DEVELOPING A UNIVERSAL GEOTHERMAL DATA MANAGEMENT SYSTEM

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ABSTRACT

The lifetime of a geothermal project typically exceeds thirty years, during which time large amounts of data are collected, personnel come and go, and techniques and methodologies change. However, one thing remains constant – a continuing requirement for access to and use of the data, regardless of data type or when and where it was collected.

A well-organized data management system will ensure that data is readily available, comprehensible and useable throughout the entire period - not just to those who initially collected and used it, but to the wider community of those involved in the project.

This "super-availability" offers the potential to maximize the cross-fertilization of concepts and ideas, which in turn ensures the best possible development decisions throughout the project. The GeoData Manager program is used as an example to illustrate the development and characteristics of a geothermal data management system.

1. INTRODUCTION

Data management styles can range from a data catalogue (such as the Dewey Decimal System used in a library) to the strongly-validated structured database used in a business accounting package. The former method works well with very diverse data (books), often collected over a long time period, and with many ways to use the data. The librarian uses the Dewey system to classify every book that enters the library, which is then used to retrieve the data.

The system does not control what data is entered (this is the responsibility of the librarian as gate-keeper), or play any part in the interpretation or presentation of the data. An accounting package, on the other hand, allows a limited range of data, acts as gatekeeper by rigorously validating data as it is entered, and also carries out calculations, interpretations and presentations.

Geothermal data falls somewhere between these two extremes. Many types of data from many locations, and over a long time period, are collected by different people using a diverse range of techniques. This primary data, mostly in the form of digital files, is usually managed with a library-type system. However, a formal company-wide structure is rarely implemented; rather, the personnel in each group (i.e., geologists, geophysicists, reservoir engineers, etc.) tend to take responsibility for the collection, collation and storage of the data pertaining to their discipline.

These primary data documents (files) are usually saved to a central server connected to a local-area network. While theoretically accessible to all technical personnel, experience indicates that the ease of searching for, finding, retrieving, and using the data within these files depends on many factors, some of which are summarized in Figure 1.

This table indicates that a file-based data management system may work well for day-to-day processing of data within individual disciplines, provided some protocols are implemented regarding folder organization, file naming, file types, and the inclusion of metadata (information as to where, when, what, how and why the data was collected).

Rules such as these are difficult to consistently enforce, especially over a long time period, so many organizations rely on redundancy, with extensive circulation lists and multiple copies. While this reduces the risk of primary data loss, it still does not guarantee that any one data collection contains all exemplars, and raises other issues, such as which is the most reliable data set, especially when corrected or modified versions are circulated.

Factor	Data Retrieval and Use Easy		Difficult
When the data was collected	yesterday	six months ago	many years ago
Who is looking for the data	person who collected data		someone else
Familiarity with the data	searcher from same discipline		different discipline
File names	describes data in the file		does not describe data
File types	spreadsheet	scanned document	printed report
Folder organization	hierarchical and logical		flat file structure
Data collection periodicity	single survey		many surveys at irregular intervals
Metadata Where, when, what, how, why	data well-described	some description	no description

Figure 1: Ease of data retrieval and use

File-based data management tends to become less reliable with the passage of time, and is most likely to fail when there are extraordinary demands for data, such as during the development of an integrated model and/or reserves assessment. The use of incorrect data, or failing to find and include critical data, could mean the difference between continued funding and the end of the project.

Many in the industry argue that geothermal data is so diverse that it cannot be adequately captured in a universal data management system (similar to a standard accounting package), but there is good evidence to show that this is not actually the case. Similar measurements are made at most if not all geothermal developments, such as:

- Well locations, deviations and casings.
- Information collected while drilling.
- Geological and alteration data from cores and cuttings.
- Digital downhole measurements from the wells.
- Well production, injection and monitor measurements.
- Geochemical analyses, rock chemistry and rock properties.

