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"Bigger on the Inside" – Time Travel with Geothermal Data Management

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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 underpinning the project 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 universal geothermal data management system that can literally travel through time.

1. INTRODUCTION

Geothermal resource data relates primarily to "the geothermal reservoir", a somewhat hypothetical underground volume, imperfectly explored and measured by a complex array of different techniques. Most geothermal reservoirs are part of a larger dynamic physical system which is driven by a heat source, mediated by geothermal fluid and modified by the physical properties of the rocks. Both the initial state and the effects of later perturbations on this physical system are of critical importance to the understanding and management of the geothermal reservoir and the geothermal resource.

A global view of the multiple forms of information gathered is necessary to make decisions based on a complete, integrated picture rather than one that is partial or disconnected., In addition, to better understand what is going on in the geothermal system at the present moment, and to manage its development into the future, geothermal scientists and engineers will always require access to measurements made throughout the life of the geothermal project. Large volumes of data are collected over the life of the project, from many different sources, and it difficult to predict what data may be useful perhaps 20 years in the future. This paper explores ways of managing this data so that the usability of the information contained within it is maximized.

2. REVIEW OF DATA MANAGEMENT STRATEGIES

Effective data management involves the methodical storing and sorting of data in a form which can be efficiently manipulated and analyzed by the available tools. Until relatively recently, data collected from a geothermal field was usually in paper format, including some standard graphical presentation. This data was commonly filed and retrieved by a dedicated file clerk or librarian, and as a result surprisingly accessible. Integrated interpretation of such data, however, was often limited by the considerable time overhead to get the data in a useful form for advanced analysis, and also by a lack of interdisciplinary knowledge.

Currently, most geothermal data is in the form of digital files, and is usually managed in a similar library-type system, catalogued according to type and location in a hierarchical computer folder structure. 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 is still limited by a number of factors, as shown in Figure 1.

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

This table indicates that a file-based data management system may work well for storing, sorting, cataloguing and processing day-to-day 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). However, there are serious potential limitations. Firstly, 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.

Secondly, file-based data management systems tend to become less reliable with the passage of time, and are 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. And thirdly, file-based data management is inherently prone to discipline-specific perspectives which may inhibit global, interdisciplinary analyses.

In fact, many in the industry argue that geothermal data is so diverse that it cannot be adequately captured in a universal data management system (with protocols and structures similar to a standard accounting package). However, 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, such as loss zones and rate of penetration.
- 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 core 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.

An alternative approach many companies adopt 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:

- The software is expensive, difficult to use and company licenses are usually limited.
- The software usually handles only spatial data, not time-dependent data.
- The model is a snapshot in time, with data pre-selected by the main user, and alternative data sets often ignored.
- It can be difficult to update the model as new data is received.
- Important data can be over-looked, as the data is sourced from a file-based system.

Experience, and a large amount of anecdotal evidence, suggests that 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 may help break down the information barriers that can exist between specialist groups within any geothermal project, and generate a truly collaborative environment.

3. DESIGN PRINCIPLES FOR A UNIVERSAL GEOTHERMAL DATA MANAGEMENT SYSTEM

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 and measurement time of all data. The results of any measurements depend on how these measurements were performed, and whether other activities were influencing the geothermal system. The measurement units need to be known, and the primary data source 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.

A universal geothermal data management system should be based on the following principles:

1. The ability to accept and store the majority of scientific and technical data collected from any geothermal project; including appropriate metadata. In particular it should reliably capture those data sets that are collected intermittently over a long period, as this data is most often misplaced or lost.

2. Rigorous validation of the data, and the associated metadata, as it is entered, to ensure data quality. Validation rules should include detection of duplicate data, checks to ensure the measurement location and measurement time is present and valid, defined measurement units and described measurement conditions.
3. An open and well-documented database structure, to ensure data consistency over time and between locations. Casual customization of the database should not be allowed.
4. Flexibility to handle regional and project data differences, including language and measurement units.
5. Ready accessibility of the data to all technical personnel involved in the project, with a common interface across disciplines. One of the biggest obstacles to cross-discipline data access is unfamiliarity with the tools to be used.
6. Standard processing functions to make the data more useful across space, time and discipline, such as the calculation of the true spatial position of well data, and true date and time from elapsed time measurements.
7. Easy data search and selection, and export in various formats to other applications. The database should function as a data "backbone" serving specialized processing and analysis programs used in the geothermal industry.
8. A robust procedure to add to or modify the database in response to industry changes of the types of data routinely collected. This should not require a major re-write, but any modifications must maintain backward compatibility and ensure that existing data is still accessible, meaningful and useable. This is perhaps the most important feature of any long-term data management system.

