especially in the physical (e.g. Lynch 2008; Bell *et al.* 2009) and environmental sciences (e.g. Porter *et al.* 2012) where much of it is collected by sensors. The use of volunteered geographic information and citizen science is also rapidly expanding the volume of water and environmental data (e.g. Fienen & Lowry 2012; Werts *et al.* 2012; Sui *et al.* 2013; Little *et al.* 2015). In

doi: 10.2166/hydro.2015.169

addition, data availability has vastly improved as governments in many countries adopt open data policies (Zuiderwijk & Janssen 2014). Yet paradoxically, despite this unprecedented access to data, limitations remain on how to use these data to best develop water management policy and further the public understanding of groundwater science (e.g. Loch *et al.* 2014).

Part of the problem is the sheer range of information sources and volume of data that is available. In Australia for example, information and data on groundwater are distributed via dozens of web-portals, web-based geographic information system (GIS) tools, password protected portals, cloud storage, portable storage devices; hardcopy maps, theses, reports, newsletters, documents, videos and podcasts. Outside of the research community, this impressive resource of data, information and knowledge is largely ignored simply because most people do not have the knowledge, capability or desire to deal with the data deluge. Many people feel increasingly time-poor and even though there is a plethora of data available, there is little opportunity or desire to undertake the research required to bring available information together in ways that best answer the questions that will guide future planning for sustainable and equitable groundwater use.

To partially address these issues spatial data infrastructure (SDI) has been developed and deployed to federate groundwater data from disparate database sources into a single web portal thereby making data more easily discoverable. Globally, the Canadian Groundwater Information Network (GIN) was the initial exemplar that was developed using open geospatial standards and technologies (Boisvert & Brodaric 2012). Other examples include the European Commission's INSPIRE network (Uslander 2005), the United States National Groundwater Monitoring Network Data Portal (NGWMN) (ACWI 2013), the New Zealand SMART system (Klug & Kmoch 2014) and the Australian National Groundwater Information System (NGIS) (Iwanaga *et al.* 2013; BOM 2015). In all cases these portals are managed by the government agencies with the statutory responsibility for groundwater management.

By contrast, the Visualising Victoria's Groundwater (VVG) portal (www.vvg.org.au) was developed outside of the government by Federation University Australia (FedUni), to federate all known groundwater data for the State of Victoria, Australia. The initial purpose of the VVG portal was to assemble datasets for university research as well as make legacy data, community-sourced groundwater information and government datasets visible to the public. The portal was launched on July 12, 2012, by the Centre for eResearch and Digital Innovation (CeRDI) at FedUni in collaboration with international and national research agencies, state government departments, regional water authorities and industry partners. It is innovative because it offers real-time access to information and data that are normally invisible to most of the community. The system seamlessly integrates data and information using international data exchange standards, federating all or parts of groundwater databases with disparate schemas and stored on disparate systems, subject to the custodians' consent. Tools for data querying and 3D visualisations were developed to assist decision making and community engagement.

Arguably the most novel aspect of the VVG research project has been in evaluating the impacts of the web portal over its initial two years of operation, through a multidisciplinary collaboration between hydrogeologists, information technologists and social scientists. This team used a combination of tools including survey instruments, expert reference groups, and internet analytics to explore the following research questions:

1. How has the VVG project and web portal impacted at the industry and community level since the program commenced?
2. To what extent has the web portal supported decision making at the industry and community level?
3. In what way has the provision of current groundwater data been improved since the establishment of the VVG portal?
4. To what extent has the VVG portal been used to assist groundwater and catchment managers?
5. To what extent have there been increased productivity gains for industry and users of the web portal?

These questions are designed to test the value of the investment required to federate groundwater data from authoritative and trusted sources and then build the tools that allow groundwater information to be visualised. The value is assessed by the end users' adoption of the project and the practice change it creates.

SOURCES OF VICTORIAN GROUNDWATER DATA

Established as a Colony in 1851, the State of Victoria occupies 227,416 km^2 of the southeast Australian mainland (roughly comparable in size to Laos, Romania or the UK). Records of drilling by the Victorian Government commenced in 1884 and were published in a series of annual reports, generally referred to as the *Boring Records,* until 1965 (e.g. Langtree 1885; GSV 1965). The first comprehensive groundwater database was assembled by the Geological Survey of Victoria (GSV) in the late 1960s with the introduction of the *Groundwater Act 1969*, the first groundwater legislation for the State. From the mid-1980s onwards the hardcopy records were progressively transferred to a digital database, and included private wells licensed as groundwater bores, as well as groundwater investigation or observation bores drilled by other government agencies such as the State Rivers and Water Supply Commission (SRWSC) and the Soil Conservation Authority (SCA) and subsequent equivalents (although these agencies also kept their own bore databases).

Machinery of Government changes in mid-1988 saw the State bore database duplicated as statutory functions were divided between various departments. One copy was merged with several rural water authority databases to become the Victorian Groundwater Data Base (VGDB), which subsequently became the Groundwater Management System (GMS) and finally the Water Measurement Information System (WMIS) currently under the custodianship of the Department of Environment, Land, Water and Planning (DELWP). The other copy remained with the GSV and was developed into the Geological Exploration and Development Information System (GEDIS), which included the mineral, stone and hydrocarbon exploration bores, currently under the management of the Department of Economic Development, Jobs, Transport and Resources (DEDJTR). Although data exchange was attempted for a few years following the split, the databases ultimately grew into quite separate entities.

In the late 1970s the SCA developed a separate bore database for monitoring groundwater levels in observation bores that were constructed for salinity investigations, now under the custodianship of DEDJTR. In addition, several other bore databases that were developed by former public utility agencies (e.g. the State Electricity Commission, SRWSC, Country Roads Board, Victorian Railways, Ports and Harbours, etc.) have now been privatised. Although much of the historic groundwater data have been captured on the WMIS, a vast amount of hydrogeological, geotechnical and lithological information has been archived.

The current situation is that groundwater data in Victoria are divided across several government departments, water agencies, research organisations, public archives and private industries.

VVG PORTAL CONSTRUCTION AND FUNCTION

In collaboration with the project partners and stakeholders, the VVG portal was designed to include the following features:

- user requests will be fulfilled via real-time access to remote databases by integrating the interoperable web services they each provide;
- the data resides with the data managers (ensuring currency and validity);
- it has a spatial map function that is intuitive to use (similar to Google Maps);
- all forms of data are included – vector, raster, text and multimedia;
- data downloads are allowed (subject to data custodian's consent);
- spatial data entities link to the original source documents and images;
- it is capable of dynamically synthesising the data;
- interactive 3D visualisations can be created for user-selected scenes;
- users can add, edit or update data (subject to quality assurance and quality control);
- the spatial data and models are credible to the user.

These features of the VVG are also reflected in allied spatial information systems built by CeRDI for broader research applications (e.g. Dahlhaus *et al.* 2011, 2012; Milne *et al.* 2014; Thompson *et al.* 2014), which share key principles including:

- use open-source and standards-compliant software wherever possible;
- build upon existing collaborative software initiatives and contribute enhancements/tools back to the research community;
- ensure the flexibility of the developed system to consume data from a variety of sources so as not to interfere with existing provider work practices;
- ensure end-user tools and applications are fast, intuitive and easy-to-use;
- software is cloud-based so there is no end-user requirement for software, updates, computation power or plug-ins.

The SDI for the VVG project builds upon software projects fostered and supported by the Open Source Geospatial Foundation (www.osgeo.org). Delivery is primarily via a web-browser, the portal interface having been built to bespoke requirements upon the foundations of the OpenLayers (openlayers.org) javascript library. Other Javascript libraries like jQuery, jQueryUI and DHTMLX Tree have been leveraged to provide additional user-interface components and functionality.

While most data are consumed via interoperable services, there are a number of datasets hosted and delivered by VVG. Spatial data engines Mapserver (www.mapserver.org) and Geoserver (geoserver.org) are used for the Geospatial processing and service delivery using Open Geospatial Consortium (www.opengeospatial.org) standards. Vector data are commonly stored within a MySQL or PostGIS database and raster data are dynamically processed from its native format. To deliver complex web feature services (WFS) such as GroundwaterML (Boisvert & Brodaric 2007, 2008, 2012), the Geoserver app-schema extension has been deployed. Geonetwork (geonetwork-opensource.org) is used as the public-facing metadata catalogue for the portal.

The general systems architecture and data flows are illustrated in Figure 1.