These data sets, derived predominantly from well measurements and easily able to be captured in a pre-defined database, are likely to comprise over 90% of all data collected during the life of the project. This data will be complemented by a more variable range of measurements such as ground-based and remote geophysical surveys, geological surface mapping and various geochemical studies, as well as specialist or research-focused measurements. In most cases, these more specialized data sets could easily be included in a pre-defined database, and their exclusion is simply because of the lack of wider support for these methods within the industry.

Over the years, a number of structured geothermal data management systems have been developed by geothermal companies and organizations. These are usually designed to meet limited data management needs (for instance, production and reinjection data only) and expect a project-specific data format. In-house systems are often poorly documented, rarely made available to the wider technical staff, and not easily extendible to other data sets or flexible enough to be used for data from other geothermal projects. These limitations often result in the system being abandoned when the prime user (or champion) of the software takes up other responsibilities or leaves the company.

Another approach employed by many companies is to use a GIS program or a 3D modeling program as a quasi-data management system. There are a number of disadvantages to this option:

1. The software is expensive, difficult to use and company licenses are usually limited.
2. The software handles only spatial data, not time-dependent data (e.g., temperature heat-up curves, production data).
3. The model is a snapshot in time, with data usually pre-selected by the main user, and alternative data sets tend to be ignored.
4. It can be difficult to update the model as new data is received.
5. Important data can be over-looked, as the data is sourced from a file-based system.

To make the most of expensive data, and the time and expertise of personnel, it is preferable to first capture the data in a data management system designed expressly for this purpose, and then select the data for any external applications. Besides minimizing the risk of misplacing, duplicating or corrupting data, a well-designed and implemented data management system will break down the information barriers that can exist between specialist groups within any geothermal project, and generate a truly collaborative environment. Investment in a sound geothermal database management system may be perceived as expensive, but is a most effective way to maximize the return from money spent on exploration and drilling.

2. DESIGN PRINCIPLES FOR A UNIVERSAL DATA MANAGEMENT SYSTEM

A universal geothermal data management system is one where the majority of scientific and technical data collected from any geothermal project can be entered and stored. Ideally, there should be little if any customization of the underlying database structure, although customization of the user interface may be necessary to show or hide various fields that reflect regional and project differences. The data should be readily available, preferably by all technical personnel involved in the project, and able to be exported to other applications. It is not suggested that a data management system of this sort would replace or displace the primary data documents mentioned in the previous section – rather, it is a *secondary database* which contains complete records of most of the commonly-measured data sets, may contain derived information from the primary database and, most importantly, *it is accessible*.

A geothermal system is a dynamic physical process (Elder, 1965) contained within a three-dimensional volume, so the data management system must reference the spatial position of all data, and the measurement time of most. The results of any measurements depend on how the measurements were performed, and of course the measurement units need to be known, and the primary data file referenced. Collectively, this information is known as the *metadata* (or the data about the data) – essential for the correct understanding and use of the data.

As the geothermal industry grows and matures, the common data types collected at any geothermal project will change. The data management system must be flexible enough to cope with these changes without a major re-write, and at the same time continue to handle all existing data stored in the database. Backward compatibility is perhaps the most important feature of any long-term data management system, ensuring that data collected at some previous date is still accessible, meaningful and useable.

3. DEVELOPMENT OF A GEOTHERMAL DATA MANAGEMENT SYSTEM

3.1 Introduction

The remainder of this paper will describe the GeoData Manager program as an example of a universal geothermal data management system, with particular reference to the design principles described above. GeoData Manager development began in 1987 (Barnett, 1987) as an in-house consultant application to manage geothermal data from diverse clients, with particular emphasis on capturing associated spatial, temporal and measurement information. To ensure the program remained relevant and useful, it was made commercially available in 1992 (GENZL, 1994; Anderson, 1995), even though this required significant documentation and user support, robust database upgrades, and a schedule of regular modifications and enhancements continuing to the present day.

GeoData Manager is now in use at over 25 geothermal projects on four continents and has remained commercially viable for over 20 years, a longevity directly attributable to the rigor required to develop software for the open market. Its open and extensible structure has allowed the software to respond to new operating systems, changes in industry operations and techniques and, most importantly, to changes in user expectations.