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*.

4. GEO-DATA MANAGER - AN EXAMPLE OF A GEOTHERMAL DATA MANAGEMENT SYSTEM

The remainder of this paper uses one specific example to outline the workings of an effective geothermal data management system in relation to the design principles outlined above. GeoData Manager has demonstrated the longevity, reliability, security and accessibility which are signs of a successful universal data management system. Initially developed as an in-house consultant application to manage geothermal data from diverse clients, it had from the start a particular emphasis on capturing and integrating associated spatial, temporal and measurement information (Barnett, 1987). 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 the implementation of a schedule of regular modifications and enhancements which has continued to the present day.

GeoData Manager is in use at over 25 geothermal projects on four continents and its longevity and commercial viability can be attributed to the rigor required when developing software in the open market. Its open and extensible structure has allowed its adaptation to new operating systems, changes in industry operations and techniques and, importantly, the changes in user expectations.

4.1 Data Scope

The GeoData Manager program currently handles 60 different types of geothermal measurements, including most of the common data sets. The different data types are summarized below:

Well and drilling:	Well deviation (actual and planned), casing structure, casing anomaly, drilling parameters.
Reservoir:	Pressure/temperature downhole, pressure/temperature transients (7 types), monitor (pressure and water level), discharge (11 configurations), tracer (chemical and radioactive).
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 chemistry.
Geophysics:	DC resistivity, 3D resistivity, gravity, microgravity, magnetotellurics, rock properties.

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.

Measured data is most commonly imported from spreadsheets or ASCII files supplied by the measurement personnel, but can be entered from keyboard. Some data in specialized format (e.g. EDI files used for magnetotelluric data) can be read directly, and this can be extended to other standard data formats (e.g. LAS files, RimBase data) if demand warrants. Metadata is usually entered by keyboard, with direct import procedures under development.

4.2 Data-specific Validation 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.

4.3 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 only in Microsoft Access and SQL Server relational databases, selected because they are likely to be still operational in thirty years or more.

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 2). 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.

ATTRIB

Attribute	Description	UnitType
Location E	The "easting" of a measurement site, expresse	Spatial Coordinate
Location Lat	The latitude of a measurement site, expressec	Location Angle
Location Lon	The longitude of a measurement site, express	Location Angle

ENTITY

Entity	Subsystem Group	Description
WELDEVI	WELL	well deviation detail
WELL	WELL	well header
WELLCAT	WELL	lookup table to list well category information

RELATION

Entity	Attribute	Key Order	Field Order
WELL	Well	1	
WELL	Well Date	2	
WELL	Location E		1
WELL	Location N		2

Figure 2 The GeoData Manager data model.

Most data management systems allow access to the data only through the program interface, so the database structure can be (and usually is) 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 (with 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:

1. The names and structures of the header and detail tables for each data type are readily available to the user.
2. The column names in each table are expressed in clear English, without obscure abbreviations.
3. Header/detail table relationships are maintained by multiple key fields.

Identifier fields of header table

Well	Well Test Type	Test Start Date	Test Start Time / ID	Well Test Comment	Well Status Type	Test Enthalpy [kJ/kg]
AT-102	PT	1/08/1999	21:38	Heating		
AT-102	PT	8/08/1999	09:28	Heating 13 days	SHUT-IN	

Identifier fields of detail table

Well	Well Test Type	Test Start Date	Test Start Time / ID	Measurement Date	Measurement Time	Depth [m]	Well Pressure [barg]	Well Temperature [deg C]
AT-102	PT	1/08/1999	21:38	1/08/1999	21:38:12	0.00	0.14	26.27
AT-102	PT	1/08/1999	21:38	1/08/1999	21:38:37	4.00		26.54
AT-102	PT	1/08/1999	21:38	1/08/1999	21:38:50	8.00		26.99
AT-102	PT	1/08/1999	21:38	1/08/1999	21:39:00	12.00	0.14	27.81
AT-102	PT	1/08/1999	21:38	1/08/1999	21:39:09	16.00	0.14	28.93
AT-102	PT	1/08/1999	21:38	1/08/1999	21:39:19	20.00	0.14	30.27

Figure 3 Typical header/detail table structure

An example of multiple key fields:

The name or identifiers of each downhole pressure/temperature survey is given by the values in the first four fields of the associated header table (see Figure 3), namely *Well*, *Well Test Type*, *Test Start Date* and *Test Start Time / ID*. These fields, which form the unique primary key of the table, are also key fields of the 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.)

