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ÍSOR's Geothermal Database of Exploration and Production Monitoring, Current Design and Status

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ABSTRACT

In Iceland geothermal measurements have been gathered for around 90 years, through both exploration and utilization. ÍSOR (Iceland GeoSurvey) and its predecessors have been involved in most of the geothermal projects for 75 years. The information that has accumulated through this costly research and projects is vital and requires both safe and accessible storage. At ÍSOR we have chosen to host our data in a relational database management system (RDBMS). The benefits of using such a database system is, among other things, to ensure data consistency, avoid data duplication, minimize human errors, maximize data security and accessibility. Data can be retrieved quickly and with ease, compared on a large or a small scale, within and between geothermal areas and reservoirs, between individual wells and other locations of measurements or sampling, and all of this between time intervals. Information can also be shared more easily, which benefits not only ÍSOR's projects, but also ÍSOR's clients, related supervisory authorities and institutions involved. This leads to improved collaboration and advances all of ÍSOR's geothermal projects. Since 2017, three of ÍSOR's largest clients in Iceland have access to their data in special databases per client hosted at ÍSOR. These client databases do not store just the data belonging to each client, they also have almost the same design and table relations as ÍSOR´s primary database. Two clients abroad, in Nicaragua and Turkey, have their geothermal databases designed according to the design of ÍSOR´s database.

The main outlines of ÍSOR´s geothermal database of exploration and production monitoring will be described here, its current design and status. The structure and general usage of the database will be presented, including main database parts, general table structure and table relations, along with many of the database tables. Some few notable examples of database reports from the database chemical part and the borehole part will be presented.

1. INTRODUCTION

Data collection is or should be of high importance in most fields of work and so is safe data storage, efficient management and accessibility for making the most use of the data. "*Data is the fabric of the modern world: just like we walk down pavements, so we trace routes through data, and build knowledge and products out of it.*" – Ben Goldacre a British physician, academic and science writer (Goldacre, 2019). "*I think you can have a ridiculously enormous and complex data set, but if you have the right tools and methodology, then it's not a problem*." – Aaron Koblin, entrepreneur in data and digital technologies (Zola, 2019).

Geothermal data obtained in costly research and projects requires safe and accessible storage. If a proper data storage is lacking, the sooner its storage is designed and initated, the better. The relational database model is the most popular type, is an extremely powerful tool to store information and to access it as well (Tech-FAQ, 2010). When planning data storage in a relational database management system (RDBMS), it is possible to choose from a variety of good systems, some of them low cost or even open source.

When a geothermal database is well structured and running safely in a good relational system, there will be so much better access to the data than before. Utilization of the data can thus be taken to a quite new level. Geothermal scientists and data analysts can then manipulate the data in many ways and look at the data from many different points of view, which can lead to greater insights and overview of projects, and thereby to better conclusions. Sharing of data between collaborators becomes easier and work procedures in all stages of the geothermal work will improve (Gunnarsdóttir, 2015).

ÍSOR‘s relational geothermal database stores data gathered from geothermal exploration and production monitoring, that is the various measurements values, metadata, and relevant geographical locations of measurements or sampling. Its first parts were developed three decades ago, when in 1988 the chemical part, for data regarding collected chemical liquid and gas samples and their analyses, was designed along with the database part for the geographical location information concerned. These first parts were revised a decade later, in 2001, and since then there have been ongoing additions to the database and revisions of its structure. There have been added parts for geophysical and geological measurements that are not related to boreholes, parts for rock samples, for storing of cuttings and for instruments and sensors used in the measurement tasks, etc. (Chapter 3).

What now is mainly left to design and add to ÍSOR‘s geothermal database is a lithological part, which will probably be designed in the next few years, and also some parts for various series of processed data, like data regarding reservoirs characteristics. The design of, and changes in, a relational geothermal database will never be quite finalized since it is an ongoing process for as long as the database is "alive" and in use (Gunnarsdóttir, 2015).

2. SYSTEM AND SOFTWARE

2.1 System for Relational Database Management and Spatial Analysis

PostgreSQL is relational database management system (RDBMS) now used for managing ÍSOR's geothermal database and was taken into use 2017. Before that, Oracle system was used. The spatial database extender that comes with PostgreSQL is PostGIS. It allows spatial analysis and typical queries to be performed on spatial data with relative ease and allows data to be accessed much easier using third party software or other programs, including web server functionality (Altaweel, 2017). PostGIS has not yet been taken into full use at ÍSOR, but it is gradually being incorporated and the MS SQL Server is phasing out for hosting our spatial data.

2.2 SQL – Structured Query Language for Managing Data

As the Indiana University Knowledge Base says: "*SQL is an ANSI and ISO standard, and is the de facto standard database query language. .... It is widely used in both industry and academia, often for enormous, complex databases*." (Indiana University IT Services Knowledge Base, 2019). SQL query language is used for managing databases, for data input on a large scale, and for listing the various outputs. SQL statements are often embedded into host languages like C, C++, Java, Python, etc., to handle queries or calls to a database, since SQL has data manipulation facilities beyond the host languages.

2.3 User Interfaces – A Special Web Interface and a few Standard Tools

A specially designed web interface for interaction with the database has been developed at ÍSOR (Marteinsson et al, 2020) and most of the staff members use only the web interface for interacting with the database. The database administrator (DBA) and the programmer of ÍSOR's web interface use mainly the standardized database tools DataGrip and DBVisualizer for managing and interacting with the database, and so do a few of the staff members, the ones who are experienced in using SQL. These standard database tools have many built-in features, like import and export wizards, report and query builders. The various database queries results, outputs, queried in these tools can be exported therefrom by choice as text or XML files, HTML documents or Excel files.

3. MAIN DATABASE PARTS, TABLE GROUPS AND STANDARDIZATION OF MEASUREMENTS

ÍSOR‘s database is, as are relational databases in general, designed with groups of tables made of columns and rows and constraints and relationships defined in and between the tables. Special kind of information is held in one table while various other related data are held in separate tables, all of which are linked together by so called primary and foreign keys (Gunnarsdóttir, 2013a).

The table groups, called schemas by the database management system, are based on what the database designers and its users think belongs together. In ÍSOR‘s database the location dependent information is stored in one schema named LAND, all chemical data is in schema CHEM and most of the information regarding boreholes is in schema HOLE (would probably be called WELL in many places, but in ÍSOR‘S database well is a reserved word for a natural well). Table 1 shows a list of the schemas in ÍSOR‘s database with descriptions of what they include.

Table 1: Table schemas in ÍSOR's geothermal database.

