Understanding Connectivity between Groundwater Chemistry Data and Geological Stratigraphy via 3D Sub-surface Visualization and Analysis

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Abstract. This paper describes the 3D Water Chemistry Atlas[1] - an open source, Web-based system that enables the three-dimensional (3D) sub-surface visualization of ground water monitoring data, overlaid on the local geological model. Following a review of existing technologies, the system adopts Cesium (an open source Web-based 3D mapping and visualization interface) together with a PostGreSQL/PostGIS database, for the technical architecture. In addition a range of the search, filtering, browse and analysis tools were developed that enable users to interactively explore the groundwater monitoring data and interpret it spatially and temporally relative to the local geological formations and aquifers via the Cesium interface. The result is an integrated 3D visualization system that enables environmental managers and regulators to assess groundwater conditions, identify inconsistencies in the data, manage impacts and risks and make more informed decisions about activities such as coal seam gas extraction, waste water extraction and re-use.

Keywords: 3D · sub-surface visualization · groundwater · chemistry · geological model

1 Introduction

The Coal Seam Gas (CSG) industry is rapidly expanding within Australia but it faces concerns from governments and communities, worried about the environmental impact of coal seam gas exploration and production [1]. Consequently, extensive regulatory frameworks have been established by both the Commonwealth and the States to minimise risks and mitigate any adverse impacts of from CSG exploration and extraction [2,3,4]. For example, in Queensland, companies are required to undertake baseline assessments for water bores in areas where petroleum and gas production or testing is planned or underway. The Office of Groundwater Impact Assessment (OGIA), stores the baseline assessment information (which includes bore registration, aquifer, casing, stratigraphy, and water analysis records) in the Bore Baseline Assessment Database (BBAD) and uses it to produce groundwater impact report. In addition to

[1] http://3dwa.metadata.net/

OGIA's BBAD database, a number of other sources of groundwater and geological information provide complementary data for assessing the impact of CSG extraction on groundwater (e.g., the Groundwater Database (GWDB) maintained by the State Government and the Surat Super geological model developed by the University of Queensland [5,6].

Stakeholders (including government, industry and research organizations) all agree that the rapid expansion of the Coal Seam Gas (CSG) industry in Queensland has led to growing demands for enhancements to groundwater data management services. These include the need for: improved data collation and integration across multiple organizations and monitoring programs; more rigorous and streamlined QA/QC procedures; and accessible easy-to-use tools for evaluating changes in groundwater chemistry due to analytical, environmental, human or geological factors.

2 Objectives

The 3D Water Chemistry Atlas project was established in 2013, through a collaboration between the University of Queensland's Centre for Coal Seam Gas (CCSG), Centre for Water In the Minerals Industry (CWIMI), School of Earth Sciences and the School of Information Technology and Electrical Engineering (ITEE). The aims of the 3D Water Atlas project are to tackle some of the gaps in groundwater data management in Queensland, as identified by stakeholders, by developing:

- A Web Portal to a unified, quality controlled database of groundwater chemistry data that is integrated with a reliable and consistent geological model, together with other freely available and relevant geospatial layers (e.g. satellite imagery, rad networks, property boundaries and mining lease boundaries).
- Streamlined QA/QC processes that automatically detect and filter erroneous data and help to guide future ground water monitoring practices.
- New visualization and analysis tools which take advantage of spatio-temporal overlay of water chemistry data and 3D geological data to enable regional interpretations of spatial and temporal water chemistry trends, by displaying outputs from multivariate statistical analyses and geochemical modelling.
- Interfaces that increase public access to water chemistry data whilst protecting commercially sensitive data.

