Drilling Hazards Inventory: the Key to Safer -and Cheaper- Wells

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Abstract

Safety and cost control are critical success factors in the realm of drilling. Actual well costs frequently exceed planned costs due to unexpected drilling incidents related to potentially avoidable geohazards. It is estimated that - in the Netherlands on average - around 20% of drilling time is spent recovering from such unexpected incidents. A significant part of this non-productive time (NPT) can be avoided if geohazards are identified upfront.

The risk assessment for a well trajectory is largely based on the experience from offset wells: boreholes in the neighbourhood that have been drilled earlier or holes drilled through similar geological settings. Easy access to relevant historic drilling data and the records of geohazards encountered in offset wells is essential for effective de-risking of future drilling programs. Currently operators typically have their own databases containing this type of information. However, their databases are often incomplete and lack data from competitor wells. Obviously, the risk assessment would greatly benefit from access to a complete set of drilling hazard data, whilst making use of “best practices” in data analyses and incident classification.

EBN B.V., the Dutch state E&P company with 0.5 million BOE/d equity production, is involved in most of the 40+ wells being drilled annually in the Netherlands. Recognising its major vested interest in improved drilling performance, EBN launched a Joint Industry Project to capture the knowledge of drilling hazards across the Industry. An important tool to classify drilling incidents is the *Drilling Incidence Triangle*. Based on this new concept, those drilling incidents that have a geological component are selected, analysed and made accessible for the Industry partners.

Background

Currently around one dozen operators are active in drilling petroleum wells in the Netherlands. Wells are positioned on and offshore and are targeting mostly gas from relatively deep reservoirs below 3km depth. In addition to offshore drilling, onshore wells are often deviated as a consequence of the limited access in the densely populated country. Consequently drilling in the Netherlands is a fairly expensive business and requires careful planning. Part of the planning has to do with the design of an efficient well trajectory that can be drilled safely and cost-efficiently. In particular, the extended reach wells need to be optimized in this respect. Experience shows that a large proportion of the wells drilled suffered from incidents that led to a change of plan and cost increases, for example as a result of sidetracking. Sometimes also the operational safety was at stake as a result of unexpected drilling incidents. The most dramatic drilling incident in the Netherlands took place in 1965 when a gaswell blowout in onshore Drenthe generated a crater that swallowed the entire drilling-rig. Fortunately, this was the first and last of such incidents in the Netherlands. Nevertheless drilling safety is increasingly and intensely debated, in particular after the Macondo incident in the Gulf of Mexico. High impact drilling risks are generally linked to overpressures or H_2S occurrences. Other drilling risks are related to salt drilling and/or hole instability. The latter category is more common and the impact is largely on the drilling costs.

EBN b.v., is involved commercially and technically in most wells as non-operator. Being a partner entitles EBN not only to petroleum revenues but also to well data including operational performances. This unique position offers EBN a good overview of the drilling performance across the country. Based on internal *drilling performance* reviews (ref. 1), it was concluded that at least 20% of the wells drilled suffered from serious cost overruns due to (unexpected) geo-drilling incidents. For this study *geo-drilling incidents* are defined as:

1) Incidents (events that are not part of the base plan) leading to at least 2 days rigtime overrun.
2) Incidents which have an underlying cause that is related to local geological features not properly identified upfront. These local geological features are referred to as geo-drilling hazards.

Geo-drilling hazards can give rise to a geo-drilling incident, in particular if not suitably anticipated in the well planning phase. We do expect an improved understanding of the geo-drilling hazards for a certain area, to result in an optimized well design. This in turn, will lead to less unexpected drilling events. Obviously, not all geo-hazards can be eliminated, but statistically, for a portfolio of drilling targets, better well performances can be expected by applying deeper knowledge.

The objective of this inventory project is to capture information from historic drilling records that is related to geo-drilling incidents and to make this available for (future) well planning. In order to specify which information is to be captured, the concept of the *Drilling Incident Triangle* is introduced.

