OIL WELL EXPLORER: DATA MINING AND INFORMATION VISUALIZATION APPLIED IN OIL & GAS DOMAIN

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OIL WELL EXPLORER: DATA MINING AND INFORMATION VISUALIZATION APPLIED IN OIL & GAS DOMAIN

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* Este documento deverá ser encadernado juntamente com a monografia em versão final.

This work is dedicated to my family and friends, who always supported me when I most needed.

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“Of all possessions wisdom alone is immortal.”
Isocrates

Abstract

Gas and oil companies produce a massive amount of data related to the oil extraction process. Without a software to support, it is complicated to process and analyze the entire collected data. The Steam-Assisted Gravity Drainage (SAGD) is a recent technology used for the extraction of heavy oil around the world. In Canada, specially in the province of Alberta, there are various gas and oil companies that currently apply SAGD technology in oil extraction, generating large amounts of data. However, the gas and oil software industry has a lack of systems capable of applying sophisticated techniques to assist the knowledge extraction by processing data. This work proposes the creation of a web-based application to visualize SAGD data with similar features present in software available in the market. Using information visualization and data mining, the application can assist petroleum experts to investigate hidden patterns in the data and analyze it with the use of visual representations to uncover unknown characteristics.

Resumo

Empresas de gás e óleo produzem uma quantidade massiva de dados relacionados ao processo de extração de óleo. Sem o uso de software para dar suporte, é complicado processar e analisar todos os dados coletados. Drenagem por gravidade auxiliada por vapor (SAGD – do inglês, *Steam-Assisted Gravity Drainage*) é uma tecnologia recente usada para a extração de óleo pesado ao redor do mundo. No Canadá, especialmente na província de Alberta, existem várias empresas de gás e óleo que atualmente aplicam tecnologia SAGD na extração de óleo, gerando grande quantidade de dados. No entanto, a indústria de software voltada a área de gás e óleo tem uma carência de sistemas capazes de aplicar técnicas sofisticadas para assistir a extração de conhecimento através do processamento de dados. Este trabalho propõe a criação de uma aplicação baseada na Web para a visualização de dados SAGD com funcionalidades similares às presentes em software disponíveis no mercado. Usando visualização de informações e mineração de dados, a aplicação pode assistir especialistas em petróleo a investigar padrões escondidos nos dados e analisá-los com o uso de representações visuais para descobrir características desconhecidas.

Table of Contents

LIST OF FIGURES XI

LIST OF TABLES XIII

TABLE OF SYMBOLS AND ACRONYMS XIV

CHAPTER 1: INTRODUCTION 1

1.1 Problem Characterization 1
1.2 Objectives and Goals 2
1.3 Document Structure 2

CHAPTER 2: BACKGROUND AND GAS AND OIL SOFTWARE 3

2.1 Steam Assisted Gravity Drainage 3
2.2 Data Mining 5
2.3 Information Visualization 8
2.4 Geographic Information System 10
2.5 Gas and Oil Software 11
2.6 Discussion 13

CHAPTER 3: OIL WELL EXPLORER 14

3.1 Data Gathering 14
3.2 Architecture 16
3.3 Technology and Project Decisions 17
3.4 Application Overview 20
3.5 Features 22
3.5.1 Highlight 22
3.5.2 Search 22
3.5.3 Polygon Selection 23
3.5.4 Filter 24
3.5.5 Data Mining 25
3.5.6 Visualization 30
3.5.7 Export 37
3.6 Discussion 37

CHAPTER 4: CONCLUSION AND FUTURE WORK 39

4.1 Conclusion 39
4.2 Future Work 39
REFERENCES 41

List of Figures

Figure 1. Scheme of oil extration using SAGD technology. 4

Figure 2. Representation of knowledge discovery as a sequence of steps. 5

Figure 3. Example of data clustering. On the left, a two-dimensional data distribution and, on the right, the same data grouped in three distinct clusters. 7

Figure 4. Numerical values mapped to a visual representation using bars. Larger numbers are represented in taller bars. 9

Figure 5. Visual Variables. 10

Figure 6. Scheme illustrating how GIS combines different data into a map. 11

Figure 7. Geographical location of Alberta, Canada. 14

Figure 8. Geospatial distribution of the wells from Firebag project. 15

Figure 9. Application architecture. 16

Figure 10. Oil Well Explorer main interface. 21

Figure 11. Highlighting wells. 22

Figure 12. Searching wells by status. Only the wells matching the status “Drilled and Cased” are shown. 23

Figure 13. Selecting wells based on their underground location. 24

Figure 14. Filtering wells with Drillers Total Depth values between 1500 and 1600. . 25

Figure 15. Wells classified by pads. 26

Figure 16. Numerical classification by average oil production into five classes, using equal interval method. 27

Figure 17. Clustering wells into four clusters by considering steam injection, oil production, and steam-oil ratio. 28

Figure 18. ARM applied to the wells data. 29

Figure 19. Emphasize the wells that match both parts of the ARM expression. 29

Figure 20. Bar chart of average injection hours. 30

Figure 21. Pie chart of well current status. 31

Figure 22. Well status timeline of a well. 32

Figure 23. Highlighting the drilled and cased status period in well status timeline. ...32

Figure 24. Visualization of injection time series data. 33

Figure 25. Visualization of production time series data. 34

Figure 26. Visualization of SOR time series data. 35

Figure 27. Visualization of SOR time series data with area chart. 35

Figure 28. Visualization of SOR time series data with bar chart. 36

Figure 29. Visualization of SOR time series data with scatter chart. 36

Figure 30. Visualization of SOR time series data of a smaller period of time. 37

List of Tables

Table 1. Technologies used to support the development of the application. 19

Table of Symbols and Acronyms

API	*Application Programming Interface*
ARM	*Association Rule Mining*
CSOR	*Cumulative Steam-Oil Ratio*
CSS	*Cascading Style Sheets*
CSV	*Comma-Separated Values*
GIS	*Geographic Information System*
GPS	*Global Positioning System*
HTML	*HyperText Markup Language*
JSON	*JavaScript Object Notation*
REST	*Representational State Transfer*
SAGD	*Steam Assisted Gravity Drainage*
SOR	*Steam-Oil Ratio*
SVG	*Scalable Vector Graphics*
UWI	*Unique Well Identifier*

Chapter 1:

Introduction

The aim of this chapter is to explain the reasons that originated this work, followed by the characteristics of the explored problem. The main and specific objectives are described as well as the structure of the document and the focus of the subsequent chapters.

1.1 Problem Characterization

There are many resources of heavy oil around the world. Canada is abundant in this substance, containing almost the same amount compared to the light oil reserves in the whole Middle East. Many different techniques were used to produce heavy oil, such as open pit mining approach and cyclic steaming technology. However, they have serious limitations, which did not allow them to be applied widely in the extraction process. In the late 1970s, Steam Assisted Gravity Drainage (SAGD) process was developed and introduced in the province of Alberta, which is proved, from theory and from scaled model experiments, simpler and more economical to operate and more efficient to recover oil bitumen (Butler, 1998). Nowadays SAGD is being widely used as a thermal production technology, which extracts oil bitumen from Alberta's subsurface oil sands deposits.

The whole gas and oil industry has been generating large amounts of data related to oil and natural gas exploration, development and production. Besides, with new data acquisition, processing and archiving solutions, the gas and oil related data grows exponentially. During commercial SAGD process – which is comprised of start-up, ramp-up, conventional SAGD and blow-down – four stages of operations, the steam circulation, heat transition and chamber distribution change dynamically due to a combination of reasons like operation conditions, reservoir heterogeneity and wellbore hydraulics. Data that are related to the dynamics include petro-physical parameters for reservoir characterization, injected and produced instances and amounts, and parameters for steam chamber. Estimating those data quickly can help technical petroleum professionals to diagnose any abnormal chamber development and recovery rate, and make further decisions on corrective or improving actions (Zhu & Zeng, 2014).

In order to manage and understand all the data from the SAGD wells, data visualization and data mining techniques are required. In Canada, the petroleum industry has a need for systems and tools providing the aforementioned techniques to support experts in their data analysis activities. This work proposes a web based application, which makes use of more complex data mining and visualization techniques, to assist petroleum experts to understand better SAGD wells data, to find patterns in it, and, consequently, to help them in the decision making process.

1.2 Objectives and Goals

The main objective of this work is to create a web-based application to facilitate the understanding and visualization of SAGD wells data. This work specifically aims to:

- Investigate how to intuitively present SAGD data to users;
- Research and make use of different visualization and data mining techniques to ease data comprehension;
- Research the main features presented by software used in oil and gas Canadian organizations to ensure they will be present in the application.

1.3 Document Structure

This document is divided into four chapters. Chapter 2 discusses about background knowledge and related works that were taken into consideration for the development of this work. Chapter 3 describes the developed application, detailing how it was designed and what are its characteristics. Lastly, Chapter 4 summarizes the main contributions and exposes future work.

Chapter 2:

Background and Gas and Oil Software

This chapter presents the concepts used for the development of this work. Section 2.1 will describe the domain, detailing the process involved in this technology for oil extraction. The following three sections present the background knowledge associated with the proposed application, detailing motivation, concepts and techniques. Section 2.5 analyzes contributions of existing software related to the domain this work is involved. Contributions from prior research on the design of the Oil Well Explorer are presented in Chapter 3.

2.1 Steam Assisted Gravity Drainage

Steam Assisted Gravity Drainage is a specialized drilling method used when the oil to extract is not conventional crude oil (Butler, 1998). Oil sand, a type of unconventional petroleum deposit, for instance, is a mixture of bitumen, sand and water. The oil in the oil sand can be extremely hard and embedded in tons of sand, so the extraction process must be different in order to separate the oil from the rest. Gas and oil companies are currently using SAGD technology to extract this kind of oil that is deep underground. Figure 1 illustrates the SAGD oil extraction process.

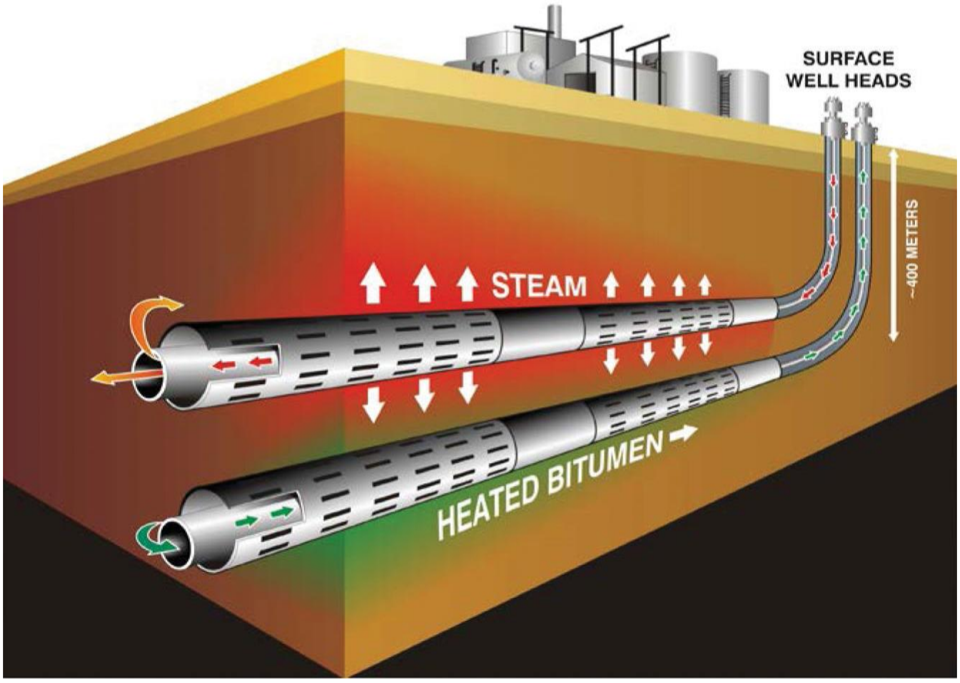


Figure 1. Scheme of oil extration using SAGD technology.

Extracted from http://www.drillingcontractor.org/dea-164-what-does-a-next-gen-ranging-mwd-look-like-18151.

The entire process consists of liquefying the oil, by using steam, to melt it away from the sand while it is below the surface. The water used in the process to generate steam is improper to consume or use in agriculture, as it contains too much salt. Typically, SAGD employs a horizontal well pair configuration with an upper injection well and a lower production well drilled with five meters separation in parallel (Parmar, Zhao, & Graham, 2009). Natural gas is used to heat the water to make steam, which is injected into the top well, the injector, to heat up the reservoir and form a chamber. In about a month, period to liquefy the oil, gravity makes the water from the steam and the oil drip into the bottom well, the producer, through small slots that serve as a filter to block the sand (How steam-assisted gravity drainage (SAGD) works, 2014; Unconventional Technology & Innovation - SAGD, 2014). After that, the water and the oil are pumped from the producer well to the surface, where they are separated. The water is reused to, once again, make steam, while the oil is sent to the refineries though pipelines. After getting to the surface, the oil receives a light oil or natural gas liquid to avoid getting hard again, flowing freely through the pipe.