3 Technical Architecture

One of the critical requirements for the system was that it should support 3D subsurface visualization of geological and ground water data. Hence one of the first tasks was to assess existing platforms and to choose the optimum for this application. Although there are a plethora of "virtual globe" software systems available, they mostly support spatial information layers displayed above the earth's surface (street maps, digital elevation models, satellite imagery, etc.) i.e., they do not support 3-D subsurface data or strata visualisation. Five visualisation systems were identified that could potentially provide the visualisation capabilities required for the 3-D Water Chemistry Atlas:

- NASA World Wind [7] including Geoscience Australia's World Wind Suite [8] and EarthSci [9];
- Google Earth [10];
- ParaViewGeo [11];
- QUT's Groundwater Visualisation System (GVS) [12];
- Cesium [13];

To evaluate each of these systems, three sets of data were acquired (OGIA's Baseline Assessment data, the GWDB and GOCAD geological layers/models) and the relative ease and precision with which these datasets were ingested, searched, browsed and visualized was assessed. The criteria used for evaluating each system included: speed/efficiency; open source, free software; easy to install; cross-platform (Windows, Mac, Linux); intuitive user interface; support for common formats; visualisation richness; customisability; cross browser support (Chrome, Firefox, Internet Explorer).

Following an evaluation of the five visualization platforms above, the decision was made to use Cesium[2], "a JavaScript library for creating 3D globes and 2D maps in a web browser without a plugin". Because Cesium uses WebGL, it is cross-platform, cross-browser, and supports dynamic-data visualization enled by hardware-accelerated graphics. In addition, NICTA's "ground-push" plugin[3] was adopted to enable sub-surface excavation and visualization. Figure 1 provides a high-level view of the system's components:

- A PostGreSQL database with PostGIS indexing for storing the Groundwater and Baseline Assessment datasets and the CSG companies' borehole datasets;
- Cesium – the visualization platform that enables 3D sub-surface visualization of groundwater chemistry data and geological strata using "ground push" and runs on WebGL compatible browsers, including Chrome or Firefox.
- Geological Models, Map data and Digital Terrain models (acquired from the UQ School of Earth Sciences) that are loaded into Cesium on-the-fly.

4 QA/QC Process

It is critical to apply a rigorous QA/QC procedure to the geochemical data before producing geochemical plots and interpreting geochemical trends as this ensures that the data presented is of a consistent quality [14]. Incorrect data may be introduced due to errors in groundwater sampling methodologies and/or laboratory analysis methods. The QA/QC process applied to the data in the 3D Water Atlas, was based on a review of previous studies [15,16,17].

Some examples of specific QA/QC criteria that were applied to the geochemical data include: 1) removal of geochemical results that were produced through chemical analysis prior to 1950; 2) removal of geochemical results where the major ion "charge balance error" is outside of the range of ± 5%. These criteria account for errors introduced by laboratory analyses. The first criteria relates to changes in analysis methods

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2 http://cesiumjs.org/

3 https://github.com/NICTA/cesium-groundpush-plugin

over time [15], the second criteria relates to incomplete analyses and errors in analyses [16,17].