SCHEMA	DESCRIPTION
LAND	Area and location information concerning the database data.
CHEM	Data regarding collected chemical liquid and gas samples – from wells, hot springs, boreholes, etc. – and their analyses.
HOLE (WELL)	Borehole information and all borehole measurements – that is other than chemical data from their liquid and gas samples.
GEOL	Geological data and measurements – that is other than from boreholes.
PHYS	Geophysical data and measurements – that is other than from boreholes.
ROCK	Data regarding rock samples, thin sections, etc.
CUTT	Data regarding borehole or well cuttings, that is how all well cuttings are kept in storage, be it on pallets, in shelfs, in boxes, so it is easy to see if they exist and where to find in storage, etc.
PROC	Processed data.
SENSOR	Data regarding measuring instruments, to log their use, placement, status, etc.
DEVICE	Data regarding other instruments than measuring instruments, like cars, cranes, sheaves, winches, etc.
ISOR	Data regarding ÍSOR's staff, clients, agents, project numbers, etc.
AUDIT	Tables for the database system to automatically log into about everything regarding inserts, updates and deletes of important tables in the database and when they happened. This is done by so called triggers that are designed on tables and then used autmatically by the database system. By having these tables it becomes easy to find out when failures have been made and do necessary corrections.

In the following sub chapters are descriptions of three of the schemas listed in Table 1, LAND, CHEM and HOLE (WELL), with some relational diagrams of their tables. The other schemas in Table 1 are not described further in this article.

3.1 LAND – Location Dependent Information

In ÍSOR‘s database the location dependent information regarding all the data from geothermal measurements and collected samples is stored in one schema named LAND. *Area* and *Location* are the main tables in LAND and they hold chief information about each and every area and location that has data attached to it in the database. The columns or fields in these tables are actually quite few, but it is of high importance that all data regarding area and location are as correct as possible and every data record should be at least double checked after being inserted into these tables (Gunnarsdóttir, 2013b). The tables for types of areas and locations include records with unique numbers and related items, like high temperature area, low temperature area, cold water area, preserved area etc., and borehole, rockopening, hotwaterspring or well, coldwaterspring, heatpump etc. Figure 1 shows a relational diagram of these tables and also two of the location table‘s main dependants in other database parts, *Borehole* in HOLE and *Sample* in CHEM. Some more main tables in other database parts relate to, or can be related to, the table *Location*, tables like *Hotspring*, *Fumarole*, *Mudpool*, *Rockopening*, *Rocksample*, *Lake*, *River*, *Swimmingpool*, *Coolingtower*, etc., depending on what is needed here and there in the various geothermal databases (Gunnarsdóttir et al, 2012a). Table 2 shows a list of the main tables in LAND and what data are stored in them.

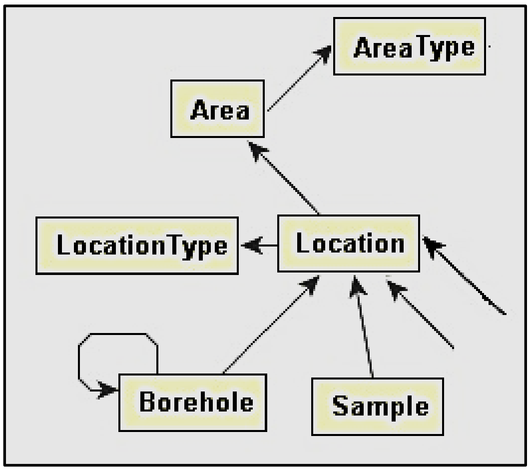

Figure 1. A relational diagram showing the two main tables in schema LAND and their types tables, along with two main tables in other database parts, Borehole and Sample etc. that are linked to the Location table.

Table 2: The tables in schema LAND and what information is stored in them.

TABLE	DESCRIPTION
Area	Table for holding a list of geothermal areas in Iceland, one record for each.
AreaType	Table for holding a list of all the area types.
Location	Table for storing a list of locations within the various geothermal areas as defined in the area table; that is the locations that will have any information about them in the geothermal database.
LocationType	Table for the location types having information about them in the geothermal database, like borehole, hot spring, etc., that is all the kinds of places where measurements are made at or samples are collected from.

3.2 CHEM – Data Regarding Chemical Liquid and Gas Samples and their Analyses

The chemical part of ÍSOR's database, named CHEM, stores data regarding collected chemical liquid and gas samples and their analyses. It is for storing all samples of geothermal fluids collected from any kind of a location, also the ones from boreholes, so boreholes have much chemical data related to them in this chemical part of the database. In addition to these geothermal samples there is also a small amount of chemical data regarding cold water samples in the database, like from cold water springs, rivers, lakes, etc. The main table in CHEM is *Sample* which stores information on water and gas samples collected from geothermal sites and elsewhere, from boreholes, hot springs and some other types of locations. The table *Analysis* is for data resulting from analyses of the chemical samples and *Analysis* depends on *Sample.* This structure of the chemical tables is shown in Figure 2, which shows a relational diagram of the chemical tables group. This structure is based on the fact, that one sample could be divided up and thus be analyzed more than once, with different working procedures and even at different laboratories. The other tables in here are so called peripheral tables and data inserted into *Analysis* get various information from those tables regarding how the analysis was performed and how the sample was preserved or treated, i.e. *Precipitation*, *Method*, *Filtration*, *Dilution*, *Component, Acidification and Laboratory*. The *Component* table stores a list of chemical components analyzed. Table 3 shows a list of the main tables in CHEM and what data are stored in them (Gunnarsdóttir et al, 2012a).

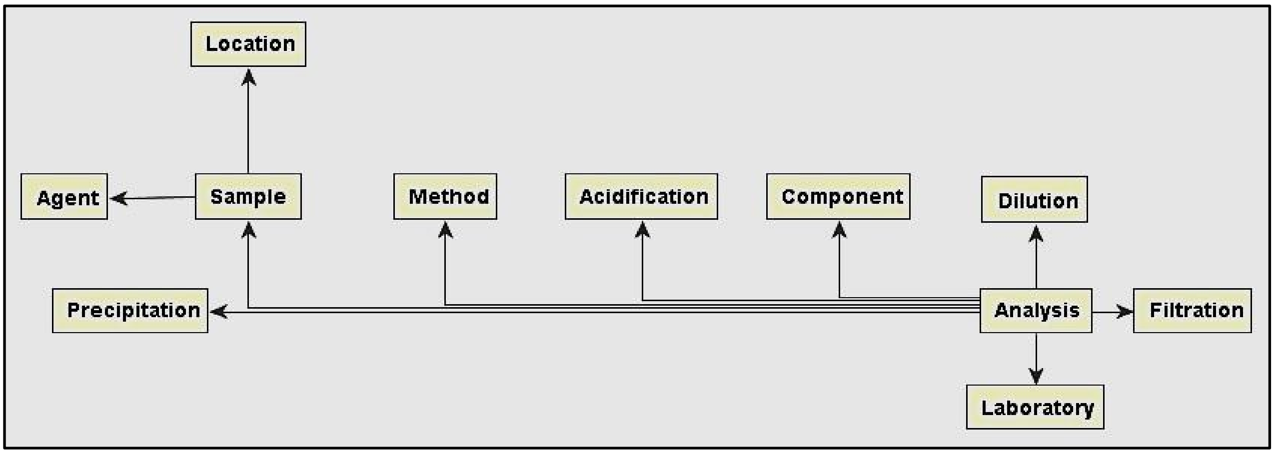

Figure 2: A relational diagram showing database tables for collected chemical liquid and gas samples and their analyses.