GeoData Manager was designed to include the following features:

1. Ability to handle most data collected during the course of a geothermal project.
2. A long life expectancy, commensurate with the duration of a typical geothermal project.
3. An open and accessible structure in the underlying database, allowing direct data mining by suitably qualified personnel.
4. Provision for the capture of the metadata of each data set. In particular, the system must enforce the measurement units, spatial position, and time of every measurement.
5. Flexibility to cope with regional variations (for instance, measurement units and language).
6. A common interface for all data sets, to promote interaction between disciplines.
7. General validation rules to prevent entry of duplicate data and data that is not referenced to spatial position and/or measurement time.
8. Effective sort, filter, and search tools to find data using a range of search criteria.
9. Appropriate security to allow wide-ranging use of the data while protecting data integrity.
10. Ability to import data in a range of formats from the primary data files.
11. Ability to select and export data in a wide range of formats to other programs.
12. A robust method to add or modify data sets in response to changes of operations and procedures within the industry.

3.2 Database and Structure

Geothermal data generally conforms to a one-to-many relationship – for instance one well and many temperature profiles, one temperature profile and many temperature measurements. This can be described as a master-detail or header-detail relationship. A relational database management system (DBMS) is ideally suited to store and manage this type of data. An important added advantage is that a relational DBMS offers powerful data searches, right to the level of individual measurements. At present, GeoData Manager can store data in Microsoft Access and SQL Server relational databases.

Most data management systems only allow access to the data through the program interface, so the data table structures can be (and usually are) extremely obscure. GeoData Manager was designed with understandable table and field structures to ensure that the data was readily accessible through the DBMS management tools (this of course presupposes that only suitably-skilled personnel are granted appropriate permissions). There are a number of reasons for this specification – to ensure the data remains available even in the worst-case scenario of failure of the management system, to be able to carry out specialized ad-hoc cross-tabular queries and searches not available in the application, to be able to make "backdoor" modifications to the data (scary but sometimes necessary) and simply to retain ownership of the data within the geothermal resource group, rather than ceding control entirely to the IT department.

To ensure this level of database access, the following design elements were implemented:

- The user can easily find the names of the header and detail tables for each data type.
- The column names in each table are expressed in clear English, without obscure abbreviations.
- Header/detail table relationships are maintained by multiple key fields.

3.2.1 An example of multiple key fields:

The name of each downhole pressure/temperature survey is given by the first four fields (Well, Well Test Type, Test Start Date, Test Start Time / ID) in the upper table of Figure 2.

Well	Well Test Type	Test Start Date	Test Start Time / ID	Well Test Comment	Well Status Type	Test Mass Flow [gpm-80F]	Test WHP [psi abs]	Note
AT-102	PT	7/25/1999	22:03	Injection 200 gpm	INJECTION	-192.76	14.50	LOC
AT-102	PT	7/26/1999	01:15	Injection 300 gpm	INJECTION	-289.14	290.00	LOC

Well	Well Test Type	Test Start Date	Test Start Time / ID	Measurement Date	Measurement Time	Depth [ft]	Well Temperature [deg F]	Well Pressure [psi abs]
AT-102	PT	7/25/1999	22:03	7/25/1999	22:03:40	65.62	78.44	141.09
AT-102	PT	7/25/1999	22:03	7/25/1999	22:03:55	82.02	78.44	148.34
AT-102	PT	7/25/1999	22:03	7/25/1999	22:04:10	98.43	78.44	155.44
AT-102	PT	7/25/1999	22:03	7/25/1999	22:04:25	114.83	78.48	162.84
AT-102	PT	7/25/1999	22:03	7/25/1999	22:04:40	131.23	78.51	169.94
AT-102	PT	7/25/1999	22:03	7/25/1999	22:04:55	147.64	78.53	177.19
AT-102	PT	7/25/1999	22:03	7/25/1999	22:05:10	164.04	78.58	184.01

Figure 2: Typical header/detail table structure

These fields, which act as the unique primary key of the table, are also key fields of the lower detail table, together with Measurement Date, Measurement Time and Depth. This style contrasts with the more orthodox approach of a single primary key field in the header table referenced as a foreign key in the detail table. By including site and survey keys in every detail record, the data is future-proofed by being more understandable and accessible (Garmany, 2005). (Note that the redundant identifiers in the detail table are usually hidden when using GeoData Manager.)