2.2 Data Mining

Data mining has been a term heavily used in the information industry in recent years with the huge increase in data acquisition. The massive amount of data to analyze complicates the extraction of useful information and knowledge. Data mining is the exploration and analysis of large amount of data to discover patterns and rules in them (Berry & Linoff, 2004). It is used as a more efficient way to analyze data, to perceive information from large amount of data, and it represents one of the steps of data processing to knowledge discovery, as illustrated in Figure 2.

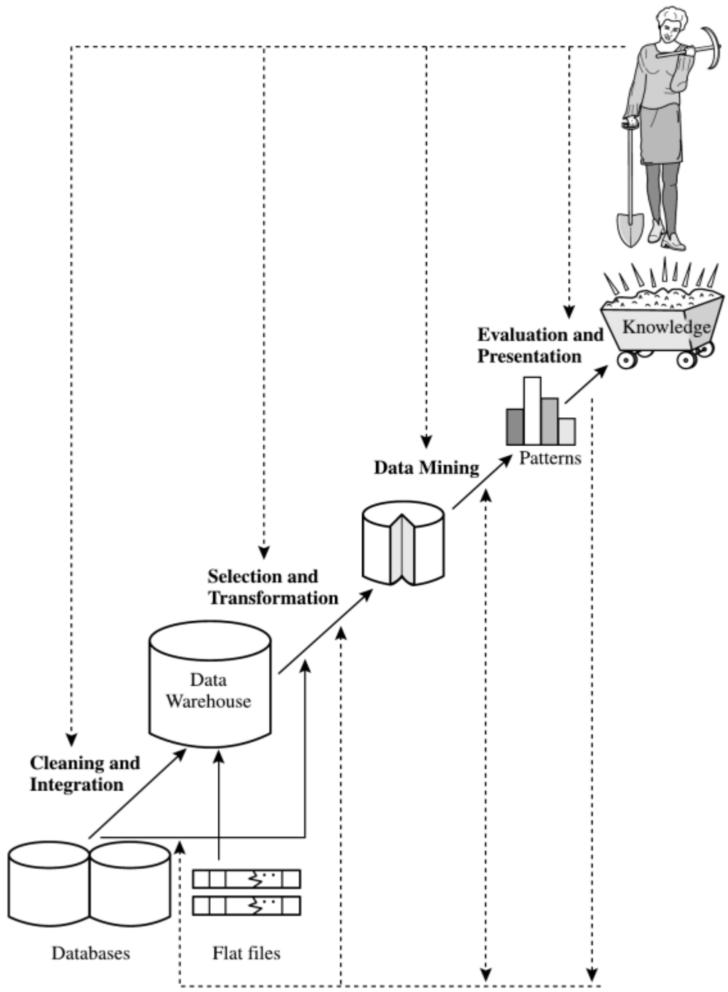


Figure 2. Representation of knowledge discovery as a sequence of steps.

Extracted from (Han & Kamber, 2006).

The entire process of knowledge discovery is represented as a sequence of steps: preprocessing, which comprises of removing noise and inconsistency, and integrating all data, if collected from multiple sources; selecting the relevant data to analyze and excluding what is not of interest; transforming the data, if applicable, to a form better suited for data mining techniques; making use of data mining techniques and methods to extract data patterns; evaluating the patterns discovered from the application of data mining techniques, usually done by a domain expert; and finally presenting the knowledge extracted, by using visualization representations techniques, discussed in the next section.

Data mining is involved with different classes of tasks, such as anomaly detection, association rule mining (ARM), clustering or grouping, classification, regression and summarization.

Classification is the problem of assigning objects to a predefined set of classes (Berry & Linoff, 2004). It is associated with various tasks used nowadays around the world, such as: classifying credit applicants as low, medium, or high risk; assigning an email as spam or non-spam; and assigning a diagnosis to a person by considering identified symptoms.

Differently from classification, cluster analysis does not categorize objects into known classes. It tries to organize, separate data in groups, so that objects in the same group are more similar than objects in different groups, but its intention is not to establish rules for separating future data into categories or clusters (Jain & Dubes, 1988). A cluster consists of similar objects grouped together. It is also defined as an aggregation of points in space such that the distance between two points in the same cluster is smaller than the distance between a point in a cluster and another that does not belong to it. An example of grouping data can be seen in the following figure.

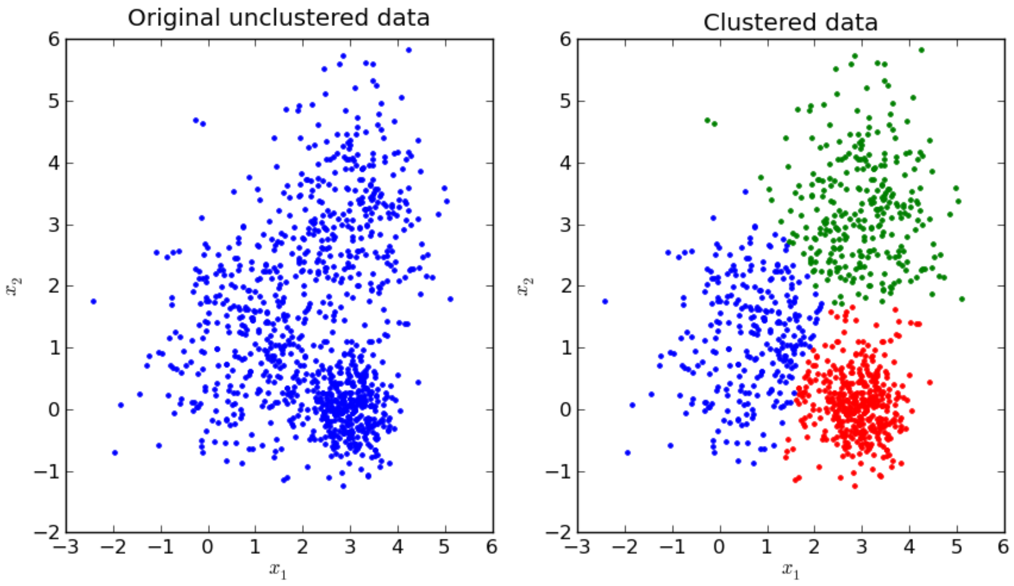


Figure 3. Example of data clustering. On the left, a two-dimensional data distribution and, on the right, the same data grouped in three distinct clusters.

Extracted from http://pypr.sourceforge.net/kmeans.html#k-means-example.

Humans can easily identify clusters when dealing with three or less dimensions. However, the task gets much harder when the data has more than three dimensions. In addition, different people can perceive different clusters when seeing a data collection. To ease the process and avoid inconsistency, different clustering methods were created. There are many ways to define clusters and many techniques used for this purpose. One of the most commonly used clustering algorithms is the k-means (Jain & Dubes, 1988). The "K" in its name is a reference to the number of defined clusters, as it must be defined prior to the algorithm execution. In summary, the algorithm is defined in three simple steps:

1. The algorithm randomly selects K points to guide the process – called seeds.
2. Each record is assigned to the closest seed. There are many metrics to define distance. The Euclidian Distance is the most famous one, defining the distance between two points as the length of the line segment connecting them (Han & Kamber, 2006).
3. After assigning each element to a cluster, the algorithm determines the centroids of the K clusters by calculating the average value of each dimension for all the elements of a cluster. The calculated centroids become the seeds for

the next iteration and the steps two and three repeat until the clusters do not change anymore.

ARM is used to find frequent patterns, or called strong association rules, with two measures of rule interestingness – support and confidence. An association rule is comprised of an antecedent part (if) and a consequent (then) part. For example, a rule can be represented by “computer => antivirus_software [support = 2%, confidence = 60%]” meaning if a customer buys a computer, the customer will tend to buy antivirus software as well (Han & Kamber, 2006). There are two metrics to evaluate a rule: support and confidence. The support number indicates that 2% out of all the transaction records in the database have both a computer and a software. The confidence number indicates that 60% of the customers who purchased the computer also purchased the software. Frequent if and then patterns satisfying minimum support and minimum confidence are identified as strong association rules.

To discuss about other data mining techniques and to go into further details about classification and ARM is beyond the scope of this work.

2.3 Information Visualization

Extracting useful information from data is getting harder due to the huge increasing in amount of data collected every day. Analyzing data is an old activity practiced by mathematicians and statisticians for many years. However, evaluating data based on numbers is not always straightforward, as many patterns can be hidden in it. To mitigate this problem, different visualization techniques can be used, as humans can identify patterns and perceive information more easily by interpreting visual representations (Murray, 2013). Information Visualization as defined by Card et al. (1999) is:

“The use of computer-supported, interactive, visual representations of abstract data to amplify cognition.”

Figure 4 shows an example of how visual representations can enhance the data understanding. In it, numerical values are mapped to a bar chart and for example, just by looking to it, is possible to say which numbers are the largest and the smallest among all of them. Moreover, even people who do not properly understand numbers, such as kids, can extract some basic information from this visual representation.

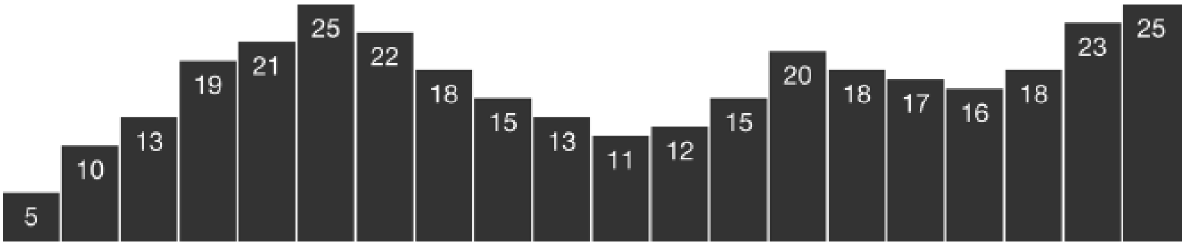


Figure 4. Numerical values mapped to a visual representation using bars. Larger numbers are represented in taller bars.

Extracted from (Murray, 2013).

Different methods and techniques have to be applied in order to understand the data present in systems around the world. Visualization is applied to show data in various ways, but it must also have a mechanism to tightly couple users to the applications, exploring human creative capabilities in data analysis (Fayyad et al., 2001). Static visualizations do not give a variety of perspectives on the same information, which can be interesting when analyzing multidimensional data. Therefore, dynamic and interactive visualization can ease data exploration, adjusting itself based on users needs. Interactive visualization can also address concerns of different people, from those not familiarized with the data to those already familiarized with it.

The characteristics of data can be represented by various Visual Variables (Carpendale, 2003). They are visual characteristics that can differ in position, size, shape, value, colour, orientation, and texture, as illustrated in Figure 5. Varying the values of these variables allows the creation of visualizations with multiple variables and dimensions.