Table 3: The tables in schema CHEM and what information is stored in them.

TABLE	DESCRIPTION
Sample	Table for storing the main information on samples collected from geothermal sites or boreholes.
Analysis	Table for data resulting from analyses of chemical samples collected from geothermal sites or boreholes.
Component	Table for storing a list of chemical components analyzed, their names and abbreviations or formulas and units of measure.
Laboratory	Table for holding a list of laboratories which are available for analyses, including field laboratory used for analyzing samples in the field or on site.
Method	Table for holding a list of analytical methods.
Acidification	Table for holding a simple list of acidification options in water sampling.
Dilution	Table for holding a simple list of dilution options in water sampling.
Filtration	Table for holding a simple list of filtration options in water sampling.
Precipitation	Table for holding a list of precipitations options in water sampling.
Agent	Table for holding a list of institutions, organizations or companies, persons or employees in charge of what is recorded in many of the tables in the database.

3.3 HOLE (WELL) – Data Regarding Boreholes and Measurements in them

The borehole part of ÍSOR's database, named HOLE (WELL), stores the various borehole information and logs, that is without the chemical data from boreholes which are stored among other chemical information in the chemical part CHEM. The main table in the borehole table group is *Borehole*. Other tables here are linked to *Borehole*, such as tables storing various information of boreholes. These are mainly *History* with the main information of a lifespan of boreholes, *OfPathDownhole* which along with two tables attached to it stores information of measured and calculated paths of directionally drilled boreholes, *Drilling* and *Casing* storing information of the main aspects of drilling and casing work of boreholes, *TaskGroup* for information regarding every group of tasks performed in one trip to a borehole site (one trip now defines a task group, but that might soon be divided further up), *Task* for information about performed measurements in the boreholes, and finally *Data* (in fact some few tables) for storing all the values and depth or time, or both, of the borehole measurements (Gunnarsdóttir et al, 2012a). Figures 3 to 6 show relational sub diagrams of some of the groups of the borehole tables, and Table 4 shows a list of many of the borehole tables, along with description of their ingredients.

Note that if a borehole is "forked out" as a branch from another borehole, the one that is forked out must have the id-number (primary key) of its "parent" in a special column in the borehole table for parent-id, and also the depth, where it takes off from the parent borehole (common depth), into a special column for that. *Borehole* has thus a foreign key pointing to its own primary key, and that is shown in the following table diagrams with a line with an arrow pointing to the table itself (Gunnarsdóttir et al, 2012a).

Some more tables regarding boreholes are being designed and will be added to ÍSOR's database as needed. These include tables for lithological information, some additional tables for data regarding cuttings and thin sections, tables for information on measurement methods for use in boreholes, etc. (Gunnarsdóttir, 2013b).

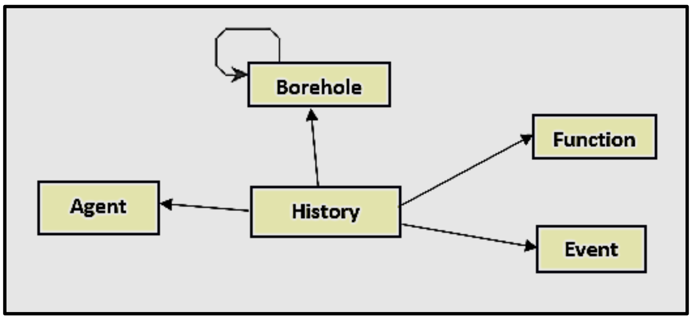

Figure 3. A relational diagram showing the tables playing a role regarding history of boreholes.

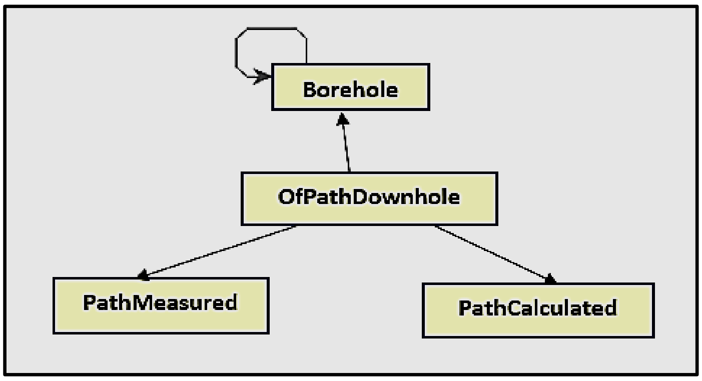

Figure 4. A relational diagram showing tables regarding paths of directionally drilled boreholes.

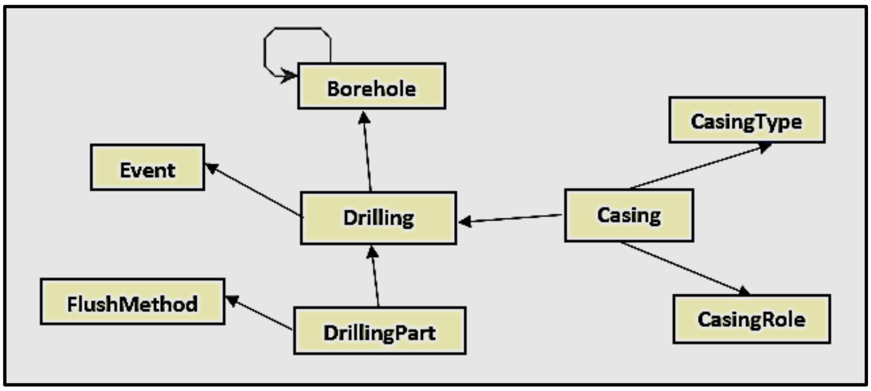

Figure 5. A relational diagram showing tables regarding drilling and casing of boreholes, and the table Event with the main information of a lifespan of boreholes (i.e. drillrig up, …, maintenance, closure, etc.).