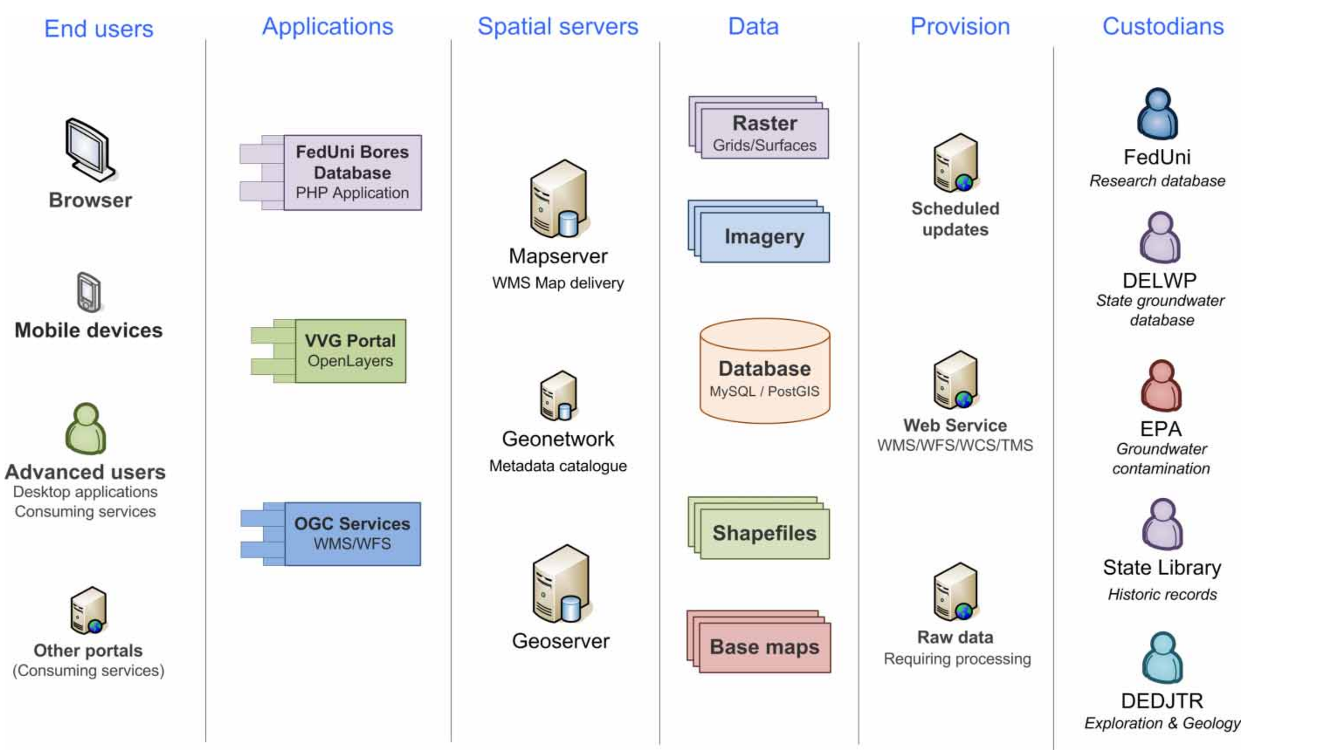

Figure 1 | Generalised systems architecture and data flows for the VVG system.

At present the VVG portal seamlessly federates 79 datasets on Victorian groundwater from six disparate custodians. These are as follows:

- Bore data from: (1) WMIS, containing groundwater bore data for wells drilled under the statutory licences, managed by DELWP; (2) GEDIS, containing mineral, stone and hydrocarbon exploration bores, managed by DEDJTR; (3) the salinity observation bore database managed by DEDJTR; and (4) the research bore database managed by FedUni. The latter also contains data on existing bores that are not recorded elsewhere (termed 'orphaned bores'). In total, data on over 400,000 bores have been federated.
- Groundwater spring data from the Victorian Mineral Springs Database managed by an individual researcher (Dr Andrew Shugg).
- Sites where groundwater contamination may have occurred and have either been issued with a Certificate and/or Statement of Environmental Audit; been declared a Groundwater Quality Restricted Use Zone; or been listed on the Priority Sites Register for environmental clean-up or pollution abatement notice. These sites are managed by EPA Victoria, the State environment protection authority.
- Groundwater surfaces interpolated for the Victorian Aquifer Framework (VAF) including the predicted depth to water table, predicted groundwater salinity, elevation of the natural surface, elevation of the geological basement, and the structure surfaces of the 17 aquifers and confining beds that make up the state-wide groundwater systems framework (SKM 2012). Additional modelling was undertaken in the VVG project to derive the depth to, thickness, and bottom elevation from these structure surfaces, resulting in 68 surfaces in total.
- Seamless geology map supplied as a web service from the GSV (DEDJTR).
- Boring records in digital form from the State Library of Victoria. Where the information can be matched, the boring record is linked to the data for that individual bore shown on the map portal.

In some bore databases, such as the FedUni groundwater research database and the WMIS, additional materials such as images, documents and sketch maps may be linked to the bore data. The intention is to always provide the source documents where possible.

The website includes background information about the project, the project partners, the data sources, historical context for the data, an extensive user guide, answers to frequently asked questions, news and newsletters, a documentary video about the project, a research blog and contact details. The web portal includes a Plain English disclaimer to alert the user to the facts that the data and information may not be accurate, current or complete; is subject to change without notice; is continually being validated, enhanced and updated; and is subject to the usual uncertainties of scientific research. Hence data quality and data provenance (metadata) are issues for the data custodians. It is their data and they set the rules of service.

Tools in the map portal include the ability to select between different base layers (supplied by Google), reorder the data layers, adjust the transparency of the layers, vary the query radius for bore data, export data as Excel spreadsheets, search for a street address and search for a bore identifier. Drawing tools are also included to allow users to mark on the map and send a comment via email. This function has been used by researchers and the general public to indicate where data may be incorrect, such as the location of a bore, and thus allow the data custodians to improve their data veracity.

Four query modes are available: a bore query that finds all the bores within a user-selected radius; an EPA data query that is used to discover the information behind a contaminated site; a query which returns the data related to a polygon on the geological map; and the ability to query the predicted depth to water table, water quality and hydrostratigraphy at any selected point. This last query effectively provides a virtual borehole log at any selected location in Victoria, based on the layers provided in the VAF.

Specialised functionality was developed to deliver 3D groundwater visualisation via the web-browser (Figure 2). In collaboration with the Queensland University of Technology, a modified version of their Groundwater Visualisation System (GVS) (Cox *et al.* 2013) has been deployed on a dedicated 3D server at FedUni. The VVG portal communicates with the 3D engine via HTML5

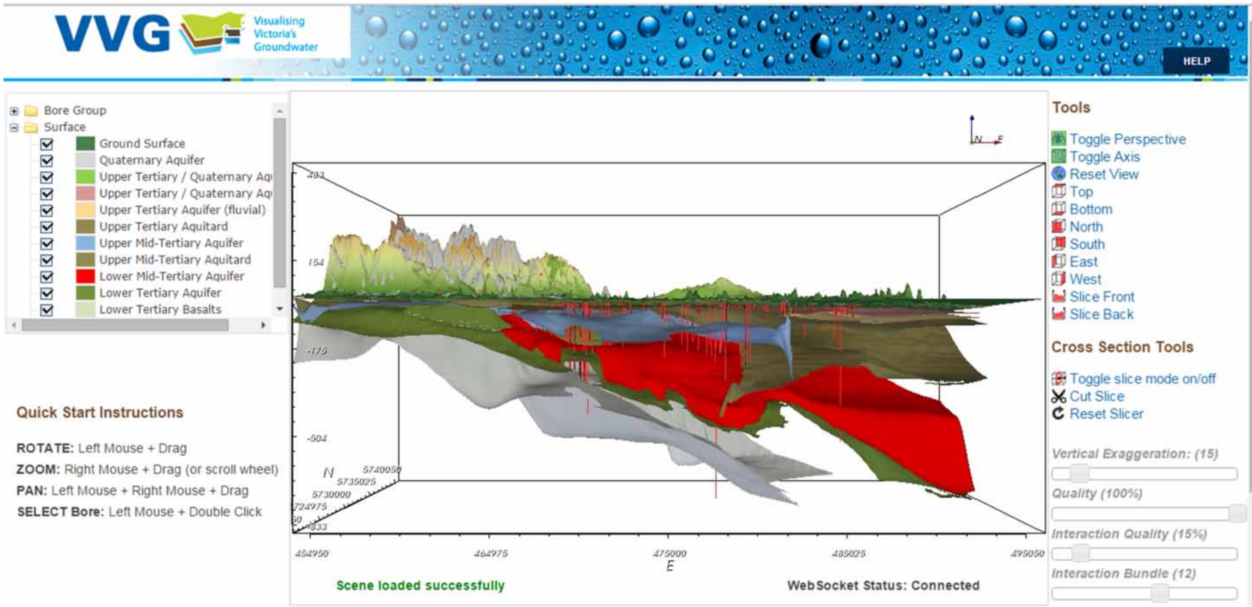

Figure 2 | An example of the user-selected 3D visualisation screen.

web-sockets (MacLeod *et al.* 2013). All processing and rendering is handled by the server which simply sends an image stream back to the client. The HTML/Javascript front-end client handles user interactions with the generated 3D Scene using a custom JSON-based messaging protocol. Bore information is dynamically requested and rendered into the scene by the 3D engine in real-time via a GeoJSON data feed. The visualisation becomes selectable only once the zoom level is around 1:100,000 or larger and displays the top surface of the landscape and aquifers or confining beds beneath. The user can interactively change the orientation of the view, select/deselect layers and bores and create cross-sectional slices.

