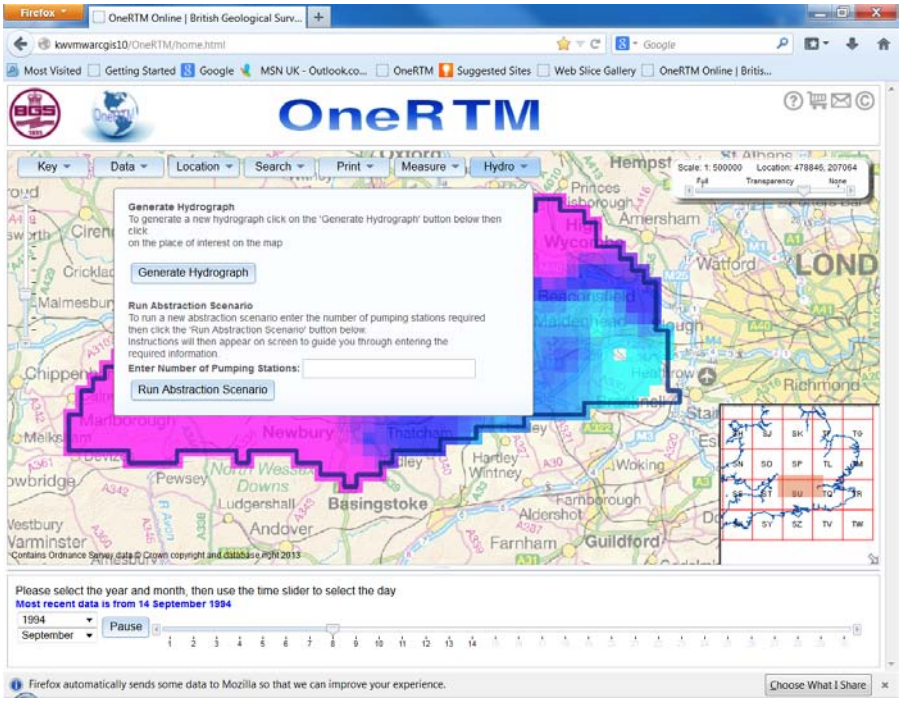
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

OneRTM: a pilot study for exploring the business case for the next generation of online real-time numerical modelling and data services

Environmental Modelling Programme

External Report OR/13/043



BRITISH GEOLOGICAL SURVEY

Environmental Modelling Programme

EXTERNAL REPORT OR/13/043

OneRTM: a pilot study for exploring the business case for the next generation of online real-time numerical modelling and data services

Wang, L., Kingdon, A., Shelley, W.A. and Smith, N.A.

Keywords

NERC datasets; real-time modelling; real-time datasets; online modelling.

Front cover

Screenshot of working OneRTM system

Bibliographical reference

WANG, L., KINGDON, A., SHELLEY, W.A, AND SMITH, N.A. 2013. OneRTM: a pilot study for exploring the business case for the next generation of online real-time numerical modelling and data services. *British Geological Survey External Report*, OR/13/043. 28pp.

Keyworth, Nottingham British Geological Survey 2013

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488

email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683

email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270

Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501

www.nerc.ac.uk

Website www.bgs.ac.uk

Shop online at www.geologyshop.com

Acknowledgements

The follow people are acknowledged for their help:

Kate Royse and Andrew Hughes for editorial assistance

Wayne Shelley and Nikki Smith were instrumental in the delivery of the web GIS component of OneRTM and also the extranet access to the system. Chris Blunsdon gave valuable support on the network security aspects of the project. Their efforts are greatly appreciated.

Contents

FIGURES

Summary

This report summarises the output of the NERC grant “OneRTM: a pilot study for exploring the business case for the next generation of online real-time numerical modelling and data services.” The project sought to develop a new and innovative method to automatically keep models up-to-date and serve outputs of environmental models directly to the end-user. This will aid those users’ understanding of and interaction with modelling functions online. Work was undertaken both to improve the concept of the system at a technical level and also to establish a business case for its wider implementation. During the lifespan of this funding a fragmentary initial pilot was expanded and professionalised. Significant effort was expended developing the GIS capabilities which moved from simplistic viewers to tools for fully navigating the data and manipulating model functions.

1 Introduction

1.1 BACKGROUND

This project highlights new technologies for maintaining and serving environmental models developed within the BGS in response to NERC pilot funding entitled "OneRTM: a pilot study for exploring the business case for the next generation of online real-time numerical modelling and data services."

1.2 EXISTING TECHNIQUES FOR MAINTAINING AND DISTRIBUTING ENVIRONMENTAL MODELS TO END-USERS.

In our increasingly dynamic world there is an imperative to identify potential stresses and threats in the environment and to respond quickly with sound decisions. Numerical modelling has been applied in many fields to better understand and predict the behaviours of different natural processes; it allows the study of responses of these natural systems to changes in their stimuli. If government policies or physical infrastructure are affected by such processes, environmental modelling allows alternative designs and/or policies to be evaluated without experimentation on real systems. These may be prohibitively costly, time-consuming, or simply impractical to do.

However, there are limitations in the way that models are traditionally applied:

- Models are built using historic data for a given period of time, it is costly and time consuming for modellers to keep them up-to-date.
- It generally takes a "long-time" from the inception of a modelling program for modellers to deliver models and results / outputs from the models.
- It is difficult for non-modellers to understand modelled results and to learn how to make best use of models. This limits the value of numerical modelling in supporting decision making because it is hard for decision makers to evaluate their plans or decisions using the models.
- It's hard for end-users to get access to numerical models developed or owned by institutes or companies.

1.3 PROBLEMS CREATED BY TRADITIONAL MODELLING PROCESS

The traditional modelling process makes it difficult for people to respond quickly to rapidly developing events, such as floods, draughts and toxic chemical leakage.

Decision makers need robust datasets and numerical models to underpin understanding of natural systems. Limitations in our traditional methodologies for developing numerical models and supplying their results hinder the development of our capability for reacting quickly to the changing world. A timely response to solving these problems would be to develop a new way for maintaining and providing numerical modelling outputs to users. Against this background an Online Real-Time Modelling system (OneRTM) has been developed. This work concentrated on problems related to water as these are the most dynamic elements of the geosphere, have real economic impact due to its resource value and the relatively simple modelling situation (a mass balance) compared with say coastal erosion where not just the processes but the directions of their arrival are major factors thus complicating the modelling efforts.

2 Rationale

2.1 WHAT IS ONERTM AND WHAT DOES IT DO?

OneRTM is a new method for maintaining and disseminating numerical environmental models and datasets which ensures that:

- Models and modelled datasets are updated automatically as soon as sufficient new input data to allow a model run becomes available.
- Models are automatically linked and synchronised based on data flow.
- Datasets are visualised and served to end-users instantaneously through an internet browser.
- Historic, real-time and forecasted datasets are automatically managed and stored for query.
- Modelled datasets are visualised as dynamic GIS layers, and can be graphically queried, making it easy for non-modellers to understand these datasets.
- It provides functions that allow non-modellers to manipulate models including running pre-defined scenarios via the internet.
- The system automatically sends out alert messages when a dataset, such as groundwater level, crosses a preset threshold value.

2.2 THE ONERTM "REAL-TIME" AND "DYNAMIC" CONCEPT

2.2.1 The "real-time" concept

"Real-time" in OneRTM does not automatically imply models running every second; rather they are updated whenever sufficient data to trigger a run becomes available meaning that available results are always current. Also the datasets and models' functions in OneRTM are accessible at any time.

2.2.2 The "dynamic" concept

The datasets and models in OneRTM represent the environmental processes that change with time under different natural and anthropogenic situations that also vary with time; OneRTM contains functions allowing end-users to travel through time to explore the environmental status in the past, current and (subject to some further development) near future; and it also provides functions to generate "dynamic" results based on the conditions defined by end users, such as the location of groundwater hydrograph and the location and abstraction rate of pumping boreholes.

3 Enhancements undertaken to OneRTM during the project

3.1 STARTING POINT

Figure 1 shows the interface of an early prototype OneRTM version that was funded by BGS beginning in 2011. We engaged with various types of end-users to explore the possibility of different business cases, originally we only focused on the water companies by taking groundwater flow modelling as an example due to the short nature of the project. The NERC Environmental Data project has enabled BGS to enhance the OneRTM. OneRTM has been developed into a pilot product tailored for modelling groundwater in the Thames Basin with improvements to: the interface, the dynamic GIS layers representation and the internet accessibility. The functions of the OneRTM pilot are described in section 3.3.