4.4 Regional Flexibility

Data Differences

Different measurement techniques and regional variations are allowed for by including a number of optional fields in many tables. These can be displayed or hidden by user-specified views.

Measurement Units

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, where the Factor and Adder parameters are those required to convert from SI to user-specified units, as demonstrated below:

$$T' \,°F = \text{Factor} * T \,°C + \text{Adder} \qquad \text{Factor} = 1.8, \text{Adder} = 32.$$

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

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.

4.5 The User Interface

A master system table, P-Tree, is used to generate a menu tree (Figure 4) 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 5), an important contribution to the principle of openness and accessibility that has driven the design.

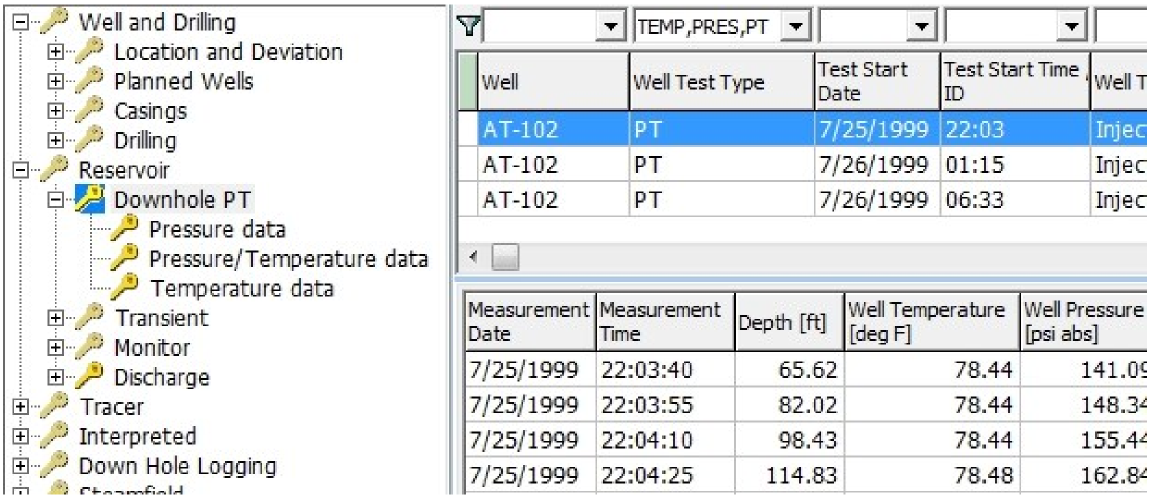


Figure 4 Part of the GeoData Manager menu tree, showing corresponding data

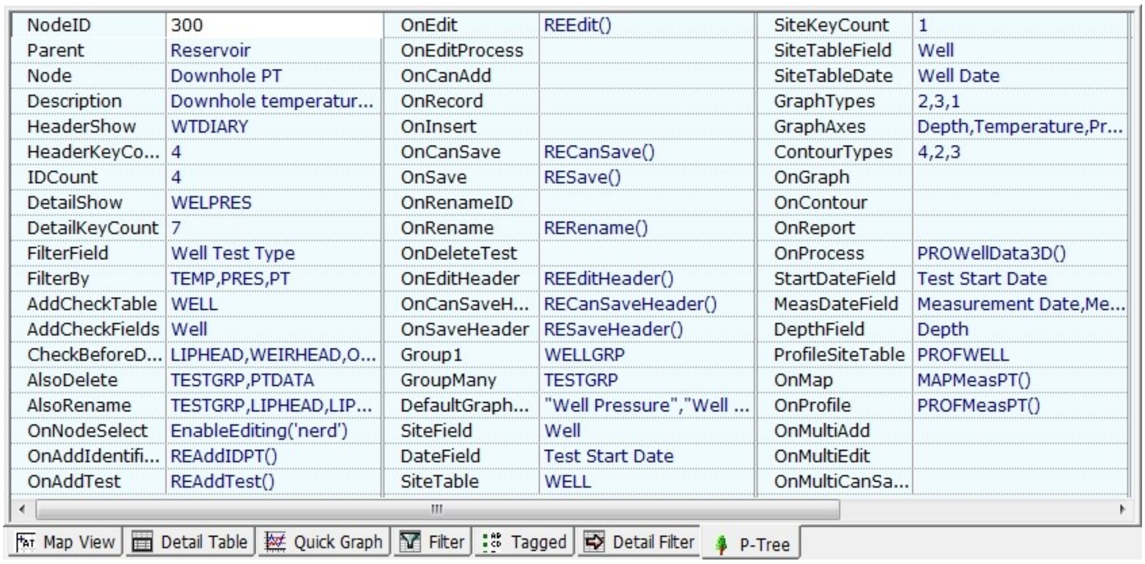


Figure 5 Table and program details at node 300 (Reservoir | Downhole PT)

Reflecting its emphasis on data quality and consistency, GeoData Manager uses lookup fields extensively, where a pick list of values is provided for the user to select from (Figure 6). 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.