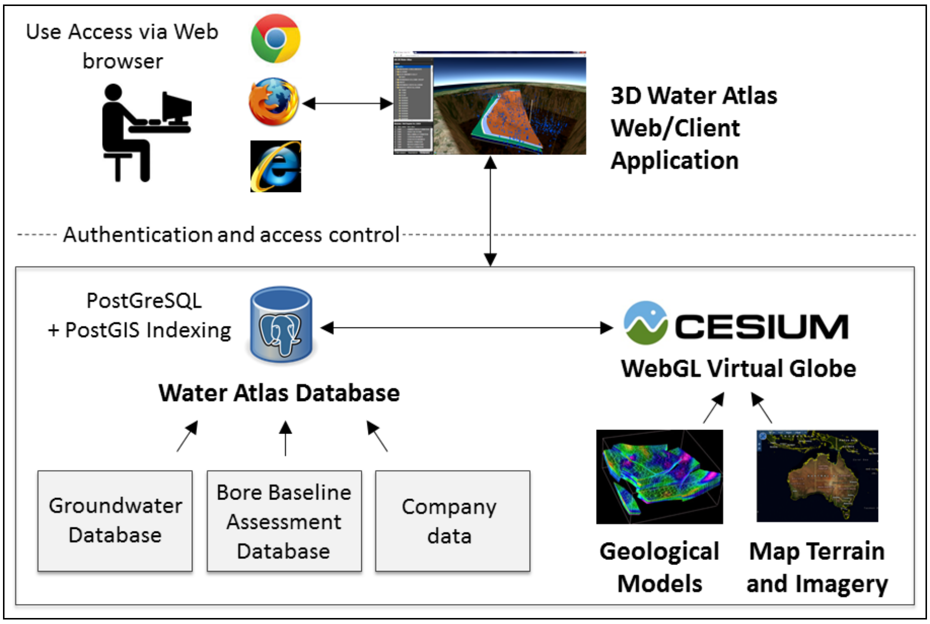

Fig. 1. High Level Architectural View of the 3D Water Chemistry Atlas

Automating the QA/QC steps saves time and hence reduces the time lag between analysis of water quality samples and release of the geochemical data to regulators (and ultimately to the general public). Automation also enables flexible implementation of QA/QC steps (e.g. user defined QC criteria) – allowing raw data to be displayed if it is of interest to specific users or enabling easy modification of QA/QC criteria if thresholds change over time or location.

5 Search, Filtering, Analytical Services

Access to the 3D CSG Water Atlas Portal is via a secure login interface on the project's Web site[4]. The user interface currently supports the following capabilities:

- Ability to overlay and visualize wells/bores and their water chemistry data overlaid on the 3D Geological (Gocad) Model and geological strata (Figure 2);
- Ability to search/filter and retrieve datasets based on specific spatial regions, well/bore numbers, time periods or company/organization bore data (Figure 3);
- A range of analytical services including:
  - Groundwater analysis charts (e.g. Piper diagrams, Stiff diagrams, line charts and pie charts) (Figure 4);
  - Geological model cross-sections (Figure 5);
  - Comparison of formation assignments from different sources