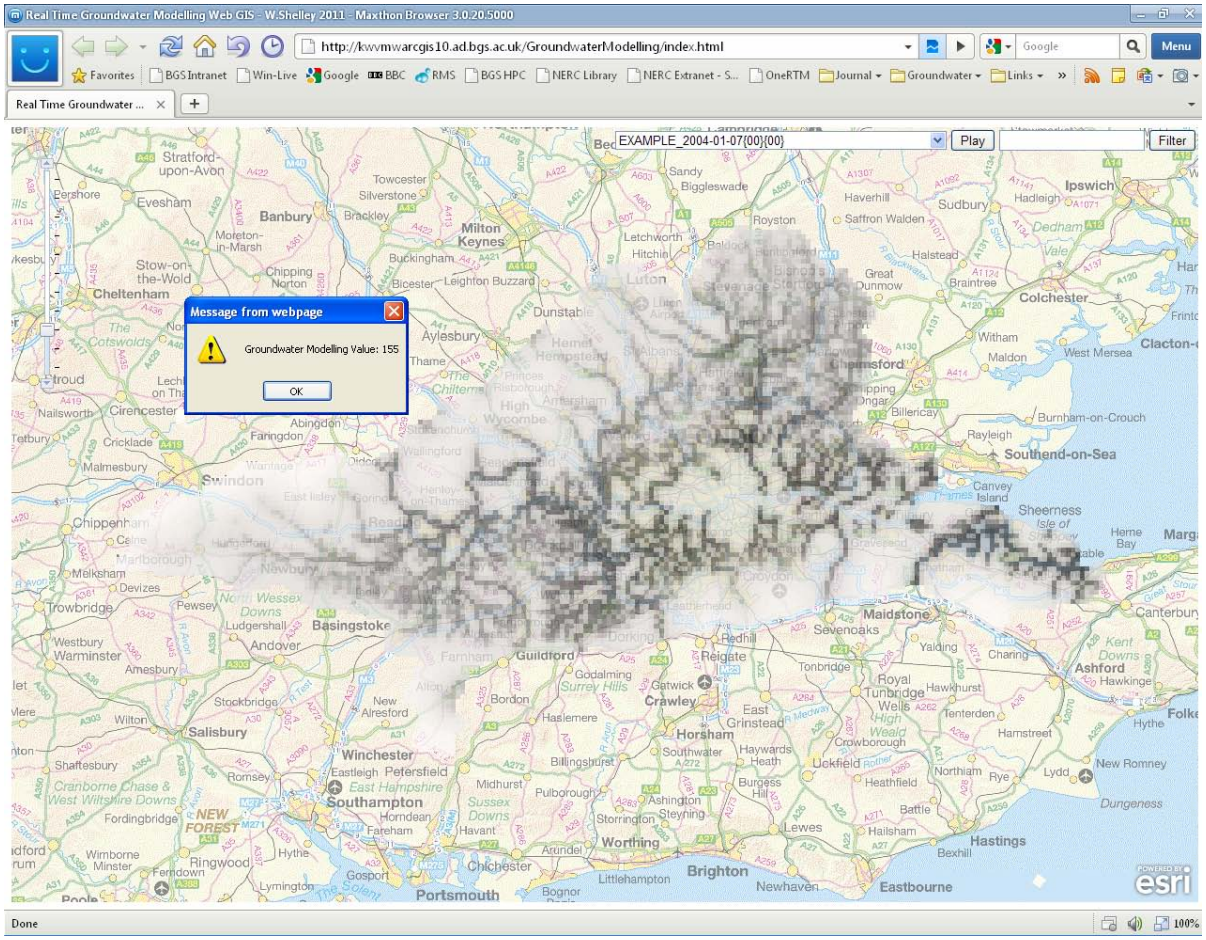


Figure 1. The initial interface of OneRTM

3.2 DATASETS AND MODELS USED IN THE PROJECT

The datasets used in this project include:

- Digital Terrain Model
- Land Cover Map 2000 (from NERC CEH)
- River network (from NERC CEH)
- River flow gauging data (from NERC CEH)

- Daily distributed rainfall data (from NERC CEH)
- 1:625k geological map (from NERC BGS)
- 1:625k hydrogeological map (from NERC BGS)
- Observed borehole data of groundwater levels (from NERC BGS)
- "MORECS" potential evapotranspiration data (from EA and Met Office)

NERC models used in this project include:

- Groundwater flow model of the Marlborough and Berkshire Downs and South-West Chilterns (Jackson *et al.*, 2011) using ZOOMQ3D (developed by NERC BGS) (Jackson and Spink, 2004)
- Groundwater recharge model in the area (developed by NERC BGS)
- Groundwater flow model of the area developed using GIS-Groundwater for groundwater abstraction scenarios (from NERC BGS) (Wang *et al.*, 2010)

All these datasets and models have been successfully integrated and synchronised in OneRTM to form a complete data and model service flow. "The area" described in this report refers to the Marlborough and Berkshire Downs and South-West Chilterns.

3.3 STORYBOARD

The functions of OneRTM are described below using a storyboard based on screenshots taken from the OneRTM pilot. Once the OneRTM page is open in an internet browser, it shows a map of the UK (Figure 2). End users can use a mouse to navigate the interface and explore the map by holding the left mouse button and zoom in or out by rolling the mouse wheel or by a map scale slider on the left top side of the window.

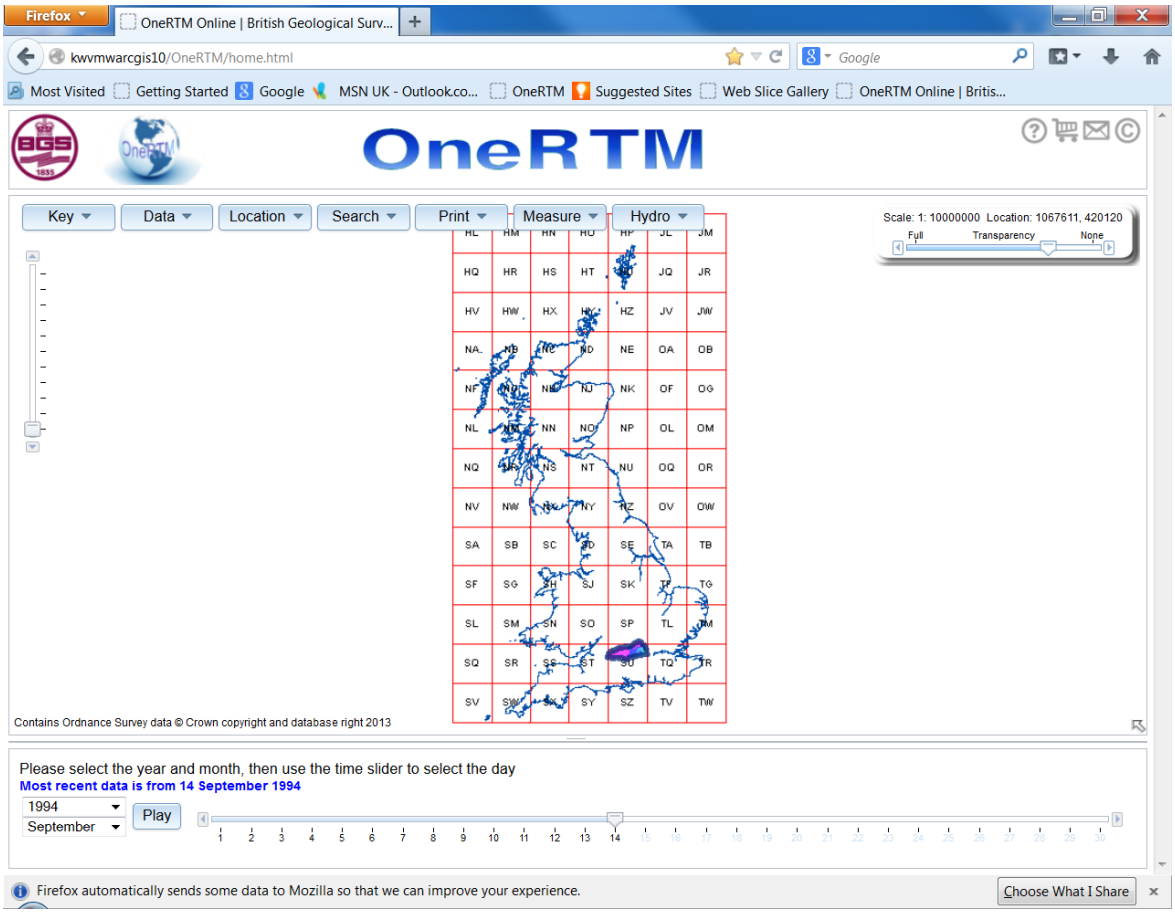


Figure 2. The interface of the OneRTM as configured for a water company (whole UK)

After zooming into an area, the interface is as shown in Figure 3. The transparency of the top most GIS layer can be controlled by a display bar on the top right of the window that also shows that current mouse coordinate information. OneRTM contains functions that, for example, control switching of layers on and off (Figure 4), location bookmarking and search (Figure 5), data search (Figure 6), printing (Figure 7) and distance and area measuring tools (Figure 8).

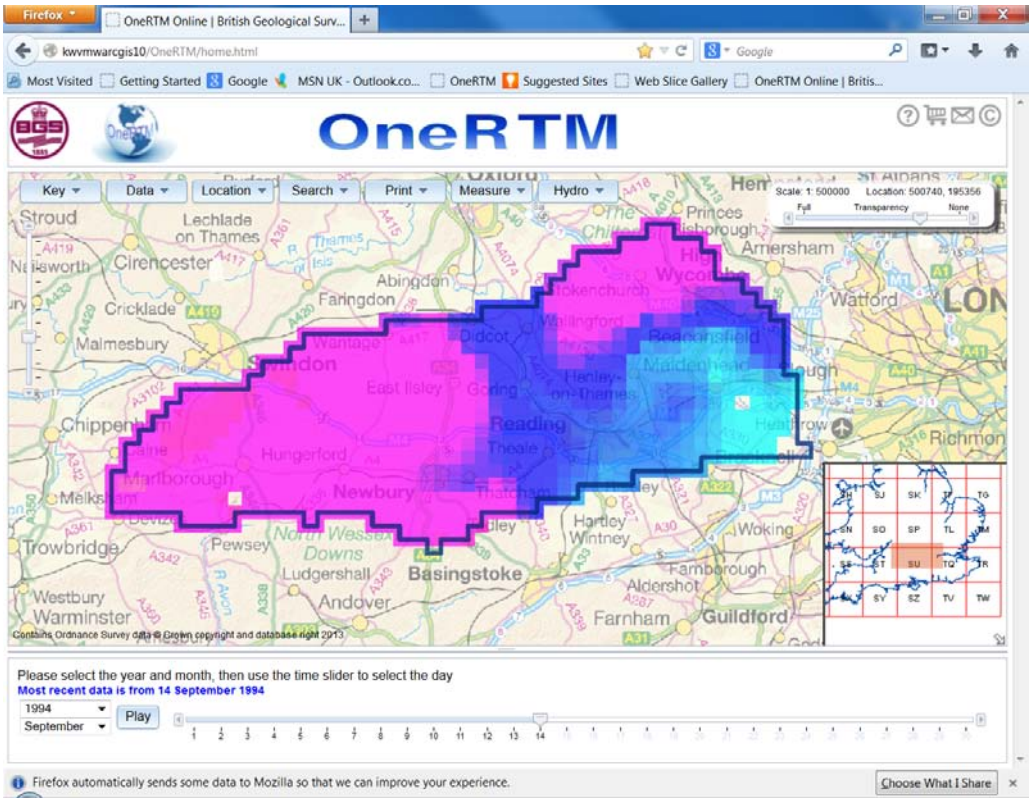


Figure 3. The interface of the OneRTM for a water company (zoomed into the area of interest).