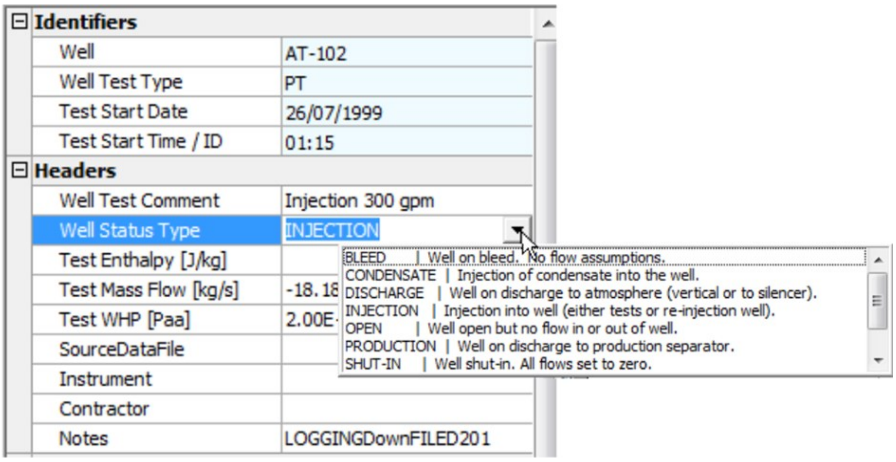


Figure 6 An example of a lookup field, showing the available pick list

4.6 Data Processing

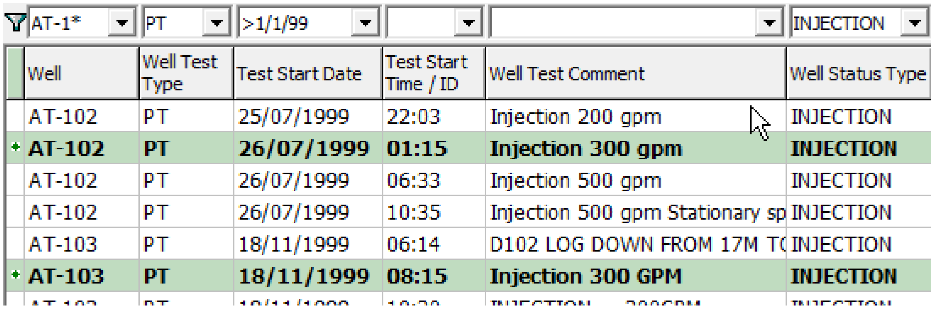
The pre-defined database structure of GeoData Manager allows many data-sensitive procedures and calculations to be embedded in the application. Common procedures applicable to many data types (e.g. depth/elevation conversions) are included in the main program, while more data-specific calculations are located in Python scripts. Procedures include the following:

- 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).
- Data entry calculations related to each data set (e.g., geothermometers from chemical samples, flow calculations from lip pressure measurements).
- Appropriate graphics for each data set, to assist in data search and quality control.
- Generalized spatial calculations for well data (conversions from measured depths to vertical depths and elevations).
- Ability to graphically compare and contrast data between different locations, times, and data types as appropriate.
- 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.
- Spatial calculations (distance, elevation, value) to project parameters from different sites on to a cross-section, again to facilitate data comparison.
- Procedures to export selected data in an appropriate format to GIS applications and 3D modeling programs.

