

Internship report

Analysis and inventory of Geo-Drilling Events in the Dutch subsurface; a TIBCO Spotfire interface application

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1. Abstract

Well safety and cost are of major importance for E&P companies. Unexpected drilling events can cause the costs of drilling to exceed the planned costs. Risk assessment during development of the well planning relies on experience from offset wells. For that reason a joint industry project was launched to investigate drilling events throughout the industry (*Hoetz, 2013*). Offset wells are drilled in close proximity to the proposed well and provide valuable information about the area since these wells are drilled through similar geological settings. The Drilling Events Triangle was an important tool, which has been developed from the conducted study by Hoetz (*2013*), to classify drilling events. The drilling events which are caused by a geological underlying hazard, are selected, analyzed and documented in a database: The Geo-Drilling Events database.

The objective of this internship was to assist in maturing a conceptual database into a well planning tool that can be rolled out to EBN's partners. Contribution include analyzing well reports for information regarding Geo-Drilling Events, coding Excel and Spotfire applications and designing the user-friendly user interfaces. This database will be made accessible by EBN for analysis and well offset reviews. This Spotfire-tool will be available to the operators in the Netherlands via a hosted cloud service by TIBCO.

2. Introduction

2.1 Background of the Geo-Drilling Events database

In the Netherlands, there are multiple operators active in the petroleum industry, drilling wells in the Dutch subsurface. These wells are expensive to drill and need careful planning in order to ensure safety. From experience, it is known that a significant portion of wells encounter events which cause delay on the well planning or even require a contingency plan and therefore increased well costs (*Hoetz, 2013*). In some cases even the operational safety was at risk as a result of unexpected drilling events, such as the Macondo-incident in the Gulf of Mexico. An example in the Netherlands of dramatic consequences is the Sleen-2-incident, where the entire drill-rig was lost in an onshore crater caused by a catastrophic blow-out in 1965. Drilling events that happen can occur due to a combination of three factors, as shown in figure 1. Every event plots on this triangle based upon the root-cause of the event. The root-cause for events can be of engineering origin (tool or mechanical failure), human error (wrong decisions concerning drilling equipment/settings) or can have a geological cause (*Hoetz, 2013*). EBN, the Dutch state oil and gas company, is involved in almost all hydrocarbon field projects in the Netherlands as non-operator and has major interest in improved drilling activities.

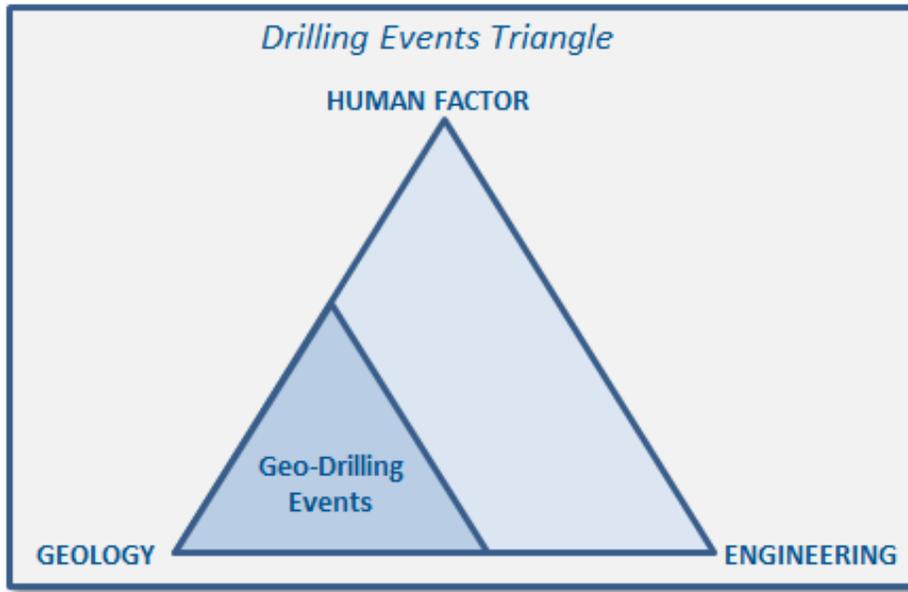


Figure 1, Drilling Events Triangle indicating the causes for drilling events. (Source: after Hoetz, 2013)

EBN has worked together with TNO on classifying drilling events related to the local geology. After a proof of concept of the developed classification, EBN started establishing a Geo-Drilling Events database. As commercial and technical partner in most wells, EBN is in an unique opportunity to investigate the available well data on operational performances.

2.2 Goals of this project

EBN believes that analyzing Geo-Drilling Events (GDE) improves well safety and reduces well costs related to Geological Drilling Hazards, which reduces Non Productive Time. The GDE database provides a better understanding of the Geo-Drilling Hazards (HAZ) which can occur in the Dutch subsurface. This gives the opportunity to learn from past Events encountered by (other) operators, because the data is shared so well designs can be optimized by using high quality offset well data. The aim of this project is to develop a tool to use and analyze the data from the GDE database. By better understanding of the local geology, geo-hazards can be anticipated on and mitigated by careful planning. For this purpose, a tool has been develop to analyze the available data in the GDE database. The software of TIBCO Spotfire has been used to build an user-friendly interface for this data-visualization. This Spotfire application will be hosted by EBN via an online cloud, which can be accessed by the partners of EBN. The online cloud can be accessed via <https://www.ebn.nl/analytics>, where a link is given to the cloud environment.



Figure 2, TIBCO Spotfire logo. Source: TIBCO

3. Methods

3.1 Geo-Drilling Events workflow

For the GDE database a workflow has been established by Ivo Nijhuis (WellSpec) for managing the database and how data is added to the GDE master database and the Spotfire tool. This workflow is shown in figure 2. The input for the database consist of data extraction from NLOG and Livelink, the local EBN database. The information in the database is condensed from data provided in the End Of Well Reports (EOWR), Weekly and Daily Drilling Reports, Final Well Reports, Geological Reports and Composite Well Logs. From NLOG, also the lithostratigraphy of the well and deviation data is used. This input data is analyzed for drilling related events and unexpected delays on the well planning. These possible drilling events are then investigated for what their cause might be. Once is established that the GDEs have an underlying geological cause, the GDE and the underlying HAZ are inserted into the database. EBN well data is used to verify specific metadata e.g.: the current operator of the well and under which license the original well was drilled. For this project, the operator coding was originally developed by Mathijs Kuiper. After multiple interests for a unified operator coding, this coding-list has been integrated into the

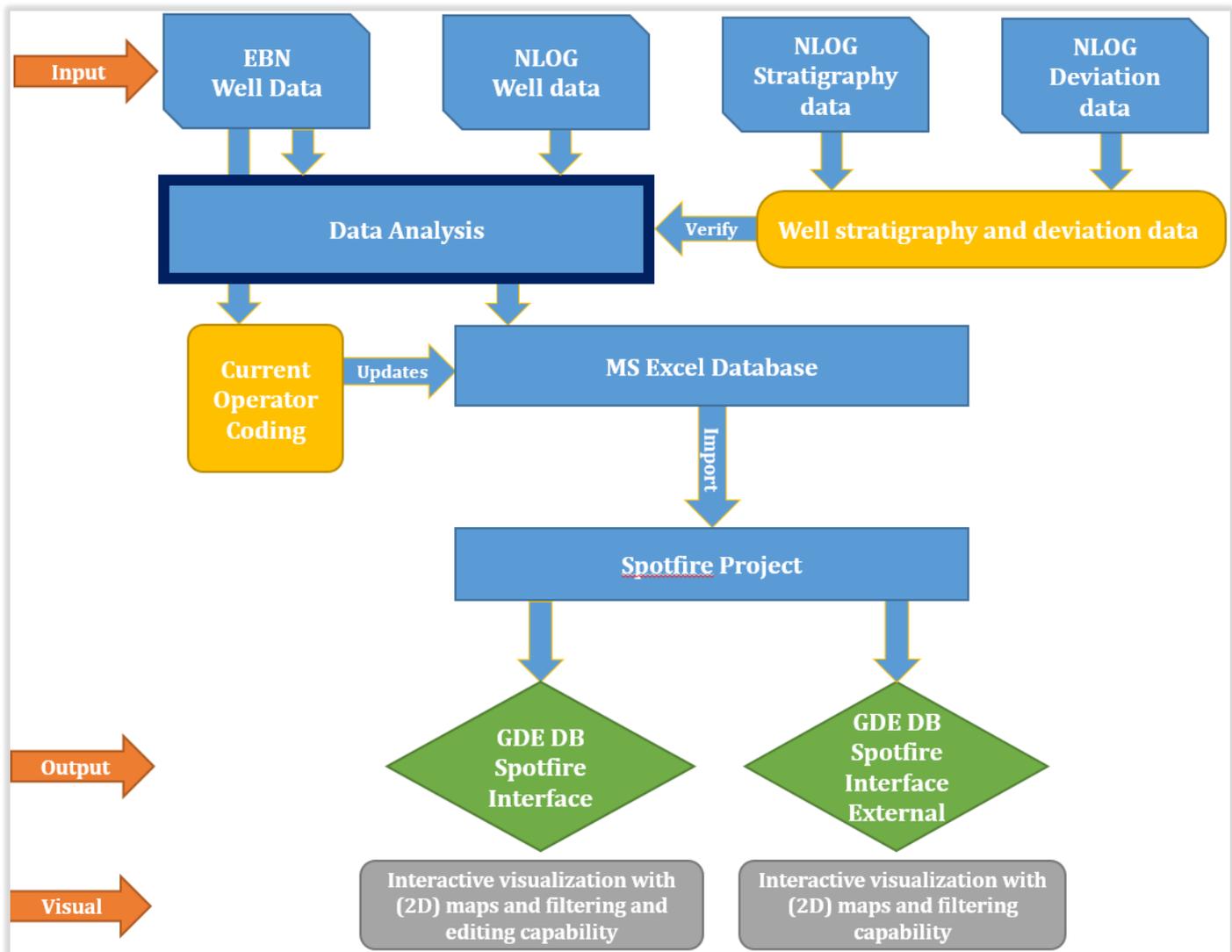


Figure 2, Workflow of the GDE database

“Basisregistratie” for companywide use in reports and documentations within EBN. The structure of this Excel-project and how data is processed and displayed will be explained in paragraph 3.2. The total database, which is a .xlsm-datafile (Excel 2013) is loaded into TIBCO Spotfire software where an user-friendly interface is made for analysis of the collected dataset. The build-up and functionality of the TIBCO Spotfire interface is discussed in paragraph 3.4 and chapter 4. Using the Spotfire-datafile (.dxf), the interface of the TIBCO Spotfire-environment can be edited. Further development of the Spotfire-environment is also done in this .dxf-file. These changes can be made by an assigned project engineer for the Spotfire-interface. Ideally the project engineer for the Spotfire-interface is the also data analyst for the database itself. The project engineer develops the interface itself and makes sure the data is visualized properly and completely. The Spotfire-interface is then uploaded to an online Cloud-environment for external usage. Partners of EBN can apply for log in credentials via the “Request Access” link on the EBN Analytics page (<https://www.ebn.nl/analytics>). The project engineer approves the applicant and provides them with an invitation to make an user-account for the TIBCO Cloud where the partners are granted access to the shared Spotfire-interface. The project engineer remains the contact person to the TIBCO Cloud users concerning technical support on the GDE-project.