Drilling incidents can originate from a variety of causes. Some are directly linked to mechanical equipment failure. Others incidents can be traced back to organizational issues which include operational judgments errors. A third category of incidents is related to geological surprises in the subsurface. In many cases a combination of the above factors do play a role in the cause of such drilling incidents. Conceptually, this can be illustrated by the Drilling Incidents Triangle (fig.1). In principle, every drilling incident can be plotted in this triangle, depending on the (relative) contribution of the three main causes. This study is concentrating on geo-drilling hazards and therefore targets only those drilling incidents which have a significant component of *geological surprise*s in the cause of the incidence. Given its nature, it is obvious that *Geo-Drilling incidents* require geoscientists for understanding the underling geo-hazards. Moreover, *Geo-Drilling incidents* can often be avoided by doing meticulous geological homework.

Geo-drilling hazards: examples

Typical geo-drilling hazards occurring in the Southern North Sea area, including the Netherlands, include:

- High pore pressures originating from brines or hydrocarbons (ref. 2).
- Mobile (squeezing) formations giving rise to high torque on the drill string and in extreme cases: twist-off and loss of the bottom hole assembly (ref. 3, ref.4).
- Faults giving rise to hole instability and stuck-pipe risk. (ref. 4)
- Abrasive formations, leading to bit wear and (premature) failure of equipment (ref. 1)
- H_2S occurrences leading to toxic emissions and/or equipment failure.

Certain types of drilling hazards, with their typical consequences for drilling, are depicted in figure 2.

Capturing geo-hazard information

In order to set up a database with observations of geo-drilling incidents, a classification and coding scheme has been developed. Good quality drilling *End-of-Well reports* do list the incidents that have occurred during the execution. A useful way to spot drilling incidents in drilling reports is inspection of the TZ curves (fig. 3). Unexpected delays in drilling show up as deviations from the plan. The depth of the incident is readily available from the graph whilst typically in the chronological description of the operations, the incident is discussed and interpreted. Sometimes the learnings are also listed there. For this project an incident classification and coding system is set up that describes the observations of the drilling incident made by the drilling crew. A second code allows description of the underlying geological cause which led to the incident: the geo-hazard. This second code requires interpretation of the observation(s) and, preferably, is carried out with geological knowledge of the local subsurface. In case the drilling incident had no geological component (e.g. *broken crane* or *waiting on weather*) there is no need for coding the observations as the purpose here is to capture geo-hazards only.
It turned out that, for the Dutch drilling scene, a classification scheme with just 8 types of (geo) drilling incidents is sufficient to describe all observations (Table 1). Depending on the type of geo-drilling incident, several types of *geo-hazards* can be at the root of the incident. So far 9 types of geo-hazards have been identified which are relevant for the study area (Table 2).

Category - Geological Drilling Incident		
Type of Drilling Incident Based on observation:		
DI_CODE	**Type**	**Description**
1	High Torque/Overpull	High torque or vertical resistance of the drill/casing string which can lead to stuck drill string/casing and/or excessive reaming and/or significant hole cleaning.
2	Collapsed hole	After RIH again, drilled hole found to be too tight or completely collapsed, necessitates re-drill.
3	Difficult Drilling	Excessive wear of the drill bit resulting in reduced rate of penetration or excessive number of round-trips.
4	Kicks	Flow of formation fluid into the borehole due to a higher formation fluid pressure than the fluid pressure in the borehole.
5	Losses	Flow of drill fluid/cement into the formation
6	Depth prognosis error	Actual depth significantly different than prognosed.
7	HC (unexpected)	The unpredicted occurance of hydrocarbons while drilling.
8	H2S (unexpected)	The unpredicted occurance of H2S.
9	Other geo incident	Drilling incident that has not been defined in this drilling incident list.