- 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).
- A process to generate a chronological history for each well.

4.7 Search, Selection and Export

A wide range of search and selection tools are provided. Every data set displays a filter bar which is used to display data that meets specified criteria (Figure 7). Individual data sets can then be identified, using graphical confirmation if necessary, and selected or tagged (shown in green).



Well	Well Test Type	Test Start Date	Test Start Time / ID	Well Test Comment	Well Status Type
AT-1*	PT	>1/1/99			INJECTION
AT-102	PT	25/07/1999	22:03	Injection 200 gpm	INJECTION
AT-102	**PT**	**26/07/1999**	**01:15**	**Injection 300 gpm**	**INJECTION**
AT-102	PT	26/07/1999	06:33	Injection 500 gpm	INJECTION
AT-102	PT	26/07/1999	10:35	Injection 500 gpm Stationary sp	INJECTION
AT-103	PT	18/11/1999	06:14	D102 LOG DOWN FROM 17M TO	INJECTION
AT-103	**PT**	**18/11/1999**	**08:15**	**Injection 300 GPM**	**INJECTION**

Figure 7 The filter bar, using wild cards, inequalities and selected lookup values, and tagged records.

Tagged data can be saved to a user-defined group in the database, which is available for repeat operations on that particular data, or for other members of the resource group. A group of sites (e.g. "Deep Wells") can be used to filter data, and also to control the display of sites in the spatial view of the geothermal field. Sites can also be directly selected from the spatial view.