3.2 Build-up of the Geo-Drilling Events database

The GDE-project builds upon the joint industry project findings of NOGEPa, EBN and TNO. The proof of concept in SPE-paper 166254 (Hoetz, 2013) has been refined and perfected after these findings. In this proof of concept 10 operators each provided information on some 10 wells regarding drilling related events. Many additional wells have been added to the initial 100 wells already present. Currently over 55% of the recent wells (since 2000) and over 10% of all wells since 1960 (with a 500m depth cut-off) have been analyzed. By mid-2017, the GDE_DB counts 624 wells being analyzed with 482 GDEs recorded. During analysis of the well data, a classification scheme is used in order to categorize the GDE and the HAZ. This classification scheme is developed by Hoetz, 2013 and since then small changes have been made to this scheme to make it MECE-compliant. The classification scheme is shown in figure 4. The GDE classification is subdivided into multiple levels, indicating the severity of the GDE. The guidelines for this severity subdivision is given in figure 5. The severity levels range consists of “low”, “medium” and “high” labels depending on the (financial) impact of the drilling event. Once a GDE and HAZ are classified, the data is inserted in the .xlsm file in a worksheet called “DATABASE”. A screenshot of “DATABASE” is provided in appendix 1. “DATABASE” in the Excel-project consists of 4 main pillars:

Pillar 1 (column A up to K): Generic well data

The first pillar of the database consists of generic well data which can be found on NLOG. The provided information in this part consists of:

- *Well Name;* the name of the investigated *borehole*
- *Original operator;* the name of the original operator who drilled the well
- *Current operator;* the name of the current operator of the well
- *License;* the license under which the well is drilled
- *Well type;* the type of well, e.g. Exploration, Production, Appraisal, etc.
- *Spud date;* the date on which the drilling of the well started
- *Trajectory;* the indication for the maximum reached drilling angle
- *Wellhead coordinates;* the easting and northing coordinates of the well head in UTM31 ED50 format

Geo-Drilling Event Classification		Geo-Drilling Hazard Classification	
GDE_Type	GDE Description	HAZ_Type	HAZ Description
Hole Geometry		Rocks	
Stuck Pipe	Stuck pipe and/or excessive overpull and/or torque of the drill string or casing. Incidents may include: Stuck pipe occurrence during the drilling phase; Casing stuck and/or prematurely set due to no further progress while running in; Hole pack-off; Excessive reaming and/or hole cleaning required in combination with excessive overpull/torque; Differential sticking; Obstruction running liner or casing in the hole	Fault (Faults/fractures in the borehole)	Destabilised rocks due to (natural) faulting/ fracturing. Resulting in anomalously high permeability (losses) and/or excessive cuttings/ cavings. Note that karstification might show up similarly as faults but is strictly spoken a different geological phenomena (see R)
Bit Balling	Swelling and sticking clay causing a packed off drilling assembly	Swelling Clay (Chemically unstable sediments)	Reactive formations (eg. swelling clays)
ROP	Excessive wear of the drill bit resulting in reduced rate of penetration and/or excessive number of bit trips; Unexpected reduction in ROP resulting in significant delay	Squeezing Salt (Unstable evaporites)	Borehole formation deforming caused by high (litho) pressures mobilising evaporites
Steering	Difficulties while steering the drilling assembly during drilling, either in rotary or sliding mode. For example due to formation change or formation dip angle.	Unstable Sediment (Mechanically unstable sediments)	Unconsolidated formation (eg. washouts); Cavings due to high pressure; Weak zones in formation
Washout	Unconsolidated formation, collapsing into the hole. Washed out formations as a result of mud type or excessive local circulation, possibly in combination with (anomalous) geology.	Boulders (Unexpected boulders/pebble layers)	Large detached rocks in borehole, typically originating from conglomerate
Deformed Casing	Deformed or collapsed casing during well construction or re-entry of an existing well, possibly in combination with (anomalous) geology.	Rock Properties (Unexpected hard/soft or unexpected permeability)	Unexpected hard or soft formations; Abrasive formation causing excessive bit wear; Steering difficulties due to soft/hard alternation; Dip angle
Pressures		Fluids	
Kick	Flow of formation fluid into the borehole during well construction.	Depleted Reservoir (Low in situ pressure)	Unexpected low reservoir pressure (e.g. due to nearby production of seal break)
Losses	Lost drilling fluids and/or cement into the formation during well construction	Shallow Gas (Unexpected shallow gas shows)	Unexpected gas shows at shallow depths
Geology and Fluids		Anomalous Pressures (Unexpected high pressure pockets)	Unexpected or unpredicted high or low geopressures: High pressures exceeding expected formation pressures (e.g. unexpected brine flows, brine pockets); Formation fluid pressures lower than expected (e.g. depletion due to nearby production)
HC	The unpredicted occurrence of hydrocarbons while drilling	H2S (Unexpected H2S shows)	Unexpected occurrence of hydrogen sulfide gas in borehole
H2S	The unpredicted occurrence of H2S while drilling	Other	
Lithology	Unexpected and/or unpredicted formation encountered while drilling. Actual formation depth significantly different than prognosed.	Mapping Uncertainty (Unexpected stratigraphy)	Subsurface mapping is generally based on well and/or seismic data. Results are based on interpretation and can contain errors or has large uncertainty. Structural complexity, T2D conversion, flanks, unexpected fault/offset
Other	Other geological-related incidents that cannot be categorized by any other code in this table. Note: Non-geological drilling incidents are not recorded in this	Other / Unknown (Other/Unknown Geo Hazard)	Other geologic hazard (e.g. unconformities) or unknown geological hazard.

Figure 3, showing the used classification scheme for the Geo-Drilling Events and the underlying geological cause (source: after Hoetz, 2013)

Pillar 2 (column L up to AB): Geo-Drilling Event

The second pillar displays the data gathered by the analyst concerning the GDE. The provided information consists of:

- *GDE Y/N*; Yes/No labelling, whether there is was GDE, for filtering purposes
- *GDE type*; The type of GDE as by the GDE classification scheme shown in figure 4
- *GDE severity*; The severity of the GDE following the guidelines in figure 5
- *GDE summary*; A short, one sentence, summary of the GDE (for easy analysis in particular visualizations)
- *GDE narrative*; A more detailed full description of the GDE
- *GDE date*; Start date and end date of the GDE
- *GDE depth*; The depth of the GDE, given both in Measured Depth along hole relative to rotary table and True Vertical Depth
- *GDE coordinates*; The easting and northing coordinates of the GDE in UTM31 ED50 format

Severity Guidelines		
High	Medium	Low
examples	examples	examples
Lost drilling assembly in hole Prematurely set casing string in different than planned formation with effect on shoe strength Prematurely set casing string	Excessive jarring, reaming and/or circulation required Differential sticking requiring to spot a light fluid (e.g. base oil) pill to reduce overbalance Hole obstruction during casing running requiring an additional BHA check trip or opening up the hole	Excessive torque and/or overpull, but manageable
Lost top hole and/or sidetracked due to pack-off and subsequent stuck pipe	Significant time delay due to bit balling. Multiple trips required. High-volumes swabbing occurrence due to bit balling	Bit balling occurrence but manageable
Excessive number of bit trips required due to extreme bit wear	Multiple bit trips required due to excessive bit wear	Reduced ROP and significant bit wear observed
Failed to reach objective	Steering difficulties, multiple BHA's required. Trajectory outside targetbox (at objective)	Steering difficulties, more time required to steer BHA
Washout resulting in accidental sidetrack Washouts resulting in insufficient cement around casing or liner	Washout resulting in significant quality loss of logging results	
Deformed casing or liner due to squeezing (salt) formations.	N/A	N/A
Influx exceeding kick tolerance Kick-loss situation Well Control situation resulting in 4+ days regaining well control Kick resulting in prematurely setting casing	Well control situation requiring well to be circulated to heavier fluid in controlled manner (over the choke) High pressures requiring a contingency liner to be set to allow drilling ahead	Able to control influx whilst drilling ahead Increased mud weight to overbalance formation pressure
Total losses, unable to keep the hole full. Total losses leading to a kick/loss situation. Losses during cement job resulting in lower TOC than planned Losses compromising section target Losses resulting in prematurely setting casing	Numerous LCM pills required to cure losses Gunk and/or cement pills required to cure losses	Losses curable whilst drilling (eg. By adding LCM material)
Mitigating the unpredicted occurrence of HCs giving rise to significant operational delay (> 5 days NPT)		
Mitigating the unpredicted occurrence of H2S giving rise to significant operational delay		H2S < 10ppm and no operational delay
Missed final drilling target Failed to find objective	Found objective but after significant delay e.g. after sidetrack.	E.g. Formation coming in significantly deeper or shallower than prognosed (>100m) but no compromises on well design and/or target missed

Figure 5, showing the guidelines for the severity scale, given by examples (source: after Hoetz, 2013)

- *Stratigraphy*; Lithostratigraphic interval of the GDE, both calculated and inferred from well data
- *GDE max inclination*; The maximum inclination of the borehole at the measured depth of the GDE

Pillar 3 (column AC up to AE): Geo-Drilling Hazard

The third pillar shows data about the underlying geological cause (HAZ) for the GDE. It consists of:

- *HAZ type*; The type of Geo-Drilling Hazard as by the scheme in figure 3
- *HAZ description*; A full description of the geological cause for the GDE

Pillar 4 (column AF up to AH): References

The fourth and last pillar contains data on the documents where the data in the database was found and the analyst:

- *Documentation*; List of filenames of the documents used in the GDE investigation
- *Analyst*; Name of the interpreter who studied the data
- *QC*; Check whether the data shown has been subjected to a quality and control check by a different person

Besides “DATABASE”, there are multiple datasheets in the Geo-Drilling Events Database Excel project-file:

- On the “STATS”-sheet, information on the GDE’s and HAZ’s are compiled in graphs. A screenshot of this sheet is given in appendix 2. The sheet pulls its data from the “DATABASE”-sheet and visualizes the total number of wells and boreholes with events. It also shows in a pie-chart the abundance of the different types geological events together with the abundance of the geological hazards.
- The “NoEVENTS_DB”-sheet is a (stranded) attempt to provide context to the GDE database. This was made because the GDE database only shows the cases in which something went wrong on a specific stratigraphic interval, whereas there is no regard for the fact that the rest of the borehole was drilled successfully and without events. Also when no geological related events were recorded in a certain borehole, the whole well got one green symbol and label “NoEvent”, grouping all formations together. When using statistics on such data it gives a very skewed image of the abundance of geological related drilling events. In order to provide context surrounding the GDE database, an attempt was made to set up a database with data points per stratigraphic interval where no GDE was recorded from both boreholes with and without any GDE’s. This has proven to be very labor-intensive and was abandoned. The pilot study however remained a datasheet in the Excel-project for later project managers to resume expanding this datasheet when techniques are developed to obtain the desired data in automated and easier ways so statistics can be applied more accurately on the database. In the recommendations there will be further explanations on this concept.
- The “GDE_CODE”-sheet shows the classification scheme used for the GDE types seen on the left of figure 4 together with the guidelines for the severity index of the events. The “DATABASE”-sheet is linked to these classifications, so if adjustments are suggested for the classification scheme, the “DATABASE”-sheet is automatically updated to these renamed GDE types.

- The “HAZ_CODE”-sheet is similar to the “GDE_CODE”-sheet but represents the classification scheme for the underlying geological hazard, HAZ. In a similar way as with the “GDE_CODE”-sheet, the “DATABASE”-sheet is linked to the “HAZ_CODE”-sheet.
- The “STRAT_CODE”-sheet shows the list with abbreviations for the stratigraphic intervals used in the database. These stratigraphic coding is shown in appendix 3 and originates from the stratigraphic nomenclature of the Netherlands, set up by TNO. The assigned color coding to the different stratigraphic intervals is according to the Commission for the Geological Map of the World (CGMW).
- The “DB_FIELDS”-sheet consists of a list of the names of the headers used in the “DATABASE”-sheet. The “DATABASE”-sheet is linked to this sheet in a similar way as with the “GDE_CODE”- and “HAZ_CODE”-sheets. Also descriptions are given on what the column of that header represents. This short description is also shown in the “DATABASE”-sheet (row 3). Furthermore it is shown which columns are used in the Spotfire-interface and which parameters can be filtered on in the different Spotfire-visualizations. This will be further discussed in chapter 4.
- The “OPER_CODE”-sheet shows the abbreviations used for the different operators of the wells in the Netherlands. It is the same list used in the ‘current operator coding’ step in the GDE Workflow of figure 3. The is comprised of generic and unique names for operators on company level. The table is shown in appendix 4.
- The information on the “LICENCES_OPER”-sheet is acquired from internal EBN data, containing current information on which operator owns what exploration or production licenses. This data need to be updated manually in order to stay up to date. Petra van Staalduinen, Legal assistant at EBN, is the manager for the licenses-administration and holds the most up to date information. The “DATABASE”-sheet is linked to this page so ‘*Current Operator*’ column is always fully up to date when the “LICENCES_OPER”-sheet is provided with correct data.
- The “DEVIATION_TOOL” is a macro-enabled worksheet which has been developed by Peter Bange, Technical data coordinator at EBN. It uses the deviation data, as found on NLOG, which is incorporated in the EBN database. By inserting a well-name and a Measured Depth (MD; measured along hole relative to rotary table) the tool will provide deviation data of the borehole relative to the wellhead coordinates. It also gives a True Vertical Depth (TVD). This sheet is linked to the “DATABASE”-sheet, which is in turn linked to the data this sheet provides. The “DEVIATION_TOOL”-sheet gets automatically the well name and the MD from “DATABASE”. Because the MD indicate the depth of GDE, it means that “DEVIATION_TOOL” only calculates deviations for boreholes with a GDE, since wells without a GDE are not provided with a MD. After running the Macro, “DATABASE” is linked in such a way, so that the obtained deviation data appears in the ‘*GDE X coordinate*’ and ‘*GDE Y coordinate*’ columns of “DATABASE”, where the in situ easting and northing coordinates of the GDE are calculated. This is done by adding the deviation data to the wellhead coordinates of the wells. The “DATABASE”-sheet also is linked to show the TVD calculated by “DEVIATION_TOOL”.