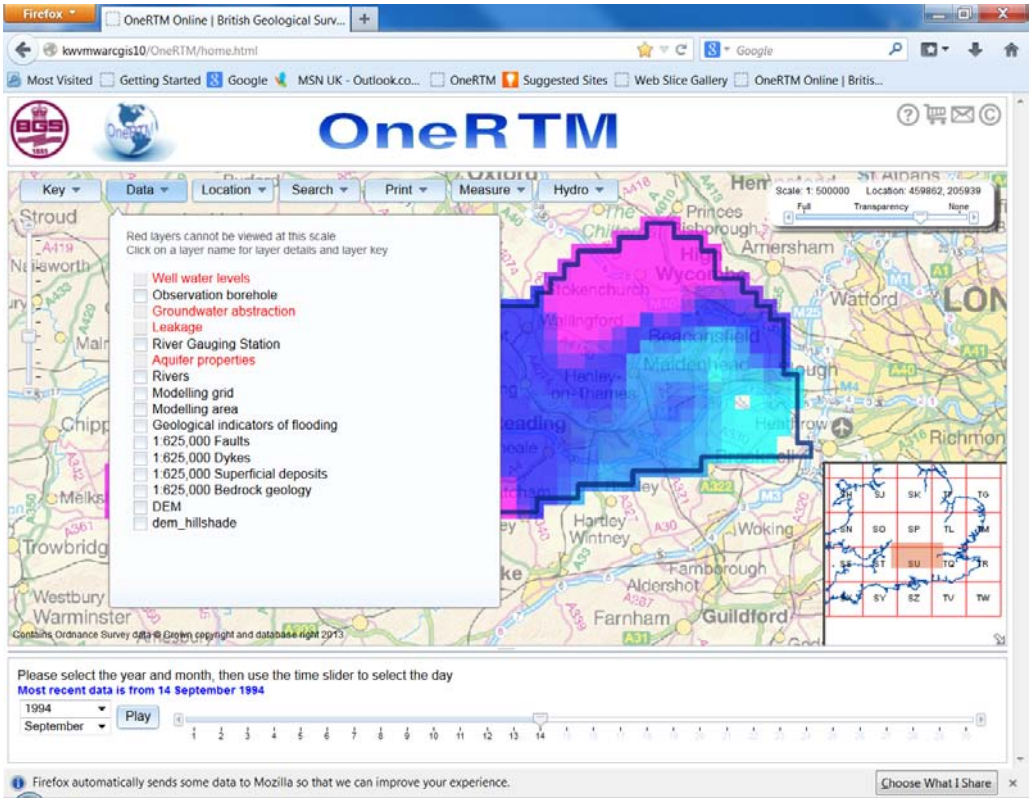


Figure 4. The interface of the OneRTM with data layer display function

As well as these functions, the OneRTM has unique functions that help solve the problems that could be encountered easily using the traditional numerical modelling as described in section 1.2.

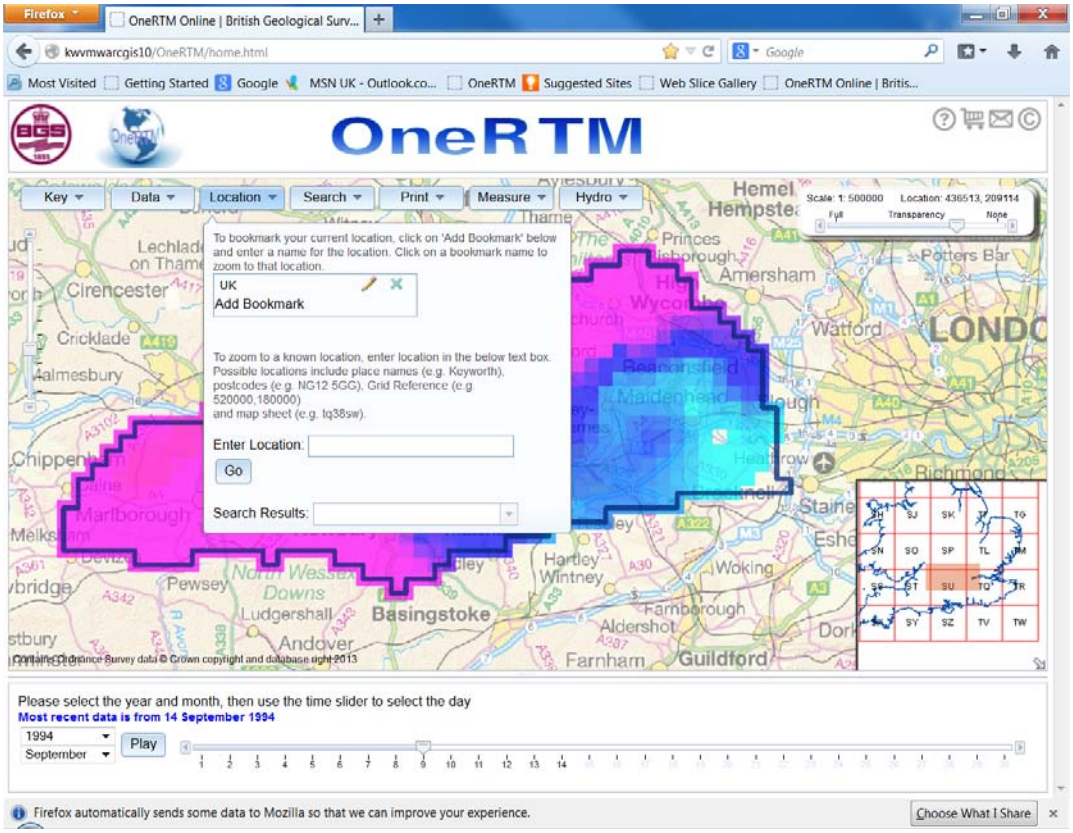


Figure 5. The interface of OneRTM highlighting location bookmarking and search function

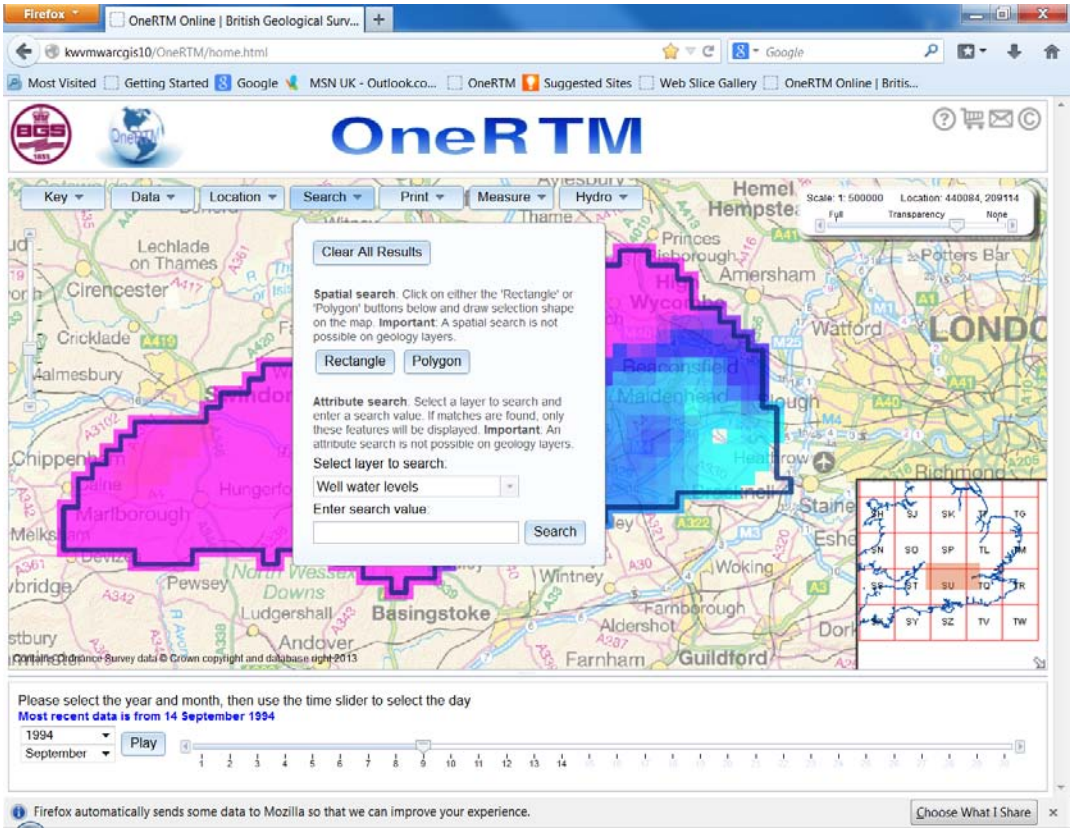


Figure 6. The interface of OneRTM highlighting search functions.