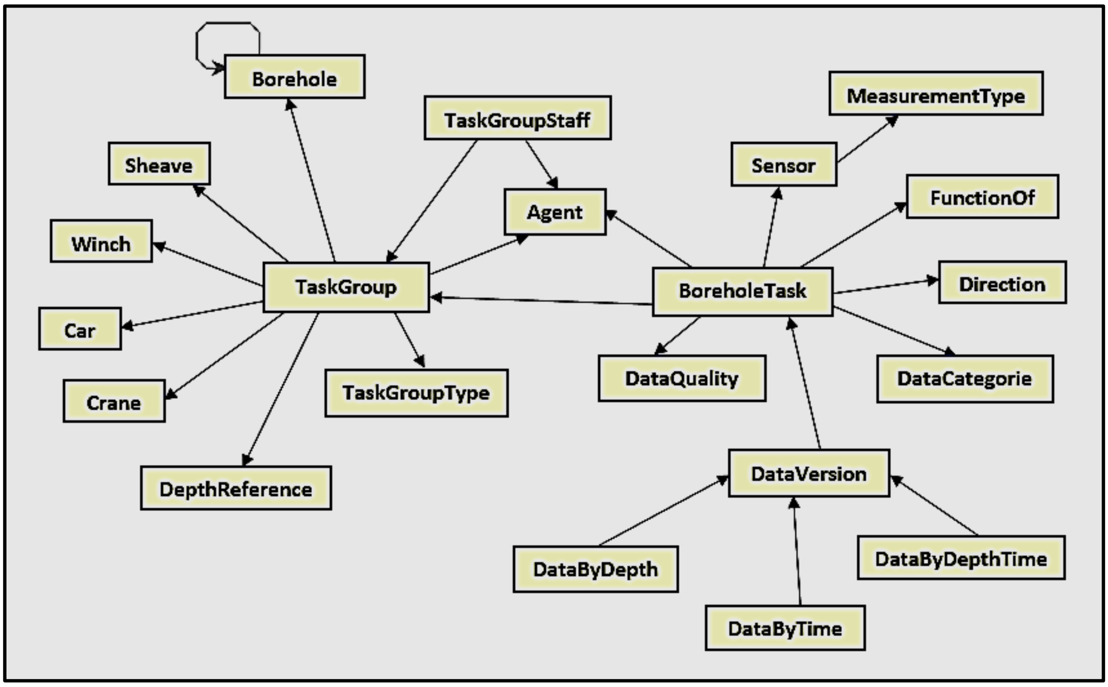

Figure 6. A relational diagram showing many of the tables involved in measurements tasks performed in boreholes.

Table 4: Some of the tables in schema HOLE and what information they store.

TABLE	DESCRIPTION
Borehole	Table for storing the main information on the various boreholes (drilled wells), their locationID, current depth, if directionally drilled or not, and if they are combined in a fork or not.
Casing	Table for storing data regarding the main aspects of the casing work in boreholes.
CasingRole	Table for holding a list of possible casing roles regarding borehole casings.
CasingType	Table for holding a list of the various casing types used inside boreholes.
Condition	Table for storing the main information on the condition of boreholes, data that are regularly obtained with some estimates and quite simple measurements that are maybe not intended to be inserted into the *Task* and *Data* tables.
Data	Table for storing data from the various measurements in boreholes, both one shot measurements and series of downhole measurements. Here represented as one table, but in fact we have these data in 3 to 4 tables.
Drilling	Table for storing information on merely the main aspects of the drilling of the various boreholes.
DrillingPart	Table for storing information on parts of the borehole drilling work that are a bit more detailed than the parts in the *Drilling* table.
FlushMethod	Table for holding a list of possible flushing methods in the various parts of the drilling work.
Event	Table for holding a list of possible events that can be ongoing in projects in a borehole, like the various steps of drilling, utilization, changes (e.g. changing of direction, depth, function, agent, etc.), closure, and more.
Function	Table for holding a list of objectives or functions of boreholes, like production, injection, etc.
History	Table for holding a list of main aspects of the lifespan of boreholes, like when drilling and the various drilling stages started, the start and end of production, when a borehole is on hold, etc., and when it is finally shut down or filled up.
PathMeasured	Table for storing directional (gyro) data for directional boreholes.
PathCalculated	Table for storing data regarding calculated paths of directionally drilled boreholes.
TaskGroup	Table for storing main information on every measurement task group that takes place in a borehole.

TaskGroupType	Table for holding a simple list of types of measurement task groups.
Task	Table for storing the main information on every measurement or measurement series that take place in a borehole.
TaskType	Table for holding a simple list of types of measurements, which can take place in boreholes, like temperature, pressure, etc., and their descriptions.
Agent	Table for holding a list of institutions, organizations or companies, persons or employees in charge of what is recorded in many of the tables in the database.
Unit	Table for holding and maintaining a list of all the units of the various measurements data in the database, their abbreviations and descriptions.

3.4 Standardization of Measurements and Data Checks

How various values are inserted into columns in database tables must be standardized from the beginning of using a database, that is which units to use, like coordinates columns, the *x* and *y*, must always be filled in the database according to the standard that has been decided on using, values in columns representing depths regarding boreholes and collected samples, whether they shall be in meters or another unit and with how many decimal digits, similar goes for columns for temperature, pressure, and more. In ÍSOR's database this was standardized from early on, see part of that information in Table 5. Regarding insertion of values into some table columns there are various built-in features in the database which are used to check up on insertion whether values are obviously wrong and prevent their insertion. The database administrator does this by creating table constraints which raise alarm and hinder insertion of, like depth values over 5000 metres, temperature values lower than minus few °C or higher than 500 °C, etc. In addition to many built-in checks there are various database reports run regularly by the database administrator to cross examine many things regarding the data, like if measurements from a borehole are logged at more depth than the boreholes depth itself, etc. The users of the database also show caution when entering data into the database or retrieving data from it, and they check and compare various things regularly in their data handling. To do so they mainly use the specially designed web interface VINNSLA for interaction with the database (Chapter 2.3) where they can view figures and diagrams, make comparisons, qualify measurements data into categories, like no data, good data, bad or ruined data, and enter the quality category into the borehole task table.

Table 5: Standardized units in ÍSOR's database.