- The “INPUT_BH”- and “FORMATION”-sheets are similar to “DEVIATION_TOOL”. These sheets are also developed by Peter Bange to calculate borehole data. These sheets however calculate borehole data for individual boreholes instead of for a whole series, such as “DEVIATION_TOOL”. The “FORMATION” sheet is connected to the input given in “INPUT_BH”. It shows a calculated stratigraphic interval of the borehole at the given MD. This calculated formation is manually inserted in the ‘*Stratigraphy calc*’ column in “DATABASE”.

3.3 Updates to the database

During this project, besides providing more data to the database, changes have been made to the data itself and the interface of the dataset. Since December 2016 several major updates were implemented to the Excel-project and the Spotfire-interface of the GDE database.

3.3.1 Changes made to the Excel-project

Within the Excel-project some cosmetic changes were made in order to make filtered results more clear. Originally, the “DATABASE”-sheet had a default appearance where GDEs were sorted per well and those rows were grouped together because of the usage of the borders in Excel and different font and fill colors. When filters were applied to the dataset, this appearance changed and it became very difficult to understand the data. This was solved by making an universal format for the data in “DATABASE”, so when filtering was applied, all the data has the same appearance making it easier to distinguish between different rows and separate data strings. Besides this cosmetic change, the dataset was checked for inconsistencies, errors and missing data. This could range from typing errors, wrong data input and absence of available data in the database.

A major change to the dataset was the new coding scheme for the operators which was introduced to cancel out all different names for the same companies. Here were major inconsistencies in how the same company was named in the ‘*initial operator*’ and ‘*current operator*’ columns. For the Dutch operator NAM for example, the following names were used:

- Nederlandse Aardolie Maatschappij B.V.
- Nederlandse Aardolie Maatschappij
- Nederlandse Aardolie M.
- Nederlandse Aard. Maat.
- Ned. Aard. Maat.
- NAM

This has been resolved by the newly introduced operator codes developed by Mathijs Kuiper, where all operators in the Netherlands are given an unique three or four letter code to maintain consistency. For the example case this resulted in the operator code ‘*NAM*’. This also improves user-friendliness when using the dataset, since filtering the data is much more efficient. Another problem that has been resolved was the new coding scheme did not incorporate old names for companies. Total for example has had multiple merges over the past decades. These earlier names or old names from merged companies (CFP, Total-CFP, Elf Aquitaine, Elf Petroland, Total Fina, TotalFinaElf, Total S.A.) are now all considered under one operator code: ‘*TOTA*’.

Furthermore some new terminology was introduced for style-reasons. Because if a cell remains blank in the Excel-file, when loaded in the Spotfire interface, it created the value '<Empty>'. This does not resemble a professional lay-out and therefore terms were created in order to fill the cells in Excel, so no '<Empty>' values were shown in the Spotfire interface. Any missing data was looked up, but if it did not exist or the data was unavailable the term 'NoData' is used. In case of the GDEs also the terms 'NoEvent' and 'No Geo-Drilling Event mentioned' were introduced when no GDE was found in the well log data. This resolved the problem of the empty cells in Excel and gave the Spotfire Interface a more professional appearance. Besides these new terms, one existing term has been renamed. The term 'Stratigraphic Supergroup' has been wrongly used to label the data in that column. The column shows the first two letters of the formation/member (if known) of the interval of the GDE. This is however a stratigraphic group and not a supergroup. The term has been changed to 'Stratigraphic group'.

A major change to the database was the implementation of the Deviation Tool of Peter Bange into the Excel-workmap. The Deviation Tool uses deviation data from the EBN database to calculate in situ x, y, z positions of along hole depths of boreholes. By inserting this Excel macro-enabled tool into the database, a lot of computational work has been automatized. It makes adding data to the database much easier and saves a lot of work. A quality check has been made in "DATABASE" to check whether the computation from the "DEVIATION_TOOL"-sheet is correct. This is done by the traffic-light symbols in column 'W'. This column contains an IF-statements which for row 70 reads:

```
=IF(AND(J70=U70;K70=V70;L70="Yes";NOT(DEVIATION_TOOL!G70=0);NOT(DEVIATION_TOOL!H70=0);NOT(DEVIATION_TOOL!I70="BH not found"));1;0)
```

This means that if the AND-statement is fulfilled for that row, the value of column 'W' is 1, and if not, the value is 0. Subsequently, there are rules connected to column 'W' regulating the color of its cells on the basis of the value in the cells of that column. If the value is 1, the cell color is red (indicating wrong coordinates are shown) and if the value is 0, then the cell color is green (indicating the coordinates are correct). The AND-statements checks if the indicated values of the 'GDE X coordinate' and 'GDE Y coordinate' are correct. The idea behind this AND-statement is that the transposed coordinates are wrong if the transposed coordinates are the same as the wellhead coordinates ('J70=U70;K70=V70') and there has been a GDE ('L70="Yes"'). This is because if no GDE has occurred in a particular well, the wellhead coordinates are shown in this column, so this 'NoEvent'-case has a location on the map. However, some wells do have GDEs but are vertically drilled or are not available in the "DEVIATION_TOOL"-database. This is overcome by excluding the cases where the X- and Y-deviation is 0 ('NOT(DEVIATION_TOOL!G70=0;NOT(DEVIATION_TOOL!H70=0)') and when the data of the borehole is not available ('NOT(DEVIATION_TOOL!I70="BH not found"').

3.3.2 Improvements made to the Spotfire-interface

For the Spotfire-tool, a conceptual model was made by Tom Leeftink as a proof of concept and as a format for the lay-out of the eventual interface. This format consisted of five tabs: 'Information', 'Map View', 'Cross Plot', 'Well Offset Review' and 'Detailed Description'. These tabs have partly been renamed into 'User Guide', 'Map View', 'Scatter Plot', 'Well Offset Review' and 'Detailed Information' for a more clear understanding of their content for the user. For the rest, the changes are mainly concerning the lay-out of the tool itself, providing a more professional and straight-forward appearance which is user-friendly and is both intuitive and easy to work with.

Major changes to the lay-out of the Spotfire-tool have been in the ‘*Map View*’-tab, where multiple interactive layers have been added in to display as much valuable data as possible. The map contains an outline of the continental shelf of the Netherlands (*‘Licence_Blocks’*) with additional overlays indicating the offshore sub-blocks (*‘Licence_SubBlocks’*) together with exploration and production licenses for both hydrocarbons (*‘HC_LicenseSNS’*) and geothermal energy (*‘Geothermal_LicenseNL’*). On top of these licenses the hydrocarbon fields (*‘HC_Fields’*) are plotted. Furthermore the wellhead locations of most the wells in the Netherlands are plotted (*‘NLOG – Boreholes_DB’*). There has been a 500m depth cut-off applied to avoid plotting the coal mining shafts in Limburg and wells older than 1960 have been ignored here too. Finally an interactive layer is plotted with the locations of the GDE in the Netherlands (*‘Geo-Drilling Events database’*). This layer shows the data of the GDE database in a spatial visualization.

Besides the map itself, the settings of the available data has been pre-set. This means that color-schemes are introduced for certain categories which are more intuitive in order to enhance the appearance of the data. The Stratigraphy is now listed in the chronological order instead of in alphabetical order. Also default color-settings have been assigned to the stratigraphy making sure that the shown colors in the map view represent the true color of that stratigraphic interval as set by TNO. In a similar way, the severity-scale has been given traffic-light colors to represent the severity in a more logical manner.

4. Designing the TIBCO Spotfire application interface

For the design of the Spotfire interface, there are multiple layers, settings and properties that have been added to the visible interface in order to establish the final Spotfire-tool with its user friendly functionality and possibilities. The Spotfire tool was designed in TIBCO Spotfire version 6.5.3 HF-025, build version 6.5.3.30 and is hosted from the TIBCO Cloud version 7.8. The architecture and design used in the Spotfire interface will be discussed per tab.

4.1 ‘User Guide’

The ‘*User Guide*’ is comprised of one text area. At the top of the text area there is a banner, similar to the one used as thumbnail on EBN’s Analytics page. The image is a stock photo of a tri-cone drill-bit used in the old house-style presentation formats of EBN which has been modified. In a subsequent overview, information is provided on the GDE project and the tool itself together with contact information for correspondence. Following, a summary is given on the available tabs of the tool. The name of the tab is an Action Control. In the example in figure 6, it is shown how this Action Control is set. The display text is the name of the tab and the control type is set to be a link to the tab in question. At the bottom of the text area there are the appendices which are referred to in the text shown as images. There are four appendices showing the GDE classification scheme together with the guidelines for the severity of the event, the HAZ classification scheme, the glossary of the abbreviated names for the operators in the

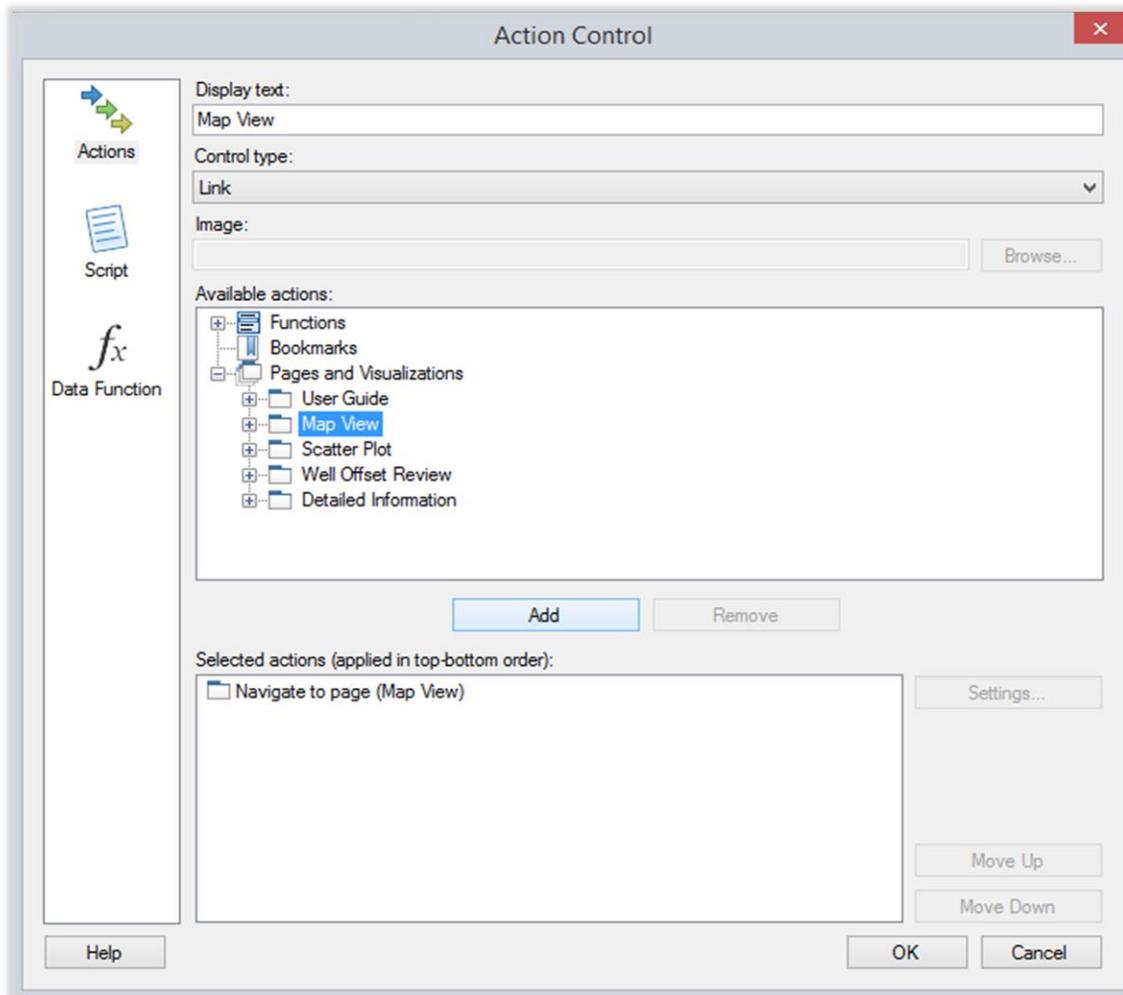


Figure 6, showing an example of the settings of the Action Control for the links used in the 'User Guide'. This screen is reached via using the action control button in the toolbar of the text area when editing.

Netherlands used in the Spotfire-tool and a list of the nomenclature used for the stratigraphic intervals. This nomenclature is in line with the TNO standard for the Dutch stratigraphy.