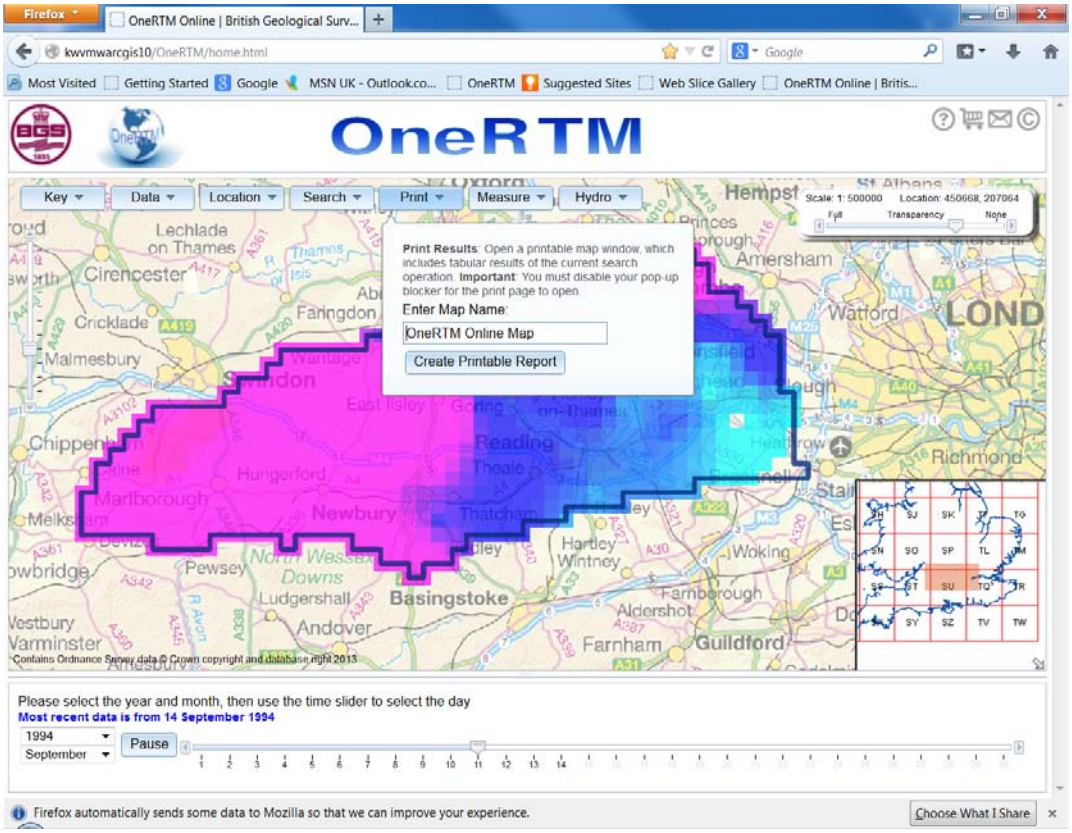


Figure 7. The interface of OneRTM highlighting the print function

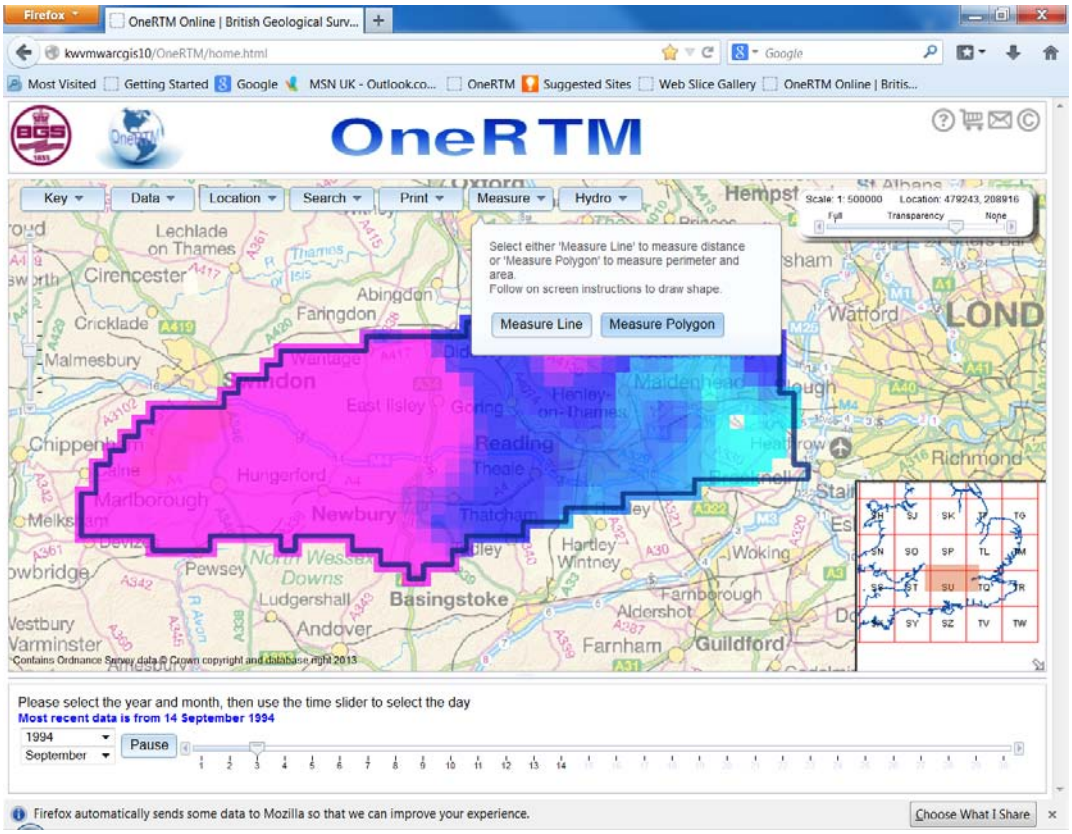


Figure 8. The interface of OneRTM highlighting the measuring functions

3.4 POTENTIAL USES OF ONERTM

The following describes how OneRTM could be used.

3.4.1 Quicker and easy model maintenance

It is both costly and time consuming to keep numerical models up to date as this is generally carried out by manual intervention by professional modellers. In this example, OneRTM automatically keeps the groundwater flow models up to current once the latest rainfall and potential evapotranspiration (calculated using weather and land cover data by Met Office) whenever datasets become available. This means that a model runs automatically and is always up to date without further intervention.

3.4.2 Immediate and cheap dissemination of models and modelled results

Traditionally, it has taken a long time for modellers to prepare a report based on the modelled results, and then send it to end-users along with tables or GIS maps of the modelled results (built for specified historic periods of environmental data) and modelled data. OneRTM immediately delivers the models and datasets through the internet, thus allowing end-users to access up-to-date information. This is potentially very useful in supporting quick decision making. Datasets including modelled results are also automatically archived in the system allowing users to view or query past groundwater levels by selecting year, month and day (Figure 9, Figure 10 and Figure 11).

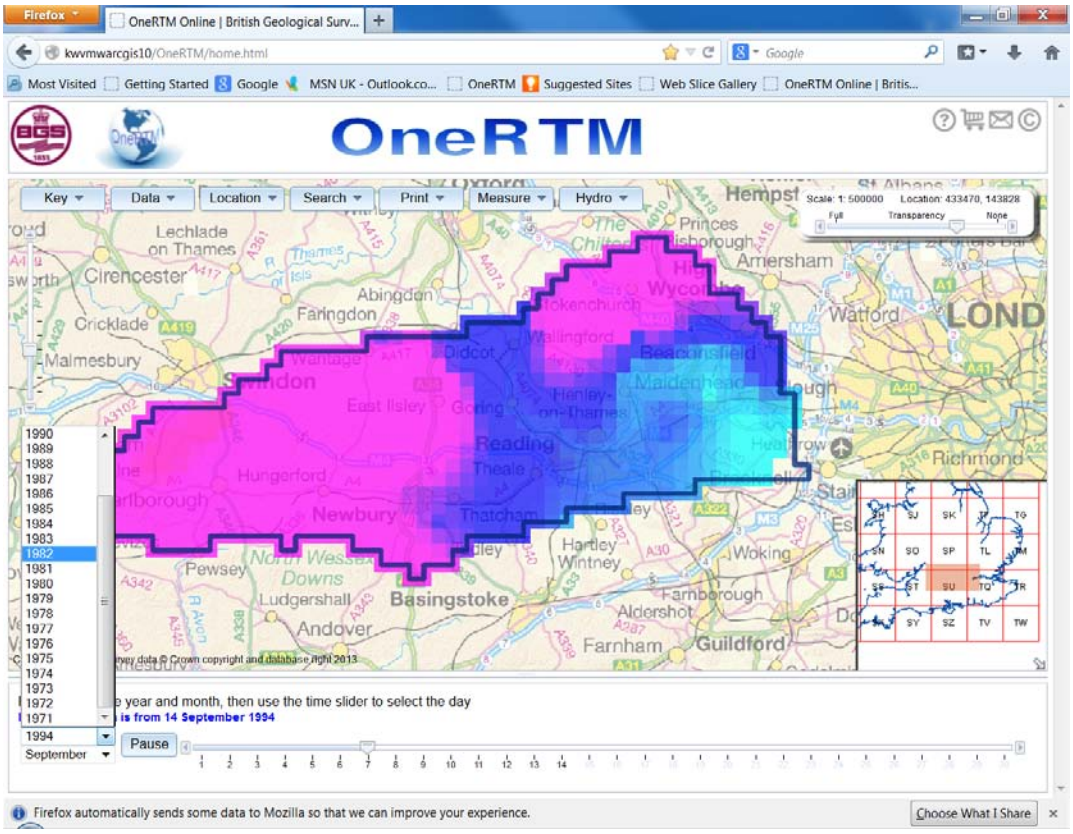


Figure 9. The interface of OneRTM highlighting with historic data view function (selecting year)