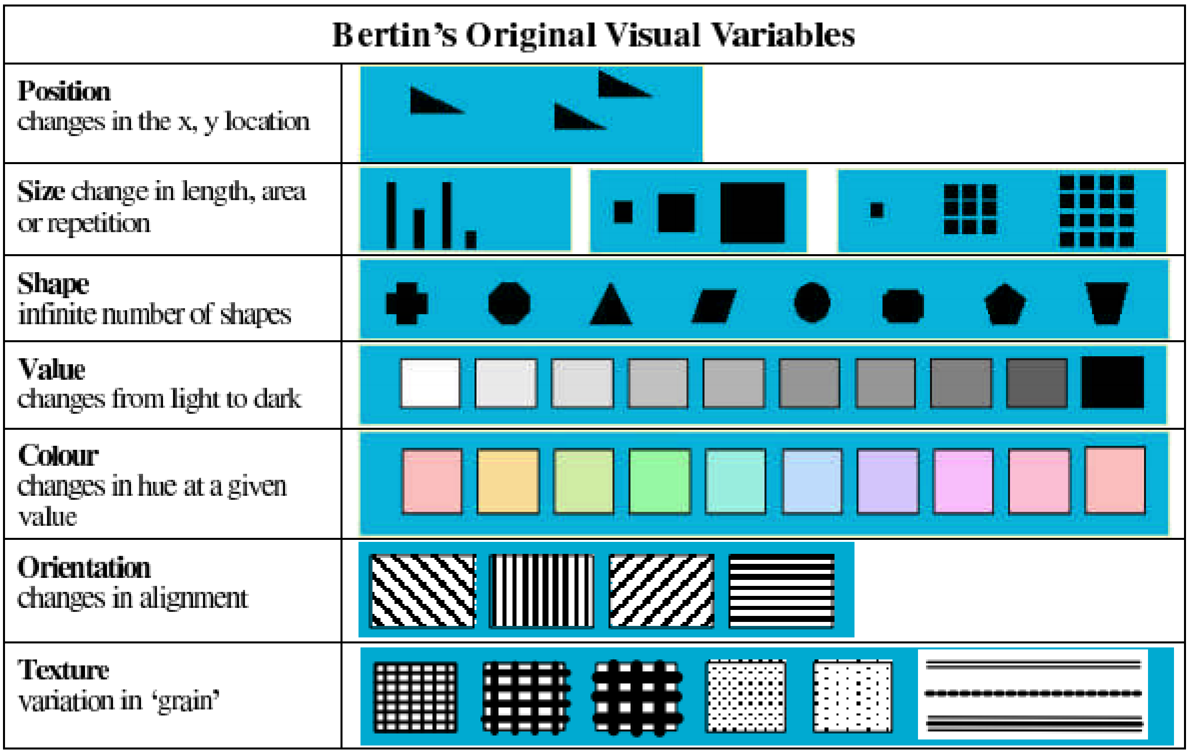


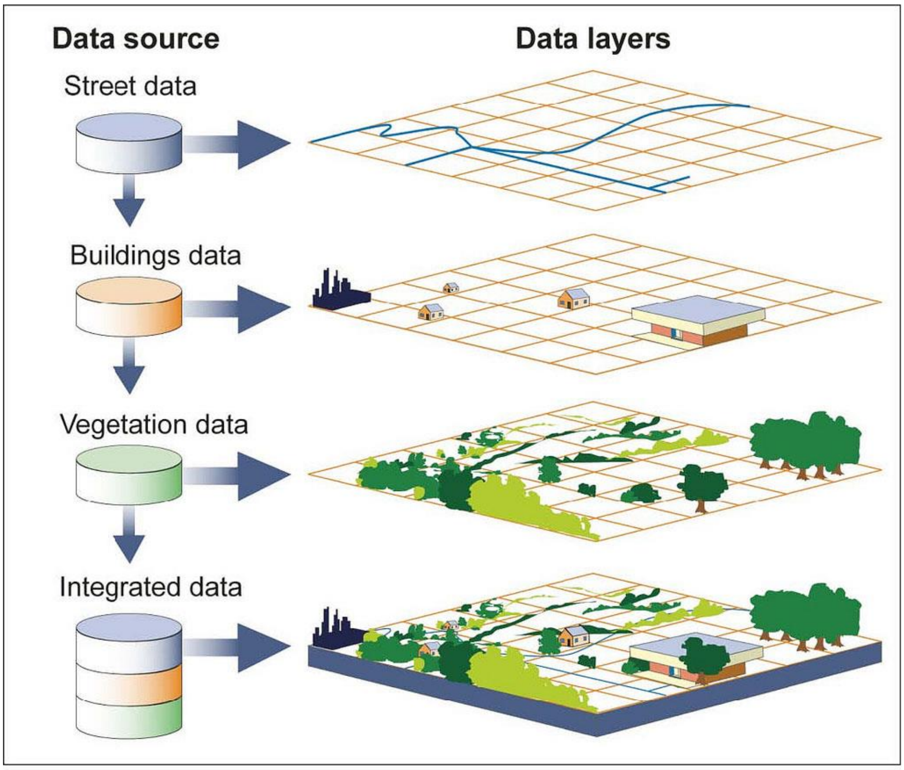
Figure 5. Visual Variables.

Extracted from (Carpendale, 2003).

2.4 Geographic Information System

A Geographic Information System (GIS) is a computer application capable of capturing, storing, checking, and displaying data related to positions on or near Earth's surface (Longley et al., 2005). It is directly related to information visualization as it presents geographical information to the users by creating visual representations for different aspects of information. It is a fairly new concept, with almost sixty years, and uses any information that is related with location in order to allow users to more easily analyze characteristics of multiple places or perceive patterns on them. GISs are used in many different kinds of applications, from distribution management of companies to emergency response and even in military, for targeting missile systems, planning battlefield tactics, and gathering intelligence. Nowadays GISs are more popular due the advances in technology, including maps services available on the web, such as google maps (http://maps.google.com) and bing maps (http://www.bing.com/maps), and the Global Positioning System (GPS) used to help navigation around the world.

Furthermore, Figure 6 shows how GISs overlay data of different areas to create a unique representation for them.



Source: GAO.

Figure 6. Scheme illustrating how GIS combines different data into a map.

Extracted from (GIS (geographic information system), 2014).

2.5 Gas and Oil Software

The whole gas and oil industry has been generating large amounts of data related to oil and natural gas exploration, development and production. Besides, with new data acquisition and processing solutions, the gas and oil related data grows exponentially (Holdaway, 2014). Applications assisting in storing and managing the huge and ever-growing quantities of gas and oil data are definitely in demand. In Alberta, some gas and oil data companies have commercial products such as Accumap by IHS® (http://www.ihs.com/products/oil-gas/ep-data/tools/accumap), GeoCarta by Divestco® (http://www.divestco.com/Solutions/Geological/GeoCarta.aspx), and geoScout by geoLogic® (http://www.geologic.com/products-services/geoscout) that provide software solutions for users to access data from different domains like mineral land, geology and geophysics, engineering and midstream data.

The displaying of gas and oil data necessitates a GIS environment within the data management and analysis system. For petroleum objects like wells, pipelines, facilities, GIS can manage the spatial components of different objects in databases and apply spatial analysis and modeling efficiently across the system. GeoCarta by Divestco is a software tool attached to ArcMap, the central application used in ArcGIS (http://www.esri.com/software/arcgis), and has an additional interface for data management (GeoCarta GIS for All, 2014). ArcMap and the database management system work interactively for searching and locating for oil and gas related objects. Those spatial objects can be either located in the intuitive mapping interface or searched by its industry standard location description, the unique well identifier (UWI), in the data management interface; and the searched results are synchronized in both interfaces. GeoCarta simplifies the workflows for accessing and exploring disparate gas and oil spatial or relational data by integrating a GIS environment.

As for installing those software, normally it is required to obtain the software package and the license number. With software or database updated, new packages need to be installed. As for GeoCarta, ArcGIS Desktop is required to be installed as well since it is the mapping interface. It is desired to facilitate more convenient access to the latest software and data. WebGISs, GIS system built based on web technologies, can give users access to the system and make use of the mapping and analytical functionalities as long as they have access to the Internet. Different thematic applications like flood management and ecological restoration have employed WebGIS technology, proving an interactive, flexible tool (Lienert et al., 2011; Freyman & Glennemeier, 2014).

The aforementioned commercial software basically focus on data management, but have limited analysis functionality for the gas and oil data. In terms of analyzing the large quantities of data in oil and gas industry, visualization tools and other digital techniques have helped with exploring data, making decisions and improving production (Evans et al., 2002).

Graphic methods like diagrams, charts, plots and other forms of visualizations are the most common and straightforward ways to summarize datasets. Bar charts, pie charts, line graphs, and other kinds of graphs are implemented in some commercial gas and oil data management systems like GeoCarta and AccuMap, providing users quantitative or qualitative observations for numerical and categorical data. Moreover, cross-plots are commonly used to visualize the relationships between some reservoir characteristics or production data (Sharma et al., 2010). To determine the reservoir drive mechanism, a cross-plot can be plotted between recovery efficiency and reservoir pressure or gas-oil ratio and cumulative oil (Zangl & Hannerer, 2003). Information is implied in the shape of the resulting curve or some extrapolated trend lines.

2.6 Discussion

The analyzed software are extremely powerful for various kinds of applications, as geographical data is used in many businesses around the world. While these software can precisely present information to users, mainly related to geographical coordinates, when dealing with SAGD data, for example, users may not be able to extract useful knowledge from the data due to the lack of more data mining and information visualization techniques. Employing some of the available techniques discussed in this chapter can enhance data understanding and consequently support some of the critical decisions made in a company. The techniques by themselves are insuficient, as the way to present information to users also must be taken into consideration.

The proposed application integrates the aforementioned concepts and techniques to provide features not available in related systems. Details of the application and its features are described in the following chapter.

Chapter 3:
Oil Well Explorer

This chapter describes the developed application, detailing about the data gathering and processing, selected technologies, architecture, and the main features of it.

3.1 Data Gathering

Considering the quantity of data that SAGD projects could have been generating, public available data are limited and scattered. Some SAGD in situ and surface facilities collect real-time data, which are compiled and only distributed within the organizations. Through Alberta Energy Regulator, annual reports on in situ performance of each SAGD projects in Alberta are accessible, containing summary information on geology and geophysics, drilling and well instrumentation, seismic, and operation performance, displayed in forms of maps and graphs (In Situ Performance Presentations, 2014).

Figure 7. Geographical location of Alberta, Canada.

Extracted and adapted from http://maps.google.com.

On the other hand, data can be obtained through commercial software platforms, which purchase oil and gas data through some oil and gas companies or specialized data companies. In this work, data on wells in Alberta SAGD projects were collected from Alberta Energy Regulator and Divestco GeoCarta. The province of Alberta was selected because most of the gas and oil companies using SAGD have projects currently in activity. Moreover, Alberta Energy Regulator provides reports with some public data and in addition to Divestco GeoCarta, which was available during the development of this work, more data could be collected.

Having the UWIs is necessary to collect data of wells. To acquire the UWIs, wells in one specific SAGD project are selected with assistance of visual interpretation in the ArcMap interface of GeoCarta, based on the general location of a SAGD project and the distribution of SAGD wells – aggregated surface locations to dispersive underground bottom locations. The Firebag project from the Suncor company was selected among many in Alberta due to the availability of the data as well as the increased amount of wells in the project. With the UWIs and a template of data attributes in need, data was collected from GeoCarta data explorer and, as a result, 301 wells were extracted. Their geospatial distribution can be seen in Figure 8.

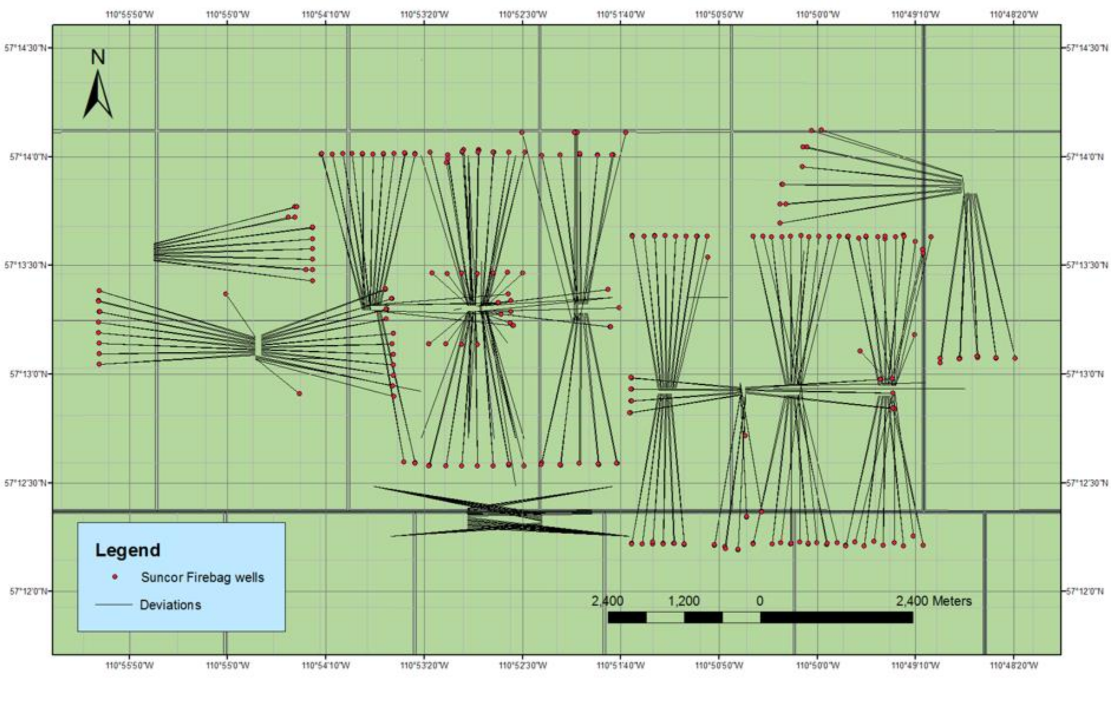


Figure 8. Geospatial distribution of the wells from Firebag project.

Produced using the software Divestco Geocarta.

The wells contained a huge number of atributes which were not important for the study. Therefore, the raw data was trimmed and finally added into the database, containing, at the end of the entire process, time series of injection and production in addition to basic attributes, such as latitude, longitude, type, operator, status history, and depth, among others.

3.2 Architecture

The architecture of the application, internal organization, created files and the relation between them, is illustrated in the following figure.