[4] http://3dwa.metadata.net/?page=Portal

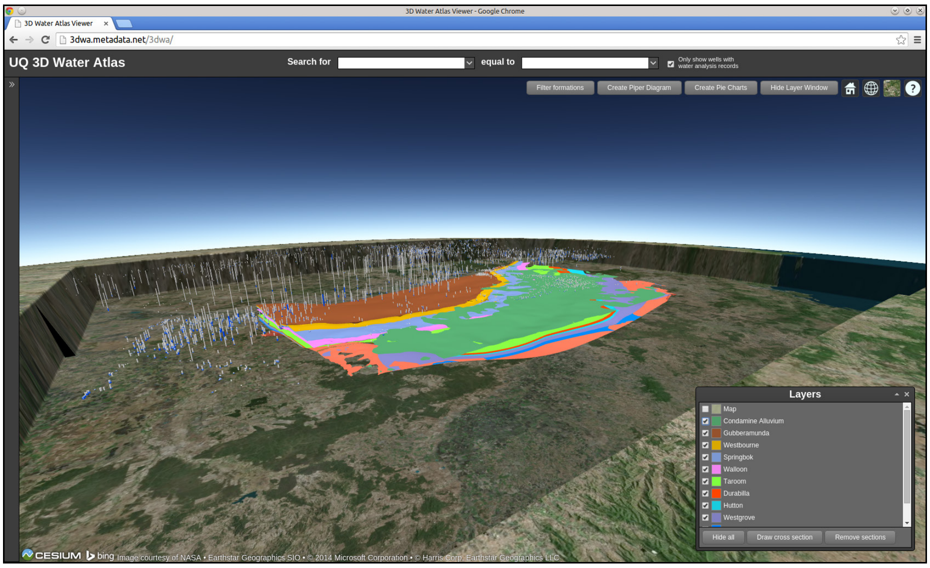

Fig. 2. Groundwater Monitoring Wells overlaid on the Surat Basin Supermodel

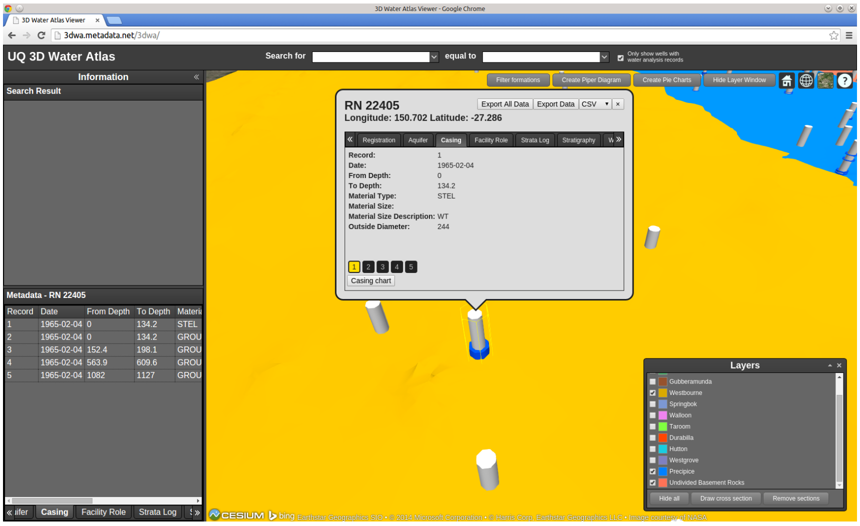

Fig. 3. Metadata and Data displayed for a single selected Well

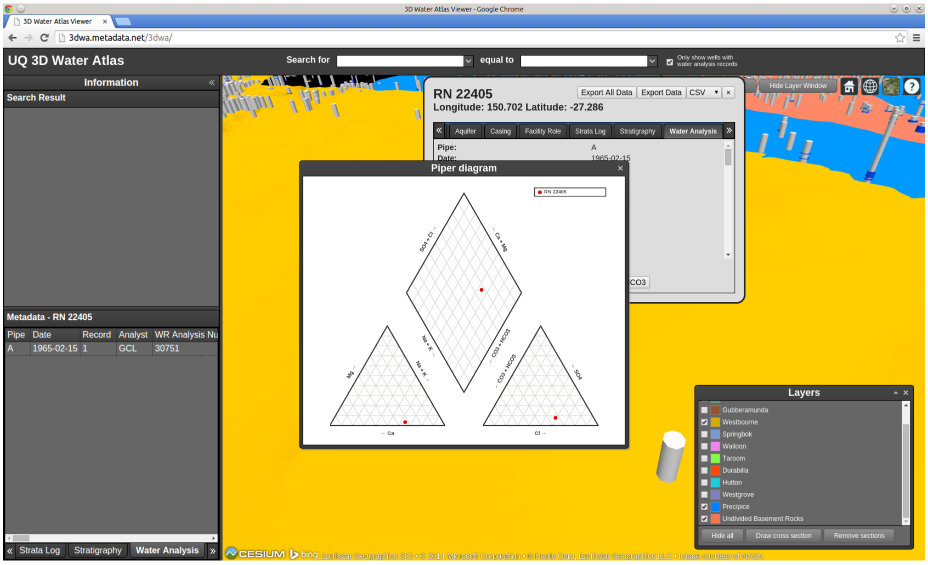

Fig. 4. Example of a Stiff Diagram generated for a particular well

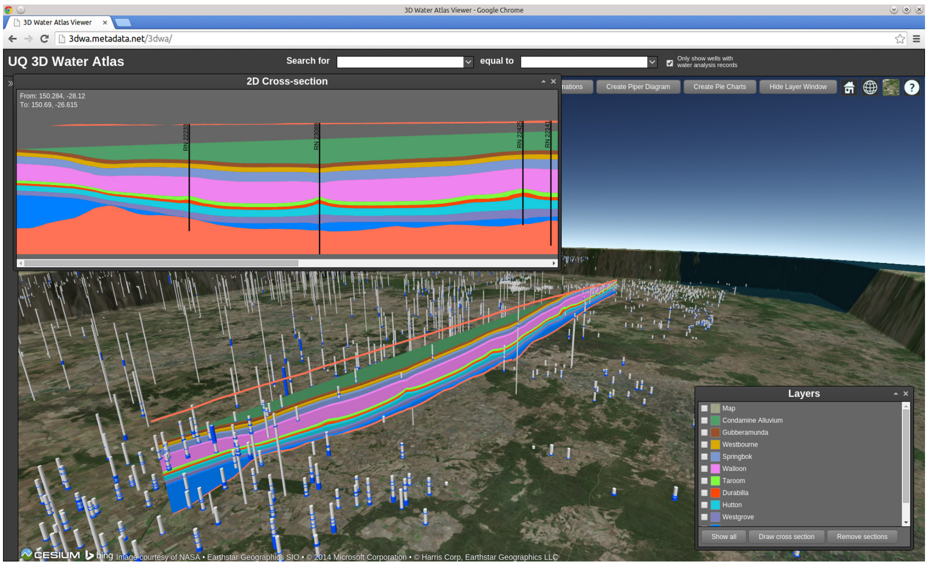

Fig. 5. Example of a geological cross-section dynamically generated from two user-defined endpoints