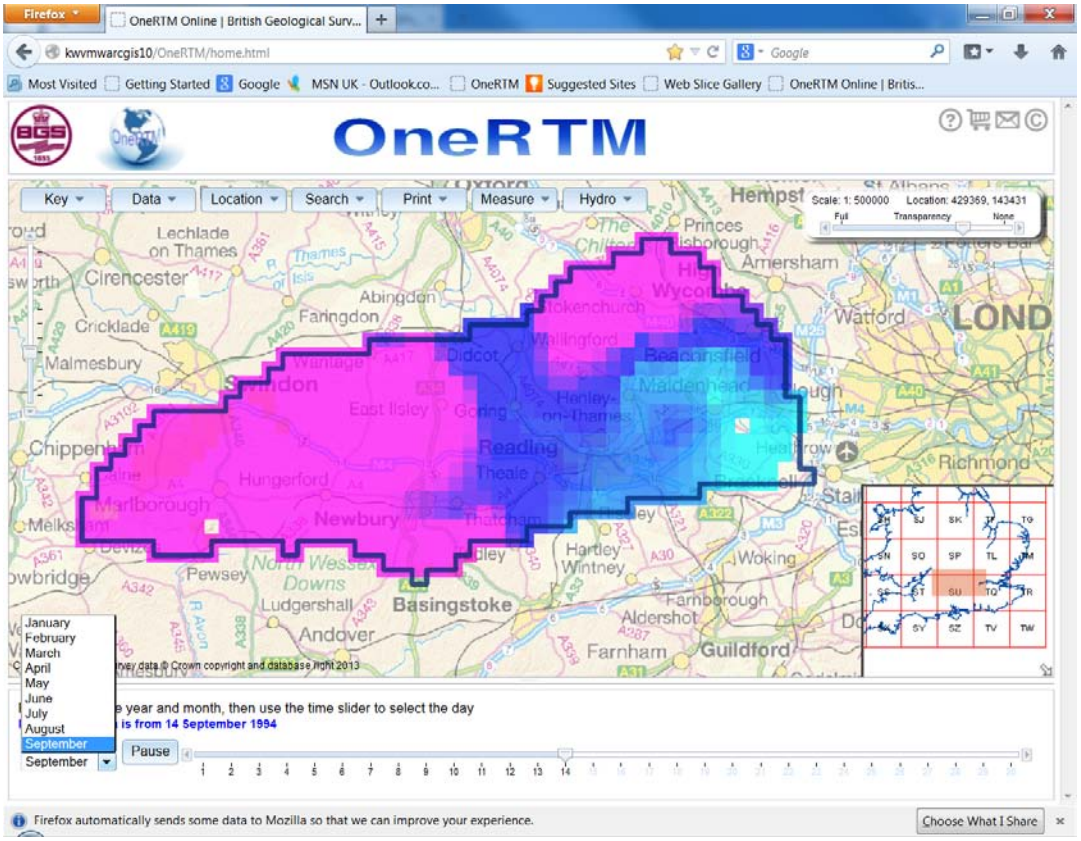


Figure 10. The interface of OneRTM highlighting historic data view functionality (by selecting individual months)

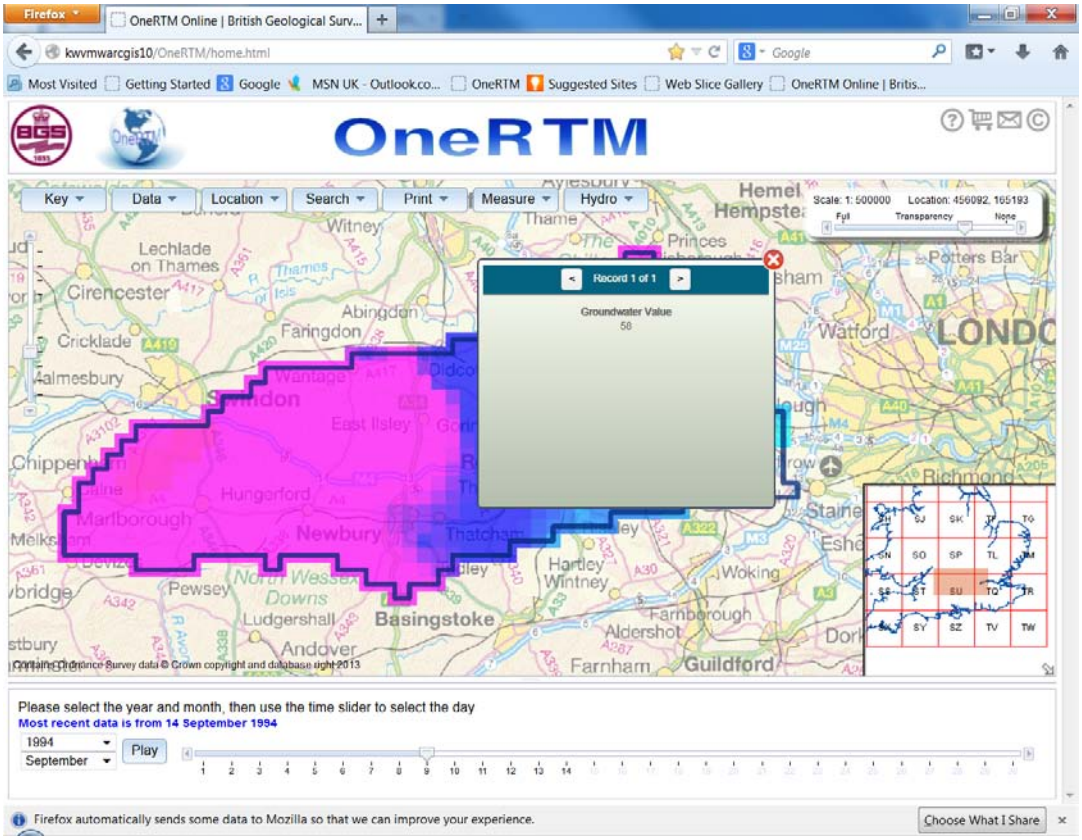


Figure 11. The interface of OneRTM highlighting querying functionality

3.4.3 Allowing non-modeller to use modelling functions

Training is generally needed to allow people to use numerical models and interpret the modelled results. This creates a significant barrier for using numerical models by those who make decisions. Modellers' time has to be sought to help in numerical modelling or in translating the modelled results into the format that is understandable to non-modellers. OneRTM hides the complicated model interface behind the internet browser so that a person without any modelling experience can easily view and interrogate modelled results (such as groundwater levels) which are shown as GIS layers.

As an example OneRTM provides online modelling functions to generate hydrographs and run abstraction scenarios (Figure 12) thus allowing a user, who has no or very limited modelling knowledge, to directly interact with online modelling functions. This in turn reduces the need for model developers to support model users and also the time associated with interpreting model outputs. The "generate hydrograph" function allows users to easily generate a groundwater hydrograph at any location in the model area via an internet browser. After clicking the "Generate Hydrograph" button, a message box appears that prompts for selection of a location to generate a hydrograph (Figure 13) and after a short wait then a groundwater hydrograph is displayed in the browser. This provides information on changes in groundwater levels with time at the selected location and also statistics about this such as the average groundwater level over a time intervals and frequency histograms of past groundwater levels (Figure 14). If the selected location is accidently outside of the modelling area, a warning will also be shown to let users to select a valid location.