VVG PORTAL EVALUATION METHODS

For the impact assessment, a mixture of qualitative and quantitative methods was used, viz:

1. *Surveys:* An on-line benchmark survey of the stakeholders, collaborators and participants in the VVG project was undertaken at the commencement of the project in July to December 2012. Two years after the implementation of the site, two further surveys were undertaken: (1) a 1-minute 'snapshot survey' as an on-line pop up invitation available to those accessing the portal and (2) a 10-minute on-line survey, by invitation to key end users. Data across these three surveys was reviewed for compatibility, analysed and cross referenced, as appropriate.
2. *Individual interviews:* Structured interviews were held with targeted individuals to gain subjective insights into user perceptions of service delivery, levels of satisfaction and issues of concern. This provided data that supplement and validate the other data collected for the research.
3. *Document analysis:* Program documentation (internal) was thematically analysed to identify the synergies between the aims and the implementation of the VVG. In addition external documents, particularly audit reports posted on-line by EPA Victoria, were analysed to gain significant insights into the role of the VVG portal as a decision making tool.
4. *E-mail feedback:* Feedback was collected on an ongoing basis from the inception of the VVG portal. This provided longitudinal data for the study and enabled feedback on a variety of issues (e.g. technical enquiries, service improvement, service gaps, data queries, etc.) to be gathered across the life of

the project. Both email requests and responses to requests were analysed as part of this data collection method.

5. *Website analytics:* Time-series statistics on portal usage were reviewed through the mechanism of Google Analytics. Data validity was ensured through a filtering process that verified only valid portal visits were included in the analysis.

Ethical approval appropriate for research involving individuals was gained from the Human Research Ethics Committee of FedUni and principles guiding the data collection and analysis process were observed to serve the best interests of all participants at each stage of the research process (Ethics Approval Number A14-015).

Data collection for the study was contemporaneous with the VVG portal implementation as there was no capacity to undertake pre-testing due to the funded research program timelines. The benchmark survey was intended to provide the initial gauge for impact measurement, although much of the interview and feedback data also provided insights into working with groundwater data prior to availability of the VVG. Consequently, while the absence of a structured pre-testing process (resulting in no comparative data from before the VVG portal implementation) and the absence of a control/comparison group slightly reduces the rigour, the scope of data gathered *in situ* provides for high levels of data validity.

In particular, the mix of methods allowed cross-referencing of findings and established a process whereby issues that were not addressed or identified through one data collection method could be picked up through alternative methods. Importantly, the use of a multi method approach allows for triangulation of the methods (interview, survey, feedback, analytics and document analysis), type (qualitative cross sectional and statistical across an extended timeframe), and data source (e.g. government employees, members of community and industry and other researchers). The resulting approach overcame many of the issues often raised in relation to data validity of qualitative case studies in research and conform to recommended strategies in data collection for effective case study research (Yin 2014).

The statistics for the impact assessment methods are listed in Table 1.

Table 1 | Statistics for the various qualitative and quantitative methods used in the VVG portal impact analysis

Data collection method	Data collection period	Profile of data accessed or participant type	Quantity
Document analysis	May 2011–February 2015	All documents relevant to the VVG project (internal and external)	7 internal, 51 external
Benchmark survey	July 2012–January 2013	State and Federal Government, researchers, consultants and water authorities	12 participants
Snapshot survey	July 2014–November 2014	Consultants, drillers, industry representatives, researchers, water managers and administrators, citizens, primary producers, educators	81 participants
On-line survey	July 2014–November 2014	Government water managers and administrators, industry representatives, researchers, water authorities, citizens, primary producers, educators	40 participants
Individual interviews	September 2014–November 2014	Key representatives of: government water managers and administrators, researchers, water authorities, drillers, consultants. This included data providers	9 participants
Email feedback	July 2012–December 2014	Environmental auditors and consultants, groundwater consultants, drillers, civil engineers and geoscientists, GIS specialists and geospatial consultants, teachers, surveyors, water service companies, academics and researchers, community groups, water authorities, primary producers and environmental lobby groups	136 participants
Website analytics	July 2012–January 2015	Reports on website usage from Google Analytics	134,000 page views, 30,406 valid visits

The approach used in the data analysis was to apply a hierarchy of impact to each pool of data. The impact hierarchy has three levels, loosely based on the concepts developed by Kirkpatrick & Kirkpatrick (2005, 2006, 2007) that relate to levels of learning. Their work measured learning in terms of Reaction (initial reaction to the training), Learning (a measurable increase in knowledge about an issue), Behaviour (a change in behaviour that reflects an application of what was learnt) and Results (changes in outcomes because of the learning). The hierarchy applied to the data in this study modifies this conceptualisation to measure impact in terms of the following:

Level 1: The *Primary Impact* based on website usage statistics and feedback on the VVG portal, to measure its initial impact and value as a data resource. This level provides baseline data into the extent to which there has been an impact on practice within industry and community.

Level 2: The *Practice Impact* based on the extent to which the VVG portal is being utilised within the workplace and/or community to aid in decision making. It also considers whether the end users have modified their work and/decision making practices, made productivity savings and integrate the portal into their individual practice decisions in industry and in community.

Level 3: The *Sector Impact* based on the extent to which the VVG portal is becoming embedded in the activities undertaken and decisions made by the groundwater sector (i.e. regulators, practitioners, researchers and the community). At this level the impact of the VVG portal is considered in terms of its integration as a tool that the sector views as part of planning and decision making on groundwater use, environmental planning and research innovation.

All data were assigned a level (1–3) dependent on impact as assessed on the basis of findings across the various data collection methods.

PRIMARY IMPACT

Following a soft launch in mid-2012 the usage statistics (as measured by Google Analytics) for the VVG portal have steadily grown from 408 valid visits in the first quarter to nearly 1,600 visits by the last quarter of 2014 (Figure 3).

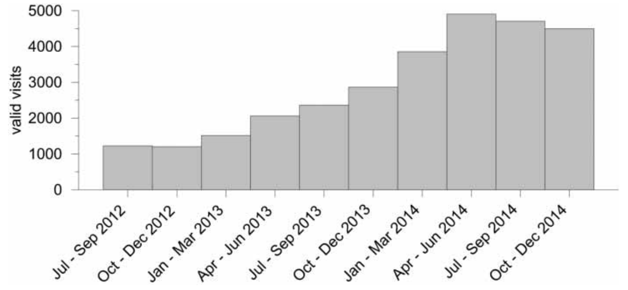

Figure 3 | Statistics on the web portal use.

Daily, weekly and monthly statistics confirm that the major use is during industry working hours with much lower usage during weekend and holiday periods. The spike in the second quarter of 2014 can be attributed to a short radio interview about the VVG portal broadcast on the Australian Broadcasting Corporation's *Country Hour*, a state-wide program aimed at rural and regional communities (Worthington 2014). The interview was replayed the following day and resulted in 803 visits over the 2-day period.

Collation of data collected from all 278 participants through interview, surveys and email feedback provided information on the various sectors actually using the site (Figure 4). While there was a significant level of interest from government departments (including water and catchment management authorities), and research organisations, the highest level of representation was from the commercial sector (primary producers, consultants, drillers) and an emerging interest from community (Landcare and environmental groups, and private individuals).

Based on the observed growth in users, it can be assumed that the VVG portal functions successfully as a data resource. This was further tested by the survey data that related to ease of use of the portal, information availability and data quality (Figure 5).