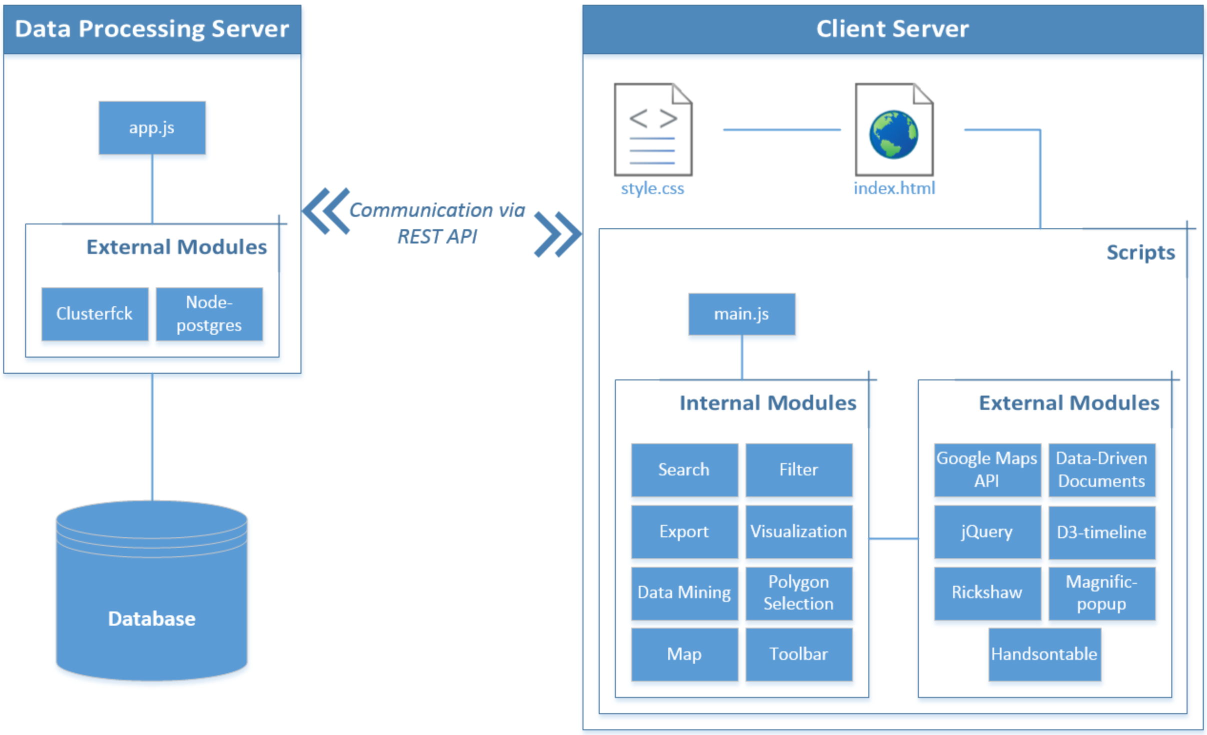


Figure 9. Application architecture.

The application consists of three main components: database, Data Processing Server and Client Server. The database is managed by PostgreSQL and currently does not receive any request to update or insert new records, only retrieve the stored data.

The Data Processing Server is the responsible to directly access the database, by using the node-postgres module, as well as executing the k-means clustering algorithm, present in the clusterfck module. The decision to execute the clustering method in the data processing server took into consideration the necessity of a short response time combined with a lower memory cost when using the application, as the algorithm might have to process high dimensionality data, significantly increasing the memory needed.

Lastly, the Client Server contains the files associated with the other functionalities, represented by both internal and external modules, and the graphical user interface of the application, represented by the *index.html* and *style.css*. The *main.js* file is the starting point, as it has the responsibility to initialize the other scripts. The internal modules consist of scripts created to fulfil the tasks that each module were meant to execute. The architecture of them resembles the Model-View-Controller (MVC) pattern, which separates the information used in the application from the way it is presented to the users (Leff & Rayfield, 2001). Nearly all scripts were created in two separated files, the view and the controller. As in the MVC pattern, the views deal with elements in interface and how the data is shown to the user, the controllers send the processed data to the view, and the model is diffused in the data processing server. Lastly, the internal modules use functions provided by the external modules, taking advantage of the tested third party implementations described previously.

The data processing server and the client server communicate with each other through a Representational State Transfer (REST) Application Programming Interface (API). For the communication to be successful, it needs a form of representation that both servers can understand, a data-interchange format, which in this case is JavaScript Object Notation (JSON). The data processing server waits for a call from the client server, processes whatever it needs, and sends data back to the client server, which interprets and updates the application accordingly.

3.3 Technology and Project Decisions

Selecting the best technologies to support the development is a fundamental step in the development process of a system or application. Their capacities, simplifications, performance, problems and flexibilities must be taken into account when comparing different technologies that can produce similar results. Developing a web application includes dealing at least with HyperText Markup Language (HTML) and Cascading Style Sheets (CSS), while other technologies can be included if needed to achieve aimed goals. This application uses HTML5 and CSS3 to deal with the graphical interface, as they are the newest versions and provide various facilities to freely modify and adjust elements conveniently.

The application was built using JavaScript as programming language. JavaScript was selected due to many reasons: it is a relatively easy language to use that resembles other object-oriented languages; it is executed on the client side, avoiding excessive communication with the web server and, therefore, reducing the processing time; and it has a huge amount of third party libraries, plugins and modules that can be used to accelerate the development (JavaScript, 2014).

The server was developed with the use of Node.js, an open source cross-platform runtime environment (Kiessling, 2012). It was chosen because it is mainly developed in JavaScript, it can run in different operational systems, it was built to optimize an application's throughput and scalability, and the communication with the database is simplified. The database, in its turn, is managed by the PostgreSQL, an open source object-relational database system that runs on all major operating systems (About PostgreSQL, 2014). It has a good, stable performance, high quality of code and documentation, and a great open source community.

Google Maps API was chosen to give some of the GISs capabilities, providing a web mapping service used to display a map with different perspectives and identify locations based on latitude and longitude coordinates (Google Maps Embed API, 2014). It was used in the development of the application because the development is done with JavaScript, it is simple to use, has an extensive documentation with various different examples, and since it is famous around the world more people should be able to better understand it, including GIS experts.

Other technologies had to be used to support the development of specific tasks in the application. All the different technologies were selected by considering their advantages and related issues, availability of documentation, quality of community feedback, and the facility of integration, as it would directly impact the development process duration. The following table describes the selected technologies, their purpose, and how they contributed to the development of the application.

Table 1. Technologies used to support the development of the application.

Technology	Description
Clusterfck	Clusterfck is a JavaScript library for hierarchical clustering. It is used on the server side to apply the K-means clustering method on the data selected by the user. More information is available at http://harthur.github.io/clusterfck/.
D3-timeline	It is a simple D3 timeline plugin to ease the generation of timeline charts. More information about the plugin is available at https://github.com/jiahuang/d3-timeline/.
Data-Driven Documents (D3)	D3 is a JavaScript library that creates various visualizations based on data. Using Scalable Vector Graphics (SVG) with the customization capabilities of HTML and CSS, complex visualization can be achieved without employing a proprietary framework. It was used to develop the different visualizations present in the application. More information is available at http://d3js.org/.
Handsontable	Handsontable is a data grid editor for HTML, JavaScript, and jQuery. It was used in the application to display the wells basic data. More information is available at http://handsontable.com/.
jQuery	jQuery is a free, open source, JavaScript library used to facilitate and simplify the development of HTML with JavaScript. This library enables the creation of abstractions for low-level interaction and animation, resulting in dynamic web pages and applications. It was broadly used to support the development of the application. More information is available at http://jquery.com/.
Magnific Popup	The magnific popup was created for jQuery and is commonly used to display pictures and videos similar to a gallery. One of its other functionalities is to display HTML content, which was used to separate the data visualization from the rest of the web page. More

	information about the plugin is available at http://dimsemenov.com/plugins/magnific-popup/.
Node-postgres	The communication between the PostgreSQL and the server is not natively available. The node-postgres is a PostgreSQL client for Node.js that allows them to exchange data. More information is available at https://github.com/brianc/node-postgres/.
Rickshaw	Rickshaw is a Javascript toolkit built on D3 that is capable of creating interactive time series graphs. It was used in the visualization of time series data in the visualization module. More information is available at http://code.shutterstock.com/rickshaw/.

3.4 Application Overview

The Oil Well Explorer is a single page application, focusing on a better user experience by providing a more fluid usability. It was designed in this manner to resemble a desktop application, without the necessity of loading a new page for each task executed by the users.

The main interface of the application is illustrated in Figure 10. A map fills the entire application window and other manipulation elements are located over it. It automatically adjust the location and zoom to display all the existing wells. Two locations are needed to represent the wells properly: the heel, surface location, and the toe, bottom location. A different shape is used for each one: the heel is represented by small red circles with a black circle inside and the toe, on the other hand, is represented by the red pins with a white circle inside. The collected data does not contain information about the underground trajectory of the well, from heel to toe, called deviation. Therefore, it is represented as a rough approximation by a straight line between both locations.

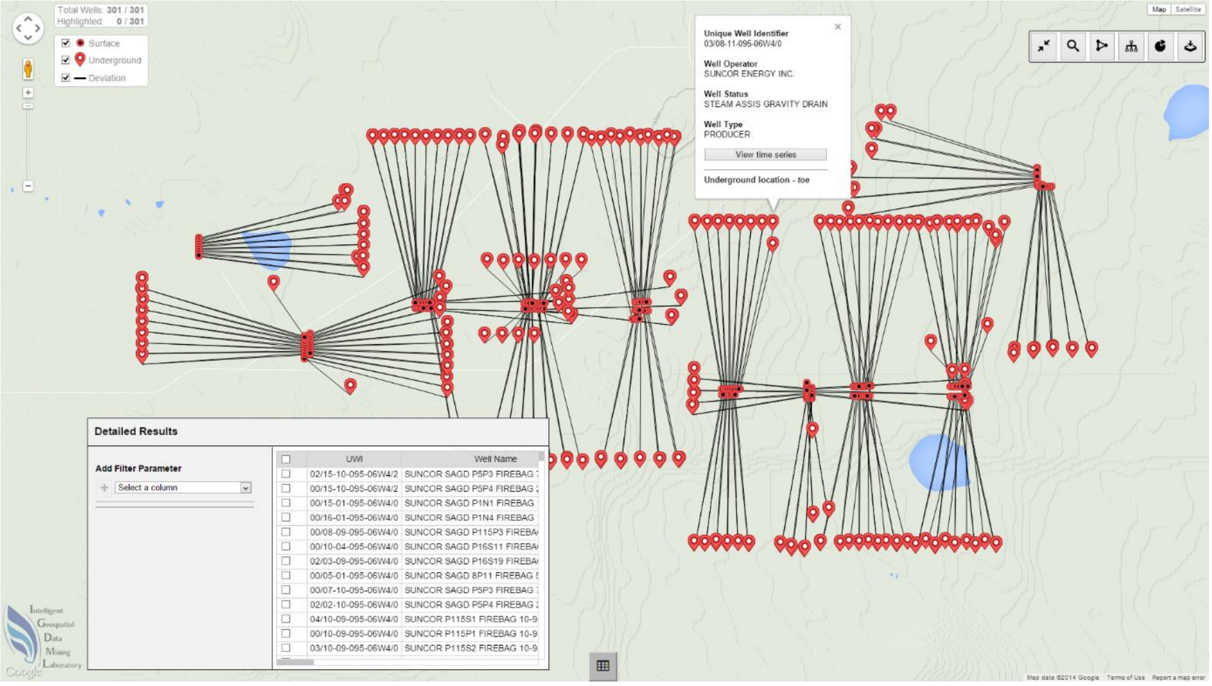


Figure 10. Oil Well Explorer main interface.

The top left corner contains two spatial navigation controls, to move around the map and adjust zoom. In addition, near the navigation controls, there are two small boxes. The one on the top gives information about the total number of wells present on the map, while the one below it allows users to enable or disable the visualization of heels, toes, and deviations on the map.

The button at the bottom shows and hides a data table with some basic data about the wells. A summary of this data can be seen by clicking on a specific well. A small window appears over the well containing its UWI, operator, status, and type.

The top right corner contains a toolbar with almost all functionalities of the application. The leftmost button contracts and expands the toolbar. The others, from left to right, open the search tab, polygon selection tab, data mining tab, visualization tab, and export tab. All the functionalities existent in the toolbar and the data table are detailed in the following section.

3.5 Features

This section describes and details all the existent features in the Oil Well Explorer, displaying figures to enhance understanding and to present the changes in interface associated with the feature usage flow. The seven features are highlight, search, polygon selection, filter, data mining, visualization, and export.

3.5.1 Highlight

Highlighting is interesting when analyzing specific wells, differentiating them among the others. As seen in Figure 11, when a well is highlighted, it changes its colour and the check box of the well in the data table is checked, showing to users the highlighted wells in both map and data table. Highlighted wells are also differenciated when creating bar charts in the visualization module, which will be discussed later.