4. THE DATA MODEL

Currently the GeoData Manager database contains over 140 different header and detail tables, as well as 60 system and lookup tables. A comprehensive data model defines the structure of each table, including primary key fields and unit type where applicable (Figure 3). In contrast to many relational databases, the master-detail relationships are defined by software, not by intrinsic table relationships. This not only offers better control over record/table locking to prevent user conflicts, but can also allow unorthodox (such as some-to-many) data relationships.

GeoData Manager uses lookup fields extensively, where a pick list of values is provided for the user to select from (Figure 4). The values, stored in a separate lookup table, are user-defined for some fields and system-defined in others. As for the master-detail relationships, the lookup fields and tables are defined by software, not by intrinsic table relationships, again to allow better control of aspects such as hard (compulsory selection) and soft (optional selection) lookups. Furthermore, the database is more stable and less inclined to lock up if one table becomes corrupted or somehow receives incorrect data.

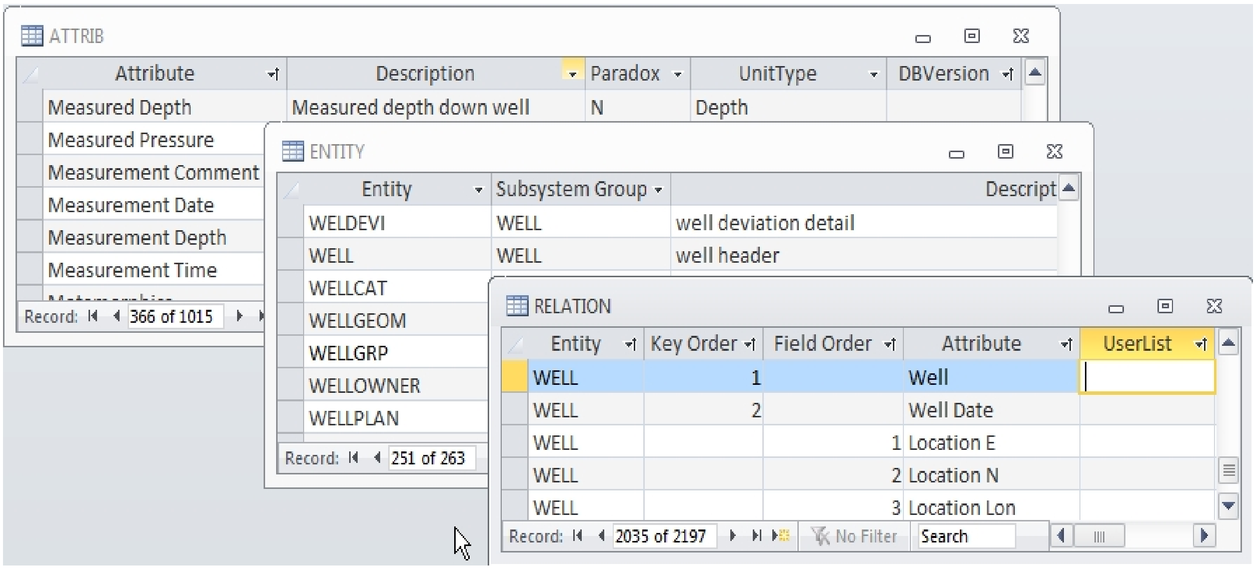

Figure 3: The GeoData Manager data model.