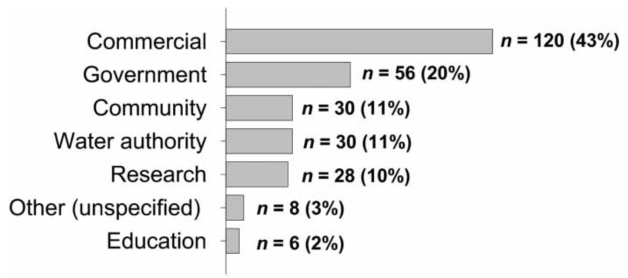

Figure 4 | VVG portal usage by sector.

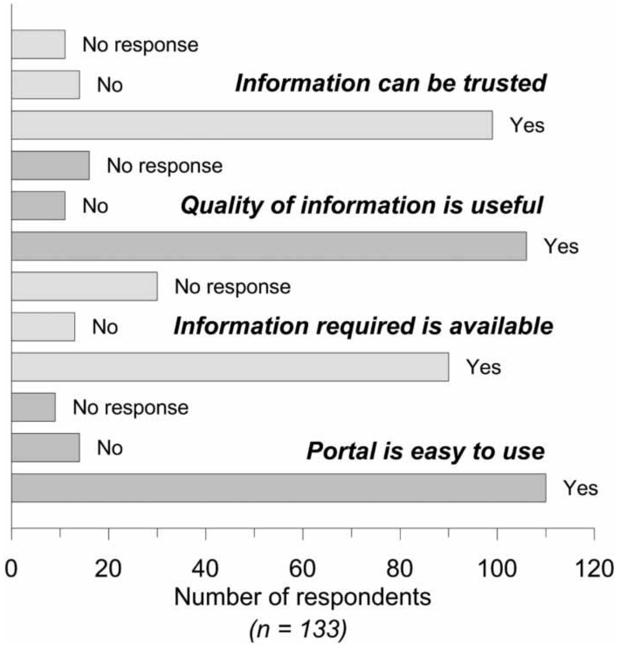

Figure 5 | Rating of portal accessibility and quality.

Triangulation of survey results with the interview feedback and written qualitative data found a high level of correlation in regard to these same variables. The following statements provide a representative sample of end user views on issues of ease of use, information availability and trustworthiness of the data:

> *'The VVG is very good in that it was set up for groundwater users. Quite often water databases are set up for surface water users and so they're a bit clunky for groundwater but the VVG has a focus on groundwater and it is very intuitive, it's very easy to access information.'* [end user – research]

> *'An easy one stop shop for most of the data I need to help a customer. I can also walk through the VVG with the customer over the phone. It is quick, it is easy and it delivers!!! It's more satisfying than a Snickers [chocolate bar].'* [end user – water authority]

Where the user understood that the VVG dynamically accessed updated information from source data bases, the rating was high, e.g. *Interoperability standards … you're really leading the way in that kind of thing [end user – government].* However where the notion that remote databases were accessed in real-time was not readily understood, there were greater concerns around data reliability, e.g. *The difficulty with the VVG is … because [it doesn't have] direct access to the information, it's knowing whether it's got the latest readings [end user – sector unknown].* While this type of feedback was limited to less than 1% of the qualitative data collected from the participant pool, it nevertheless indicates a need for ongoing end user education on how dynamic access to remote databases ensures that the data are always current.

The impact data analysis also highlighted that some end users remain confused around data ownership and the integrity of the datasets available through the VVG portal. There were 8% of respondents who assessed that the quality of data not useful and 14% who assessed that the data could not be trusted. Qualitative insights highlighted that some end-users misunderstood that data accuracy remains the responsibility of the data custodians rather than the VVG web portal managers, for example:

> *'There is not enough available geological and hydrogeological data, i.e. lithology and standing water level. There is also not enough water quality data. Also, when looking at the map, not every existing bore is represented by a dot. This can make it a long process to ascertain the exact location of each bore and is frustrating.'* [end user – sector unknown]

> *'[A suggestion which] may help improve VVG: ensuring the GPS position of all onshore water bores – for example there are some bores that appear in the offshore Gippsland basin near petroleum wells, that have obviously been plotted in the wrong location.'* [end user – sector unknown]

However, the data show that the vast majority of end users understand that the VVG portal provided data that were as accurate and as current as possible and was drawn from existing and known data sources. The findings align with the published literature that identifies a positive association between ease of access and increased frequency of use (e.g. Shanahan 2009) and the importance of high quality data as a fundamental component of innovation in technology (Haug *et al.* 2011; Anstiss & Marjanovic 2012; Li *et al.* 2012; Horn *et al.* 2013).

The extent to which the web portal has become an integral part of the practice of end users is further reinforced by data on the frequency of use, identified by two data pools (Figure 6). The first examines the frequency with which the user accessed the portal (daily, weekly, monthly) and is drawn from two out of the three surveys ($n = 52$). The second data pool is drawn from the participants to the third survey ($n = 81$) and depicts how often each respondent has returned to the site for a repeat use of/access to the information available through the web portal.

One of the most definitive trends to emerge from the written and verbal qualitative data for this study was the consistency with which participants identified that the VVG portal had increased user capacity to manage the knowledge themselves. The single point of data access was consistently identified as a significant attraction:

> *'People love it, because it's so easy to get on. I just say, if it's a farmer or whatever, are you in front of a computer right now? Just type in VVG. It comes up quite quick, one button to get into the portal and I think you've got the map in front of you. People just zoom in, and we're looking at the same screen, and we're looking at their little patch of Victoria. We can look up the same information on the same bore within a couple of minutes of hitting the go button. It makes my life a lot easier, so instead of trying to explain everything over the phone, they've got it in front of them as well. So for someone who is just getting into it, having that visual aide, it's just brilliant.'* [end user – water authority]

> *'It's made the data open source. In previous years you had to go to a consultant to get the data, and they held it and they probably held onto it tightly. So now you don't have to rely on one company or one source to get the data, it's freely available … giving people a place where they can access groundwater information that anyone with a decent browser can access.'* [end user – industry]

The *Primary Impact* identifies clear alignments between the VVG study findings on access, quality and usage, with those of previous research (Table 2), particularly in terms of:

- building community capacity through facilitating access to data that was previously not directly available;
- enhancing the capacity for decision making by providing a single point of access for facilitating sharing and ownership of information; and
- ease of information access for increased participation and education.

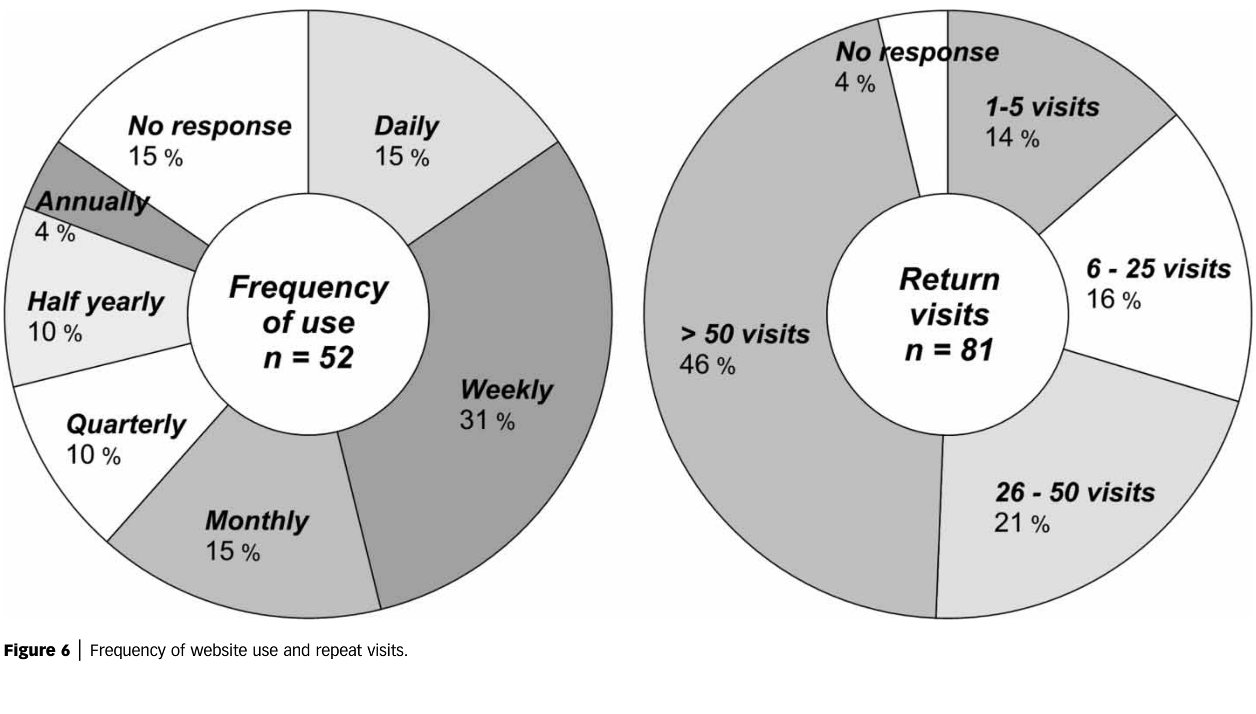

Figure 6 | Frequency of website use and repeat visits.