4.2 'Map View'

The second tab is the 'Map View', which is built up of multiple visualizations. There is a map chart on the left side of the tab (see appendix 5) and on the right side of the tab there are two visualizations; namely a table chart and a text area. The map chart shows a standard topographic map of the world, which has been preferably set with the Netherlands shown by default. On top of this standard map, there are multiple GIS-base feature layers from the Microsoft SQL server at EBN and Excel-linked marker layers inserted (see figure 7). The marker layers contain the X and Y coordinates (in the EPSG:23031 – ED50/UTM31N coordinate reference frame, see figure 8) of the GDE locations in the 'Geo-Drilling Events Database'-layer and the wellhead locations of all wells in the Netherlands, with a 500m and pre-1960 cut-off in the 'NLOG – Boreholes_DB'-layer. The feature layers consist of binary geometries from the GIS-base, which are inserted to display spatial information about the on- and offshore license blocks, the contours of the Dutch continental shelf and the extend of the hydrocarbon fields.

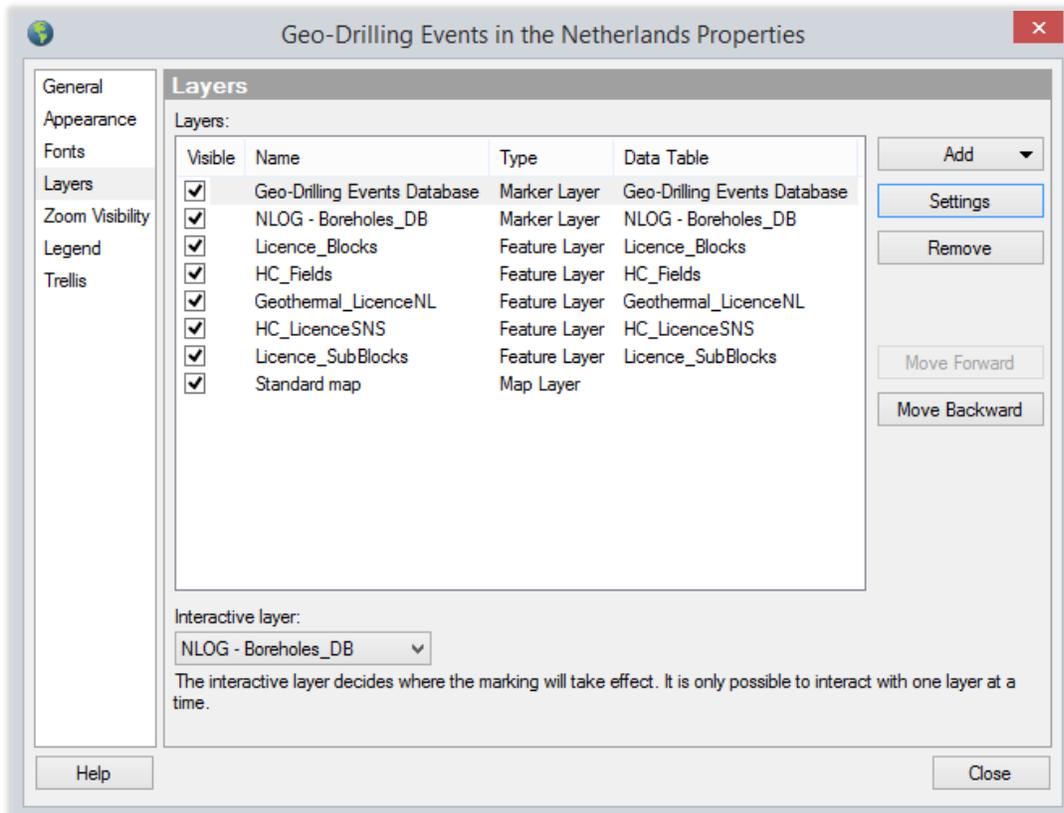


Figure 7, showing the settings of the map chart with all the added marker and feature layers. This screen is reached via 'properties' in the map chart

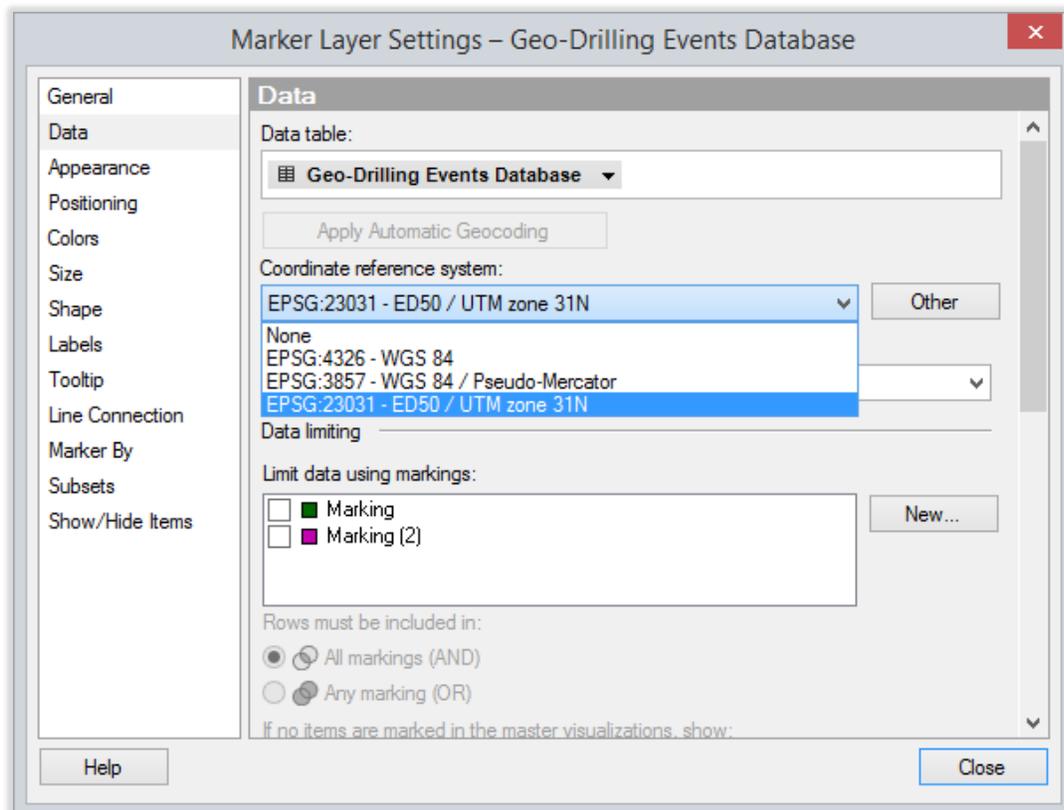


Figure 8, showing the settings of a marker layer in Spotfire, indicating the used coordinate reference system. Also visible, are the different green and pink Marking-levels used in the Spotfire-tool. This screen is reached via 'layer settings' (annotated in figure 7) of the 'Geo-Drilling Events Database' layer

The data can be selected using one of the selection tools on the map. This can either be clicking on a data point or by selecting multiple data points. Spotfire works with different selection levels, called 'Markings' (visible in *figure 8 & 9*). The hierarchy of these 'Markings' is as such, that when data is selected in a particular marking, a sub selection can be made in a lower Marking-level if a visualization is set to that lower marking-level. This has been used in the "Map View". If data is selected in the map chart, it is selected in the green "Marking"-layer (which is the highest order). The selected data is then shown in the table chart. This feature is established by altering the settings of the table chart as such so that the shown data in the table is limited by the green "Marking"-layer (see *figure 9*). Subsequently, in this table chart a subset of the data can be selected, because if data in the table chart is selected, it selects in a lower order marking, namely the pink "Marking (2)"-layer. This also means that if no data is selected in the map chart, there appears no data in the table chart. The table chart however is set, that if there is no data shown, the following message appears: "Mark items in the Map View to view detailed information here." to instruct the user of its functionality. The text area in the 'Map View' visualization has the sole purpose of

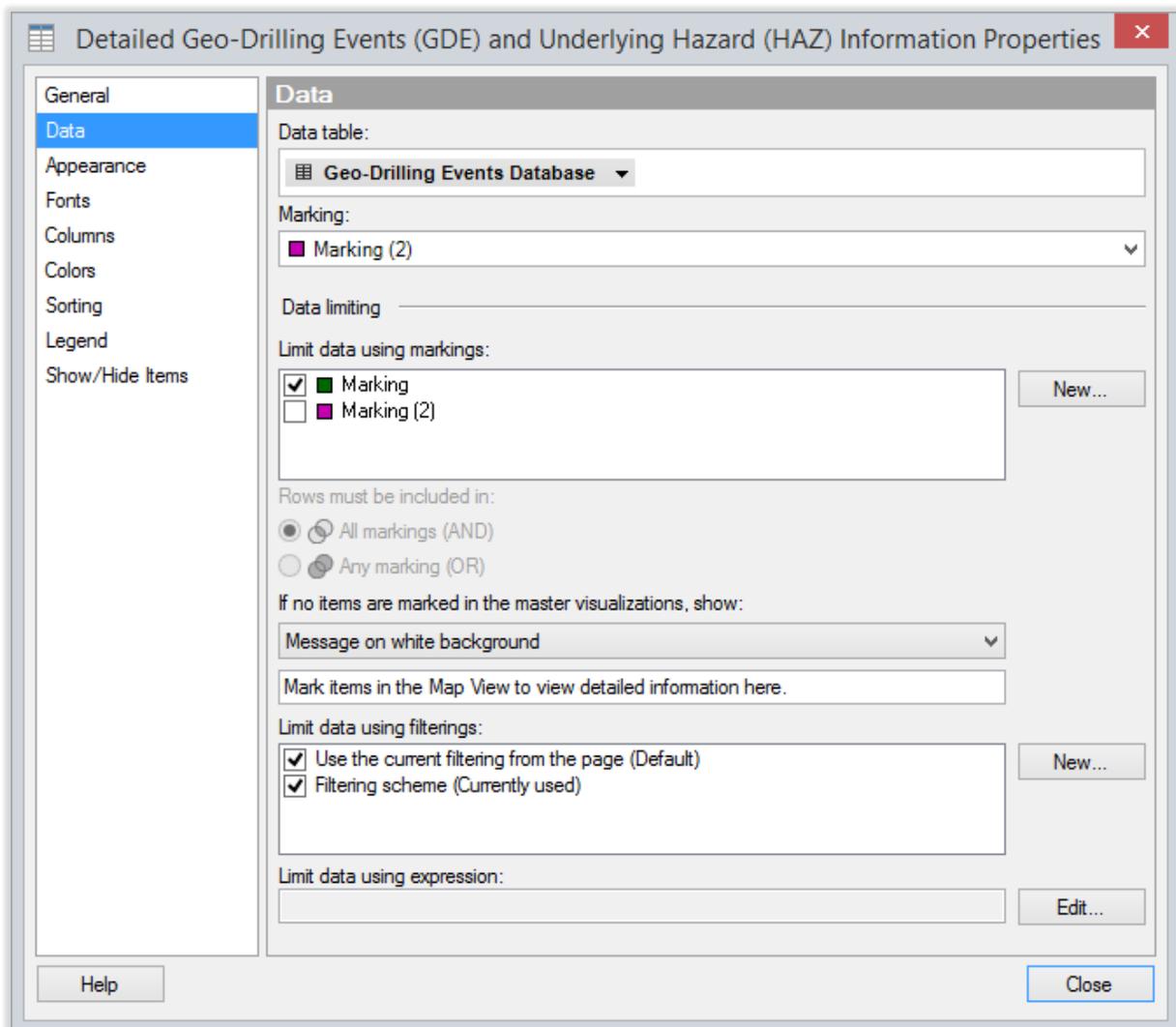


Figure 9, showing the settings of the Markings. In this example for the table chart in the 'Map View', the data is limited to the green Marking selection. The table chart itself selects data in the lower order pink Marking (2). If no items are marked in the master visualization, the mentioned text is shown on a white background for instruction. This screen is reached via 'properties' of the table chart