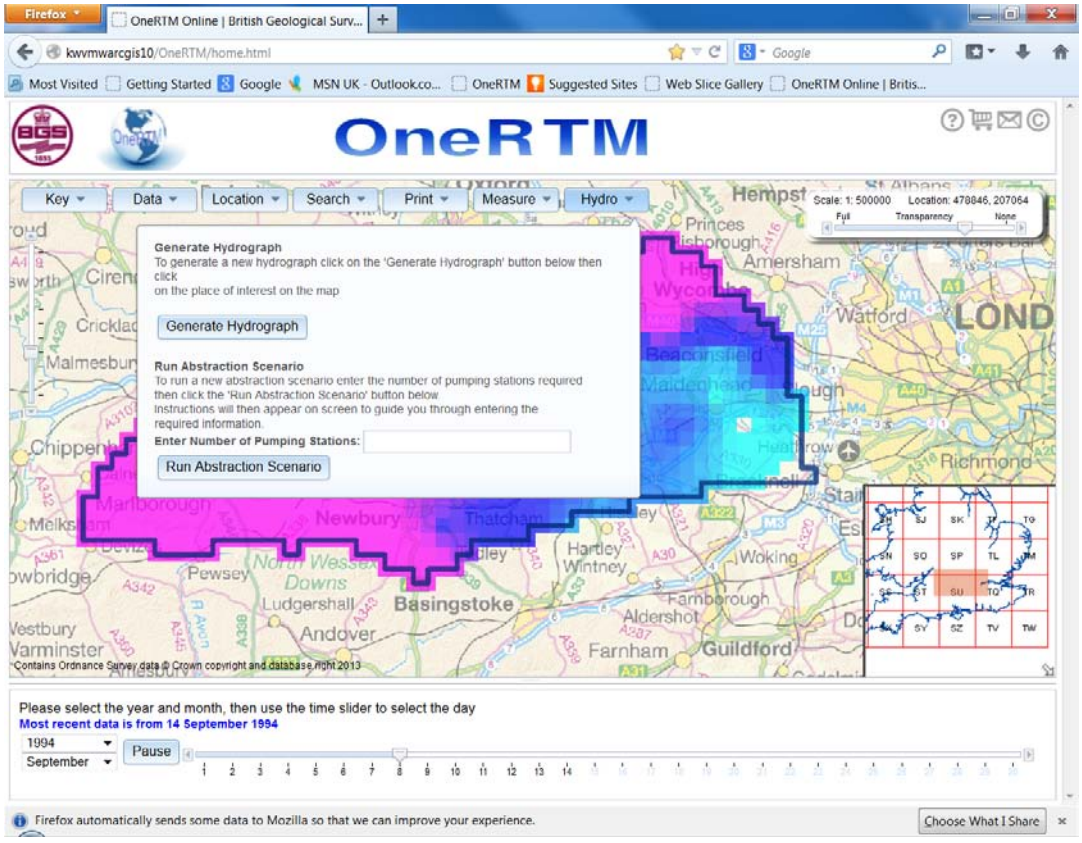


Figure 12. The interface OneRTM highlighting online interrogation functionality to generate hydrographs and to evaluate abstraction scenarios

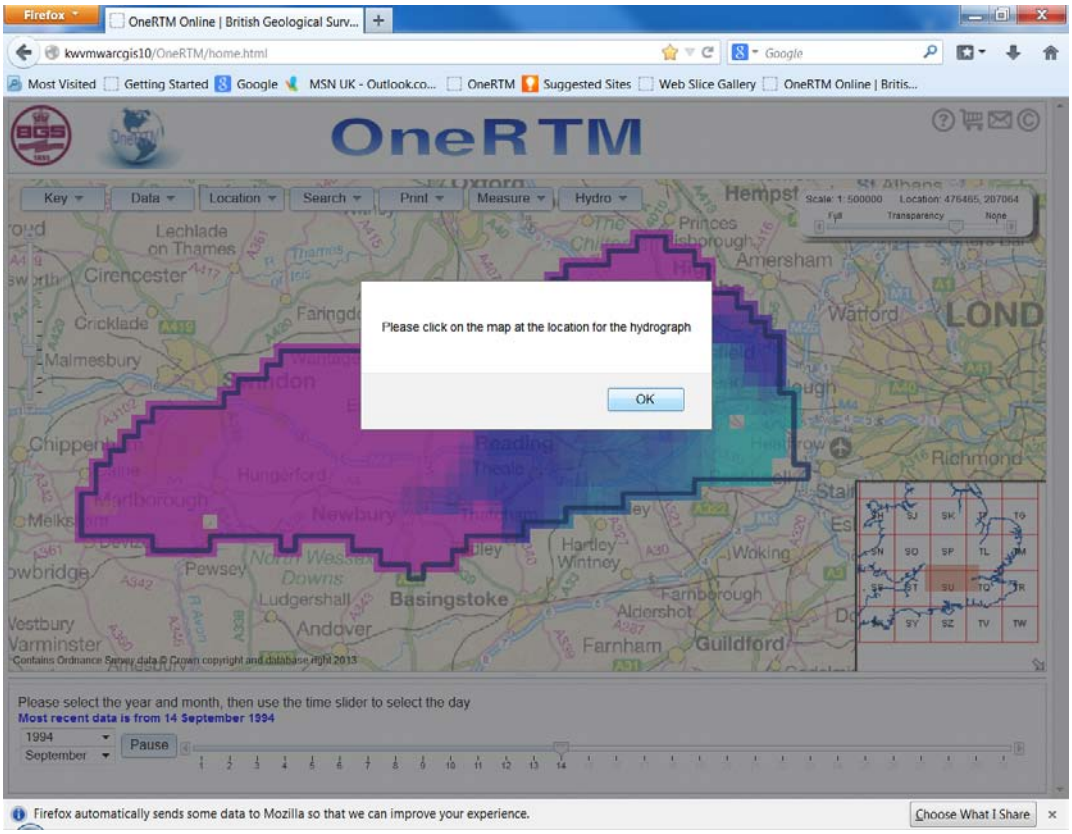


Figure 13. The interface of OneRTM highlighting the hydrograph generation functionality

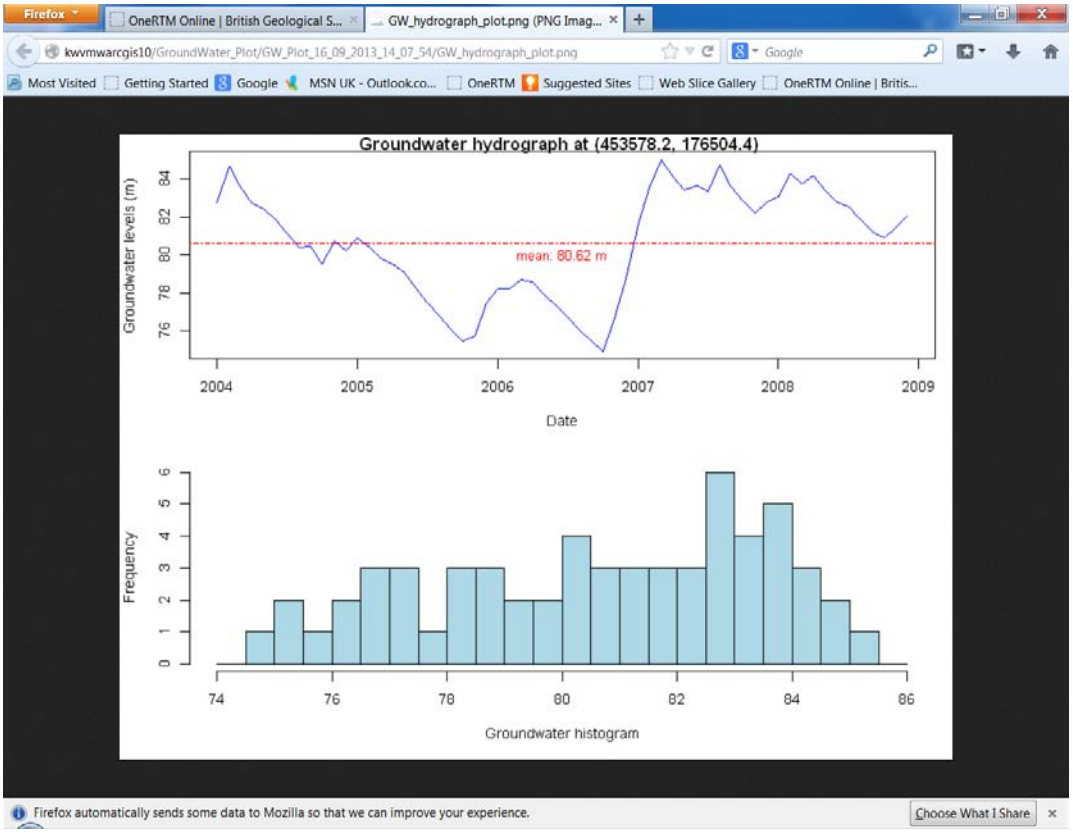


Figure 14. A OneRTM hydrograph generated “on-the- fly.”

As an example of how users can tests scenarios using OneRTM the “Run abstraction scenario” function was developed to show how decision makers might assess the impact of changing conditions, in this case the effects of a newly proposed abstraction boreholes. A decision maker can specify the number of proposed pumping boreholes and then click the “run abstraction scenario” button in a browser (Figure 12). A prompt appears to select a location for generating the groundwater hydrograph at a potentially impacted location some distance away (similar to Figure 13); followed by prompts to enter the location and abstraction rate for the proposed borehole(s) (Figure 15). After a short wait hydrograph pops up providing the information on average groundwater levels and groundwater level changes with and without proposed pumping borehole scenario (Figure 16).