Table 2 | Aligning the VVG impacts with existing research knowledge

Key findings from the existing literature	Aligned *Primary Impact* measure of the VVG (data discovery)
1 Ease of access and visualisation is critical to an enhanced understanding of groundwater/natural resources and improved environmental management (e.g. Lewis *et al.* 2008; Iwanaga *et al.* 2013; Garcia-Rodriguez *et al.* 2014)	A single geospatial data portal as a means by which to better access and understand groundwater data
2 Technology provides a mechanism through which to build social capital by enhancing equity in information access and knowledge building.(e.g. Simpson *et al.* 2003; Lloyd-Smith 2009; Busch 2011; Thornton & Leahy 2012; Cegarra-Navarro *et al.* 2014)	An innovative and equitable mechanism for knowledge building and knowledge sharing
3 Technology driven knowledge building enhances public participation in planning and decision making (e.g. Ramirez 2007; Jankowski 2009; Martins De Freitas 2010; Jackson *et al.* 2012)	A publicly available portal that facilitates user participation and enhanced decision making
4 Access to data (natural resource, groundwater or other types) provides a platform for public education on critical community issues (e.g. Zimmerman & Meyer 2005; Klug & Kmoch 2014)	A portal for building community and industry education around groundwater issues

PRACTICE IMPACT

In moving beyond the *Primary Impact*, evidence emerges that the VVG portal has a higher order level of impact when considering the changed nature of user feedback since the inception of the project (Figure 7). A noticeable shift is apparent from end users initially providing positive feedback and requesting help on site use, to suggested enhancements and queries on how to maximise their knowledge building.

It should be noted that the data provided in Figure 7 is cross sectional (taking and analysing data at a single point in time) rather than longitudinal (data involving the same individual over a set timeframe), hence it provides indicative rather than definitive evidence of change. Nevertheless, these data show an emerging shift in the type of input and information being sought by end users of the web portal. This can be further explored by the qualitative feedback, such as:

'Are you able to provide the layers for groundwater depth and salinity that we can incorporate into our GIS system? If not, can you please advise which public body can provide this information.' [end user – not specified]

'I am a consultant working with a local Council in south western Victoria on domestic wastewater management planning. Domestic wastewater relates to onsite systems also called septic tanks. Depth to water table is one of many risk factors relevant to onsite effluent management, so I was interested to see the 'Depth to water table layer in the VVG portal' (see attached screen shot) … I am wondering if this data available for download in geotiff (or some other relevant), format?' [end user – consultant]'

'I'm wondering whether it is possible to be provided with the GIS data (preferably in ESRI shapefile format, or AutoCAD) of EPA Victoria sites within the Brimbank

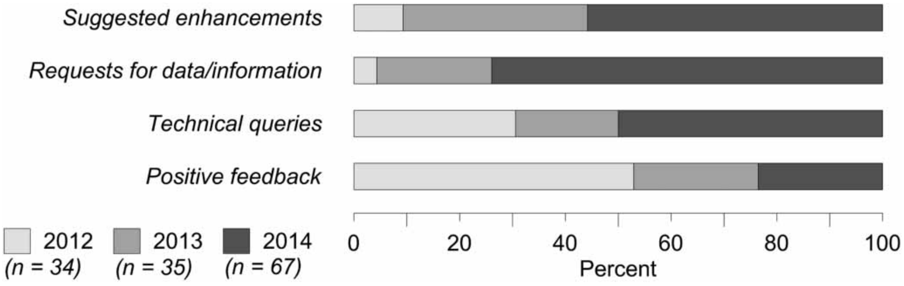

Figure 7 | Change in VVG portal feedback over time.

City Council area? Coordinates of sites that have had a 53x or 53v EPA audit should be sufficient, but if information on the sites could be included that would also be helpful.' [end user – not specified]

The steady increase in the number of requests made via VVG portal feedback for the raw data of the publicly available data indicate that they remain invisible or difficult to access for a number of end users. As a result, the VVG portal is seen as a *de facto* information provider and in some cases, has responded by providing web services to make the government information provision easier. The scope of these requests, and the regularity with which they are received, highlight that:

- since establishment, the VVG has become a central resource in terms of knowledge management and the provision of trusted advice on groundwater issues;
- ease of access and an open access policy plays an important role in building end user confidence in seeking information relevant to their needs;
- the VVG, through the provision of support, advice, and web services is addressing a service need not currently addressed in more traditional areas of groundwater information provision.

Further validation of the shift to Level 2 (*Practice Impact*) is found in the analysis of data relating to how the VVG portal is impacting on decision making, productivity gains and groundwater data integrity. A sub-set of 49 interview and survey participants, from the original pool of 142 participants, were asked to identify the extent to which information accessed through the VVG portal was used to inform decision making. There was surprising uniformity in the results, with many of the types of data assessed as similarly valuable for decision making (Figure 8).

For the sub-set of 49 interview and survey participants, 40 (82%) assessed the depth of data and 41 (84%) assessed that the volume of information available through the VVG was important for informing and supporting decision making. This was confirmed by the qualitative data, such as:

> *'I'd say that we are definitely end users. There's about 30 people in my company and in contaminated land consulting in Melbourne there's probably another 30–40 big companies that do similar work. I would say 90% of [those] companies use the VVG as the first port of call to look at what groundwater data might be available on that site.'* [end user – consultant]

> *'Pretty much everyone in the industry uses it. You can get the geology, how many bores are in the area, depth to groundwater, salinity.'* [end user – industry]

> *'I heard the interview on the Country Hour today and think this site will be invaluable to me as I do farm water designs for clients across the Western District as well as well as advising clients on how to improve their farming water management.'* [end user – agricultural advisor]

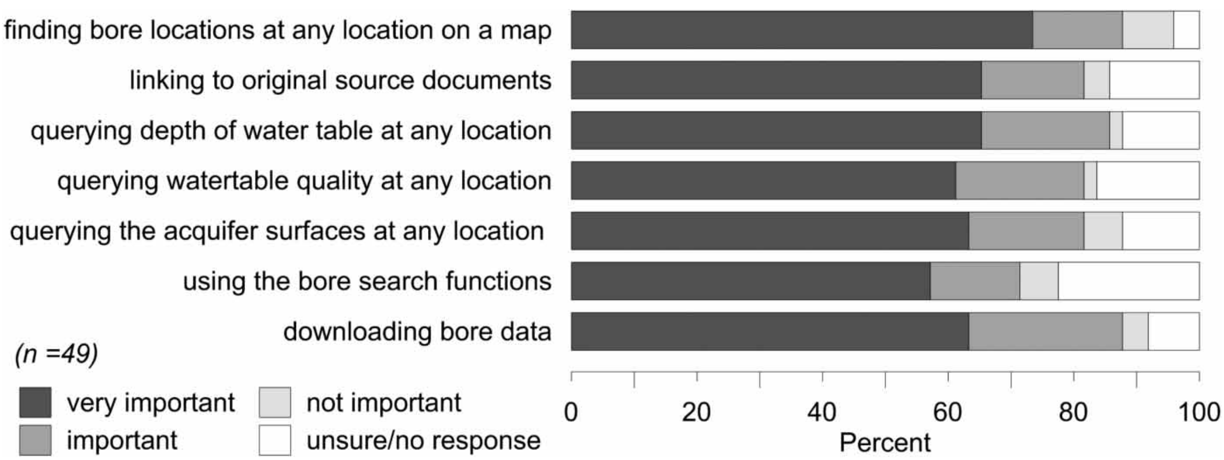

Figure 8 | Assessed importance of VVG functions in decision making.

Overall, the vast majority of participants assessed that the VVG was an important resource which provided a better basis for groundwater planning (Figure 9).