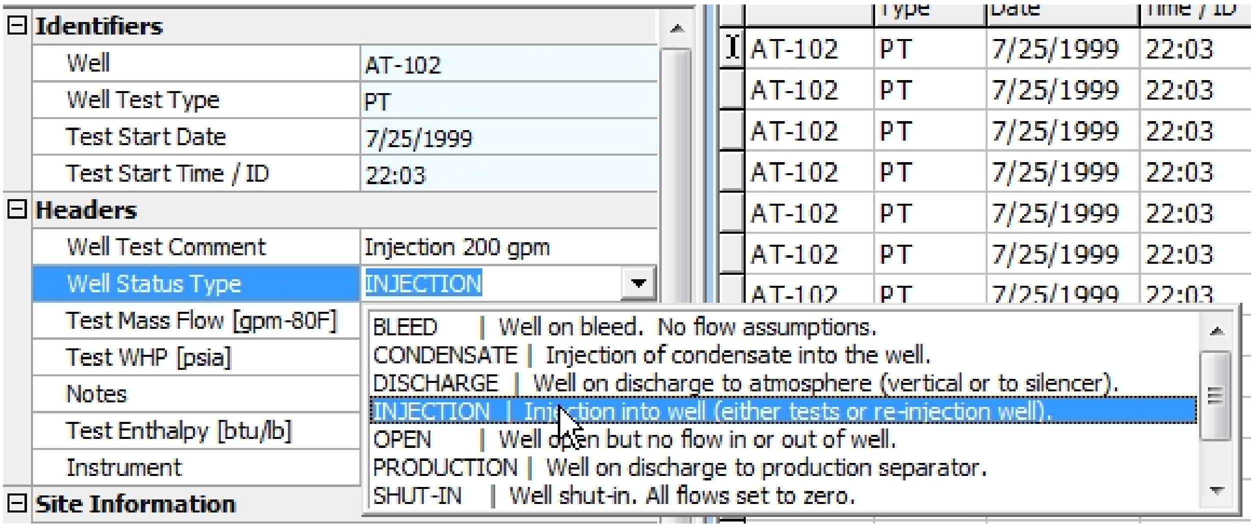

Figure 4: An example of a lookup field, showing the available pick list

A master system table, P-Tree, is used to generate a menu tree (Figure 5**)** that the user navigates to access the different data types in the database. This system table defines the header and detail tables, table relationships (e.g., to control data rename and deletion), site relationships (every data set is related to a physical site), available graph types, and the data-specific procedures for validation, calculations and export options. The contents of this table are available at every node of the menu tree (**Figure 6**), an important contribution to the principle of openness and accessibility that has driven the design.

4.1 The Unit System

The data model defines a unit type (such as depth, pressure, or temperature) for each numeric field in the database. All numeric data in the database is stored in SI units to minimize interpretation errors if data is directly extracted from the database at some later time. The unit system contains the parameters required to convert data entered in any measurement units to SI units as the data is stored, and to extract and present the data in any user-specified units. It is possible to use a range of units for the same unit type – reflecting the common situation where a wellhead pressure gauge is calibrated in psi, while downhole tools give readings in bar.

All data conversions conform to a simple two-term relationship, as demonstrated below:

T' °F = Factor * T °C + Adder

where Factor = 1.8 and Adder = 32.

The Factor and Adder parameters are those required to convert from SI to user-specified units.

The unit system does include variable factors, to convert mass-based to mole-based chemical concentrations and vice versa, and also variable adders, to handle gauge/absolute pressure conversions at different altitudes and varying rig floor heights when converting drilling depths to ground reference level.