Columns in tables for ...	Standard unit decided on	Remark
coordinates (X and Y)	EPSG:3057	
altitude (Z)	metres	Should always be filled with accuracy up to two digits.
depth	metres	Depth columns in the database tables, for depths regarding boreholes and samples, should always be filled in this database in metres with accuracy up to two decimal digits. Columns for depths are currently found in over ten of the database tables.
elevationReference	default is 'Earth's surface'	Is for text regarding benchmark, i. e. if it is 'Earth's surface' or the height of the platform of the drill rig being used, f. ex. 'Platform of drillrig XX'. etc. If it is not filled in by the user, the system puts in the default value 'Earth's surface'. It is important, regarding the benchmark, to know the height of it in relation to some known reference, for example the documented height above sea level of the borehole (as part of the coordinates of the borehole).
elevationAbsolute	metres	
pressure	bar-g	Pressure columns are defined with two decimal digits and must be filled in this database as bar-g. Same goes for pressure values that are inserted into the column *value* in the *BoreholeData* table, they are filled in as bar-g.
wellheadPressure	bar-g	WellheadPressure columns are defined with two decimal digits and must be filled in as bar-g.
temperature	°C	Temperature columns are defined with one decimal digit and must be filled in as °C. They are found in the tables *Analysis* (to enter the temperature of the 'components' pH and con-ductivity) and *Sample* (for temperature of the sample). Same goes for temperature values inserted into the column *value* in the *Analysis* table, they are filled in as °C.
enthalpy	kJ/kg	Enthalpy values inserted into a column *value*, should be filled in as kJ/kg. Enthalpy columns are defined as whole numbers and are filled in this database as kJ/kg. Same goes for enthalpy values that are entered in to the column *value* in the *BoreholeData* table, they are filled in as kJ/kg.
discharge	kg/s	Discharge (flowrate) columns are defined with no more than two decimal digits and must be filled in this database as kg/s. Same goes for discharge values that are inserted in to the column *value* in *BoreholeData* table, they are filled in as kg/s.
drawdown	bar-g	Drawdown columns are defined with no more than one decimal digit, and must be filled in the database as bar-g. Same goes for drawdown values that are entered in to the column *value* in the *BoreholeData* table, they are filled in as bar-g.
chemical concentration	µg/L	
chemical concentration	mg/L	
chemical concentration	mg/kg	
chemical concentration	%-vol	
chemical concentration	‰-smow	
chemical concentration	Bq/L	
…	…	…

When a geothermal database includes information on forked boreholes (boreholes with two or more legs) and data regarding them is inserted or retrieved from the database, the users must show caution, since much of that data represent a whole fork, but some of the data represent one of its legs only. Information representing only a specific leg of a forked borehole are data on each leg's path (coordinates downhole), cuttings, lithology, temperature and pressure logs. Information regarding the whole fork, that is the production data and/or chemical data, must only be linked to the *boreholeID* of the parent fork, since it cannot be known from which part of the fork the produced water, gas, steam or condensate comes (Gunnarsdóttir et al, 2012a).

4. EXAMPLES OF DATABASE REPORTS

In a relational database various so-called database reports, or data outputs, regarding its data can be selected from it with ease, be it on a regular basis or whenever needed, by making calls to the database with commands programmed in SQL. In this chapter a few outputs from ÍSOR's database chemical part and borehole part are presented. The database reports presented here are just a small example of all our database reports. Some of the reports are based on a big part of the database data, like all the database boreholes, while others are based on a small subset, like one or a few boreholes, some chosen geothermal areas, selected types of locations, or chosen time intervals, etc. Please note that some of the data listed in the following database reports are real data but some are fictional.

4.1 Reports from the Database Chemical Part – CHEM

The reports from the chemical part of ÍSOR's database that are listed in Tables 6 to 13, either present information of one borehole sample's analyses, some information regarding all the chemical data or some chosen parts of that data.

A database report regarding how analyses are distributed within location types is shown in Table 6. This report is based on the whole data set in CHEM and it shows, among other things, how many samples and locations are behind the analyses counts. It also shows that there are over 300 thousand analyses in ÍSOR's database, that around 30 thousand samples have been analyzed and the samples the analyses are based on were collected in some 3 thousand locations. The data thus indicates that there are on average 10 analyses per sample, but some few boreholes have thousands of analyses based on hundreds of samples collected from them, whereas most have only a few analyses, or even just one. The report also shows that well over half of all the analyses is based on samples that are collected from boreholes, that is from around 1270 boreholes.

Table 6: Analyses counts of how many samples collected from how many locations.

type of location of collected sample	count_of_analyses	% of analyses per location type	cnt_of_samples_ analyzed	count_of_locations_ of_samples
Borehole	173589	56%	17137	1268
Place of collection not known (very old samples)	44174	14%	4439	3
Some building structure, powerplant, etc.	34232	11%	4014	402
Hot spring, fumarole or natural well	20887	7%	1327	637
Cold water spring	19148	6%	1939	441
Waterlevelmeter	16611	5%	1547	311
A certain company (exact location not known)	2419	1%	278	13

Database reports are often made to look at top counts of various things in the database. Like in Table 7 there is a list of the top five counts of analyses based on samples collected from boreholes, and Table 8 lists a similar output for samples collected from hot springs or natural wells.

Table 7: Top five counts of samples analyses from boreholes.

Borehole name	cnt_of_analyses_ in_borehole	cnt_of_samples_ analyzed
QQ-07	2774	115
QQ-08	2357	217
CC-04	2108	560
CC-07	2039	106
OO-08	2023	106

Table 8: Top five counts of samples analyses from hot springs and natural wells.

Hot spring name	Cnt_of_analyses in hot spring	cnt_of_samples_ analyzed
Grjótagjá karlagjá	1666	102
Langivogur lind	1058	58
Stóragjá aðalop	819	44
Hrunalaug	664	29
Bjarg lind	498	39

A database report listing top ten analyses counts of samples collected in all boreholes in ÍSOR's database is shown in Table 9. Table 10 lists the same, but just from boreholes situated in high-temperature geothermal areas.

Table 9: Top 10 counts of components analyses on all the database samples collected in all the database boreholes.

formula	name	analyses counts of samples in water phase	samples from how many boreholes
Cl	Chloride	9035	1070
SiO2	Silica	8669	1051
SO4	Sulphate	7983	1042
Mg	Magnesium	7246	967
K	Potassium	6730	946
Na	Sodium	6547	943
Ca	Calcium	6543	968
	Conductivity	6393	936
F	Fluoride	6215	990
pH	pH	5633	1013

Table 10: Top 10 counts of components analyses on samples collected from boreholes in high-temperature geothermal areas. The top 3 are artificial tracers.

formula	name	analyses counts of samples in water phase	samples from how many boreholes
2,7-NDS	2,7-naphthalene disulphonate	4270	140
2,6-NDS	2,6-naphthalene disulphonate	3512	156
2-NS	2-naphthalene sulphonate	3107	134
SiO2	Silica	2535	141
Ca	Calcium	2491	139
Na	Sodium	2488	136
K	Potassium	2485	137
Mg	Magnesium	2463	139
SO4	Sulphate	2119	135
pH	pH	2069	144

Most of all collected samples for chemical analyses are in liquid phase. Table 11 lists counts of analyses of samples in the different phases, samples that were collected from boreholes, hot springs, cold water springs and building structures or powerplants, along with concerned sample counts and location counts from where they were collected. The report shows among other things that vast majority of samples are collected from boreholes and that 80% up to 95% or more of all the samples are in water phase.