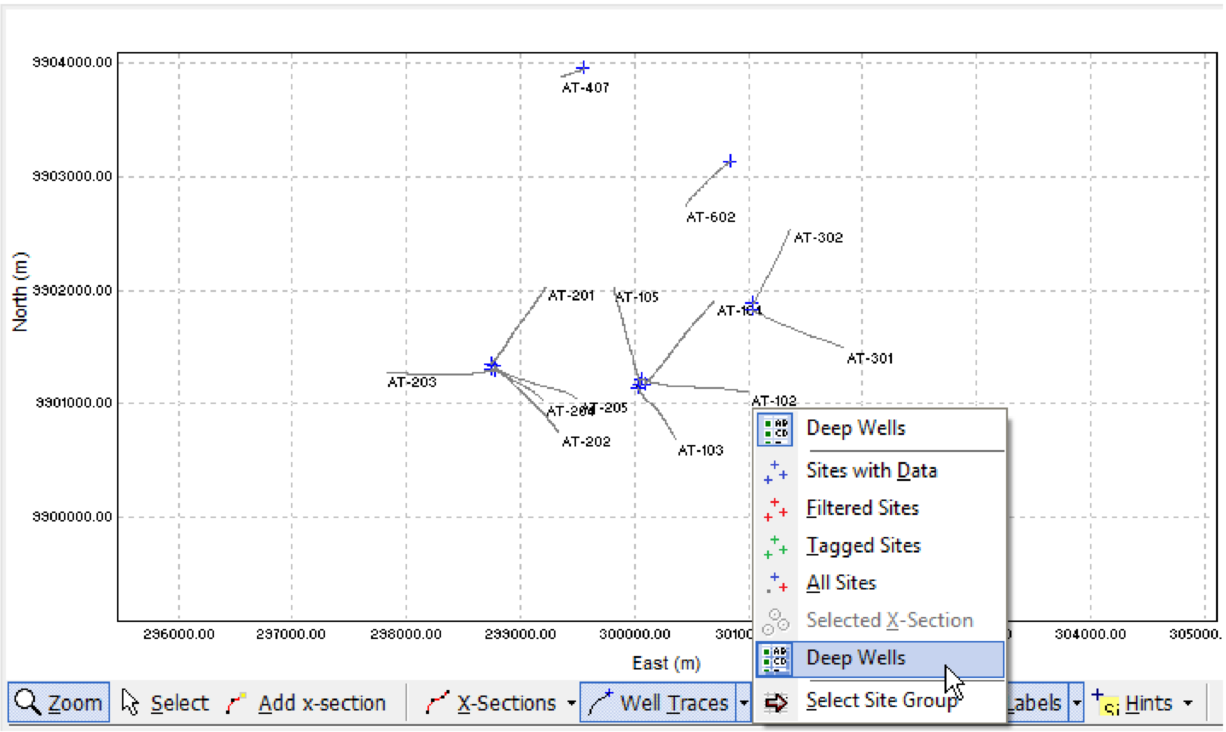


Figure 8 Spatial view of the geothermal field, displaying deep wells.

Data can be exported at every node in a variety of formats, including clipboard (able to be pasted into a spreadsheet) and ASCII files. At selected nodes there are additional export options to specialized programs such as 3D modeling applications and TOUGH2 (production history files).

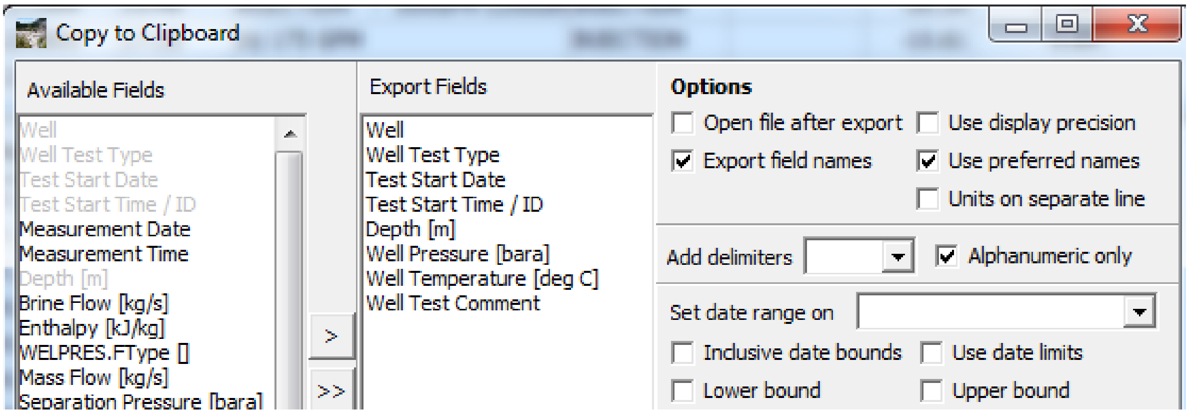


Figure 9 Copy to Clipboard Dialog for Tagged Header and Detail Data.

4.8 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.

4.9 Evaluation

The benefits of using GeoData Manager as a geothermal data management system have been found to 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. A geo-referenced database structure, ensuring ready compatibility with GIS applications.
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.
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.

Current areas of weakness include the following:

1. 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.
2. Manipulation and graphical presentation of closely-spaced downhole surveys can be slow (mainly because of the unit conversion calculations), and currently requires a compromise between speed and inclusion of complete data sets.
3. Presentations of spatial relationships and some graphical types require export to external applications.

The apparent high cost, in particular the initial overheads involved in data entry from the original data files, training personnel to use the program, and the relatively high cost of the software license, are seen by some potential users as a drawback. However, it is a highly specialized and effective tool which has been developed within and for the geothermal market. It is regularly upgraded in response to internal review and user requests, with some of key current goals for future development identified as being:

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 modeling.
5. General graphics improvement (point labeling, 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.

5. CONCLUSIONS

A reliable, accessible, secure and long-lasting data management system which can be used by all personnel to handle the bulk of data collected is clearly a powerful tool for the geothermal industry, helping to maximize the effective and profitable ongoing exploitation of geothermal resources. GeoData Manager has been developed to provide a near-universal geothermal data management system. 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.

It is important to note that a key 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 adopting 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. Investment in a sound geothermal database management system may be perceived as expensive, but is a most effective way to maximize the return from the significantly larger amounts money spent on exploration and drilling. This is a situation where scientific rigor can be of great benefit to business.

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 toolbox for the geothermal industry that can generate outcomes and benefits far greater than its modest exterior.

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