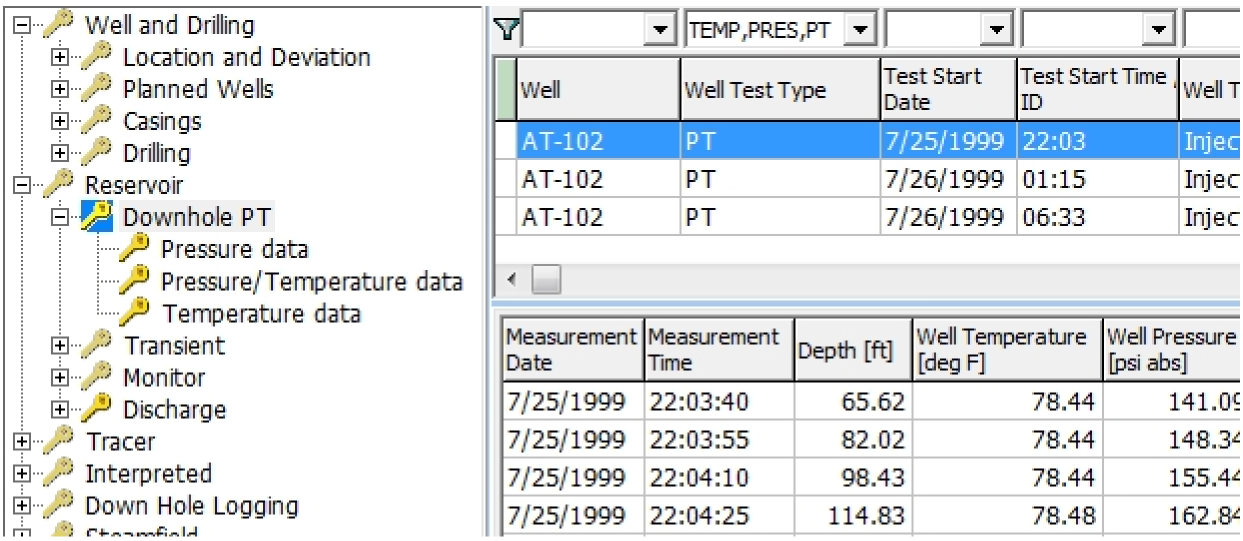

Figure 5: Part of the GeoData Manager menu tree, showing corresponding data

NodeID	300	OnEdit	REEdit()	SiteKeyCount	1
Parent	Reservoir	OnEditProcess		SiteTableField	Well
Node	Downhole PT	OnCanAdd		SiteTableDate	Well Date
Description	Downhole temperatur...	OnRecord		GraphTypes	2,3,1
HeaderShow	WTDIARY	OnInsert		GraphAxes	Depth,Temperature,Pr...
HeaderKeyCo...	4	OnCanSave	RECanSave()	ContourTypes	4,2,3
IDCount	4	OnSave	RESave()	OnGraph	
DetailShow	WELPRES	OnRenameID		OnContour	
DetailKeyCount	7	OnRename	RERename()	OnReport	
FilterField	Well Test Type	OnDeleteTest		OnProcess	PROWellData3D()
FilterBy	TEMP,PRES,PT	OnEditHeader	REEditHeader()	StartDateField	Test Start Date
AddCheckTable	WELL	OnCanSaveH...	RECanSaveHeader()	MeasDateField	Measurement Date,Me...
AddCheckFields	Well	OnSaveHeader	RESaveHeader()	DepthField	Depth
CheckBeforeD...	LIPHEAD,WEIRHEAD,O...	Group1	WELLGRP	ProfileSiteTable	PROFWELL
AlsoDelete	TESTGRP,PTDATA	GroupMany	TESTGRP	OnMap	MAPMeasPT()
AlsoRename	TESTGRP,LIPHEAD,LIP...	DefaultGraph...	"Well Pressure","Well ...	OnProfile	PROFMeasPT()
OnNodeSelect	EnableEditing('nerd')	SiteField	Well	OnMultiAdd	
OnAddIdentifi...	REAddIDPT()	DateField	Test Start Date	OnMultiEdit	
OnAddTest	REAddTest()	SiteTable	WELL	OnMultiCanSa...	

Map View | Detail Table | Quick Graph | Filter | Tagged | Detail Filter | P-Tree

Figure 6: Table and program details at node 300 (Reservoir | Downhole PT)

4.2 Language

Although the GeoData Manager user-interface is written in English, alternative languages can be used in two separate areas. Firstly, the unit system includes provision for user-specified or (preferred) field names, unit types and units. These preferred names are displayed throughout the program, in table headings, graph axes, pick lists and data exported from the program, so that users can present data in the language of their choice. The preferred names can be turned on and off, so it is possible to switch between English and another language.