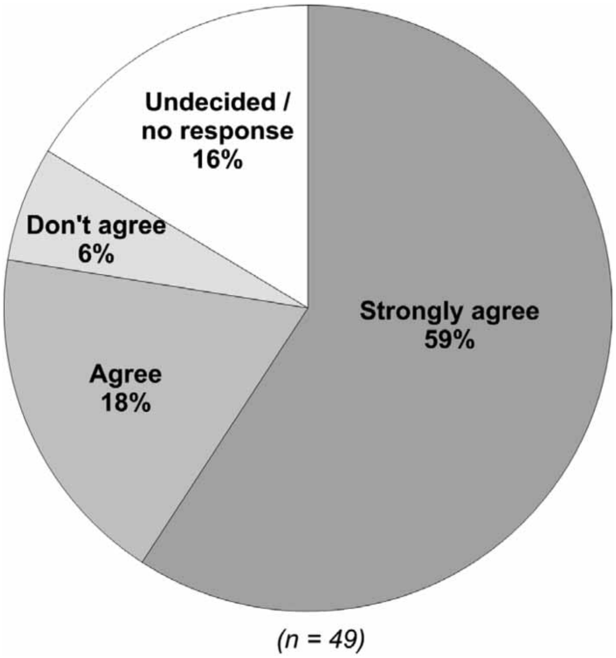

Figure 9 | VVG data provides a better basis for groundwater resource management.

The analysis of overall value placed on individual datasets was gathered for 40 participants through one survey tool (the on-line survey), so provides only a snapshot of views across the participant pool (Figure 10).

The value of the various datasets also varies by industry. For example, although the EPA Victoria sites (contaminated sites) rated lower in the on-line survey (Figure 10), an analysis of the contaminated site audit reports for 2012–2015 show that these data are of great value to the environmental consultancy industry. Since the launch of the VVG portal, a total of 321 audit and consulting reports have been added to the EPA Victoria file management system. Of these, 51 (16%) have included data that were identified as sourced from the VVG web portal, providing evidence of the influence of the VVG portal in that industry.

The final evaluation of the *Practice Impact* was in examining, within the subset of 49 participants involved in the survey and interview process, the issue of potential for productivity saving (Figure 11).

While not formalised through economic modelling, the analysis does provide a consistent view that the VVG portal reduces time spent in the preparation and sourcing

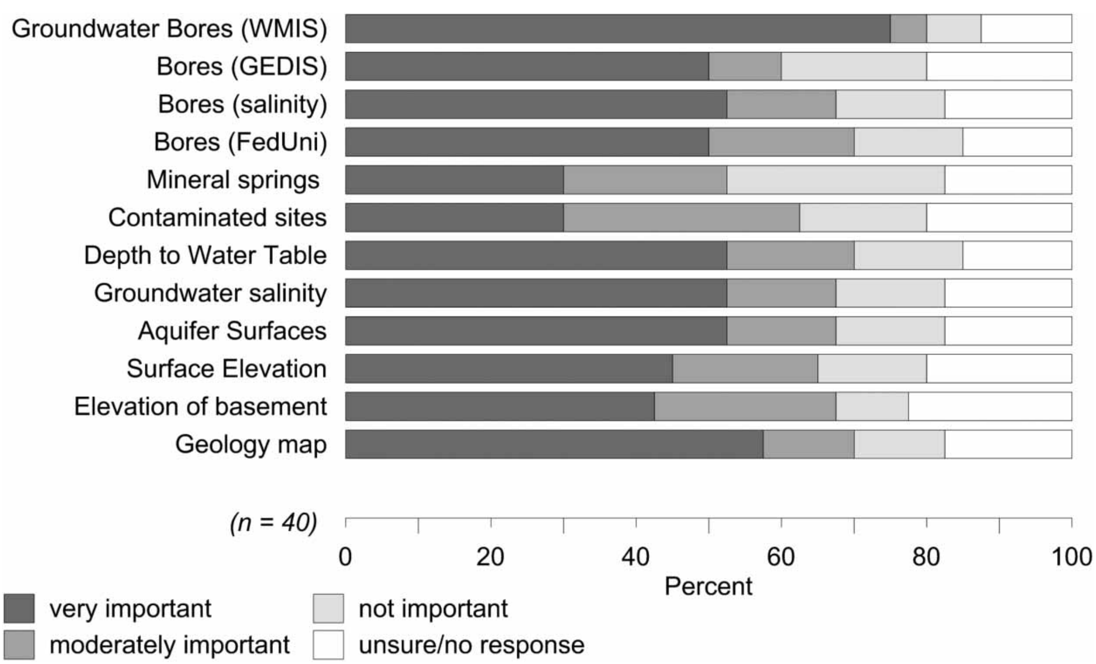

Figure 10 | End user value attributed to the individual datasets.

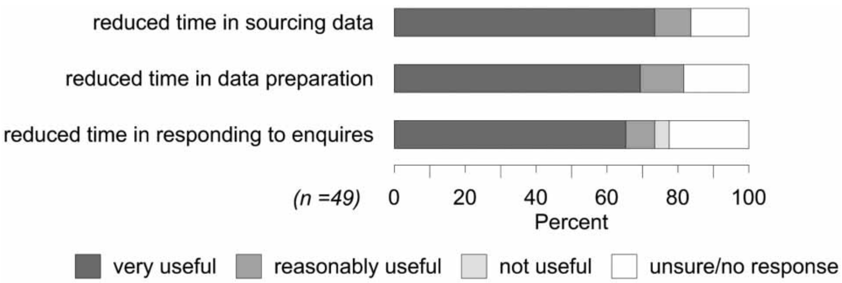

Figure 11 | An assessment of productivity saving through efficiencies.

of data, and in responding to requests for information. Again this was reinforced by the qualitative data:

> *'All the drillers I speak to use it a fair bit because it has all the information in one area. Rather than going to ten different websites … it's good like that. It saves you time. Especially when you run your own business, time is money sort of thing, so it's good that it's [the information] all in the one area and it's pretty much tailored to what you want. You've got the existing bores in the area, the geology, depth to groundwater and salinity.'* [end user – drilling industry]

> *'Yes there are efficiencies absolutely. I guess internally at [sic] we have our own systems operating and the VVG complements those systems very well. Where we find the greatest benefit to the VVG is in getting information quickly and getting a good picture. … So because of that there are benefits in time savings because we can get information quickly and make decisions quickly.'* [end user – water authority]

> *'Frees you up when you don't have to track down and work with data to do other things.'* [end user – industry]

SECTOR IMPACT

Finally, when looking at the shift from Level 2 (*Practice Impact*) to Level 3 (*Sector Impact*), two impact measures were explored: the first is the opportunity for the VVG to meet diverse information needs and the second is the ability of the VVG to improve data accuracy and research potential.

While data were collected on the use of individual datasets (Figure 10), there was no measure within this survey data of the value end users found in the ability to draw on multiple sets of data at a single point of time. For this benefit, insights were drawn from analysis of the qualitative data which found that there were 172 instances (from the total participant pool of 278) in which feedback was provided specific to the value of the capacity to browse multiple datasets when making an inquiry about or investigating a groundwater issue.

> *'I like the way you've brought together all the data sets from different agencies and made them appear as seamless data sets. There is a lot of contextual data that's interesting. I particularly like the 3D, it's absolutely amazing, it's cutting edge.'* [end user – not specified]

> *'Putting on all the EPA water site locations and then the link to the actual EPA audit … for me that's by far the most beneficial [addition] … I've found the Advanced Aquifer tools where you click on it and it drills you the theoretical borehole through the ground to be useful … It provides a one-stop-shop for accessing this type of data.'* [end user – consultant]

> *'The best tool currently available for locating groundwater bore and aquifer information. It provides in the one web-based place, access to groundwater data and related information (e.g. Depth to Water Table, geology etc.) with which I can gain a quick appreciation of the defining groundwater features of an area … One stop, single interface access to multiple sources of data … has broad value to the groundwater industry and the community of Victoria.'* [end user – not specified]

In addition, 53 participants had specifically referred to the value of the multiple datasets in supporting accurate and timely responses, e.g.

> *'Being a geologist and a drilling contractor it gives us more information that we can pass onto your clients about possible water sources for bores. Also gives us some information about previous drilling and construction methods used in the area, which helps quoting etc.'* [end user – drilling industry]

> *'Quick provision of various datasets checking data against various sources quick source of information to help with enquiries.'* [end user – not specified]

A total of 46 participants made reference to the value of the spatial features of the VVG, for example:

> *'The ability to see the information spatially which has been the big leap I think. Previously we could access groundwater information but as a RWA [rural water authority] we could access the information but it was slow, we would just be able to extract it as tables and we would then have to manipulate the data, plot the data, to be able to see how the levels were responding over time, or the quality or whatever it might have been and the rock types that they might have intersected if they were drilling a bore at a particular location. But again being able to see that information spatially is where the VVG has been a real benefit to our organisation and we've been able to couple that with some of the other work that's been happening at a state-wide level as well so we've been mapping groundwater aquifers across the state.'* [end user – water authority]

Before the implementation of the VVG portal, groundwater data were only brought together by individuals on an as needs basis, so there was less potential to systematically identify data shortfalls or duplications. However, being able to bring together a range of datasets that otherwise are not normally viewed together has provided end users with the ability to rapidly see data duplication, data shortfalls, data gaps and/or data inaccuracies in existing groundwater information. This ability was assessed as an important development by the groundwater data custodians, the industry and the community as it facilitates improved groundwater data management and enhanced data accuracy for the sector.