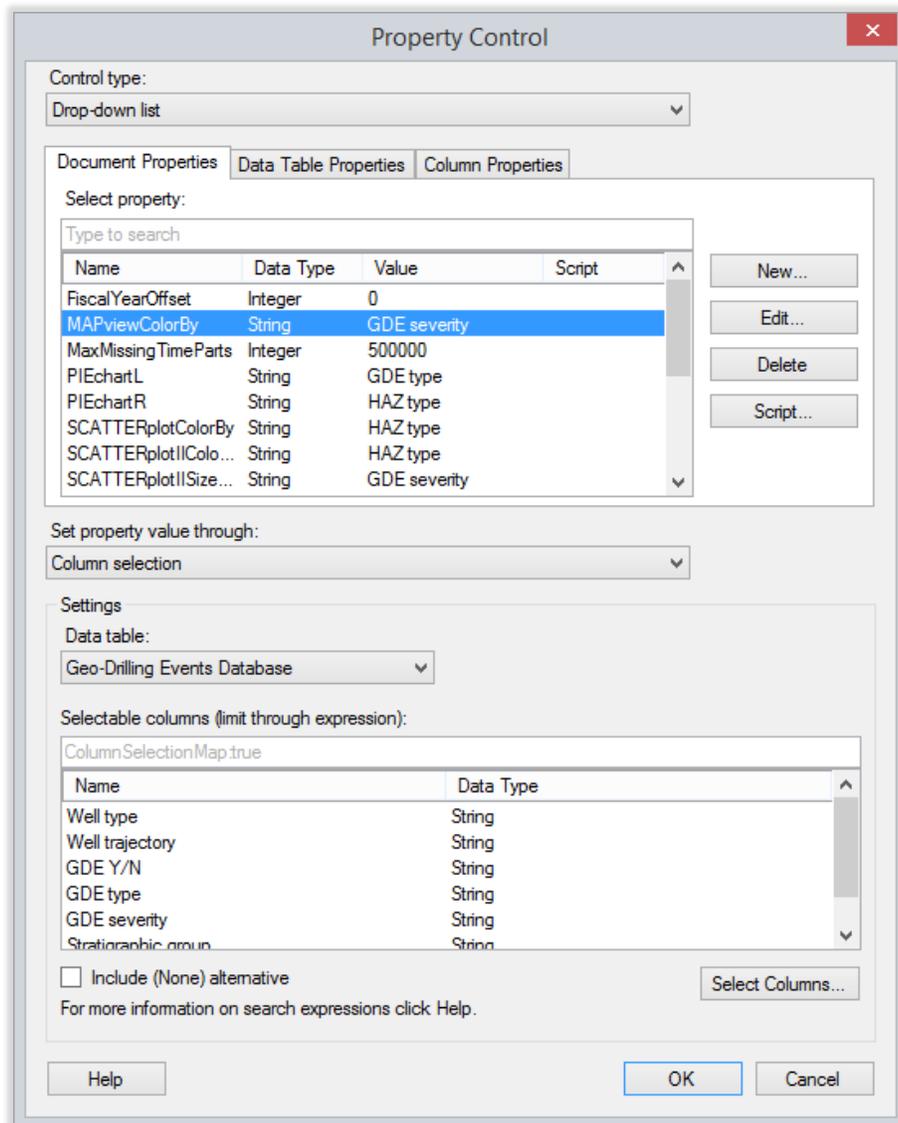


Figure 11, showing the Property Control for the property in the text area of the 'Map View'. It shows the name of the property that is controlled by the drop-down list. The default setting is set to "GDE severity". In the lower part of the screen, the columns are selected which will be available in the drop-down list of the property. This can be manually adjusted. This screen is reached via 'edit property' via the property itself during editing mode of the text area.

to choose from has proven to be the best in practice. In the lower part of figure 11, the columns which appear in the drop-down list can be selected. For the different visualizations and properties in the Spotfire-tool, there are different demands for parameters, so every property is customized to show only the columns useful in the visualization that property controls. A list of which columns are used in a particular visualization is given in the tab "DB_FIELDS" of the Excel-database. If the option "Include (None) alternative", is selected, an extra choice is added to the drop-down list of that property. It now also shows the option "None", to show the data point in plain color, without any color coding by any parameter. In some of the cases this option has been selected.

This property setting can be adjusted for any parameter in the map chart (size, shape, color, etc.), but it was decided to only use it for color coding in the 'Map View'. The color coding used for the different

hosting the drop-down list with which the parameter can be changed that controls the color coding of the 'Geo-Drilling Events Database'-layer in the map chart. This property is inserted in the text area and controls the property: "MAPviewColorBy" (see figure 10). In the map chart you can control multiple parameters by altering the settings in the legend, or in the 'layer properties' screen. These settings can be set to be controlled by a property. For the map chart, the color coding is set by the property "MAPviewColorBy". This results in the fact that the setting of map chart is coupled to the property "MAPviewColorBy", which is controlled by the drop-down list in the text area. For every property, there are multiple ways of choosing parameters to select. For the GDE database, the drop-down list with a selection of the columns from the database

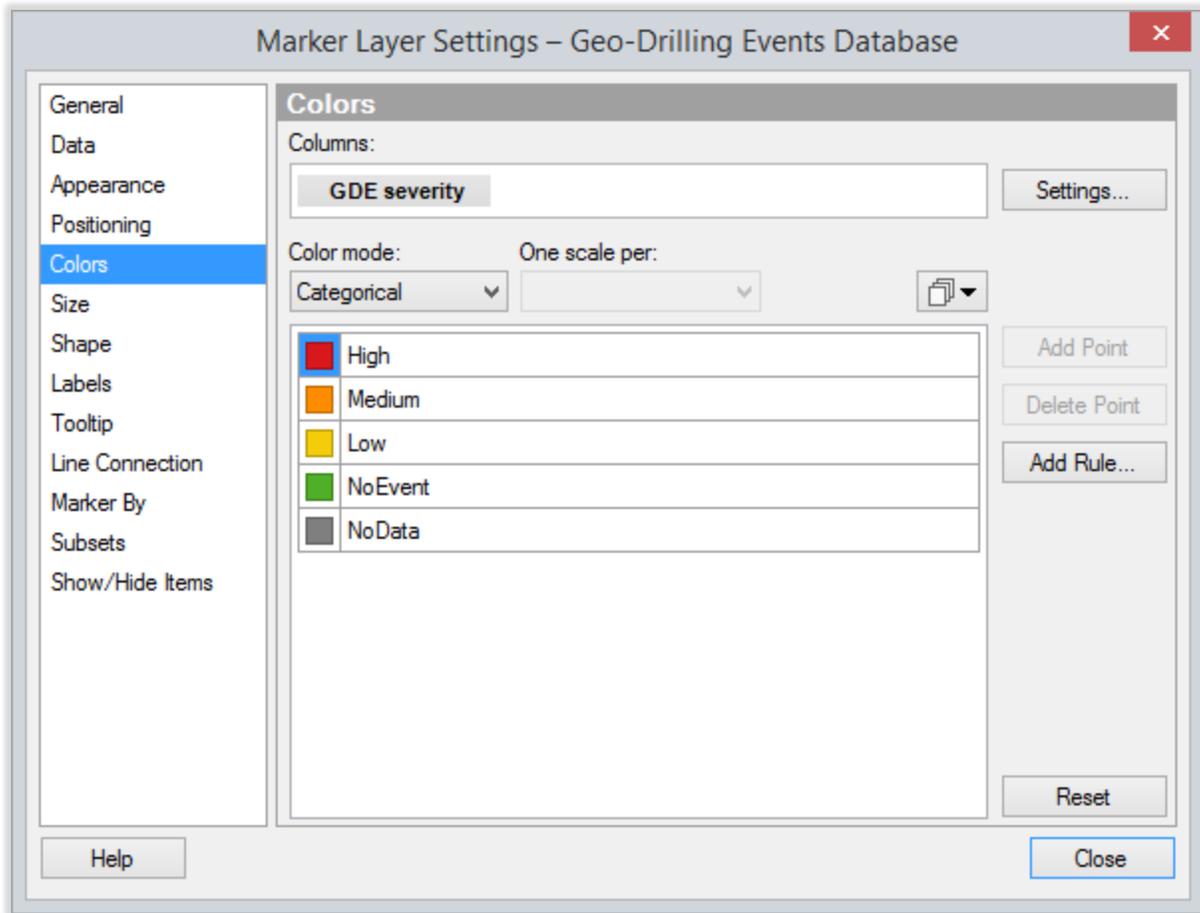


Figure 12, showing the traffic light color schemes used for the 'GDE severity'. This screen is reached via layer properties in the map chart.

parameters in the "MAPviewColorBy" property has been set manually. There have been multiple color schemes designed to make the interface of the different tabs of the Spotfire-tool more intuitive. For the column "GDE severity", a traffic light-color scheme has been chosen to show the data points in the map chart in an intuitive way (see figure 12).

In a similar way, color schemes have been developed for some feature layers, such as the hydrocarbon fields layer ('HC_Fields') and License blocks (HC_LicensesSNS, Geothermal Licenses) and for multiple parameters of the 'Geo-Drilling Events Database'-layer such as Stratigraphy or Stratigraphic group. The default color scheme (see figure 13) for 'HC_Fields' is the common international convention, with green indicating gas and red indicating oil fields. In this column properties menu, also the sort order has been changed for some parameters. For the "GDE severity" the order has been changed to a more logical 'high', 'medium', 'low' sequence. The order for the "Stratigraphy" and "Stratigraphic group" has been changed, so the order is now in the correct stratigraphic order instead of an alphabetic order (see figure 14).

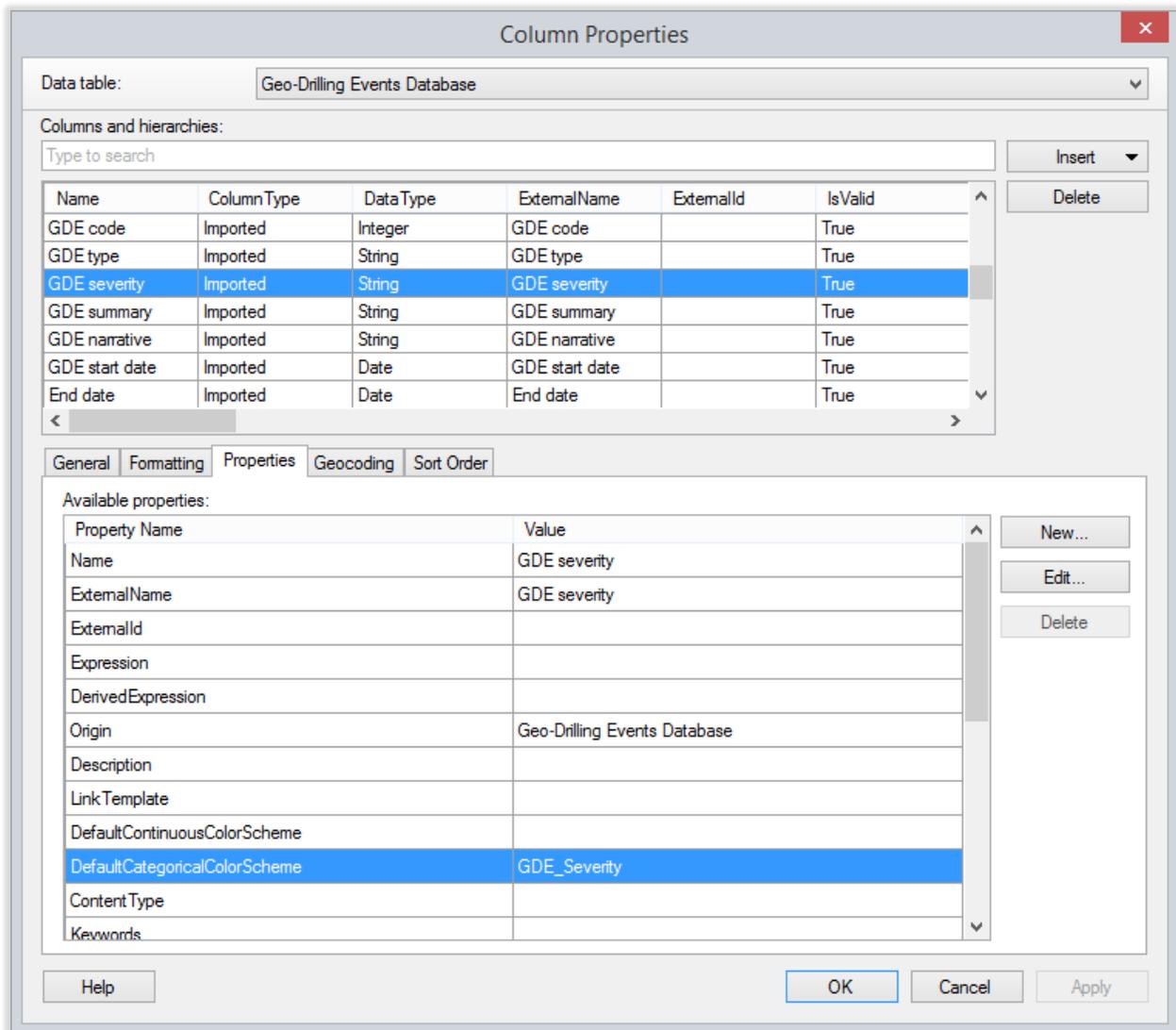


Figure 13, showing the default setting for the categorical color scheme used per column. This screen is reached via column properties.

A drawback of TIBCO Spotfire is the way it plots the data on the map, namely in chronological order per parameter. For example, when the color is set to “GDE severity”, the sort order reads: ‘High’, ‘Medium’, ‘Low’, ‘NoEvent’, ‘NoData’. Spotfire plots this series in a way that it first plots the upper classification, so ‘High’, and then plots subsequently the following classifications on top of it. This results in the fact that the most interesting drilling events are often overprinted by ‘NoEvent’ and ‘NoData’ labels. This problem is been overcome by including an option to invert the drawing order in the TIBCO Cloud environment (see figure 15).