6 Performance Evaluation

To evaluate the system performance as the size of the geological model is scaled up, multiple copies of the Surat Basin geological model were rendered simultaneously within different locations/offsets in the 3D scene. The sizes of the compressed and uncompressed models are listed in Table 1 below.

Table 1. Sizes of the compressed and uncompressed geological models

Name	Compressed Size	Uncompressed Size	No. of Layers
Surat_gocad	18 Mb	48 Mb	11
Surat_gocad x 2	35 Mb	87 Mb	22
Surat_gocad x 3	53 Mb	131 Mb	33
Surat_gocad x 4	71 Mb	174 Mb	44

Caching of the model was disabled so that the model is reloaded each time and the benefits of caching won't impact on download and rendering speeds. For performance testing, the Google Chrome browser version 38 (which comes with simulated network throttling) was used. Tests conducted were with no throttling (on campus), 30mbps (wifi), 2mbps (dsl, residential broadband), and 750kbps (3G, mobile broadband).

Table 2. Time to download the model to the client (secs)

Connection Speed	SuraGocad	Gocadx2	Gocadx3	Gocadx4
AarNet	9	19	33	48
30 Mbps	9	20	33	48
2Mbps	72	144	216	282
750 Kbps	198	384	582	774

Table 3. Time for the 3D Water Atlas to become responsive to user input (secs)

Connection speed	No model (wells only)	SuratGocad	Gocadx2	Gocadx3	Gocadx4
AarNet	5	20	30	51	60
30 Mbps	6	22	42	64	70
2 Mbps	20	77	151	227	305
750 Kbps	60	208	410	604	792

Table 4. Comparison of Cesium's performance (frames per sec) on different clients

System	No model (wells only)	SuratGocad	Gocadx2	Gocadx3	Gocadx4
Dell Latitude E7740 Windows 64 bit	20-25 fps	8-10	5-6	4	2
Dell Optiplex 980 ubuntu 64 bit	11-12 fps	6	3-4	3	2

The evaluation results indicate that the 3D Water Atlas performance depends primarily on model size and network speed. If the model becomes 4 times larger than the current model, it would take about 1 minute on a high speed network before the 3D Water Atlas becomes responsive. On the Cesium performance side, the frame rate drops quite a bit on a 4 times larger model. On the largest model the frame rate dropped to 2 fps on both systems but the Water Atlas was still usable. The test hardware used were not the latest models and performance would improve on faster systems with better graphic cards. This is not a problem specific to Cesium but would be present with any 3D visualization systems. Further research is required to optimize performance as the model scales up to cover a larger region beyond just the Surat basin.

7 Feedback and Conclusions

Stakeholder feedback from both government agencies and CSG companies has provided valuable direction for future development, including: requests for: the ability to upload, overlay and compare different geological models; interactive selection of regions, time periods and formations to display geochemistry using standard tools (e.g. piper diagrams, stiff diagrams; pie charts, scatter plots); incorporation of new datasets including: property boundaries, mining lease boundaries, road networks; more sophisticated authentication and access control mechanisms to support restricted access to certain datasets, models, services; predictive models that enable users to choose different scenarios and to visualize modelled outcomes.

By combining the open source Cesium virtual globe platform with a common data model and PostgreSQL database, we have been able to quickly develop a rich 3D subsurface visualisation interface to an integrated knowledge-base that provides an effective communication tool for CSG stakeholders (industry, government and community groups), project partners and the general public. The availability of a common Web-based portal to multiple integrated datasets that have undergone rigorous QA/QC, will facilitate greater sharing and re-use of data and knowledge, encourage engagement between stakeholders and streamline interpretations of the monitoring data, ultimately improving our ability to assess the impact of human activities (CSG extraction, agriculture, coal mining) on ground water chemistry.

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