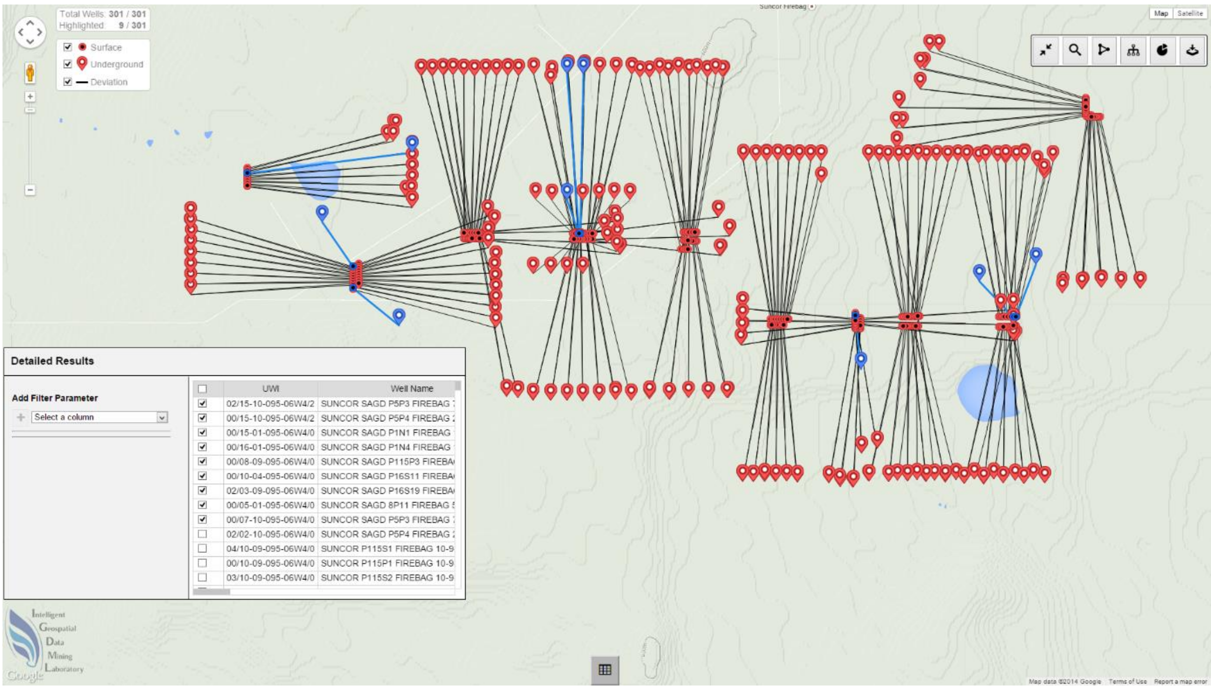


Figure 11. Highlighting wells.

3.5.2 Search

The search functionality was designed to decrease the process overhead of retrieving records in the database, selecting only wells that match the applied condition. This functionality can be applied over three different attributes: UWI and segments of it, operator, and status. However, the application only allows the search to be executed on one attribute at a time. When a new search value is entered, the map will update accordingly, displaying only the matching wells, as seen in Figure 12.

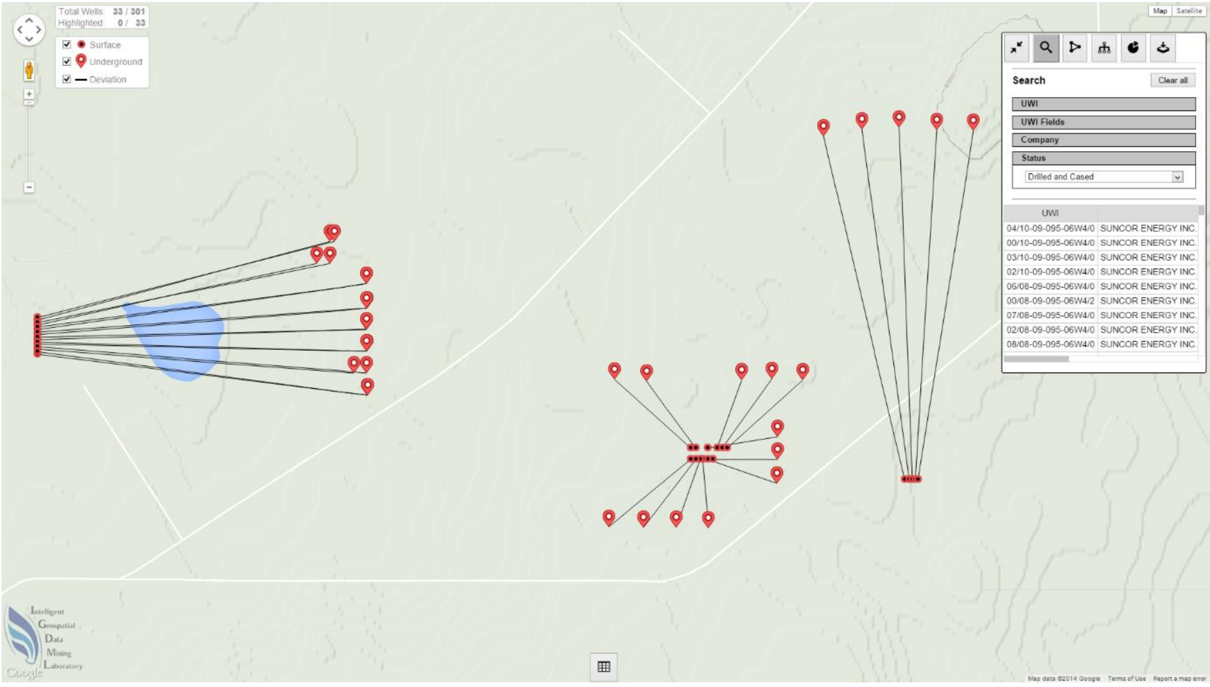


Figure 12. Searching wells by status. Only the wells matching the status "Drilled and Cased" are shown.

When a search is executed, a small data table appears under the search menu, showing the UWI, operator and status of the matching wells.

3.5.3 Polygon Selection

The polygon selection is a convenient tool to make use when the interest is not to focus on wells with the same attribute, as done in the search, but to choose them based on their geographical location. Users can define a polygon with three or more vertices and move it around the map to mark the area of interest, being able to select or remove the intersected wells and highlight or clear the highlighted ones. Furthermore, the toolbar contains the option to only intersect the wells based on their surface or underground locations. As soon as the polygon is created on the map and it overlays one or more wells, a message is displayed at the bottom of the toolbar, showing the number of wells intersected. Figure 13 illustrates the highlight functionality.

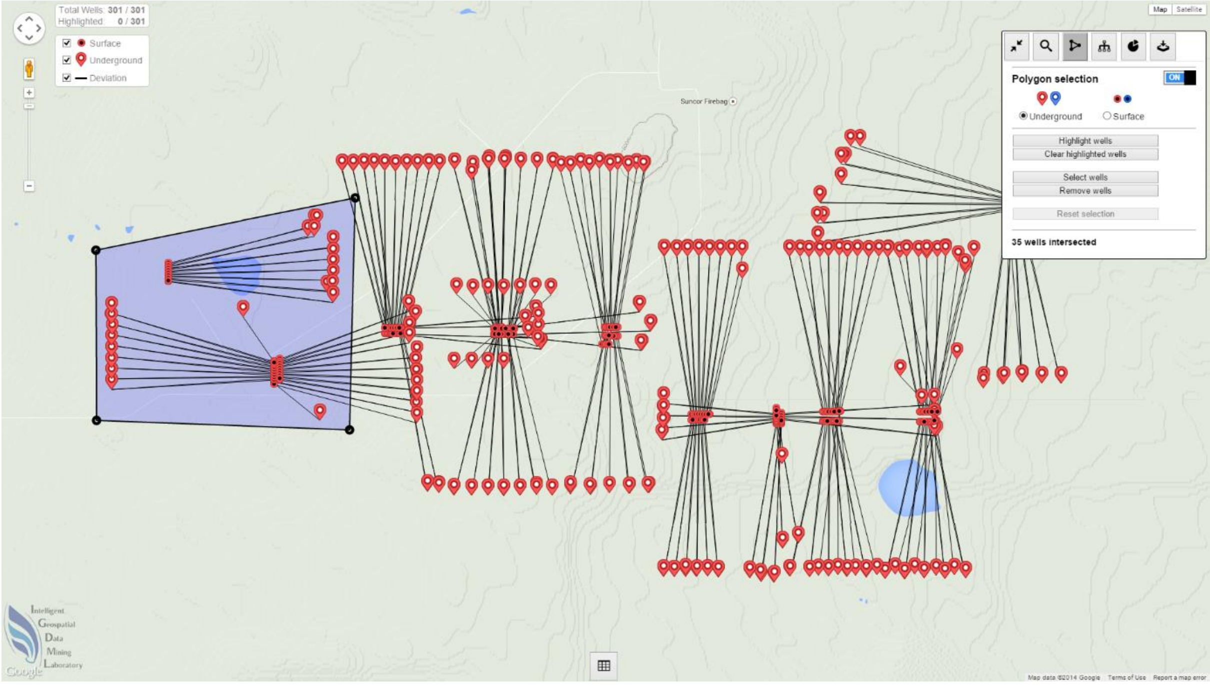


Figure 13. Selecting wells based on their underground location.

3.5.4 Filter

Filtering works similarly to the search, selecting the wells that satisfy the entered criteria. However, it allows users to filter by any attribute, entering multiple criteria with more complex inputs. Numerical values can be equal, smaller than, or greater than the entered value, while textual values can be equal or contain the sequence of characters inputted by the user.

Unlike the other features, the filter functionality is not present in the toolbar. As it deals with all the basic attributes of the wells, it had to be used where users could have a general view of the data at the sime time. Therefore, it was included in the data table accessed by clicking the button at the bottom of the application window. An example of filtering can be seen in the following figure.

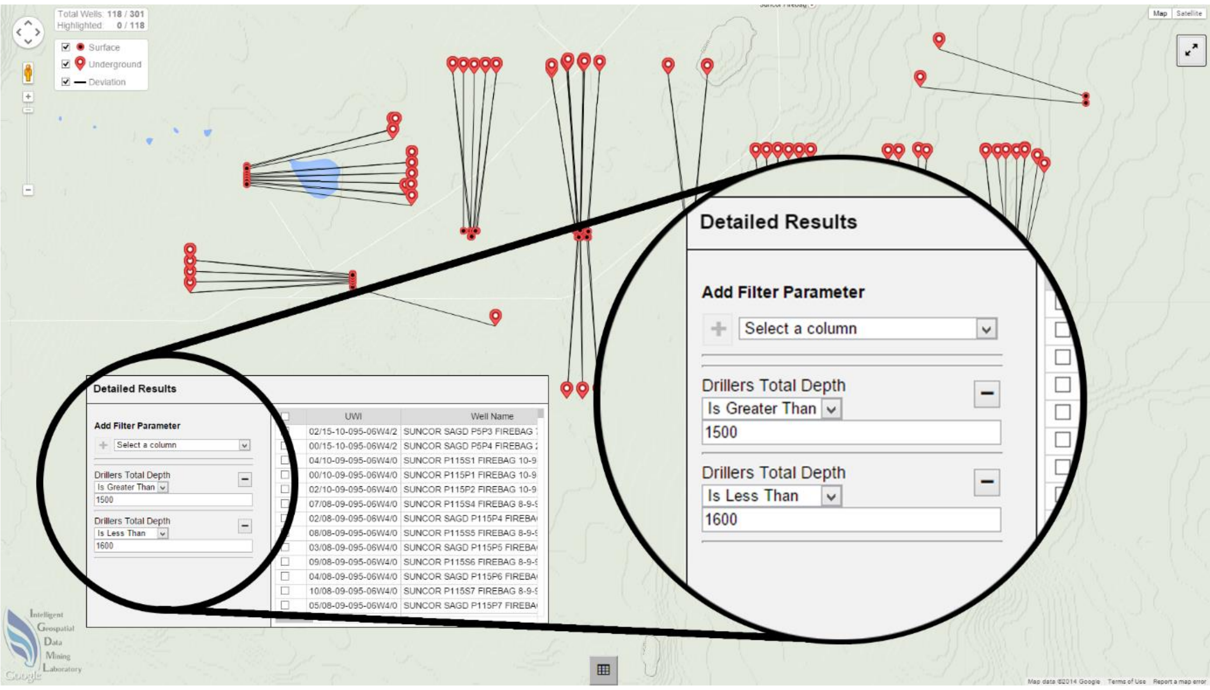


Figure 14. Filtering wells with Drillers Total Depth values between 1500 and 1600.