Table 1

Category - HAZARDS : Cause of Drilling Incident			
Type of Drilling Hazard based on observation:			
HZ_CODE	**Type**	**Description**	**Possible Factors**
A	**Abrasive formation**	Formation with abrasive effect on drill bit. The abrasive effect is caused by an high content of hard minerals in the formation: e.g. chert.	bit choice was not optimal for formation
B	**Boulders**	Large detached rocks in borehole. Typically originating from conglomerate. Can lead to trapped drillstring but also to extensive bit wear.	specific lithology, glacial channels
S	**Squeezing formation**	Borehole formation deforming under the influence of drilling activity (e.g. ductile behaviour). Movement can restrict borehole (undergauge hole), leading to stuck pipe, excessive bit	squeezing salt, swelling clays, mud properties
W	**Unconsolidated formation**	Unconsolidated formation, collapsing into the hole	
D	**Differential Sticking**	Drill string 'glued' to the borehole wall, imbedded in the filtercake, because of pore pressures lower than in the borehole	partial depletion, high permeable zone, excessive mudweight
F	**Fractures**	Formation with high permeability: e.g. karstification, fractures resulting e.g. in excessive losse	faults, fractures
G	**Unexpected Geopressures**	1) High pressures of formation fluids (gas/oil/brine) which exceeds the mud pressure and could cause influx - unstable drilling situation. 2) Formation fluid pressures lower than expected. (E.g. by depletion).	brine pockets in salt, pressure prediction
R	**Rock properties**	Rock properties different from expected	permeability, formation strength, unexpected formations
M	**Mapping Uncertainty**	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
O	**Other Geological Hazard**	Any other geologic hazards? Report to TNO to create new category.	
N	**Non-geological**	Non-geologic hazard (Weather, tool failure, human error, inadequate drill fluids, etc)	
Z	**Don't know (yet)**		

Table 2

One complete record of the drilling hazards database consists of:

1. Well name
2. Depth: where incident occurred
3. Type of drilling incident (coded according classification; table 1)
4. Underlying geological cause (coded according classification; table 2)
5. Explanation of incident and recovery (narrative, free format)

By linking above information with existing well data (e.g. as publicly available via NLOG, ref. 6), additional information can be retrieved easily. For example: date of incident occurrence, the stratigraphy of occurrence, the corresponding borehole inclination, logs available, casing schemes, etc.

Using geo-hazard information

Typically the drilling hazards database would be consulted during the well planning phase. A GIS based application allows selecting wells in the vicinity of the planned well location. Subsequently, a table will be generated that lists all the geo-drilling incidents per stratigraphic level or per casing section. In principle, one could also derive statistics on the likelihood of a certain incident to happen. Furthermore, empirical relations between, for example, hole stability and hole inclination/hole depth could be established for the local situation. Another option is to load all the 3D geo-referenced incidents into a workstation and cross-check those against seismic data. For example, it might appear that hole stability issues in the area of study, do coincide with faults identified on seismic. This offers a powerful way to integrate offset well data and seismic on one single canvas. In this way casing schemes and overall well designs can be optimized.

Feasibility tested by pilot

The concept of the drilling hazards database has been presented in 2011 to the operator community in the Netherlands via the NOGEPA (Netherlands Oil and Gas Exploration and Production Association). This body represents the interests of members, associates and the society in general and closely follows developments in safety and sustainability. It was agreed to test the concept by running a pilot which involved the compilation of all drilling incidents for a small number of wells. All operators in the Netherlands were invited to participate by making drilling incident information available. TNO, who is very experienced in well data base solutions (ref. 6.) was selected to manage this pilot project. We designed a workflow to effectively screen well files for geo-drilling incidents and offered onsite technical support where needed. The objective of the pilot was to find out how much effort it would take to extract the relevant information from historical well data. Another objective was to test the incident classification scheme and the database structure. Other non-technical objectives in the pilot study addressed political and/or commercial aspects, such as: 1) operators' opinion about sharing this kind of information and 2) the conditions to allow other parties, e.g. geothermal operators, to make use of the database. Whilst operators often consider subsurface data as confidential, many operators agreed that sharing drilling hazards information is good practice. The Macondo incident underlined once more that a serious mishap by one single operator undermines the reputation of an entire industry. A drilling moratorium as a consequence of a serious accident is felt by the entire E&P community and all parties have indeed a common interest in avoiding these altogether.