Secondly, most information and error messages in GeoData Manager are encoded in the GNU GetText format (www.gnu.org). This allows the user to develop a dictionary of these messages in another language, and GeoData Manager will provide an automatic translation.

4.3 Data-specific Checks and Calculations

Each distinct data type will usually require a different set of validity checks and calculations during data entry, as well as calculations and formatting for exporting data to external applications. These are provided by a suite of Python procedures (www.python.org), external to the main program, and referenced from the P-Tree system table. Python is a non-compiled scripting language, so this approach allows a very rapid development/testing cycle in response to changes of measurement techniques and analysis methods.

4.4 New Data Sets

While the structures of the commonly measured geothermal data sets do not change very rapidly, new techniques are always being developed at the periphery, while others are enhanced and modified. A universal geothermal data management system must be able to handle these new and/or modified data sets as they move towards the mainstream, and these changes must be managed according to a consistent set of principles and practices.

At present, GeoData Manager supports a single database structure, and user modifications are not recommended. New data sets can be requested by users and, after evaluation of their suitability for the wider geothermal community, are usually introduced as part of the regular program releases (typically twice per year).

The introduction of a new data set into GeoData Manager involves relatively little code writing but does require the following steps:

1. Design of the data tables in the data model (fields, indexes, field sizes, lookups, etc).

2. Unit assignment for all the numeric fields.

3. Creation of new records in the P-Tree table, to define the menu tree node, Python procedures to be applied, table relationships, graph types, etc.

4. Development of Python procedures to handle data validity checks, special calculations, and special outputs.

4.5 Data Processing

The pre-defined database structure of GeoData Manager allows many data-sensitive procedures and calculations to be embedded in the system. These include the following:

1. Data validation rules appropriate to each data set to ensure data is correctly described and categorized (for instance that measurements must not be deeper than the well).

2. Data entry calculations related to each data set (e.g., geothermometers from chemical samples, flow calculations from lip pressure measurements, etc.).

3. Appropriate graphics for each data set, to assist in data search and quality control.

4. Generalized spatial calculations for well data (conversions from measured depths to vertical depths and elevations).

5. Ability to graphically compare and contrast data between different locations, times, and data types as appropriate.

6. Spatial calculations (northing, easting, value) for parameters from different sites (e.g., temperature at a specified vertical depth, elevation of a specified rock type, Bouguer anomalies, etc.) to rapidly generate contour maps for data comparison.

7. Spatial calculations (distance, elevation, value) to project parameters from different sites on to a cross-section, again to facilitate data comparison.

8. Procedures to export selected data in an appropriate format to GIS and 3D-modelling applications.

9. Data-specific procedures to calculate specialized outputs (for instance, summed flows and cumulative mass from selected wells, calcite solubility calculations, core register search by rock type, production history for reservoir simulation, etc.).

10. Process to generate well chronological histories.

5. EVALUATION

In this section, the benefits, drawbacks and ongoing development of the GeoData Manager geothermal data management system are discussed.

The program handles almost 60 different types of geothermal measurements, including most of the common data sets. Different measurement techniques are allowed for by including ancillary fields, which can be used or hidden, in many tables. The different data types are summarized below:

Well and drilling	Well deviation (actual and planned), casing structure, casing anomaly, drilling returns, rate of penetration, circulation loss.
Reservoir	Pressure/temperature downhole, pressure/ temperature transients (7 types), pressure monitor, water level monitor, discharge (11 types), chemical tracer, radioactive tracer
Downhole logging	Resistivity, self-potential, spinner, density, porosity, natural gamma, sonic velocity, fracture, go-devil, xy caliper, cement bond
Steamfield	Production, reinjection
Chemistry	Fluid chemistry (water, steam and gas), soil chemistry
Geology	Well lithology, formations, alteration, secondary minerals, core register, faults, rock properties, rock chemistry
Geophysics	DC resistivity, 3D resistivity, gravity, microgravity, magnetotellurics

These measured data sets are complemented by a number of interpreted data sets, where the user can store interpretations derived from the measured data sets (for instance formation temperature from measured downhole temperatures) and also a Reservoir Simulation module, where data generated by numerical modeling of the reservoir can be directly compared with measured data.