3.5.5 Data Mining

The Data mining module comprises of three segments: classification, clustering, and ARM. The result of using any of them is similar, as the wells on the map receive different colours to categorize them in a particular group displayed on a legend. Since dealing with a great number of information on the map, it was decided to only use colour and value Visual Variables on the wells, simplifying the understanding of users when looking to the map.

Categorical classification is the simplest in this module, as users only have to select an attribute to classify by and the wells will be differentiated accordingly. An example of categorical classification can be seen in Figure 15.

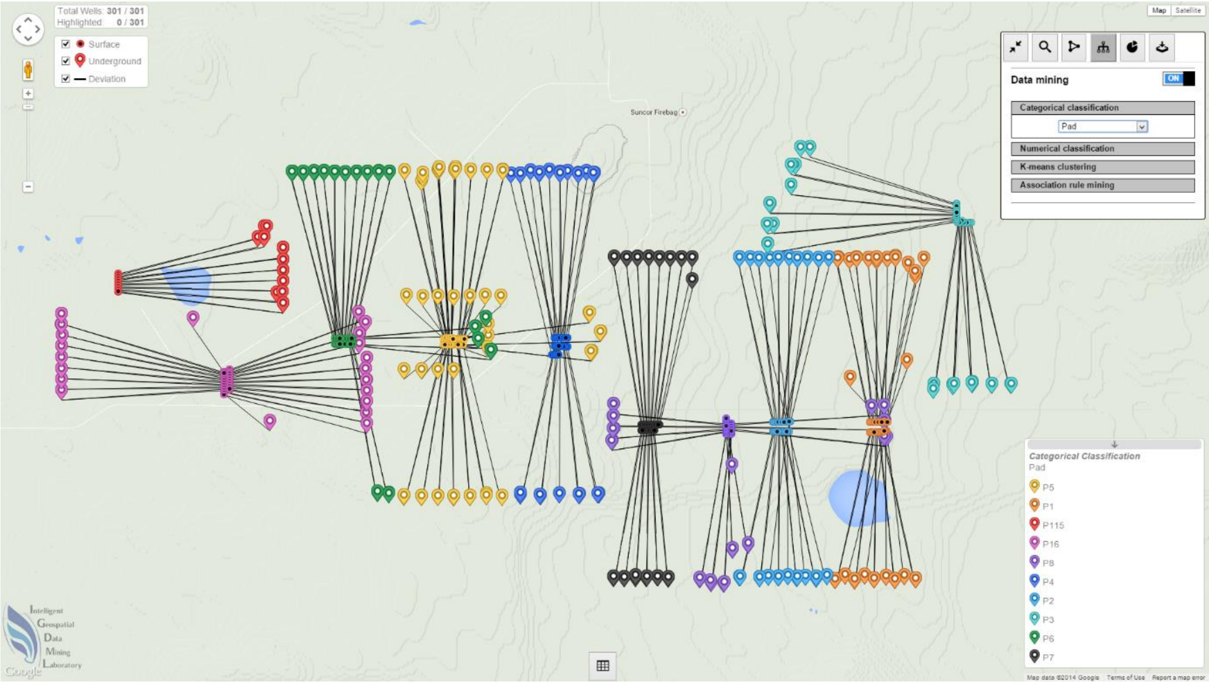


Figure 15. Wells classified by pads.

Numerical classification does not only need an attribute to be chosen by users, but also a method and a number of classes. There are two implemented methods for numerical classification: equal interval and quantile. The equal interval method sets the value ranges in each category equal in size. In other words, the entire range of data values is divided equally into the categories. Quantile, on the other hand, classifies data into categories with an equal number of units in each category (Data Classification, 2014). Figure 16 shows an example of numerical classification.

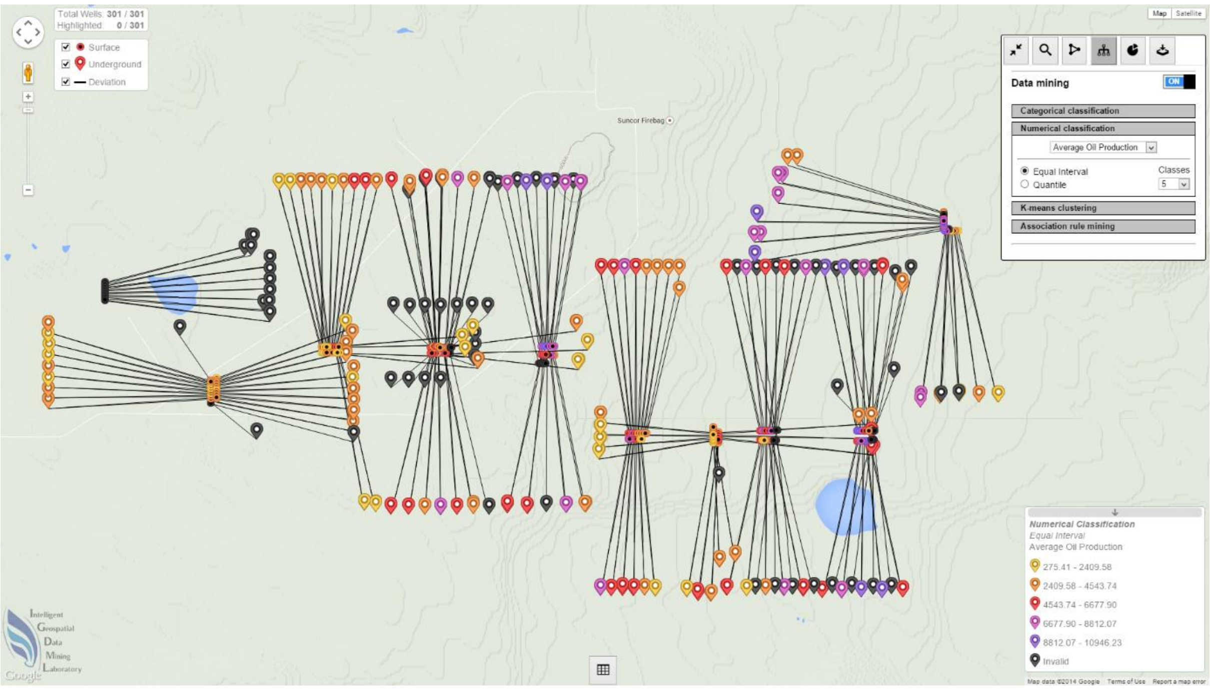


Figure 16. Numerical classification by average oil production into five classes, using equal interval method.

The clustering is done by using the k-means method. Users must select one or more attributes to be considered, as k-means deals with multidimensional data, and the number of clusters desired. Figure 17 illustrates the behaviour of clustering in the application.

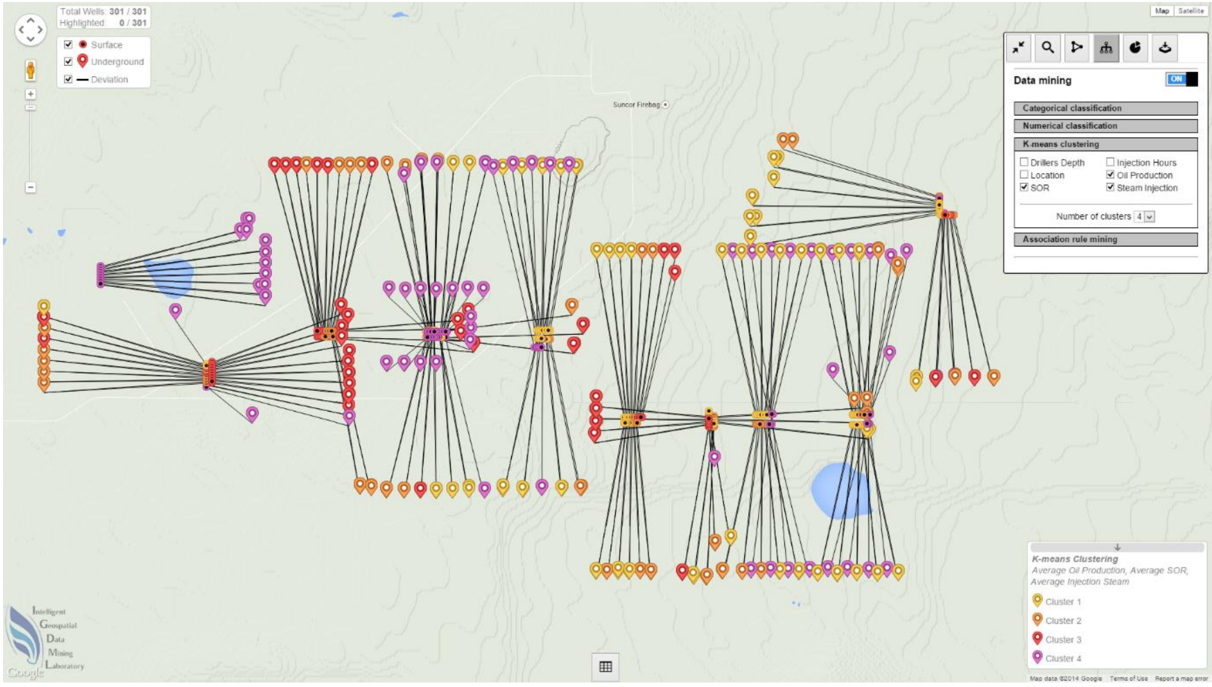


Figure 17. Clustering wells into four clusters by considering steam injection, oil production, and steam-oil ratio.

The ARM was not implemented in the application due to time constraints. However, it was added as a proof of concept since its output is similar to the other methods applied. The method was applied using an external software named Weka (http://www.cs.waikato.ac.nz/ml/weka/) and the results of it were included in the application. There were five expressions in the results that seemed to be interesting, relating injection data in the *if* part of the statement with production data in the *then* part. These rules were used to show how the ARM would behave in the application, as seen in Figure 18. When the ARM is applied, a small table appears showing the encountered rules and the confidence of each, in percentage and fraction. Selecting any rule will update the map with the corresponding colour: dark blue for the wells that match the *if* and *then* parts of the expression; light blue for the ones that match the *if* part but not the *then*; and black for the ones that do not match any part of the rule.

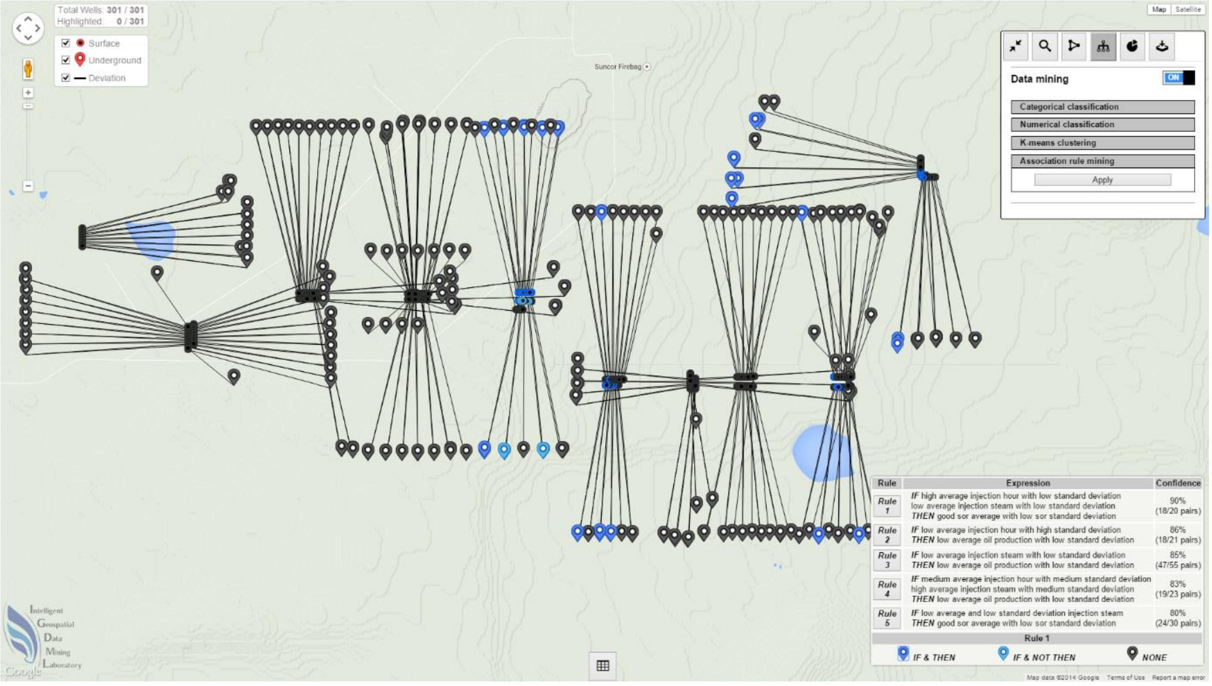


Figure 18. ARM applied to the wells data.

Clicking on one of the pins located in the table will highlight the wells with the same colour, while the others will have their opacity reduced. This behaviour also occurs in the legends of the methods mentioned before and can be seen in Figure 19.