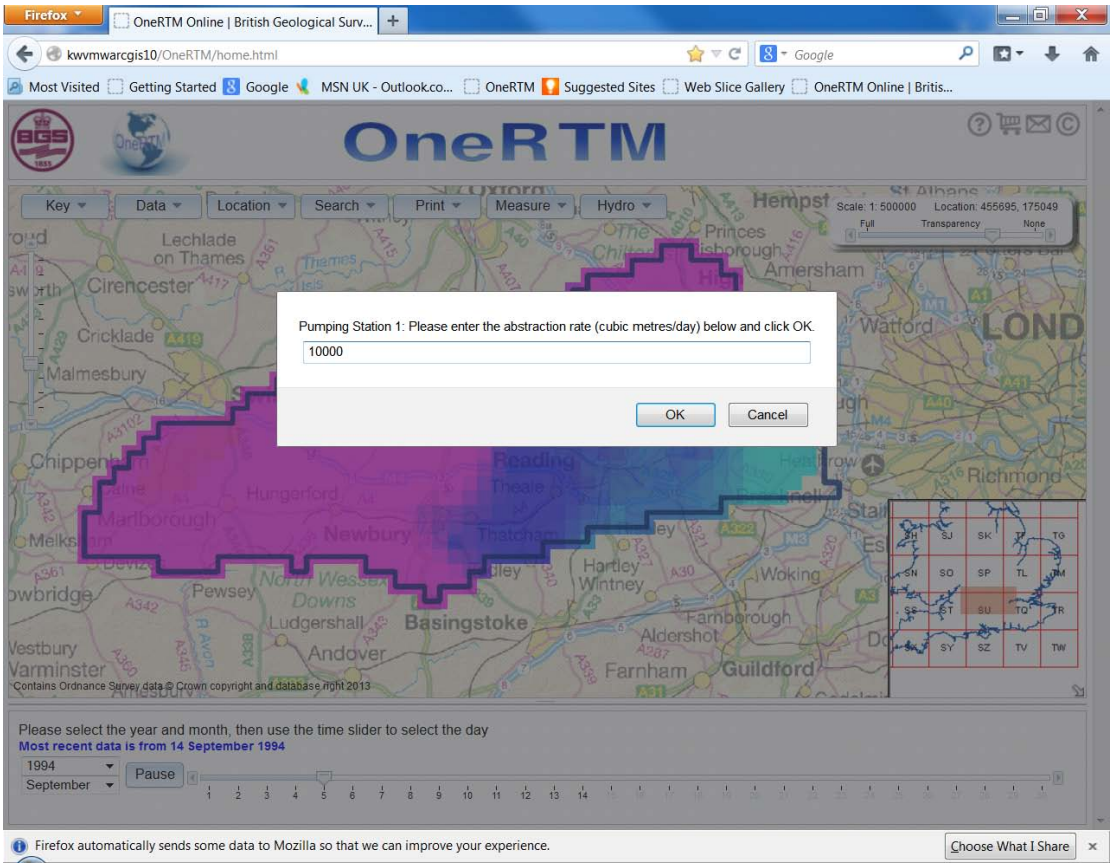


Figure 15. The screenshot of entering the abstraction rate of proposed pumping borehole for the OneRTM “run abstraction scenario” function

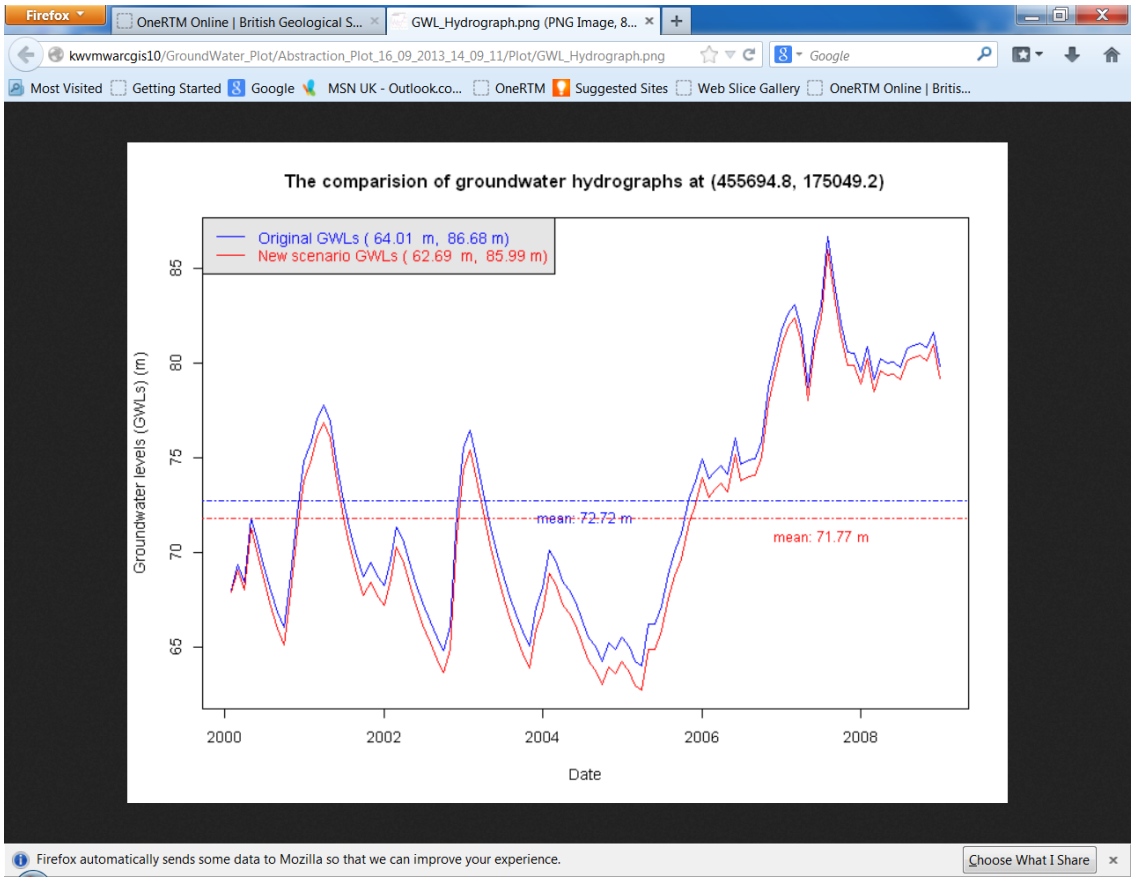


Figure 16. The screenshot of the abstraction scenario results showing the comparison of Groundwater hydrograph with and without the proposed pumping borehole(s).

3.4.4 Easy model integration

Although there are other methods for model integration, they are often not easy to implement; for example OpenMI require that all models should be OpenMI wrapped which often needs recoding the models. OneRTM integrates models based on data flow; there are only two requirements to make a model OneRTM compliant:

1. The model can be run from a DOS command line.
2. The model must be able to run a single time step at a time, so that the model is able to use the modelled results from the end of previous time step as the initial condition for the current time step simulation, and then export modelled results at the end of current time step

The OneRTM integrates three models (described in section 3.2) and synchronises them in real-time. This functionality could mean that OneRTM has potential to host and link many different types of environmental models, such as hydrological, water quality and socio-economic models.

3.4.5 Emergency alert function

OneRTM can send out alert messages by email if preset conditions are met, which provides warnings for decision makers to aid quick reactions to changes. For example the preset condition could be groundwater flooding where the groundwater level is higher than a threshold value, drought if groundwater level is lower than a threshold value, or water pollution if for example, a model showed water nitrate concentrations higher than a threshold value. Equally it could advise

on the end of an event, such as the finish of a scenario simulation. Figure 17 is an example of alert function in OneRTM; an email is automatically sent out once the abstraction scenario run finishes.

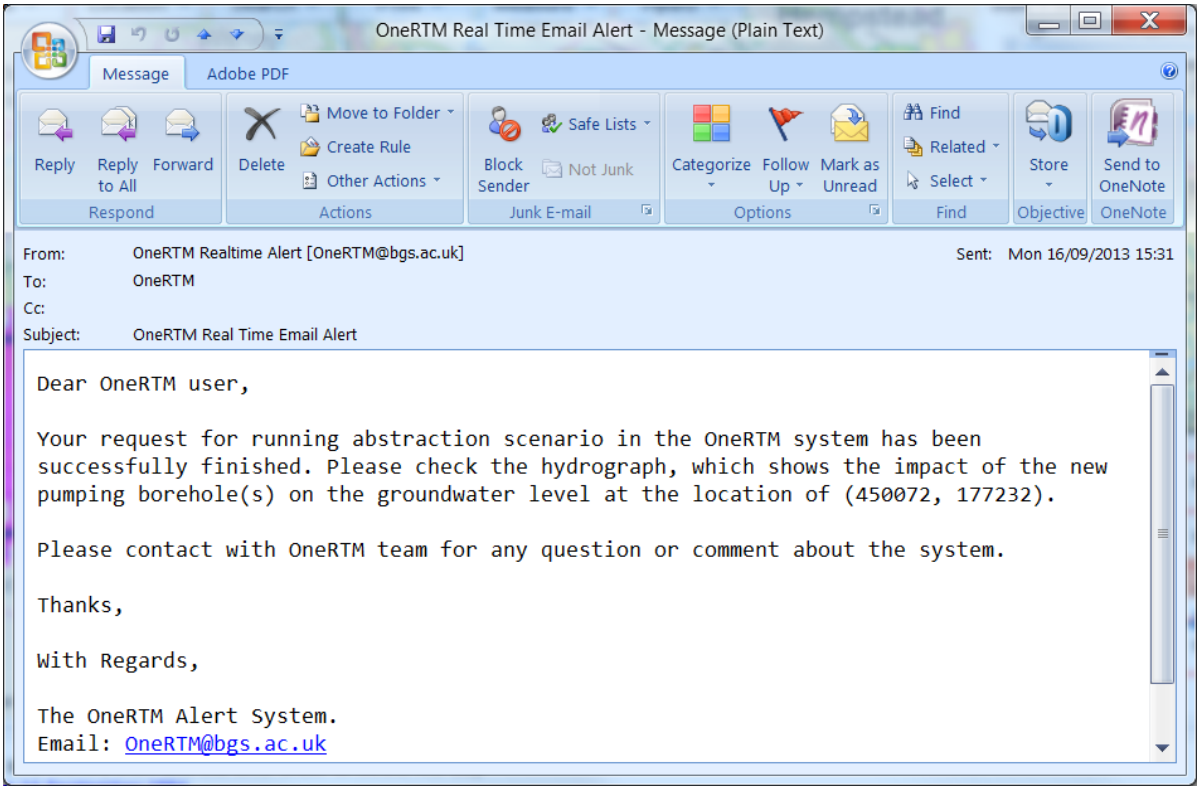


Figure 17. The screenshot of alert message sent out when the abstraction scenario run finishes

4 Suggested next steps

4.1 INTRODUCING TRUE REAL-TIME DATASETS

The OneRTM pilot uses synthesized real-time data that was derived from the historical rainfall and potential evapotranspiration datasets (1972 - 2008); such data are automatically fed into the system every 10 seconds to simulate the real-time situation. A fully functional system will require actual real-time rainfall and real-time potential evapotranspiration data (not yet supplied) from the Met Office to make this system work in real-time. Some technical issues will need to be resolved such as finding ways to automatically transfer real-time data from the Met Office to BGS, and to automatically convert the real-time data into the input formats that groundwater recharge models required in OneRTM.