Table 11: Analyses counts of samples in the various phases, collected from boreholes, hot springs, cold water springs, and building structures or powerplants, along with how many samples and locations are behind the analyses.

type of location of collected sample	phase	cnt_of_ analyses	% of analyses in location type	cnt_of_ samples	cnt_of_ locations
Borhole	Water	148823	86%	16147	1264
Borhole	Gas	12093	7%	2518	230
Borhole	Condensate	8830	5%	1915	152
Borhole	Steam	3843	2%	1887	140
Hot spring, fumarole or natural well	Water	16809	80%	1114	541
Hot spring, fumarole or natural well	Gas	2034	10%	382	223
Hot spring, fumarole or natural well	Condensate	1261	6%	325	186
Hot spring, fumarole or natural well	Steam	783	4%	363	205
Cold water spring	Water	18687	98%	1937	441
Cold water spring	Gas	34	0%	9	8
…	…	…		…	…

Table 12 and 13 list all analyses of a sample collected from a borehole, and from a hot spring, respectively, both situated in north Iceland, showing either their measured values or detection limits, along with values of mass and ion balance.

Table 12: All analyses of one sample collected from the borehole LUD-06 in north Iceland.

Borehole location	B-58506	LUD-06	
Date of sample	2018-08-30		
Sample	20180222		
Pressure [bar-g]	-		
Temperature of sample [°C]	32.8		
Water	Value	Water	Value
pH	8.06	Al [ppm]	0.0066
pH temperature [°C]	21.7	As [ppm]	0.000055
Conductivity [µS/cm]	355	Ba [ppm]	0.00337
Conductivity temperature [°C]	25	Cd [ppm]	<2e-06
CO_2 [ppm]	107	Co [ppm]	<5e-06
H_2S [ppm]	<0.03	Cr [ppm]	0.00014
O_2 [ppm]	-	Cu [ppm]	0.000143
NH_3 [ppm]	-	Fe [ppm]	0.0101
B [ppm]	0.11	Hg [ppm]	<2e-06
SiO_2 [ppm]	62.2	Li [ppm]	0.00586
Na [ppm]	50	Mn [ppm]	0.000722
K [ppm]	5.6	Mo [ppm]	0.000708
Mg [ppm]	7.69	Ni [ppm]	0.000051
Ca [ppm]	18.3	Pb [ppm]	<1e-05
F [ppm]	0.23	Sr [ppm]	0.0504
Cl [ppm]	5.12	V [ppm]	0.0115
Br [ppm]	0.01	Zn [ppm]	0.000228
SO_4 [ppm]	58.4	TDS [ppm]	255
		Ionbalance [%]	2.28
		Massbalance [%]	-18.32
		δD [‰]	-92.2
		$\delta^{18}O$ [‰]	-12.29

Table 13: All analyses of one sample collected from the hot spring Helgavogur in north Iceland.

Hot spring location	H-10082	Helgavogur lind	
Date of sample	30.8.2018		
Sample	20180223		
Pressure [bar-g]	-		
Temperature of sample [°C]	23.8		
Water	Value	Water	Value
pH	8.4	Al [ppm]	0.0141
pH temperature [°C]	22.4	As [ppm]	0.000166
Conductivity [µS/cm]	368	Ba [ppm]	0.00144
Conductivity temperature [°C]	25	Cd [ppm]	<2e-06
CO_2 [ppm]	94	Co [ppm]	<5e-06
H_2S [ppm]	<0.03	Cr [ppm]	0.000551
O_2 [ppm]	-	Cu [ppm]	0.000653
NH_3 [ppm]	-	Fe [ppm]	0.00318
B [ppm]	0.1	Hg [ppm]	<2e-06
SiO_2 [ppm]	72.9	Li [ppm]	0.00861
Na [ppm]	51.6	Mn [ppm]	0.000058
K [ppm]	4.58	Mo [ppm]	0.000849
Mg [ppm]	5.23	Ni [ppm]	0.000055
Ca [ppm]	23.2	Pb [ppm]	<1e-05
F [ppm]	0.234	Sr [ppm]	0.0329
Cl [ppm]	7.49	V [ppm]	0.0283
Br [ppm]	0.015	Zn [ppm]	0.000453
SO_4 [ppm]	65	TDS [ppm]	266
		Ionbalance [%]	4.9
		Massbalance [%]	-13.05
		δD [‰]	-88.7
		$\delta^{18}O$ [‰]	-12.24

4.2 Reports from the database borehole part – HOLE

The reports from the borehole part of ÍSOR's database that are listed in Tables 14 to 20 either show information related to all the boreholes in the database or information regarding chosen boreholes, some geothermal areas, or some other chosen variables. A database report of maximum temperature measurements values above 300 °C, in some chosen boreholes in a few high-temperature geothermal areas in north Iceland, and at what depth or depths these values occur, is shown in Table 14. The DBA lists a database output like this in just seconds, with some SQL commands to the database making a few temporary tables created on the fly to speed up the query time. The output, exported over to an excel file, shows that the maximum temperature value occurs only at one depth in most of these boreholes, at some few depths in some of them, and at a depth interval of 54 metres in one of them, ÞG-17.

Table 14: List of maximum temperature values over 300 °C measured in some chosen boreholes situated in a few high temperature geothermal areas in north Iceland along with the concerned depths.

borehole name	depth of measure log [m]	maximum value [°C]	borehole name	depth of measure log [m]	maximum value [°C]	borehole name	depth of measure log [m]	maximum value [°C]
IDDP-01	2041	346.42	K-35	1749.97	335.75	ÞG-17	1878	303.5
K-04	1400	310.8	K-36	2429	332.15	ÞG-17	1880	303.5
K-05	1280	311	K-38	2663	330.18	ÞG-17	1882	303.5
K-06	1800	344	K-39	2822	385.58	ÞG-17	1884	303.5
K-06	1900	344	B-10	1809	310	ÞG-17	1886	303.5
K-07	1900	343.3	B-11	1450	319.9	ÞG-17	1888	303.5
K-07	2000	343.3	B-12	1975	309.9	ÞG-17	1890	303.5
K-07	2100	343.3	B-13	2128.9	333.95	ÞG-17	1892	303.5
K-08	1634	306	BJ-14	2377.89	333.77	ÞG-17	1894	303.5
K-09	10	309	BJ-15	1694	329.90	ÞG-17	1896	303.5
K-10	1564	310	KS-01	2465.5	338.59	ÞG-17	1898	303.5
K-11	2100	301.3	ÞG-01	1933.23	331.6	ÞG-17	1900	303.5
K-13	1750	327.3	ÞG-03	2633.5	380.07	ÞG-17	1902	303.5
K-14	2020	323.5	ÞG-04	2122	327.9	ÞG-17	1904	303.5
K-15	2070	342.4	ÞG-04	2123	327.9	ÞG-17	1906	303.5
K-20	1730	300.9	ÞG-06	2780	310.56	ÞG-17	1908	303.5
K-24	1384	305.1	ÞG-09	2162.5	338.5	ÞG-17	1910	303.5
K-25	2079	331.6	ÞG-11	1992.09	319.18	…	…	…
K-26	1984	348.3	ÞG-11	1992.58	319.18	ÞG-17	1920	303.5
K-27	1743	336.3	ÞG-11	1993.07	319.18	ÞG-17	1922	303.5
K-29	2063	351.3	ÞG-11	1993.56	319.18	ÞG-17	1924	303.5
K-30	1500	307.5	ÞG-12	2692.5	306.23	ÞG-17	1920	303.5
K-32	1600	315.2	ÞG-12	2692.19	306.23	ÞG-18	2613	321.15
K-34	1800	307.7	ÞG-16	2690	300.9	ÞG-05B	2469.5	342.32

One typical database report of borehole measurement tasks is shown in Table 15, where there are listed borehole tasks for a chosen time interval in a project that took place in a high-temperature geothermal borehole. The list shows task type, when a task started, instrument and sensor used, starting and ending depth of measurement, if measured up or down or steady at a certain depth, etc.