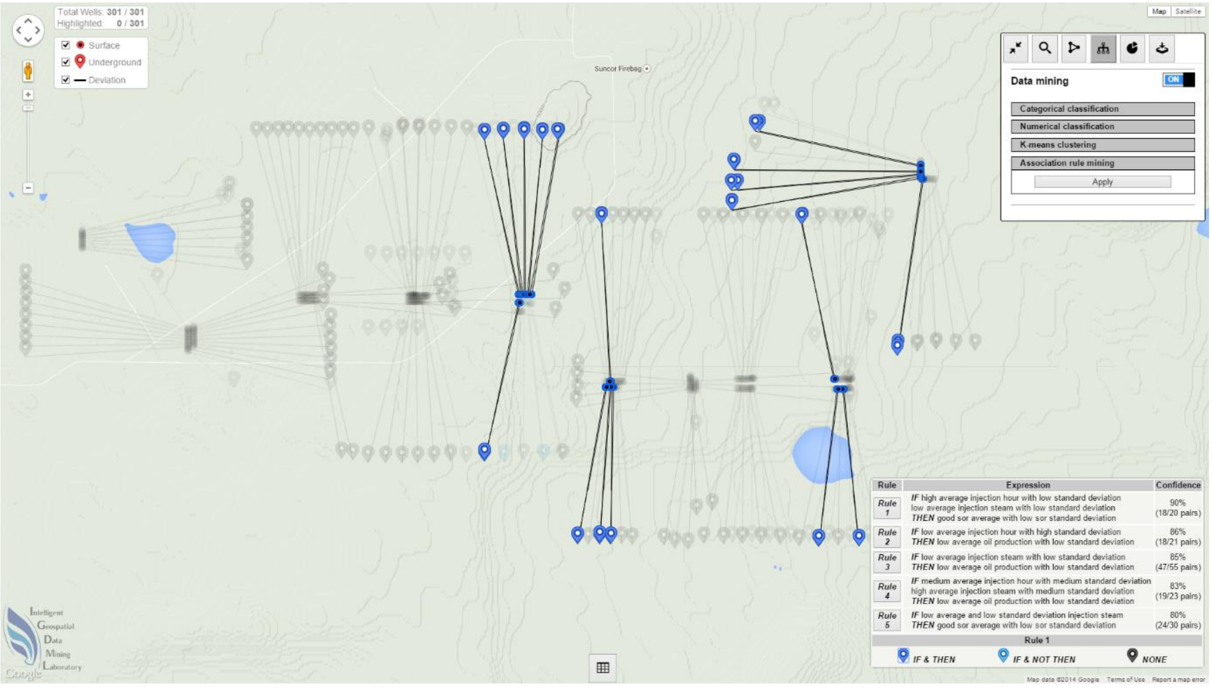


Figure 19. Emphasize the wells that match both parts of the ARM expression.

3.5.6 Visualization

The data visualization is accessed through a panel over the entire window. There are three distinct modes of data visualization in this module: overview of numerical attributes, supported by a bar chart; overview of categorical attributes, supported by a pie chart; and visualization of time series data, which includes both numerical and categorical attributes. A header is created for each visualization at the top of the screen, to avoid misunderstanding with the data visualized.

Figure 20 shows how the bar chart is presented in the application. The vertical axis represents the numerical value associated to the value of the attribute for each well and the horizontal axis, which is not plotted, contains all the wells present on the map. If wells do not contain valid data for the used attribute, the application shows a warning message, in the bottom right corner, that some wells do not have available data.

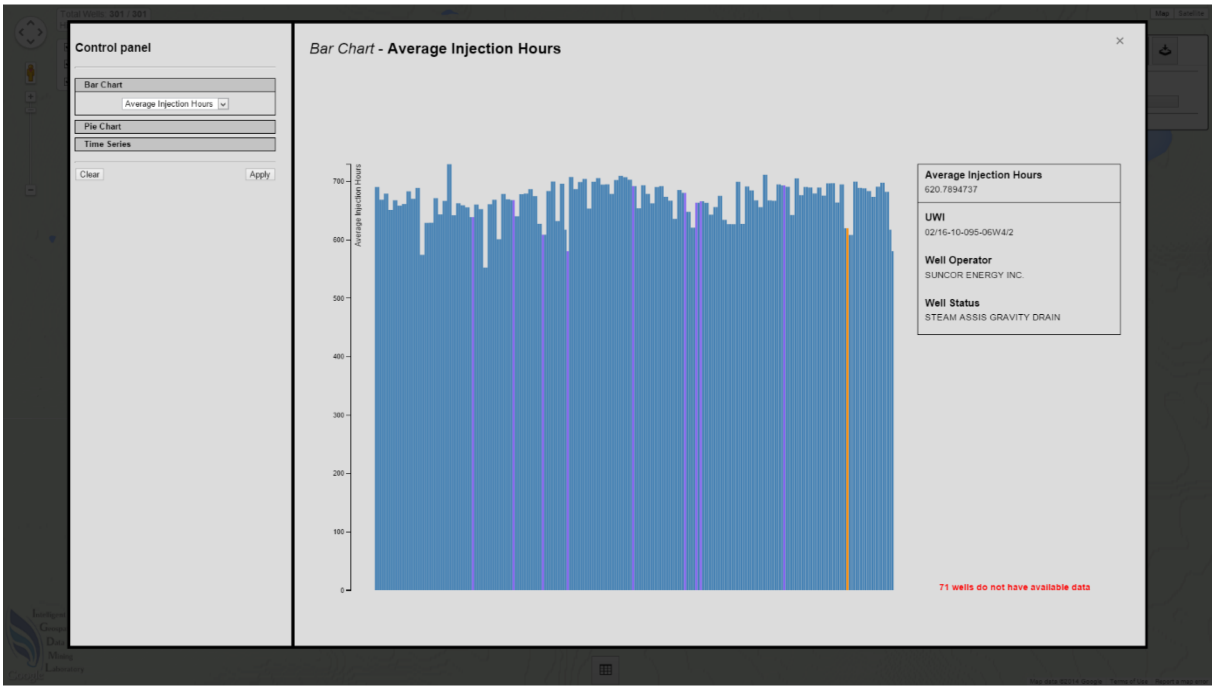


Figure 20. Bar chart of average injection hours.

When users move the mouse pointer over the chart, a box appears on the right side showing some information about the well: the attribute being visualized, UWI, operator, and status. Moreover, the bar being hovered is highlighted in orange so that users can know exactly which bar they are seeing. Lastly, the purple bars represent the highlighted wells on the map. The changes made on the map directly affects the created charts.

The pie chart works similarly to the bar chart, considering only the data of the wells present on the map. In this case, categorical data is displayed and the users cannot see which wells fall into which category. As seen in Figure 21, the pie chart is displayed with a legend by its right side, making clear which category is being represented by which colour. The legend contains the name of the category, the number of wells that fall in the category, and the percentage that it represents among all of them.

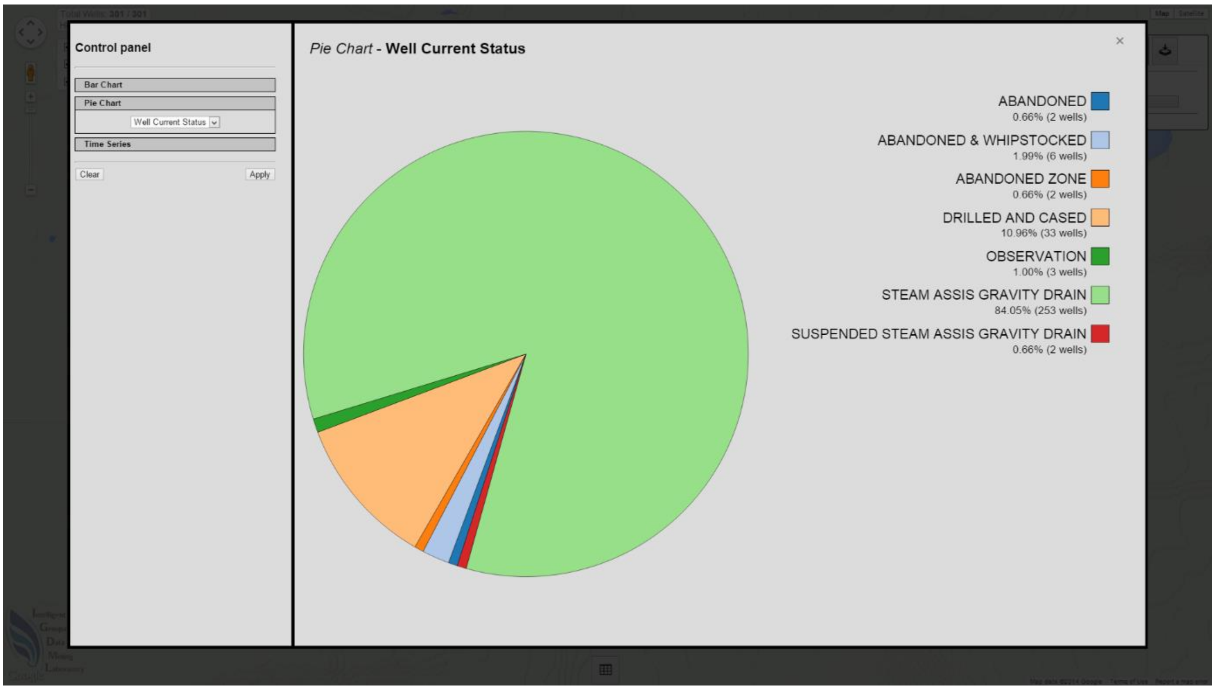


Figure 21. Pie chart of well current status.

The third and last part of the visualization deals with time series data. For now, it is possible to analyze only one well at a time. There are data visualizations of injection, production, steam-oil ratio (SOR), and status. The latter consists of categorical data, and its visualization can be seen in the following figure.

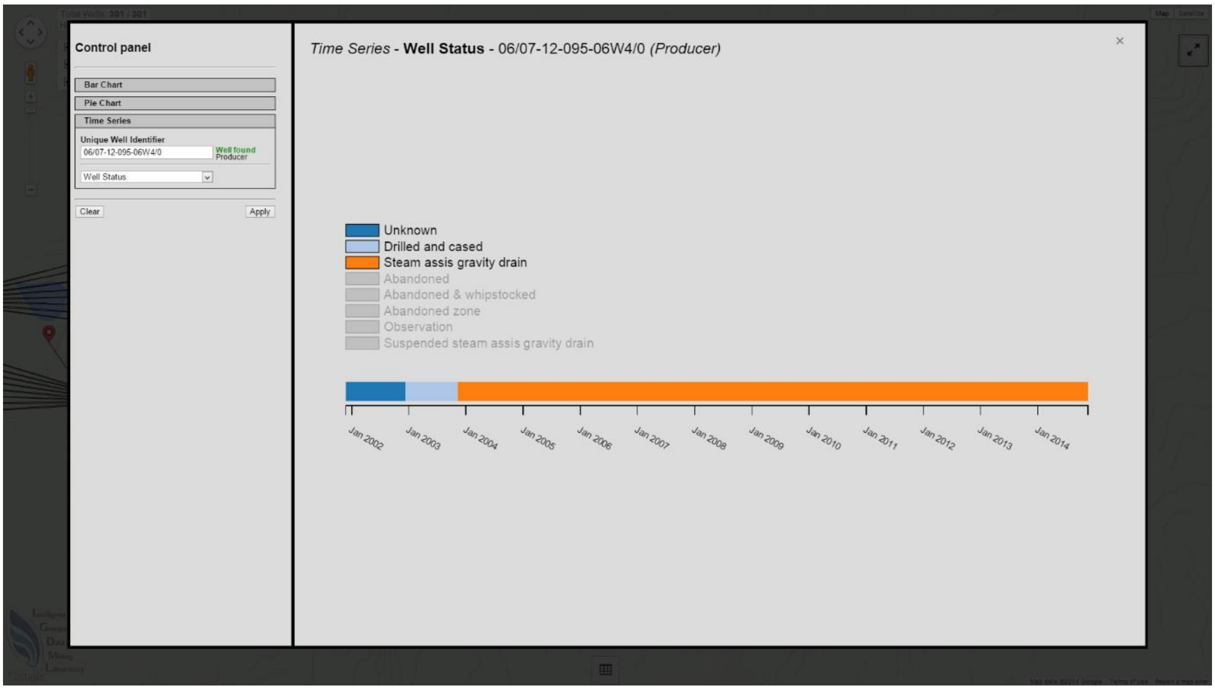


Figure 22. Well status timeline of a well.

Moreover, if the bar is hovered by the mouse pointer, the corresponding legend is highlighted and a small box appears on the right side, displaying the period duration with the initial and end dates. This behaviour can be seen in Figure 23.