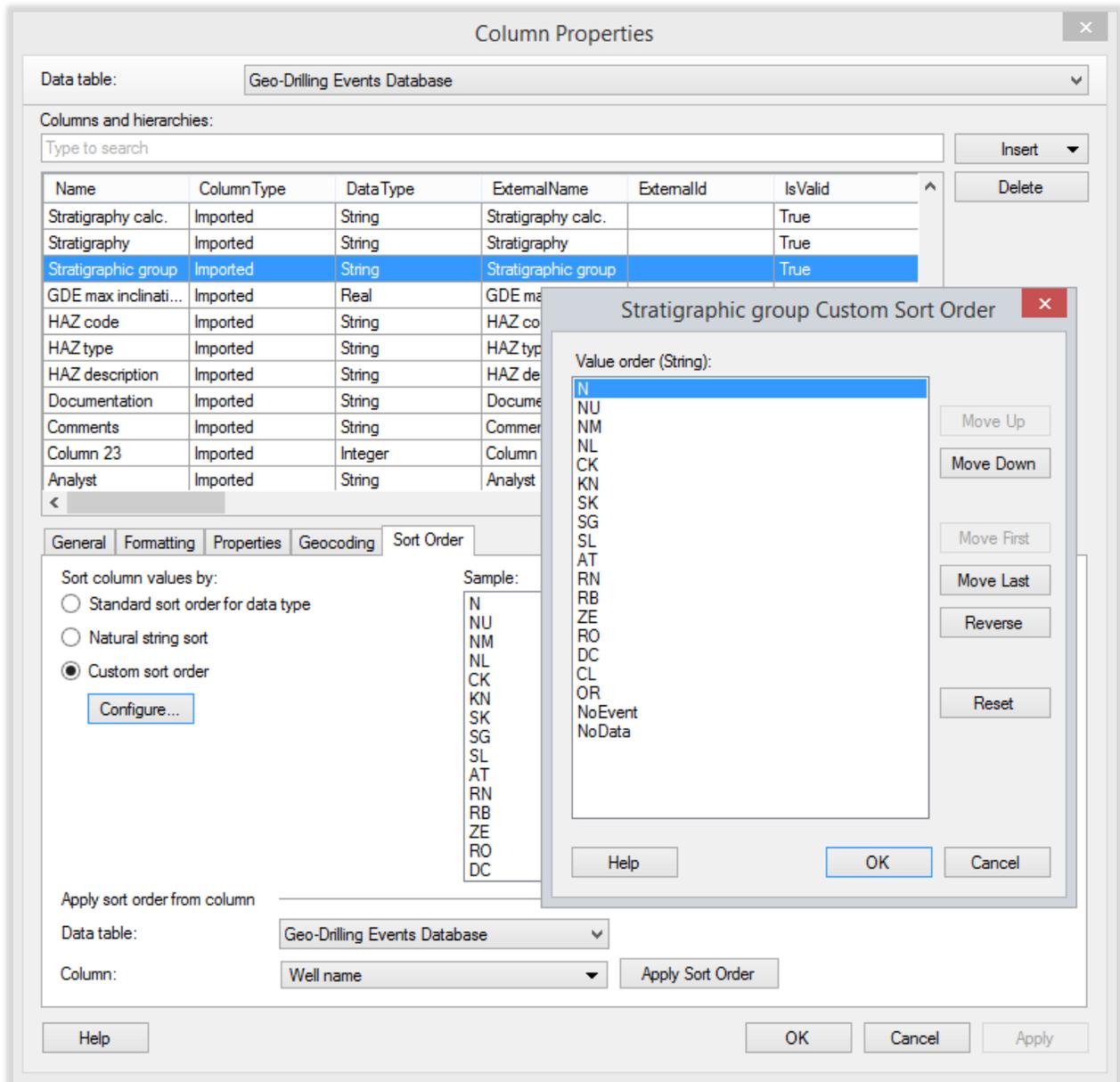


Figure 14, showing the custom sort order for the case of the stratigraphic group. This screen is reached, similarly to the screen in figure 13, via column properties.

Another feature that has been installed in the 'Map View', is that when data is selected in the map chart, labels with names of the wells appear. This is done due to the 'Marked rows' selection. The settings for this feature are shown in figure 16. The maximum number of labels that can be shown is 200.

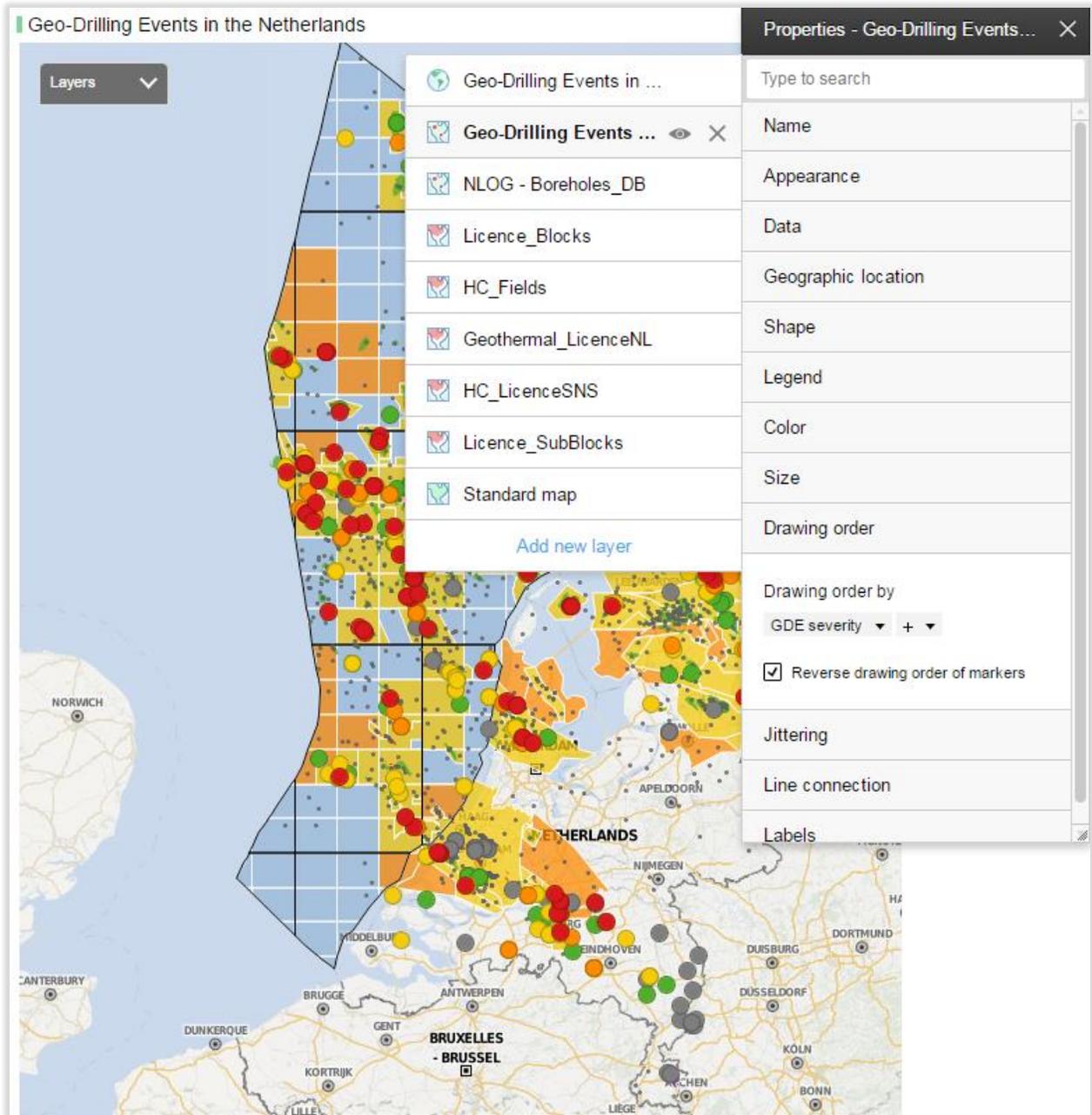


Figure 15, showing a screen from the TIBCO Cloud environment, where the drawing order of the Geo-Drilling Events Database layer has been inverted to show the 'High'-labelled data points on top, for a better representation. This screen is reached via layer properties in the map chart of the TIBCO Cloud environment.

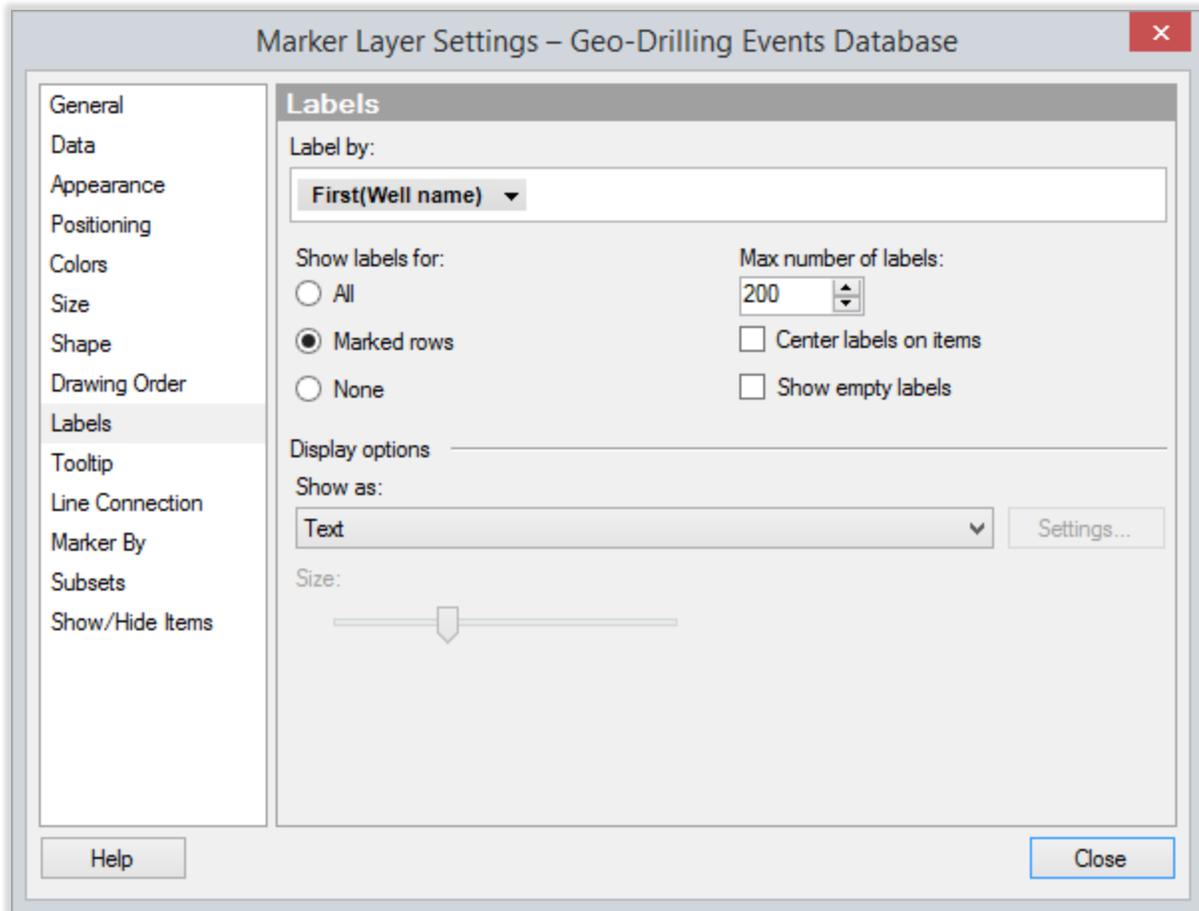


Figure 16, showing how the labels were set to show when wells are selected in the 'Geo-Drilling Events Database'-layer in the map chart. This screen is reached via the layer properties.

4.3 'Scatter Plot'

The scatter plot also has a table chart where selected data is visualized in exactly the same way as in the 'Map view'. In the table chart the legend of the data shown in the visualization is hidden, since that information is redundant here. The 'Scatter Plot' tab also has a text area with drop-down-lists for parameter selection. The scatter plot has two axes which can represent multiple parameters. The settings were made as such that the parameters for the axes, color and size can be made via properties connected to the drop-down lists. In figure 17 it is shown how the properties are connected to the parameter input in the visualization. Figure 17 shows the total list of properties made. The properties that are controlled by the drop down lists are "SCATTERplotColorBy", "SCATTERplotSizeBy", "SCATTERplotYaxis" and "SCATTERplotXaxis". There are also a set of properties called "SCATTERplotII...". These properties were made for a second scatter plot visualization. This secondary visualization is only available in a separate version of the Spotfire application, only for use by EBN. The same holds for the "PIEchartL" and "PIEchartR" visualizations. To set a parameter from a property, the button "Set from Property" must be selected in the right mouse-click menu, as shown in figure 18. This couples the choices made in the drop down list with the respective property to the setting of that parameter, which can be an X/Y-axis or the color of the plotted data.