Table 15: Example of borehole tasks that took place in one borehole for a chosen time interval.

Project number: xx-xxxx	Listed 10.1.2019 from database											
Job started	**Bore hole name**	**Bore hole nu**	**Type of measurement**	**Down Up Steady**	**Task number**	**Name of sensor**	**Instru ment**	**Car**	**Measured depth [m]**	**Length [m]**	**Sum of length [m]**
2017-07-05 23:37	XX-99	99999	Temperature	Down	130963	TG-T5	TG-T5	RR-589 Scania	10 - 2312	2302	
2017-07-05 23:37	XX-99	99999	CCL	Down	130964	TG-M4	TG-M4	RR-589 Scania	10 - 2312	2302	
2017-07-06 00:46	XX-99	99999	Temperature	Down	130965	TG-T5	TG-T5	RR-589 Scania	2312 - 2950	638	
2017-07-06 00:46	XX-99	99999	CCL	Down	130966	TG-M4	TG-M4	RR-589 Scania	2312 - 2949	636	
2017-07-06 01:11	XX-99	99999	Temperature	Up	130967	TG-T5	TG-T5	RR-589 Scania	18 - 2950	2932	
2017-07-06 01:11	XX-99	99999	CCL	Up	130968	TG-M4	TG-M4	RR-589 Scania	18 - 2949	2931	
2017-07-06 04:01	XX-99	99999	Width	Up	131015	CP-C3	CP-C3	RR-589 Scania	2295 - 2319	24	
2017-07-06 04:21	XX-99	99999	Width	Up	131016	CP-C3	CP-C3	RR-589 Scania	90 - 2450	2360	14125
2018-02-15 12:31	XX-99	99999	Temperature	Down	134311	G7019-hiti	G7019	HN-P20 Scania	-4 - 2300	2296	
2018-02-15 12:31	XX-99	99999	Pressure	Down	134312	G7019-þrýst.	G7019	HN-P20 Scania	-4 - 2300	2296	4592
2018-09-10 11:59	XX-99	99999	Temperature	Down	135378	G7019-hiti	G7019	HN-P20 Scania	0 - 2300	2300	
2018-09-10 11:59	XX-99	99999	Pressure	Down	135379	G7019-þrýst.	G7019	HN-P20 Scania	0 - 2300	2300	
2018-09-10 13:18	XX-99	99999	Temperature	Steady	135382	G7019-hiti	G7019	HN-P20 Scania	2000 - 2000	0	
2018-09-10 13:18	XX-99	99999	Pressure	Steady	135383	G7019-þrýst.	G7019	HN-P20 Scania	2000 - 2000	0	
2018-09-10 17:35	XX-99	99999	Temperature	Up	135380	G7019-hiti	G7019	HN-P20 Scania	0 - 2000	2000	
2018-09-10 17:35	XX-99	99999	Pressure	Up	135386	G7019-þrýst.	G7019	HN-P20 Scania	0 - 2000	2000	8600
										Total:	**27.3 km**

Many of DBA reports from the database are made to follow up and compare counts of various measurements, like counts per types of borehole tasks etc., in either all the boreholes having data belonging to them in the database or in some chosen boreholes, like the ones situated in high-temperature geothermal areas. Table 16 shows a database report listing counts of the various types of measurement tasks that have taken place in all the database boreholes. The output list in there shows that around 90% of the measurement tasks are regarding temperature and pressure, that is 70% temperature and 20% pressure measurements. Table 17 shows a similar report, but just listing this information from boreholes situated in high temperature geothermal areas, and there the ratio of temperature and pressure measurements is a bit different from what Table 16 shows, here there is around 80% measurement tasks regarding temperature and pressure, 54% temperature and 26% pressure measurements of the whole.

Table 16: Counts of the various measurement types in all the boreholes having data belonging to them in the database, along with in how many boreholes the concerned measurements tasks took place.

count of measure ment tasks	%	type of measurement	in how many boreholes
25963	70%	Temperature (°C)	4680
7059	19%	Pressure (Bar-g)	572
1096	3%	Inclination (° from vertical)	133
1048	3%	Azimuth (° clockwise)	122
376	1%	Flow (rpm)	30
238	1%	Conductivity	63
214	1%	Televiewer	76
164		XY-Caliper Y part (mm)	94
162		XY-Caliper X part (mm)	91
133		Cement Bond Log	18
116		Calibration	26
116		Resistivity	22
107		Natural Gamma (API)	29
83		3-Arm Caliper Log (mm)	62
68		Spontaneous Potential	23
60		Neutron-Neutron (API)	22
…		…	…

Table 17: Counts of the various measurement types in boreholes situated in just the high-temperature geothermal areas, with counts of in how many boreholes the measurements tasks took place.

count of measure ment tasks	%	type of measurement	in how many boreholes
9210	54%	Temperature (°C)	367
4490	26%	Pressure (Bar-g)	253
1039	6%	Inclination (° from vertical)	107
1010	6%	Azimuth (° clockwise)	106
364	2%	Flow (rpm)	27
133	1%	Cement Bond Log	18
126	1%	XY-Caliper Y part (mm)	66
124	1%	XY-Caliper X part (mm)	63
105	1%	Calibration	21
104	1%	Televiewer	31
94	1%	Resistivity	17
78		Natural Gamma (API)	19
59		Spontaneous Potential	18
47		3-Arm Caliper Log (mm)	29
44		Neutron-Neutron (API)	17
…		…	…

Table 18 shows a database report of some chosen boreholes that are steam production wells deeper than 2100 metres, situated in high-temperature geothermal areas in north Iceland.