> *'The congregation of all of these disparate datasets, which have been poorly managed – and I know that VVG doesn't manage the datasets but just bringing them all together – having them all together just allows us to get a better idea of the integrity of the datasets as well … Facilitating the identification of data shortfalls … It might also highlight issues with duplication of data or data that's presented in different attributable positions, for instance.'* [end user – water authority]

> *'… that gathering of intellectual property is useful and also that physical scanning and the highlighting of errors or duplication on the database … I'd go and confirm and see what was on there [the VVG] because it had not only the WMIS data but the Geological Survey's logs and also the bore database that FedUni has of its own. So I went there to basically check on my own data set and confirm whether that was right or not. Subsequently I found some errors in both sets, so I've updated mine.'* [end user – government department]

Participant feedback also provided a reinforcement of the fact that the VVG portal is a means to enhance data, as recognised by those who work closely with the datasets available through the web portal. This awareness is captured in statements such as:

> *'The quick interactions with that [VVG] portal can give someone an idea about the sorts of issues that might present themselves in their area of interest. So if they see straight away that there's information there from various parties present, then they'll know straight away that they have to go here or there to get more data.'* [end user – government department]

> *'VVG technology provides an opportunity to add extra data sets without having to rebuild.'* [end user – water authority]

CONCLUSIONS

The analysis of the impact of implementing the VVG portal found that its growing use is facilitated by the ability to federate a diverse range of data, its ease of accessibility and the quality of the data. The frequency of use and repeat visitation rates testify to its value as a viable and sustainable mechanism for information access. These characteristics of the web portal are instrumental in breaking down knowledge silos and are shifting the paradigm from one of knowledge controlled by government and statutory authorities to one of knowledge ownership and control by end users.

Multiple data sets and functionality web portals such as the VVG can enhance capacity across the industry and broader community and in terms of the provision of:

- timely, informed and accurate responses to those seeking information/answers to queries;
- improved mechanisms for monitoring – both in relation to issues of compliance and in terms of maximising the potential for good outcomes and positive developments across a field of study; and,
- increased potential for economic savings as a result of productivity through time efficiencies.

The provision of multiple datasets from disparate sources within a single portal through the facility of interoperability, establishes a unique opportunity to collate, cross reference and consolidate data that has historically been hidden. This shift establishes a new foundation in accessing research-ready datasets and a new capacity for achieving research discoveries.

The VVG portal is changing practice in the Victorian groundwater sector. Positive experiences for users in accessing such a web portal is ultimately increasing end user interaction and participation in the process of collaborative data improvement, enhancing knowledge within the sector and empowering society with the value of Big Data. As the provision of diverse and complex information through the addition of multiple datasets grows, the relevance and applicability of these data provides end users with a resource to guide future planning for sustainable and equitable groundwater use.

ACKNOWLEDGEMENTS

The authors thank the VVG portal collaborators, stakeholders, participants and end-users for their contribution to this research. The VVG project was funded through a Victorian Government Broadband Enabled Innovation Program grant (2011–2013). Thanks to Kelsey McDonald and Jennifer Corbett who assisted with the data gathering and analysis. The authors acknowledge the improvements to the manuscript suggested by the four reviewers.

REFERENCES

ACWI 2013 *A National Framework for groundwater monitoring in the United States*. Report prepared by The Subcommittee on Ground Water of The Advisory Committee on Water Information, Reston, Virginia, USA. 182p. Available from: http://acwi.gov/sogw/ngwmn_framework_report_july2013.pdf.

Anstiss, S. & Marjanovic, O. 2012 Understanding data quality issues in dynamic organisational environments – a literature review. In: *ACIS 2012: Location, location, location. Proceedings 23rd Australasian Conference on Information Systems (ACIS), Geelong, Australia, 3rd–5th December 2012*. ACIS (Australian Conference on Information Systems), Geelong, Australia. Available from: http://dro.deakin.edu.au/view/DU:30049090.

AWA 2012 Coal seam gas mining and groundwater: a review of the controversies around and potential impacts of CSG in Australia. *Water J. Aus. Water Assoc.* **39** (7), 46–48.

Bell, G., Hey, A. & Szalay, A. 2009 Beyond the data deluge. *Science* **323**, 1297–1298.

Boisvert, E. & Brodaric, B. 2007 GroundWater Markup Language (GWML): Extending GeoSciML for groundwater. *Eos Trans. AGU*, **88** (52), Fall Meet. Suppl., Abstract IN53C-03 (see http://abstractsearch.agu.org/meetings/2007/FM/IN53C-03.html).

Boisvert, E. & Brodaric, B. 2008 *Groundwater Markup Langauge Specification v. 1.0*. Natural Resources Canada, Ottawa, Canada. Retrieved 23 July 2010. Available from: http://ngwd-bdnes.cits.rncan.gc.ca/service/api_ngwds/en/gwml.html. Last updated: 30-12-2008.

Boisvert, E. & Brodaric, B. 2012 Groundwater Markup Language (GWML) – enabling groundwater data interoperability in spatial data infrastructures. *J. Hydroinform.* **14** (1), 93–107.

BOM 2015 *National Groundwater Information System*. Bureau of Meteorology, Melbourne. Retrieved 22/3/2015. Available from: www.bom.gov.au/water/groundwater/ngis/.

Boyd, D. & Crawford, K. 2012 Critical questions for big data. *Inform. Commun. Soc.* **15** (5), 662–679.

Busch, T. 2011 Capabilities in, capabilities out: overcoming digital divides by promoting corporate citizenship and fair ICT. *Ethics Inform. Technol.* **13** (4), 339–353.

Cegarra-Navarro, J.-G., Garcia-Perez, A. & Moreno-Cegarra, J. L. 2014 Technology knowledge and governance: Empowering citizen engagement and participation. *Gov. Inform. Quart.* **31** (4), 660–668.

Cox, M. E., James, A., Hawke, A. & Raiber, M. 2013 Groundwater Visualisation System (GVS): A software framework for integrated display and interrogation of conceptual hydrogeological models, data and time-series animation. *J. Hydrol.* **491**, 56–72.

Dahlhaus, P. G., Miner, A. S., MacLeod, A. & Thompson, H. 2011 A web-GIS and landslide database for south west Victoria and its application to landslide zonation. *Aus. Geomech* **46** (2), 203–209.

Dahlhaus, P. G., MacLeod, A. & Thompson, H. 2012 Federating hydrogeological data to visualise Victoria's groundwater. In: *34th International Geological Congress*, *Brisbane, Australia*, *5–10 August 2012*. Vol. Abstracts (Abstract #1382). Australian Geoscience Council, Canberra, Australia, 592p.

Fernandez, S., Bouleau, G. & Treyer, S. 2014 Bringing politics back into water planning scenarios in Europe. *J. Hydrol.* **518** (part A), 17–27.

Fienen, M. N. & Lowry, C. S. 2012 Social.Water – A crowdsourcing tool for environmental data acquisition. *Comput. Geosci.* **49**, 164–169.

Garcia-Rodriguez, M., Anton, L. & Martinez-Santos, P. 2014 Estimating groundwater resources in remote desert environments by coupling geographic information systems with groundwater modeling (Erg Chebbi, Morocco). *J. Arid Environ.* **110**, 19–29.

Gill, B. C., Webb, J., Wilkinson, R. & Cherry, D. 2014 Irrigator responses to groundwater resource management in northern Victoria, southeastern Australia. *J. Hydrol.* **518** (part A), 83–93.

Gorelick, S. M. & Zheng, C. 2015 Global change and the groundwater management challenge. *Water Resources Research* **51** (5), 3031–3051.

GSV 1965 *Boring Records 1965*. Geological Survey of Victoria, Mines Department, Melbourne, Victoria. 111p. Available from: http://handle.slv.vic.gov.au/10381/223127.

Haug, A., Zachariassen, F. & van Liempd, D. 2011 The costs of poor data quality. *J. Ind. Eng. Manage.* **4** (2), 168–193.

Holman, I. P. & Trawick, P. 2011 Developing adaptive capacity within groundwater abstraction management systems. *J. Environ. Manage.* **92** (6), 1542–1549.

Horn, M., Dane, S., Griffith, C., Kimber, J., Marquez, L., Mason, C., McInally, B. & Reeson, A. 2013 *Next generation broadband: understanding the impacts, capturing the benefits*. Report EP1312233. CSIRO, North Ryde, NSW. 30p. Available from: https://publications.csiro.au/rpr/pub?pid=csiro:EP1312233.