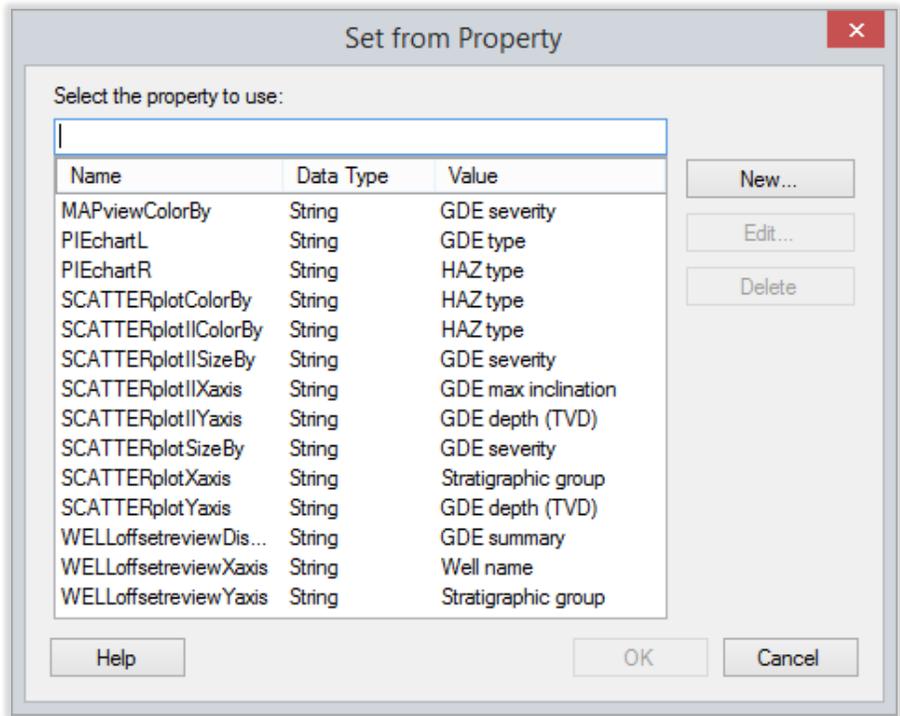


Figure 17, a list of the properties in the property menu is shown. This screen is reached via the “Set from Property” button after clicking with the right mouse-button on a parameter of choice in the legend next to the visualization (see figure 18).

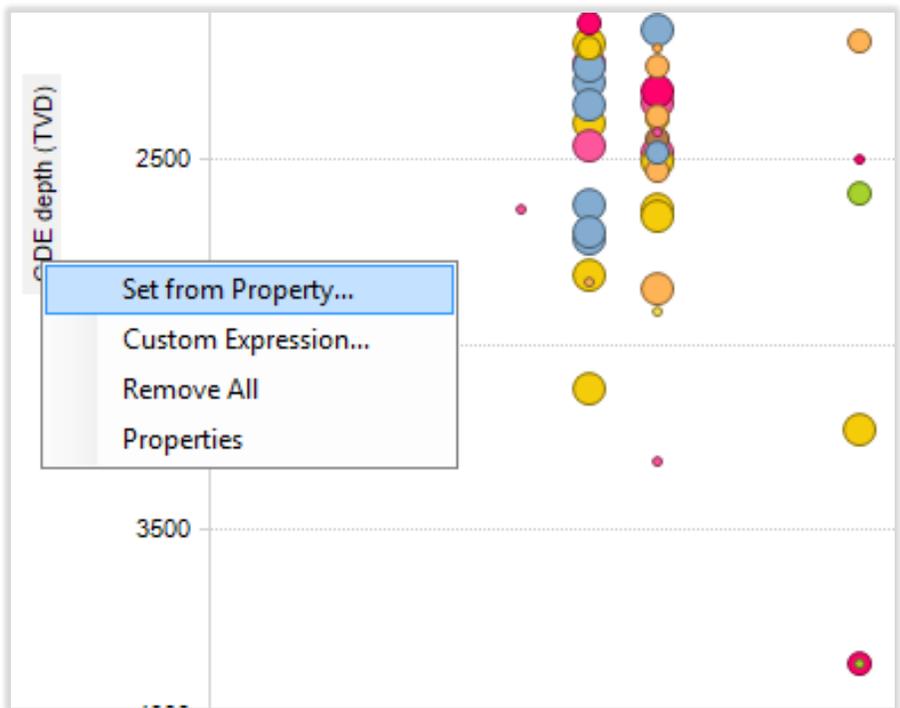


Figure 18, showing how to reach the “Set from Property” menu in order to set the variables to the parameters using the properties from figure 11 and 17.

4.4 'Well-Offset Review'

The 'Well-Offset Review' is the fourth tab in this tool, and provides a small map chart in the top left corner, as can be seen in the interface lay-out in appendix 5. This small map chart is a duplication of the map chart from the 'Map View'-tab with the same functionality and build-up, but with a different visualization of the data. Data selection is again linked, so if data is selected in the 'Map View', it will also be selected in the 'Well-Offset Review' when changing tabs. In the 'Well-Offset Review' there is no possibility to change the colors of the data in the map chart. This is again linked to the map chart in the 'Map View', so if changes to the color-coding are made in the 'Map View' these changes are also visible in the map chart of the 'Well-Offset Review'. Selected data is visualized in 2 fields besides the map chart in the 'Well-Offset Review'. The one on the top right is a data table. This data table shows information about the selected data. The displayed information contains a detailed description of the Geo-Drilling Event, the so called GDE narrative together with the stratigraphic formation in question and the Geo-Drilling Hazard. The data is also visualized in a cross-plot at the bottom of the tab. This cross-plot is set such that a small description of the Geo-Drilling Event, the GDE summary, per borehole on the x-axis is plotted against the stratigraphic group in question on the y-axis. The marking settings are the same as in the other tabs, a first order selection is made in the map chart and a subset can be selected in the table and cross plot. This setting can be seen in figure 19.

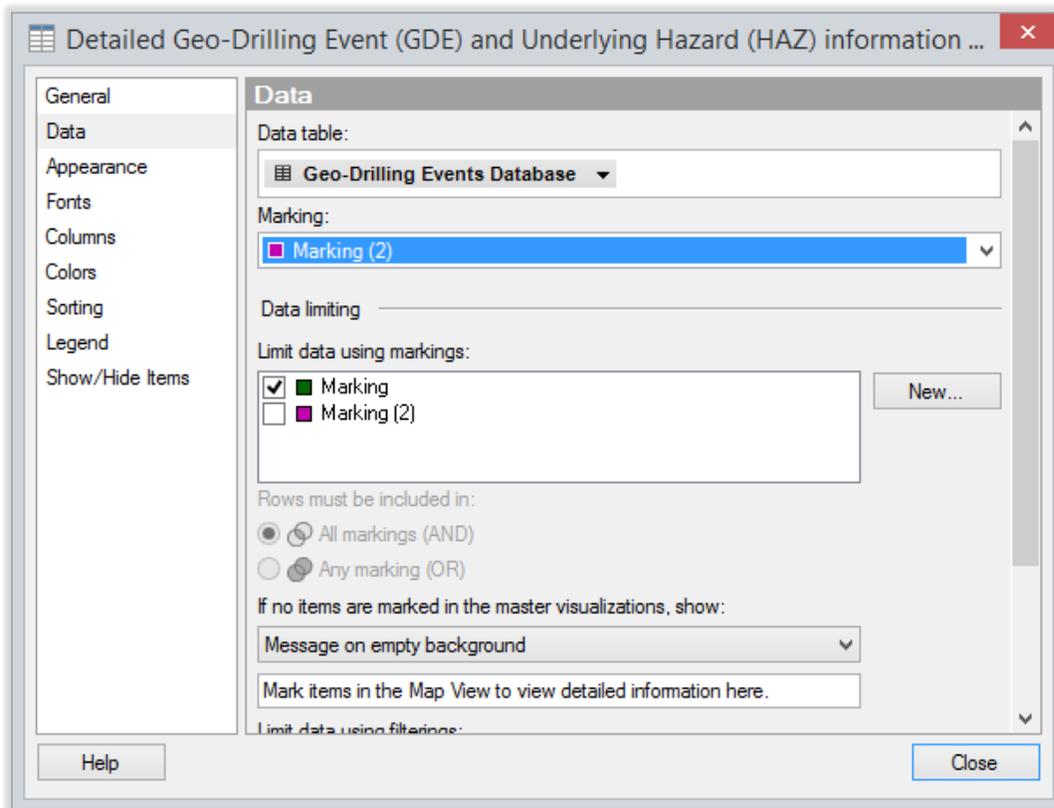


Figure 19, showing the settings for the markings used in the 'Well-Offset Review'-tab. You can see that if no items are marked, the table will show the indicated message. The projected dataset in the table is limited by the green marker layer and the visualization itself marks in the purple layer.

4.5 'Detailed Information'

The last tab of the Spotfire tool is the 'Detailed Information'. This tab is a table chart which shows almost all data which is available in the GDE Database. It is a representation of the DATABASE-sheet from the Excel file. There are no further analytical options or visualizations in this tab. The data is set as such that normally all data is shown in the table chart, but when data is selected in either one of the other tabs, only the selected set will be shown. Additional selection of a subset using the purple marker layer will also be highlighted.

4.6 Importing data into TIBCO Spotfire application

The Excel-sheet with all the data visualized in the Spotfire application is imported in Spotfire and linked in the Spotfire project. In this way new information, entered into the Excel-sheet, gets propagated into Spotfire. Data import is managed via the 'add data'-button, where a menu is entered. Spotfire can import data from certain sheets in a selected Excel file, so first the correct tab must be selected in the upper drop down list. Then, columns and rows can be selected. 'Column 23' (which is the column which holds the IF-statement for the failcheck of the GDE coordinates mentioned earlier) together with the 'Q&C' and 'Comments' columns are not added to the Spotfire project, so they are deselected. Just like column selection, rows can be selected as well. The rows resemble the information per event, but the upper rows contain generic information about the column itself. It is unnecessary to include these rows in the Spotfire project. By using the drop down lists on the left, as is shown in figure 20 these rows can be ignored. As said before, the data from the Excel-database is linked to the Spotfire project.

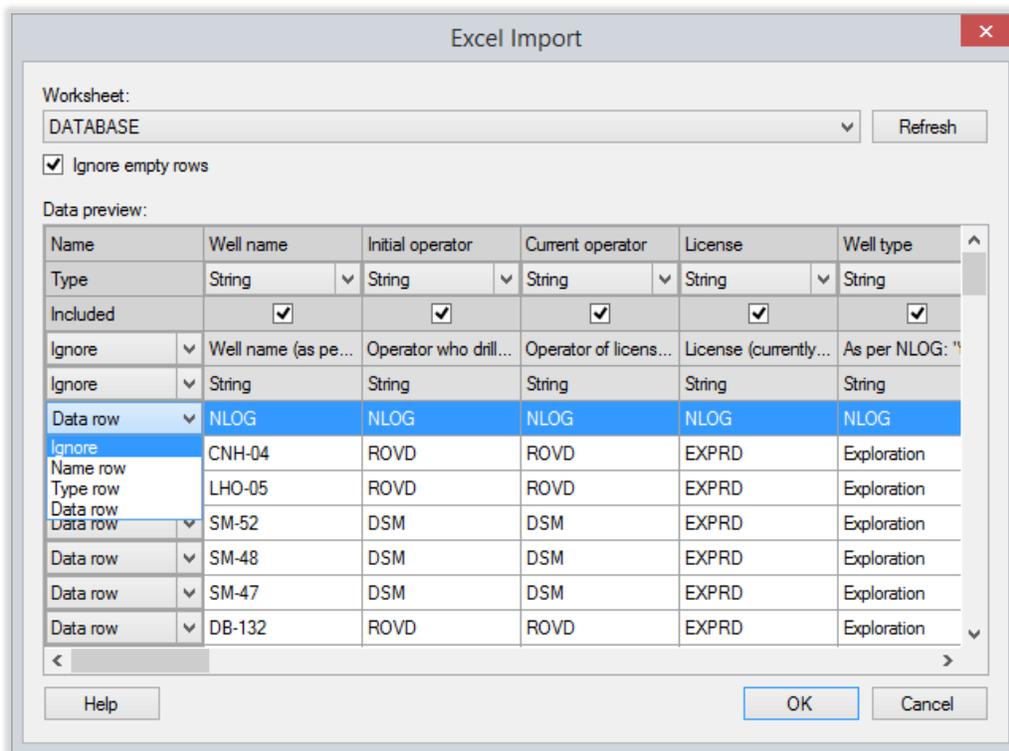


Figure 20, showing the loading settings of a dataset in Spotfire. After selecting the correct .xls-sheet in the upper drop down list, individual rows and collums can be toggled on or off.