Table 18: List of boreholes in high-temperature geothermal areas in north Iceland which are deeper than 2100 metres – listed in descending order of depth within each geothermal area.

high temperature geothermal area	borehole name	depth [m]
Þeistareykir	ÞG-06	2798.9
Þeistareykir	ÞG-12	2710
Þeistareykir	ÞG-16	2702
Þeistareykir	ÞG-03	2659
Þeistareykir	ÞG-18	2644
Þeistareykir	ÞG-07	2508
Þeistareykir	ÞG-13	2505
Þeistareykir	ÞG-08	2503
Þeistareykir	ÞG-17	2500
Þeistareykir	ÞG-14	2500
Þeistareykir	ÞG-05B	2499
Þeistareykir	ÞG-15	2260
Þeistareykir	ÞG-04	2239.5
Þeistareykir	ÞG-11	2212
Þeistareykir	ÞG-09	2194.3

high temperature geothermal area	borehole name	depth [m]
Krafla	KV-01	2894
Krafla	K-39	2865
Krafla	K-38	2700
Krafla	K-35	2508
Krafla	KS-01	2502
Krafla	K-36	2501
Krafla	K-12	2222
Krafla	K-11	2217
Krafla	K-37	2194
Krafla	K-07	2165
Krafla	K-26	2127
Krafla	IDDP-01	2104
Krafla	K-29	2103

high temperature geothermal area	borehole name	depth [m]
Vítismór	K-25	2105
Suðurhlíðar	K-18	2215
Suðurhlíðar	K-16A	2191
Suðurhlíðar	K-17	2190
Suðurhlíðar	K-19	2150
Suðurhlíðar	K-14	2107
Námafjall	BJ-15	2690.4
Námafjall	BJ-14	2506
Námafjall	B-13	2155
Hágöngur	HG-01	2360

Table 19: An example of counts of how often staff members worked at borehole task groups in the year 2018.

Staff member	count of borehole measurements jobs (borehole task groups)
Jón Jónsson	96
Jóna Jónsdóttir	85
Gunnar Gunnarsson	85
Guðrún Guðmundsdóttir	52
…	…

Table 20: An example of counts of borehole measurement tasks from the years 2000 to 2018.

year	count of borehole measurements tasks
2000	1187
2001	1213
2002	934
2003	1112
2004	1013
2005	1160
2006	1485
2007	2176
2008	3099
2009	1646

year	count of borehole measurements tasks
2010	800
2011	887
2012	611
2013	650
2014	551
2015	674
2016	1151
2017	1442
2018	1465

Many database reports are made to list various things regarding borehole tasks, how many tasks there are for a chosen time interval and which members of staff are working at the tasks. Table 19 lists top counts of a database report of staff members working at borehole logging task groups in the year 2018. Table 20 lists a database output of measurement tasks counts in boreholes for chosen years, from 2000 to 2018.

5. DATABASE TABLE VIEWS FOR CONVENIENCE AND CALCULATIONS

A view of a database table or tables is a result set of a query, or a few combined queries, to a relational database. It is made with a pre-established query command, programmed in SQL, that is kept in the database dictionary. Unlike ordinary tables in a relational database, a view is not a part of the physical schema but is usually a virtual table computed dynamically from data in the database when that view is requested. Virtual tables, views, take up very little storage space since the database contains only their definition but not a copy of all the data the views represent. Views can provide advantages over tables, they can represent a subset of the data contained in a table, they can limit the degree of exposure of the underlying tables to the users, they can join and simplify multiple tables into a single virtual table, and they can also hide complexity of data and provide extra security. (Wikipedia, 2018).

Table views made by the database administrator (DBA) make it possible to represent complicated tables in more convenient ways for the users. Changes applied to the data in a relevant table underlying a view are reflected in the data shown when users list from the view. The database users can select data from a view which they have been given access to just as they can select data from a database table. In the SQL syntax of views database tables can be joined, temporary tables made "on the fly", etc. Calculations can be made since the SQL query language has data manipulation facilities beyond many other computer languages, and makes use of the many in-built functions of the relational system, like sum, average, max, min, count, power, etc. (Gunnarsdóttir et al., 2012a).

In ÍSOR's relational database DBA has created many table views so the database users can view the geothermal data from many points of view. There are views for listing, checking and reviewing the data, and views for security purposes when some data is not for everyone to look up. Table views show data in various output forms and are often made for calculations of values or group of values. Table views can be used to speed up query time and they make it more convenient for the database users to extract data. Views regarding locations of boreholes, history, drilling and casing of boreholes have been made, regarding collected liquid and gas samples and their analysis, calculated ion and mass balances based on selected components analyses, and more.

Sometimes when database tables have a huge amount of records in them, it becomes necessary to make table views in order to speed up query time by selecting only some part of the records according to some chosen criteria. The database table for calculated coordinates and measured depths of the path down hole, hole.path_calculated, is currently the largest table in ÍSOR's database, that is it has the highest record count of all the tables, over 46 million records. To select data from such a table can be time consuming ("heavy"), and what the users in fact most often need is to select records from this table for maybe every 100, every 30 or every 10 metres interval down hole, for boreholes situated in a chosen geothermal area. The DBA has therefore made a few table views that select from this table, wherein a chosen area and a depth interval are selected. A mathematical function in the Postgres database system has a modulo operation, which finds the remainder after division of one number by another, called MOD, is used for selecting only measured_depth every 100 metres, 30 metres, etc.

By making use of temporary tables that can be created in the database system when a SQL command is run and exists only on the run, it is possible to both speed up query time and to save programming time of the SQL queries. If a selected and rather small dataset from a huge or a big table, which the query is run against, is put into a temporary table "on the fly" in the SQL command, it can be so much quicker to select from just that little dataset than from the whole table.

6. CONCLUSIONS

There are many benefits of having the data from geothermal exploration and production monitoring in a database that is well designed and running in a modern relational database system. By doing so we can ensure the consistency of our data, avoid data duplication, minimize human errors and maximize data security. It will thus ensure safe, systematic and centralized storage of the data gathered in the geothermal work, as well as better access for all the users of the data.

As soon as data have been gathered, users will be more aware of the data contents. They will be more capable of detecting which data are incorrect and need to be corrected or even discarded, and which data are qualified for experts to base their decisions on. Reviewed and reliable data can be retrieved quickly with ease and compared on a large or a small scale, from time to time, from within and between areas and reservoirs, within or between individual boreholes and other locations of measurements or sampling.

Having various database reports run on a regular basis and whenever needed, will make the data well observable from many points of view. Special database reports can be designed by database administrators according to what the users need to detect. Like if some "strange" data have been entered in the database, if there are suspiciously high or low values, if there are values that are anomalous for a chosen location or area or if changes in borehole measurements or sample analyses are observed. Reports which give counts of various measurements or borehole tasks often give good overviews and can give hints if corrective measurements need to be taken.

The experience at ÍSOR is that the design of, and the changes in, our database will never be quite finalized, since it is an ongoing process for as long as the database is "alive" and in use. After reviewing our data more accurately, our experience has show that it was necessary to make a special effort to improve our data quality checks, and we have been working on that project. A relational geothermal database, properly designed, with ingredients well checked and correctly used, will play an essential role in the research work and utilization management of the geothermal resources. It will also ensure that the geothermal information is shared more easily, resulting in improved collaboration and thus advancing the geothermal work (Gunnarsdóttir, 2015).

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