The clear benefits of using GeoData Manager as a geothermal data management system include:

1. Centralized location for data from one or many geothermal prospects.

2. Ease of capture of all data sets of each data type, using available sort and filter tools.

3. Strong validation on data entry to reduce the chance of incorrect data in the database.

4. Centralized data storage, so all data is available to all personnel who require access.

5. Rapid access to data, both familiar and less familiar, by using the common interface.

6. Enhanced project continuity - rapid data and project familiarization for new personnel.

7. User-defined site and data groups to speed up data search and selection.

8. Spatial presentation of data sites, with ability to show and hide different site groups.

9. Easy graphical data comparison between data from different locations and different times.

10. Easy spatial data comparison of dissimilar data sets (such as lithology and temperature) by contour map or cross-section (using an external application).

11. Rapid data selection and export to external applications as required, including GIS.

12. Many specialized processes, minimizing error and maximizing staff productivity.

13. Ability to make ad-hoc specialized data queries, to explore complex data relationships.

14. Links maintained to the original data files.

The drawbacks include the following:

1. The apparent high cost of the software license. This is necessary, given the limited market, if there is to be a commitment to on-going product maintenance and improvement.

2. GeoData Manager does not handle every type of data, in particular data-dense formats such as seismic reflection sections, downhole well images (e.g., FMS, FMI), remote-sensing techniques.

3. The time and cost overheads for data entry from the original data files, and for training personnel to use the program.

4. Manipulation and graphical presentation of closely-spaced downhole surveys can be slow (mainly because of the unit conversion calculations), and requires a compromise between speed and including complete data sets.

5. Presentations of spatial relationships and some graphical types currently require export to external applications.

Some of the most important goals for future development that the author has identified are:

1. Improved graphics for data sets defined by data intervals, such as casings, well lithology, cement bond. This development is underway at present.

2. Summary graphics (rapid graphical comparison of different data types). This will follow the completion of Item 1.

3. Specialized chemistry graphics (ternary, Piper, Spider plots).

4. Graphical pressure transient analysis and resistivity 1D modelling.

5. General graphics improvement (point labelling, single-axis pan and zoom, multiple axes).

6. Speed improvements to allow complete data sets to be stored and manipulated.

7. Structural changes which may be required, for example to improve the handling of geological data, or to handle specialized data sets which may be requested by users.

8. Enhanced spatial tools (base maps, fault locations, contour maps, etc.) to facilitate quick data assessment.

9. Improved tools to select and compare data between different projects.

6. CONCLUSIONS

This paper shows, by the example of GeoData Manager, that it is possible to create a near-universal geothermal data management system that handles a significant proportion of the data collected. Having and using such a system confers many advantages, the main ones being data security, and the ability to rapidly integrate and evaluate multiple types of data from any geothermal project.

However, a very important factor in the success and universality of this application has been and continues to be that it is a commercial product. Unlike an in-house system, it has had to accommodate a range of needs in varied geothermal development situations, be useable by technical staff with different languages, working styles and expertise, and to keep pace with software developments and expectations. This commercial pressure is arguably one of the strongest determinants to ensure that the program is sound and can provide the necessary tools to support good technical decisions, both when developing and managing a geothermal resource.

While the overheads of maintaining a GeoData Manager database may initially seem somewhat daunting to the user, especially the time and effort required to enter historical data, the benefits will steadily increase as the database is populated. In particular, the time spent searching for data and the risk of misplacing or even losing data is kept to a minimum, compared with a file-based data system.

GeoData Manager has been commercially available for over 20 years, and has successfully weathered the major change from DOS to Windows operating system. The open and flexible design of the program allows continual development, both of new data sets and of new functions and features of existing data sets. With on-going support, it can meet all the challenges of the future and continue to be an essential piece of kit specially designed for the geothermal industry.

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