However, for hosting of the tool in the TIBCO Cloud, the data must be embedded in order to show up in the Cloud environment. This can be established in the Data Table Properties screen, as shown in figure 21. Here it can be selected whether data is embedded or linked to the Spotfire project. Because of confidentiality, well data younger than 5 years will not be shown in Spotfire until released.

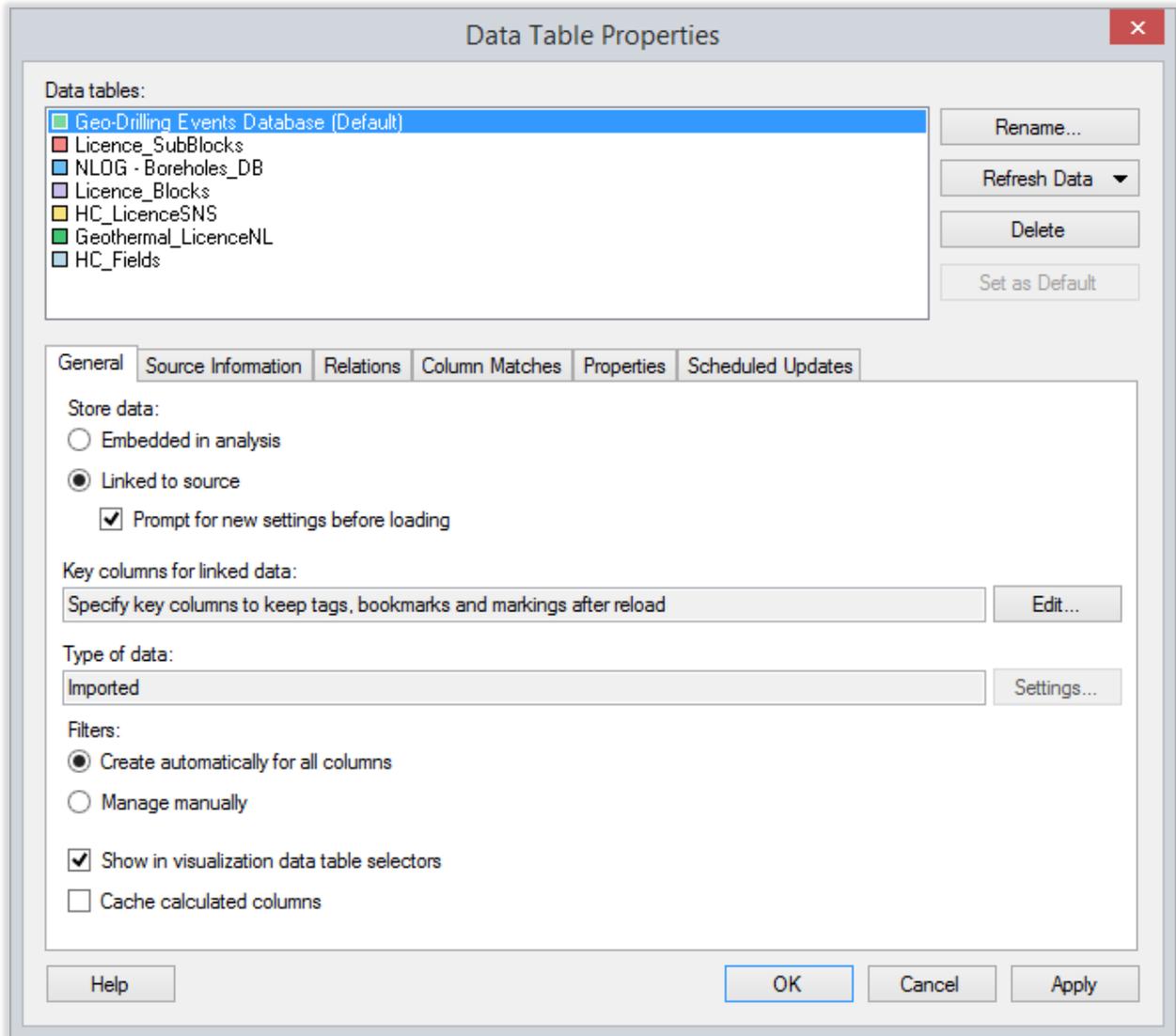


Figure 21, In this screen, the Data Table Properties screen, it can be selected whether data is linked to the source or embedded in analysis. For actualization of the data it is preferable to link the data to the source, so if changes are made to the Excel-database these changes can be seen in Spotfire as well when data is reloaded. When hosting the database in the Cloud environment or the library the data must be embedded in order to share.

4.7 Exporting data from the TIBCO Spotfire application

The hosted version of the Spotfire tool in the TIBCO Cloud environment offers possibilities to export data for professional local use. In the top right menu, data can be exported from the Spotfire-tool into a .pdf-file or a powerpoint presentation sheet. It can be chosen to either export the current tab, or only certain visualizations. If a visualization is selected, it can also be chosen to export a .png-file of just the visualization. Raw data can also be exported to a .csv-file in this export menu. For this, data must be selected in order to be exported in table form.

5. Functionality

The functionality of the Spotfire-tool has been optimized for user-friendly and convenient use. The interface is very straight forward and easy to understand. For the operators who will be working with the GDE database a walkthrough has been developed to explain all the possibilities and features of the Spotfire-tool.

5.1 'User Guide'

On the first tab of the Spotfire-tool, 'User Guide', information is provided about the Spotfire-tool itself. It emphasizes the principles of the Geo-Drilling Events database and explains how the GDEs were classified. The tab also contains the classification schemes for the GDE and its severity, combined with the HAZ classification scheme.

5.2 'Map View'

The second tab contains the interactive feature map showing all the analyzed wells on top of a map where also the licenses and hydrocarbons fields are displayed together with a subset of the wells drilled in the Netherlands. The interactive layer containing the wells analyzed in the Geo-Drilling Events database can be visualized based on different parameters which can be controlled by the drop down list "Color by". The data can be selected by clicking on them, or selecting multiple well at the same time. Data on these selected wells are then displayed in the information table. The data can be deselected by clicking on any empty area on the map or table. By selecting different filters, the displayed data can be narrowed down as requested. The data can be deselected by using the list box, check box or range filter. The selected filters can easily be deselected to reveal all the available data again. In the information table, data is shown about the selected wells in the 'Map View'. In the GDE summary a short mention is given about the nature of the Geo-Drilling Event, combined with some additional information about the well itself.

5.3 'Scatter Plot'

In the 'Scatter Plot', data can be visualized at will by selecting parameters to be displayed on the X and Y axes of the 'Scatter Plot', combined with settings for the variables controlling color and size of the data points. The data can again be selected by using the filters, but it's also possible to click on a requested parameter in the legend, to highlight that subset within all the data. The subset of the data shown in the information table can be highlighted by selecting wells within the subset. The selection of this data is connected to the different tabs, so the highlighted data is shown as well in the information tables of the 'Map View', 'Scatter Plot' and 'Well-Offset Review'.

5.4 'Well-Offset Review'

In the 'Well Offset Review', data can be selected in a small map. The data shown in this small map is linked to the large 'Map View' in tab 2. The selected data appears in the two tables, where a subset can be selected. In the lower table the Geo-Drilling Event summary is again given. By selecting the desired wells, the Geo-Drilling Event narrative can be seen in the top right table, including additional data about the Geo-Drilling Hazard.

5.5 'Detailed Information'

The final tab contains all available data of the screened wells about the Geo-Drilling Events and the underlying Geo-Drilling Hazards. Normally, all wells are shown, but once wells are selected in either 'Map View', 'Scatter Plot' or the 'Well-Offset Review', the 'Detailed Information' tab limits to the selected subset.

6. Discussion and recommendations

Hereafter several and recommendations for the Geo-Drilling Events project and Spotfire-tool will be discussed.

- The GDE classification scheme may be subjected to a revision. A term like rock properties is very general and other terms such as swelling clays or squeezing salts could also be classified as rock properties. This means that the MECE-compliance is not perfect, which is key for this classification scheme. Moreover when considering mapping uncertainties, the poor quality of seismic data could cause the incorrect interpretation of stratigraphy either as a human error or as a technical issue. These issues should be addressed, perhaps requiring a revision of the classification scheme is required.
- There are some issues with the Spotfire-tool that need to be resolved. In the "User Guide"-tab, the picture used as a banner is in the current version centered in the text area. Depending on the available screen resolution, this may result in misalignment of the text and the images. This can be resolved by changing the settings and the build-up of the text area (using tables for the appendices when applicable and changing the settings of the picture).
- For improving the technical capabilities of the Spotfire-tool, additional coding is required to improve the functionality and strength of the properties used in the tool. Coding is written in Iron-Python and can be used to give rules to certain properties. With such coding it is possible to include the GDE depth parameter as a 'colorby' option in the "Map View". In the current version of the Spotfire tool, only parameters with a categorical colorscheme can be chosen as a 'colorby' option. By use of the coding capabilities it can be arranged that both categorical and gradient colorscales can be used in the same properties without altering the other colorschemes. Use of Iron-Python can make multiple advances in the appearance of the tool.
- TNO gave advice to combine more information in the "Map View" to provide context regarding the Geo-Drilling Events. Tectonic stress maps can be overlain and show the tectonic background of the area which can give context to a certain Geo-Drilling Hazard. Another idea from TNO was to extend the concept of the GDE database to a wider spectrum. Can a similar database be made for the other causes for Geo-Drilling Events mentioned in the drilling events triangle, such as

human errors or mechanical failures? TNO is keen on working together on this project to improve the quality of the database and perform analysis on the available data. Future studies in collaboration with TNO can be of interest to EBN. This collaboration can also result in more analytical possibilities and visualizations of the Spotfire-tool because more data is available and more knowledge is used.

- There is currently no workflow for data import in the Spotfire project or data sharing via the TIBCO Cloud. The current workflow only provides information on how the information is extracted from NLOG and the EBN database and processed in Spotfire. Once the data is imported in Spotfire, still some changes have to be made to check the Spotfire-interface for flaws, before it gets uploaded. For example, wells younger than 5 years are not shown in the TIBCO Cloud version of the database, so some alteration have to be made to the data. Also the drawing order in the “Map View”, mentioned earlier is a point of interest before the Spotfire-interface is hosted. In the new Spotfire version, this setting can already be made in the Spotfire-project and not only in the Cloud-version, which changed the workflow for uploading data. Unfortunately this workflow is not documented and complex. Hence here further work is required, in particular if more people start to work on this project, which also would result in omissions and errors. For this, a workflow for the data in Spotfire might be preferable.
- The current partner version of the Spotfire-tool is hosted externally via TIBCO Cloud services. In a new release, hosting might be conducted on EBN hardware in a similar fashion as EBN’s BOON project. This second version will be the first major update of the Spotfire-tool on a technical level.
- Use of recent wells and additional data would be very beneficial for the analytical possibilities and usefulness of the Spotfire-tool. Arranging an agreement where operators and research institutes agree to share and use this data with each other would be a very serious improvement to the GDE database. Therefor last recommendation is a better collaboration between EBN, the operators in the Netherlands and research institutes like TNO. Especially in light of the recent “*Status van de Sector – Geothermie*” of *Staatstoezicht op de Mijnen*, there is a large need for a project like this to improve well safety, build quality and reduce well-costs besides the E&P industry in the geothermal sector. This collaboration would result in major contributions to the project and is of major influence to the usefulness of the Spotfire-tool when used during the well planning stage.

7. Acknowledgements

During this project, I worked together with a lot of people to get to the current results of my project. I received great help on issues with my Spotfire project and general questions about Geo-Drilling Events and the project itself. I would like to thank Guido Hoetz (EBN) for this project and his help with everything that came with it, together with Fred Beekman (UU) for his supervision of my internship. I would like to thank Ivo Nijhuis and Gert Lammers (WellSpec) for their useful contributions and suggestions to my work. I would also like to thank Pieter Slabbekoorn, Peter Bange, Tom Leeftink, Petra van Staalduinen (EBN), Roland Rutten (Quintus) and all other employees from EBN I worked with for their help with Spotfire, data-managing and any other topic we worked on. And finally, I would like to give a special thanks to all my fellow interns at EBN for the amazing time I had during my internship at EBN.

8. References

Hoetz, G., Jaarsma, B., Kortekaas, M., 2013; *Drilling Hazards Inventory: the Key to Safer –and Cheaper- Wells*, Society of Petroleum Engineers (SPE), SPE 166254-MS, SPE Annual Technical Conference and Exhibition 2013, New Orleans.

9. Appendices

<see appendices>