The TNO pilot was conducted in 2012. It aimed to screen at least 100 wells using the proposed methodology. It also explored various ways to access and utilise the data. As operators in the Netherlands vary in size and activity level, a key was formulated such that every operator would analyze a set of wells from their licenses in proportion to their activity level. In case of a successful pilot, a large, phased project will follow to obtain a meaningful database. It was proposed that, in due course, at least one third of all 6000 petroleum wells ever drilled in the Netherlands, should be screened for drilling incidents. With those numbers robust statistics can be derived for future well planning. The pilot would also indicate whether this goal was realistic and the manpower needed to populate the database.

All operators were supportive with the idea and all, but one, actively participated by analyzing part of their well files using the prescribed workflow. More than 120 wells were screened for occurrences of geo-drilling incidents and the corresponding data has been analyzed. The distribution of wells investigated and the outcome (geo-drilling incident observed: *yes* or *no*) is indicated in fig. 4.

The next step will be reporting back to the participants the results of the pilot study with recommendations for further work including a definition of the exact scope and timing of a follow-up project. Outstanding issues that need to be addressed include:
1) Level of detail: defining how much detail should be captured for each geo-drilling incident.
2) Data quality: how rigorous should the quality of the analysis be monitored? Can the quality assurance be left to the operator? Is it important to keep an audit trail of the analysis?
3) Roles of other stakeholders: what should be the role of the State Supervision of the Mines (SODM). Clarify to what extent participation should be mandatory (providing input and/ or retrieving data for new drilling initiatives).

Conclusions

There is significant value in anticipating drilling hazards, both in the area of operational safety, environmental hazards and costs. Assessing drilling risks for a given well trajectory starts with a thorough understanding of the information collected by previous wells in the area. Access to a "drilling hazards database" populated with data from a sufficient number of relevant wells would be of great value. This requires input and cooperation from the entire operator community. A drilling incidents classification scheme and a database structure have been pioneered that allow efficient description of the key characteristics for all types of geo-drilling incidents. A pilot has been run successfully: most operators were able to easily populate the trial database with geological incident- and hazard information. Furthermore the test demonstrated the general acceptability of the proposed workflow and database content.

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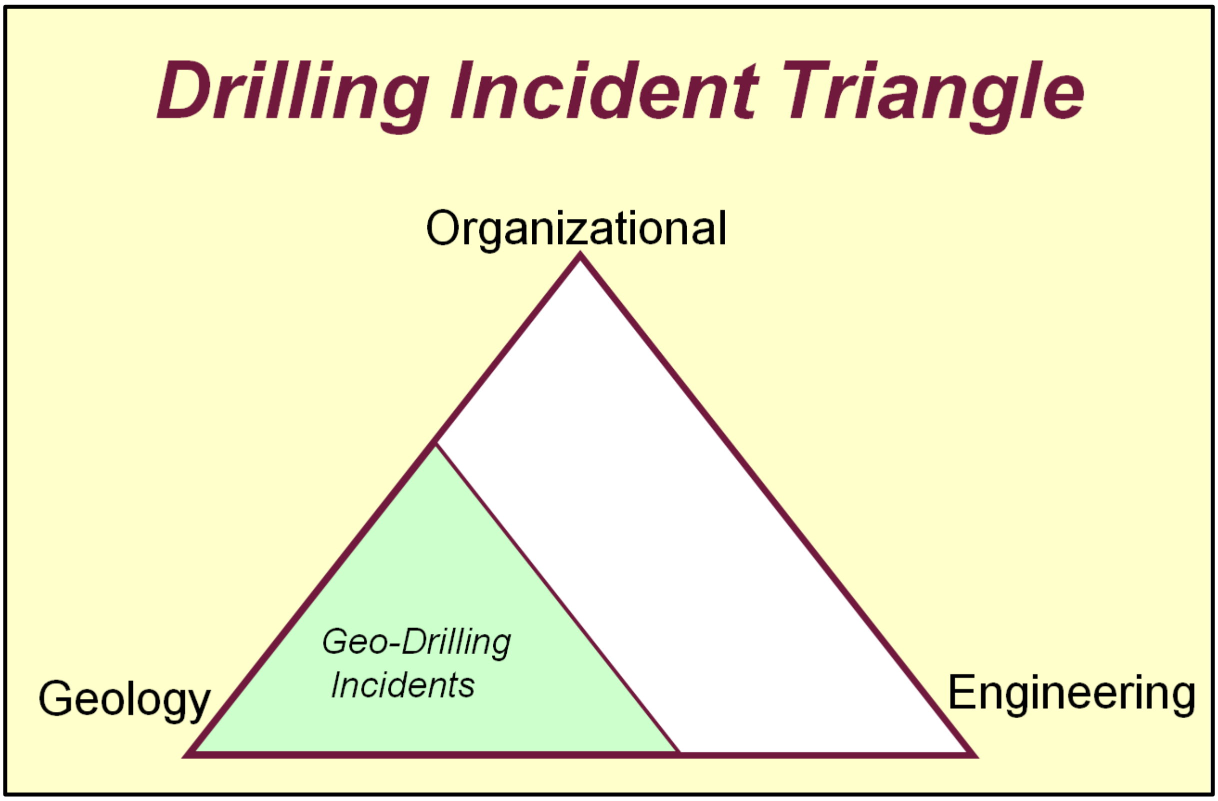