Iwanaga, T., El Sawah, S. & Jakeman, A. 2013 Design and implementation of a web-based groundwater data management system. *Math. Comput. Simul.* **93**, 164–174.

Jackson, S., Tan, P.-L. & Nolan, S. 2012 Tools to enhance public participation and confidence in the development of the Howard East aquifer water plan, Northern Territory. *J. Hydrol.* **474**, 22–28.

Jankowski, P. 2009 Towards participatory geographic information systems for community-based environmental decision making. *J. Environ. Manage.* **90** (6), 1966–1971.

Kirkpatrick, D. L. & Kirkpatrick, J. D. 2005 *Transferring Learning to Behavior: Using the Four Levels to Improve Performance*. Berrett-Koehler Publications Inc., San Francisco, California, USA.

Kirkpatrick, D. L. & Kirkpatrick, J. D. 2006 Evaluating Training Programs: The Four Levels, 3rd edn. Berrett-Koehler Publications Inc., San Francisco, California, USA, 380p.

Kirkpatrick, D. L. & Kirkpatrick, J. D. 2007 *Implementing the Four Levels: A Practical Guide for Effective Evaluation of Training Programs*, 1st edn. Berrett-Koehler Publications Inc., San Francisco, California, USA, 154p.

Klug, H. & Kmoch, A. 2014 A SMART groundwater portal: An OGC web services orchestration framework for hydrology to improve data access and visualisation in New Zealand. *Comput. Geosci.* **69**, 78–86.

Langtree, C. W. 1885 *Diamond drills in Victoria*. Report of the Acting Secretary for Mines and Water Supply to The Honorable J.F. Levien M.P., Minister of Mines for Victoria, on the work done by Diamond Drills up to 30th June, 1884. Department of Mines and Water Supply, Melbourne. 50p. Available from: http://handle.slv.vic.gov.au/10381/220261.

Lewis, S. J., English, P. M., Sandow, J. & Coram, J. E. 2008 Unravelling the Mysteries of Groundwater Systems for the Australian Public – Improved Hydrogeological Visualisation and Understanding with Computer-generated 3D Models. In: *Proceedings of Water Down Under 2008*, *Modbury, South Australia*. Engineers Australia, Barton, Australia. pp. 227–238. Available from: http://search.informit.com.au/documentSummary;dn=562075931997892;res=IELENG.

Li, D., Zhang, J. & Wu, H. 2012 Spatial data quality and beyond. *Int. J. Geog. Inf. Sci.* **26** (12), 2277–2290.

Little, K. E., Hayashi, M. & Liang, S. 2015 Community-Based Groundwater Monitoring Network Using a Citizen-Science Approach. *Groundwater* (accepted for publication and available online DOI: 10.1111/gwat.12336).

Lloyd-Smith, M. 2009 Information, power and environmental justice in Botany: The role of community information systems. *J. Environ. Manage.* **90** (4), 1628–1635.

Loch, A., Adamson, D. & Mallawaarachchi, T. 2014 Role of hydrology and economics in water management policy under increasing uncertainty. *J. Hydrol.* **518** (part A), 5–16.

Lynch, C. 2008 Big data: How do your data grow? *Nature* **455** (7209), 28–29.

MacLeod, A., Dahlhaus, P., Thompson, H., James, A. & Cox, M. 2013 Web-based visualisation of 3D groundwater models. In: *Solving the Groundwater Challenges of the 21st Century, 40th IAH Congress*, *15–20 September 2013*, *Perth, Australia*. Vol. Conference Abstracts. International Association of Hydrogeologists, Perth, Australia.

Martins De Freitas, D. 2010 The role of public participation, spatial information and GIS in natural resource management of the dry tropical coast, northern Australia. PhD thesis, James Cook University, Townsville, Australia.

Mayer-Schonberger, V. & Cukier, K. 2013 *Big Data: A Revolution that will Transform how we Live, Work and Think*. Houghton Mifflin Harcourt Publishers, New York. 242p.

Milne, R., Dahlhaus, P., Nicholson, C., Thompson, H., Macleod, A., Feely, P., McCue, T., Gillet, H. & Corbett, J. 2014 On-line Farm Trials: a research repository for Australian grain growers. In: *Digital Rural Futures. Regional Futures. Agricultural Futures. Digital Futures. Conference 25–27 June 2014*, University of Southern Queensland, Toowoomba, Queensland, Australia. Vol. Abstracts, pp. 20–21.

Nevill, J. C., Hancock, P. J., Murray, B. R., Ponder, W. F., Humphreys, W. F., Phillips, M. L. & Groom, P. K. 2010 Groundwater-dependent ecosystems and the dangers of groundwater overdraft: a review and an Australian perspective. *Pacific Conserv. Biol.* **16** (3), 187–208.

Porter, J. H., Hanson, P. C. & Lin, C.-C. 2012 Staying afloat in the sensor deluge. *Trends Ecol. Evol.* **27** (2), 121–129.

Price, M. 1996 *Introducing Groundwater*, 2nd edn. Nelson Thornes Ltd, Cheltenham, UK, 289p.

Ramirez, R. 2007 Appreciating the contribution of broadband ICT With rural and remote communities: stepping stones toward an alternative paradigm. *Inform. Soc.* **23** (2), 85–94.

Scanlon, B. R., Faunt, C. C., Longuevergne, L., Reedy, R. C., Alley, W. M., McGuire, V. L. & McMahon, P. B. 2012 Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. *Proc. Natl. Acad. Sci. U S A* **109** (24), 9320–9325.

Schmidt, E. & Cohen, J. 2013 *The New Digital Age: Reshaping the Future of People, Nations and Business*. John Murray (Publishers), London, 336p.

Shanahan, M. 2009 Using e-resources and tools to update professional knowledge in the workplace. Same places, different spaces. In: *Proceedings ascilite 2009, 26th Annual ascilite International Conference, Auckland, 6–9 December 2009*. The University of Auckland, Auckland University of Technology, and Australasian Society for Computers in Learning in Tertiary Education (ascilite), Auckland, New Zealand. Available from: http://www.ascilite.org.au/conferences/auckland09/procs/.

Simpson, L., Daws, L. & Wood, L. 2003 More than just an internet connection: building rural social capital through public access. *Rural Soc.* **13** (2), 113–125.

SKM 2012 *Groundwater SAFE: A review of the Victorian Aquifer Framework*. Consulting report by Sinclair Knight Merz for the Department of Sustainability and Environment, Melbourne, 28p.

Sui, D., Goodchild, M. & Elwood, S. 2013 Volunteered geographic information, the exaflood, and the growing digital divide, Chapter One. In: *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice* (D. Sui, M. Goodchild & S. Elwood, eds). Springer, Dordrecht, pp. 1–12.

Thompson, H., Dahlhaus, P. & MacLeod, A. 2014 The hype and the hope: Progressing towards big data insights for regional communities. In: *Digital Rural Futures Conference, 25th–27th June 2014*, University of Southern Queensland, Toowoomba, Queensland. Vol. Abstracts, p. 53.

Thornton, T. & Leahy, J. 2012 Changes in social capital and networks: a study of community-based environmental management through a school-centered research program. *J. Sci. Edu. Technol.* **21** (1), 167–182.

Uslander, T. 2005 Trends of environmental information systems in the context of the European Water Framework Directive. *Environ. Model. Softw.* **20** (12), 1532–1542.

Werts, J., Mikhailova, E., Post, C. & Sharp, J. 2012 An integrated WebGIS framework for volunteered geographic information and social media in soil and water conservation. *Environ. Manage.* **49** (4), 816–832.

Worthington, B. 2014 *Mapping and monitoring groundwater in Victoria*. Australian Broadcasting Commission, ABC Rural, Horsham, Victoria. Retrieved 9th April 2015. Available from: www.abc.net.au/news/2014-04-29/victoria-groundwater/5417308. Last updated: 29th April 2014.

Yin, R. K. 2014 *Case Study Research: Design and Methods*, 5th edn. Sage Publications Inc., Thousand Oaks, California, USA, 282p.

Zimmerman, J. N. & Meyer, A. 2005 Building knowledge, building community: integrating internet access to secondary data as part of the community development process. *Commun. Dev.* **36** (1), 93–102.

Zuiderwijk, A. & Janssen, M. 2014 Open data policies, their implementation and impact: A framework for comparison. *Gov. Inform. Quart.* **31** (1), 17–29.

First received 13 April 2015; accepted in revised form 28 June 2015. Available online 31 July 2015