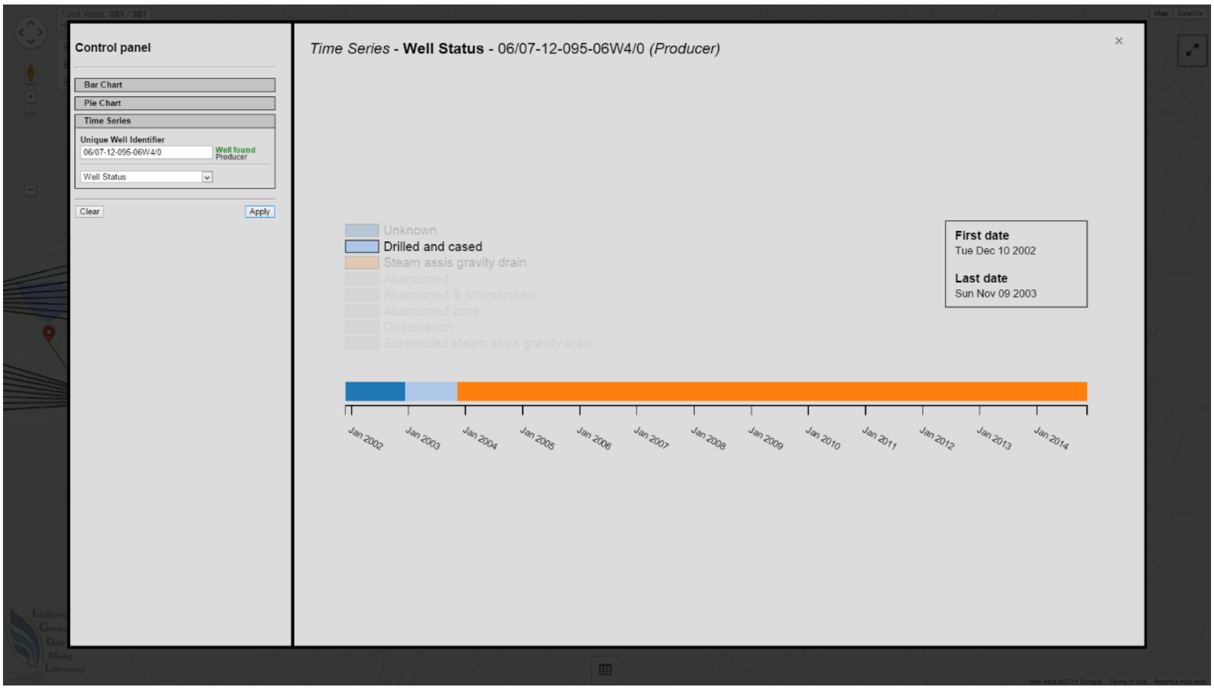


Figure 23. Highlighting the drilled and cased status period in well status timeline.

The injection, production, and SOR share the same interface and controls, only varying the data displayed. This visualization allows users to adapt it according to their needs, selecting single or multiple attributes to be displayed, changing interpolation parameters, and changing the type of the chart. The attributes are plotted in the same chart but are not in the same unit, so users must select the ones that they want to compare and analyze.

The injection shows the amount of gas, steam, and water injected, in addition to the pressure inside the well and the number of hours spent in the process. It can be seen in Figure 24.

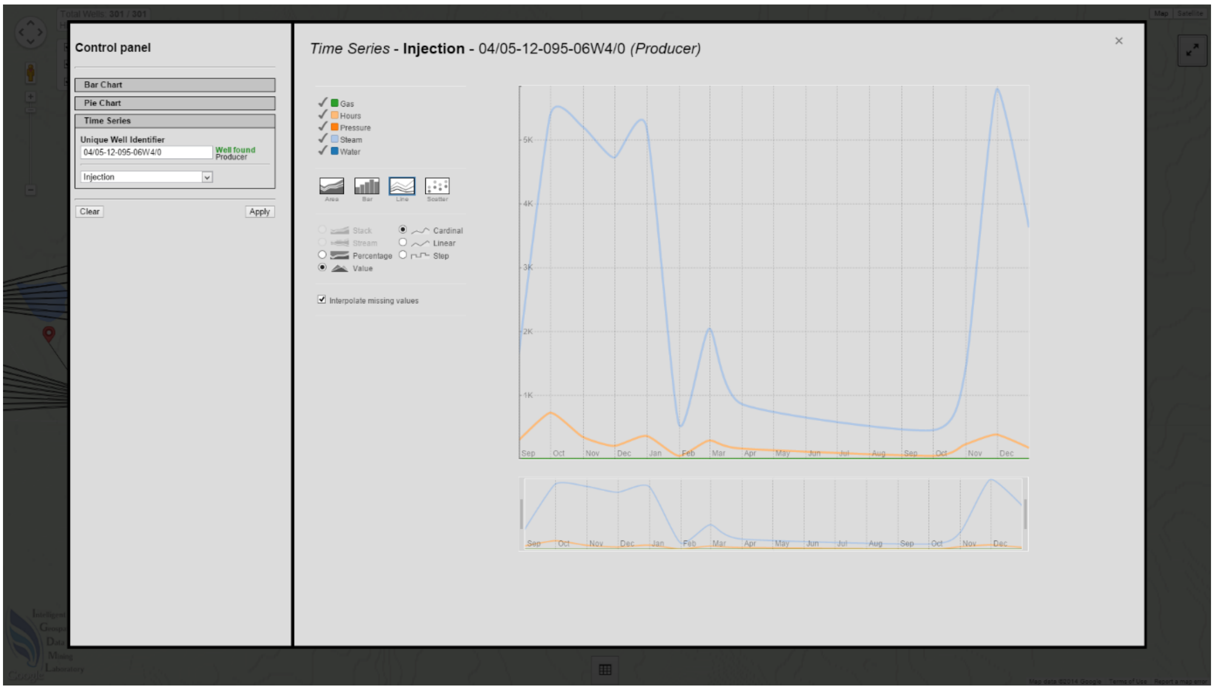


Figure 24. Visualization of injection time series data.

Similarly, the visualization of production data can be seen in Figure 25. On the other hand, it contains far more attributes, making users select the ones they have interest in.

Figure 25. Visualization of production time series data.

Lastly, the visualization of SOR contains the summary of what is essential to analyze a well performance: injected steam, oil produced, SOR, and cumulative steam-oil ratio (CSOR). To calculate the SOR and CSOR a well pair is needed, one injector and one producer. Therefore, the visualization cannot be built if there are no data from both wells. The following figure illustrates the SOR data visualization, showing the SOR and CSOR while hiding the steam and oil values.

Figure 26. Visualization of SOR time series data.

As mentioned before, users have the possibility to change the chart type in order to see the data in another perspective. They can choose among line, as presented in Figure 26, area, bar, and scatter, seen in Figure 27, Figure 28, and Figure 29 respectively.

Figure 27. Visualization of SOR time series data with area chart.

Figure 28. Visualization of SOR time series data with bar chart.

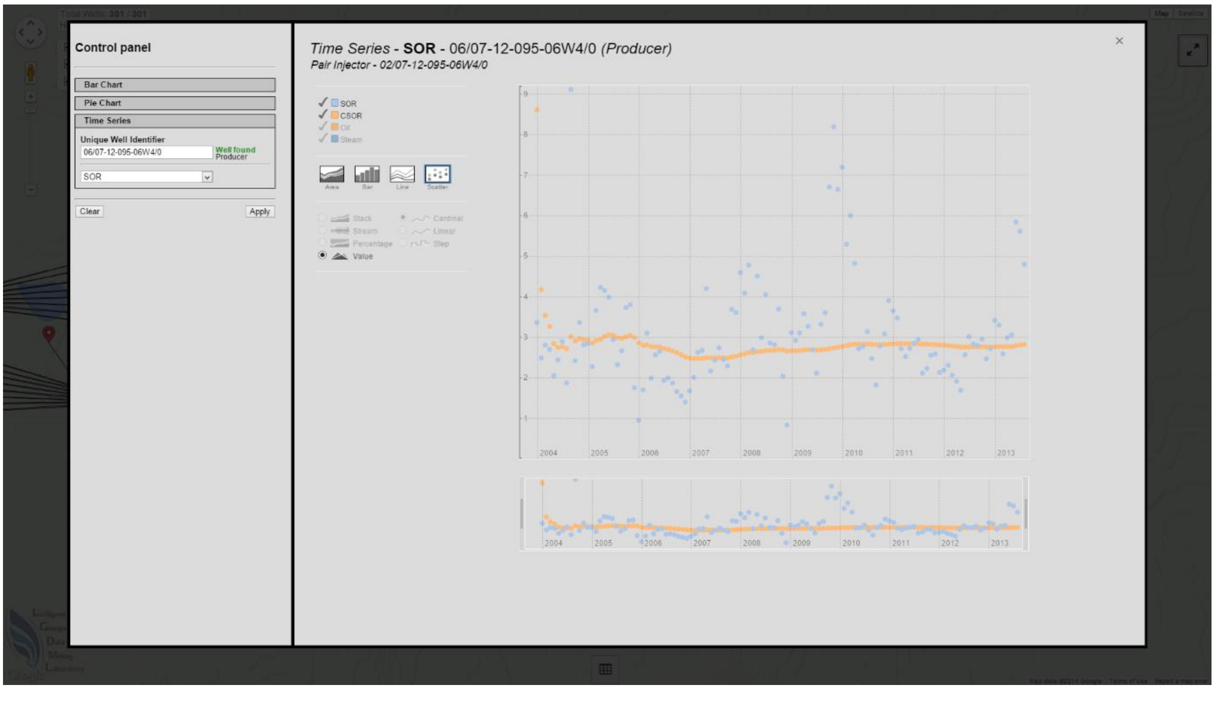


Figure 29. Visualization of SOR time series data with scatter chart.

To enhance the data analysis, users can change the time range visualized by using the control beneath the main chart. Changing the period will update the chart accordingly, as seen in the following image.

Figure 30. Visualization of SOR time series data of a smaller period of time.

3.5.7 Export

The export function allows users to save a Comma-Separated Values (CSV) file to their local contents. The grouped data will only contain records of the wells that are present in the map so that the wells data can be intuitively selected by using other functionalities. Time series data of the wells are not included, since they are private and extremely important for the well analysis and decision making.

3.6 Discussion

After finishing the development, the application was presented to several people from academia and industry of diverse areas, including Computer Science, Software Engineering, and Geomatics Engineering. It was generally well received and it generated discussion about improvements and possible future works.

The presentation towards academia had the presence of doctors, masters, and bachelors in university, who were mainly looking for research opportunities. People from three areas showed interest in the application: information visualization, discussing about various different ways the information could also be displayed to users; human computer interaction, exploring the possibility of using a multi-display collaborative environment with multiple people interacting with the application at the same time; and geospatial data mining, discussing about the usage of techniques to predict oil production based on the properties of wells.

The application was also presented to three directors of a Canadian gas and oil company, who were looking for new ideas to improve their software and to create new ones. They exposed interest, mainly due to the data visualization and data mining capabilities applied in a web application, giving feedback with a commercial perspective of features to add and next steps to take. They also considered the possibility of a partnership with university, working together with students to help both parts with the development of new systems.

Chapter 4:

Conclusion and Future Work

This last chapter is intended to the final considerations of this work, discussing about what was achieved, what can be improved and incorporated in the future.

4.1 Conclusion

The amount of data accumulated by the oil extraction companies is huge and it keeps increasing every day. These companies need to use software to help the experts process and analyze the stored data. In Canada, the software used in gas and oil companies do not always provide techniques to assist experts in finding patterns hidden in the data.

This work had the main objective of developing a web based application to display and explore data collected in the SAGD oil extraction process. A dataset of one SAGD project in the province of Alberta was collected, archived, processed, and successfully utilized in the application. By using free components provided by third parties it was possible to build a WebGIS with basic features similar to commercial software currently in the market. Furthermore, it was shown that information visualization and data mining techniques can support people to understand a great amount of data, to perceive hidden patterns in it, and to investigate the spatial distribution of the patterns.

Is it hoped that this work promotes, in the future, the creation of systems and applications based on the web for domains that depend on the use of GISs, not exclusively related to gas and oil.

4.2 Future Work

Various improvements and ideas of new features to add were discussed during the development of this work. Some of them are the following:

1. To include more SAGD projects from other gas and oil companies in the application from different parts of Canada or even from other countries. With

more data the application would have to be adapted based on some big data concepts, maybe even using a non-relational database to accelerate the data retrieval due to the data relationship complexity;

2. To add different levels of authentication, in which general users and administrators have access to different information and features;
3. To include new types of interactive visualizations, as well as the visualization of multiple wells, easing comparison of and analysis of related wells;
4. To implement ARM and add other techniques towards data prediction and optimization, such as artificial neural network, fuzzy logic, and evolutionary computation.
5. To perform a better requirements elicitation as well as evaluating the application using qualitative methods, such as surveys and interviews, in order to identify features that require further improvement.

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