4.2 DEVELOPING FORECAST FUNCTIONS

OneRTM can potentially forecast the future environmental status, and this can be demonstrated in its future development once the forecasted rainfall and potential evapotranspiration data are available from Met Office. Past, current and future modes need to be developed in OneRTM allowing end-users to choose what to view. In addition to the current database that stores the real-time and historic datasets, an extra database will be needed to hold forecast data.

4.3 DEVELOPING AUTOMATIC CALIBRATION FUNCTION

OneRTM could be further developed to automatically calibrate the groundwater models when the old version of model does not represent the current situation adequately. Beyond the issues of data access there are also technical challenges in automatically parameterising based on the simulation errors.

4.4 DEVELOPING OTHER FUNCTIONS

OneRTM will be further developed based on specific requirements from potential end users. This pilot responds to the specific requirements of the water industry and associated regulators.

4.5 VISION OF HOW ONERTM WILL WORK

Business cases will be developed to customise OneRTM to help solve the real problems in multiple business sectors. These will result in fully enabled OneRTM applications, such as real-time modelling and decision support systems for water companies or local governments. In the longer-term OneRTM could become the basis for developing a platform that serves modelling results in real-time. Services might include:

- Hosting multiple types of real-time models.
- Linking these models to simulate complex natural processes.
- Providing a wide range of real-time datasets, such as weather, river flow, water quality, crop growth, and even socio-economic activities, to multiple end users including decision makers, governments, the general public and modellers.
- Providing functions allowing customers to compare and choose datasets and (or) models.
- Providing security protection for internet access to these data and model outputs.

This platform will change how numerical models are developed, maintained, and disseminated. Models will no longer be developed just for a certain period of time but are always up-to-date utilising real-time dataset supports from NERC or other organisations; models will be linked with each other in real time through the real-time data flow between them. This process will change how datasets are created, updated, stored and shared. Currently static datasets can be

updated in real time through modelling, and stored, and automatically disseminated through the internet. This platform could provide a place where people can easily access, find and utilise both datasets from data providers such as NERC and models. This will make datasets and models created from scientific research integral to many more people's daily lives.

5 Stakeholder engagement

A series of separate stakeholder interactions was undertaken to publicise the development of OneRTM which would allow the system to be further developed. This formed four separate requirements:

- Potential business partners in developing and commercialising the system
- Potential public-sector end-users
- Potential water industry end-users
- Potential finance industry end-users

5.1 POTENTIAL BUSINESS PARTNERS IN DEVELOPING AND COMMERCIALISING THE SYSTEM

Discussion at the NERC Pure Associates meeting in Oxford on September 10 and elsewhere have identified three potential business partners with the capability to develop OneRTM as a commercial service. The requirement of this process demands that the company involved have a number of the following series of attributes:

- Involvement in a relevant field of business, such as scientific software development.
- Familiarity with environmental modelling systems.
- Consultancy in the environmental industries, for example water companies, environmental protection agencies, central or local government.
- Relationships with key stakeholders.
- Expertise in information on environmental risks.

Because of the commercially sensitive nature of the discussion with potential partners it is not possible to identify them in this report. Non disclosure agreements have been signed to protect their identities. However their principal areas of business are:

- A research consultancy with strong links to environmental modelling and the water industry.
- A scientific software developer with links to environmental modelling and provision of data to UK government.
- An IT Company software and with interests in high performance computing.

Discussions are ongoing regarding identifying the most suitable of these companies for development of a consortium for inclusion in the forthcoming TSB competition “Solving business problems with Environmental Data.” Such a consortium would require the involvement of an academic partners (BGS singly or with others).

At an earlier stage of the project the involvement of a more general software company was considered with North 51 Digital (a Nottingham based website and app development company approached. Unfortunately no response was received and subsequently the specific role and requirements for a potential business partner have been clarified. It is clear that more specialists skills than these are required to fully commercialise OneRTM.

5.2 SPECIFIC CONSIDERATIONS NEEDED TO TAKE ONERTM TO MARKET

In a follow-up application to the TSB ”Solving Business Problems with Environmental Data” call it is presumed that amongst the issues to be fully considered the following will be included:

- Development of a details business plan to commercialise OneRTM working with possible business partners.
- The different administrative models under which this could be taken forward (sale of IPR, licence to value added data reseller, joint venture, spin out).
- The different delivery models under which this expertise could be taken to market (e.g. retailed software product, as a service provided by third party, service directly supplied by BGS).
- How to professionalise delivery of OneRTM by working with business partner(s) to produce a better end-user experience.
- Customising OneRTM to meet the requirements of its real business applications including integration of specific company models for example groundwater models of other areas than were including in the initial pilot, including those developed in different groundwater modelling packages.
- Long-term opportunities for OneRTM as a platform to deliver a wider array of environmental models including delivery of modelling outputs supplied by other institutions in the NHP and ESSP which are outside BGS's specific area of expertise.
- Potentially the long-term opportunities for OneRTM as a platform to deliver a different types of modelling outputs (eg traffic forecast models) outside BGS's area of expertise.
- Examination of the potential to use OneRTM as a way of providing easy to understand warnings of potential environmental threats or risks to businesses, and local and central government functions who are unlikely to have either the capacity or capability to deal with detailed modelled outputs of the type that OneRTM is currently configured to deliver.

5.3 POTENTIAL ADDITIONAL ACADEMIC PARTNERS

During the lifespan of this project consideration has been given to widening the academic partners within this project to facilitate a wider range of outputs to be supplied by OneRTM. Contacts were sought through the Environmental Science to Services Partnership and also directly with the University of Nottingham geography Department (who have pertinent skills in many aspects of the project) but lack of a satisfactory response to these contacts has led to these activities being discontinued.

5.4 POTENTIAL PUBLIC SECTOR END-USERS

Contacts with UK Environment Agency have identified two potential areas of EA which OneRTM could directly assist the EA flood forecasting centre and EA abstraction licensing department.

5.5 POTENTIAL WATER COMPANY END-USERS

A series of contacts have been made with UK water companies to identify potential areas of interest in resolving problems within their regions. Amongst the companies contacted are Anglian, Severn Trent, Thames and Yorkshire Water as all of these have a significant component of groundwater input to their existing supply infrastructure. Whilst there are as yet no specific offers of direct involvement both Thames and Yorkshire have shown interest in the system and could constitute potential partners. Both companies have groundwater reserves that provide a significant proportion of their total supply (around 60% and 20% respectively).

5.6 PUBLIC SECTOR DATA SUPPLIER

The majority of the data that are currently used in the production of the output from the OneRTM system are provided by BGS (or through the BGS hosted NGDC) or other NERC institutes (notably CEH) and access to these data streams for the research component of this work has been straightforward. Existing NERC mechanisms can be applied for access to these if OneRTM approaches commercialisation.

However a key component of the developing business case must be the provision of forecast models to help end-users scenario plan potential opportunities and threats depending upon groundwater levels. This will require the implementation of new functionality within OneRTM. This will only be possible if BGS is able to input weather data streams provided by the UK Met Office. Unfortunately the Met Office has thus far proven unreceptive to supporting the development of this product, possibly because they have seen conflicts with their own existing commercialisation efforts. Ideally there should be a clear mechanism to facilitate interactions between the Met Office and other public sector research establishments and data suppliers. In the meantime there are a number of possible models which could be followed to bypass this roadblock:

1. Direct involvement by the Met Office in future research bids.

2. Support for this research by the Natural Hazards Partnership / ESSP as these initiatives includes both the BGS and the Met Office) as in particular this should facilitate provision of data.

3. Given the lack of assistance received from the Met Office thus far any action to commercialise this product may simply require the purchasing of the appropriate data streams to facilitate forecast product development.

5.7 WIDER POTENTIAL OPPORTUNITIES

Beyond the simple opportunities described by this the pilot project a wider opportunity exists to deliver a range of environmental models to a wider group of stakeholders. Many organisations and companies develop modelling outputs which serve a wide range of the stakeholders to multiple end-users. A significant number of these outputs could potentially be delivered to these end-users in a dynamic way by a mechanism such as OneRTM with the advantages that this confers. Whilst the next stages of this project are likely to continue to concentrate on environmental modelling with envisaged end-users in existing sectors which BGS already serves. However in the longer term it is imaginable that this technology will provide a platform for a wider distribution of time-variant spatial model outputs which will not necessarily involve an environmental component. For example, information on time variant industrial processes might be served in the same manner as environmental model outputs through a common portal.

This technology therefore meets a need that is currently unfulfilled; this offers a significant opportunity for information technology companies to both industry and government.

References

JACKSON, C.R., MEISTER, R., PRUDHOMME, C., 2011. Modelling the effects of climate change and its uncertainty on UK Chalk groundwater resources from an ensemble of global climate model projections. Journal of Hydrology, 399, 12–28.

JACKSON, C.R., SPINK, A.E.F., 2004. User's manual for the groundwater flow model ZOOMQ3D. Interal Report IR/04/140, British Geological Survey, Keyworth, Nottingham, UK.

WANG, L., MANSOUR, M., HUGHES A., 2010. Developing a GIS based finite difference groundwater flow model GISGroundwater. Internal Report IR/10/070, British Geological Survey, Keyworth, Nottingham, UK.