Fig. 1: Drilling incidents are often the result of a combination of factors: organizational (e.g. human error), engineering (e.g. tool failure) or geology (e.g. overpressures). Only those incidents that have a major geological component (referred to as: Geo-Drilling Incidents) are used for the Drilling Hazards Inventory.

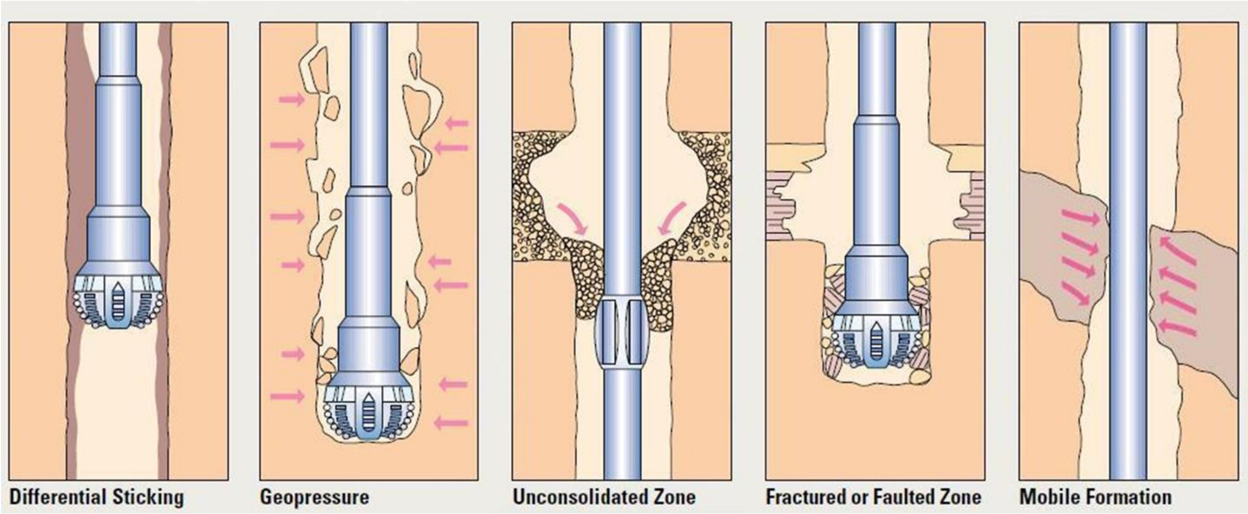

Fig. 2: Examples of drilling hazards that can lead to drilling incidents.

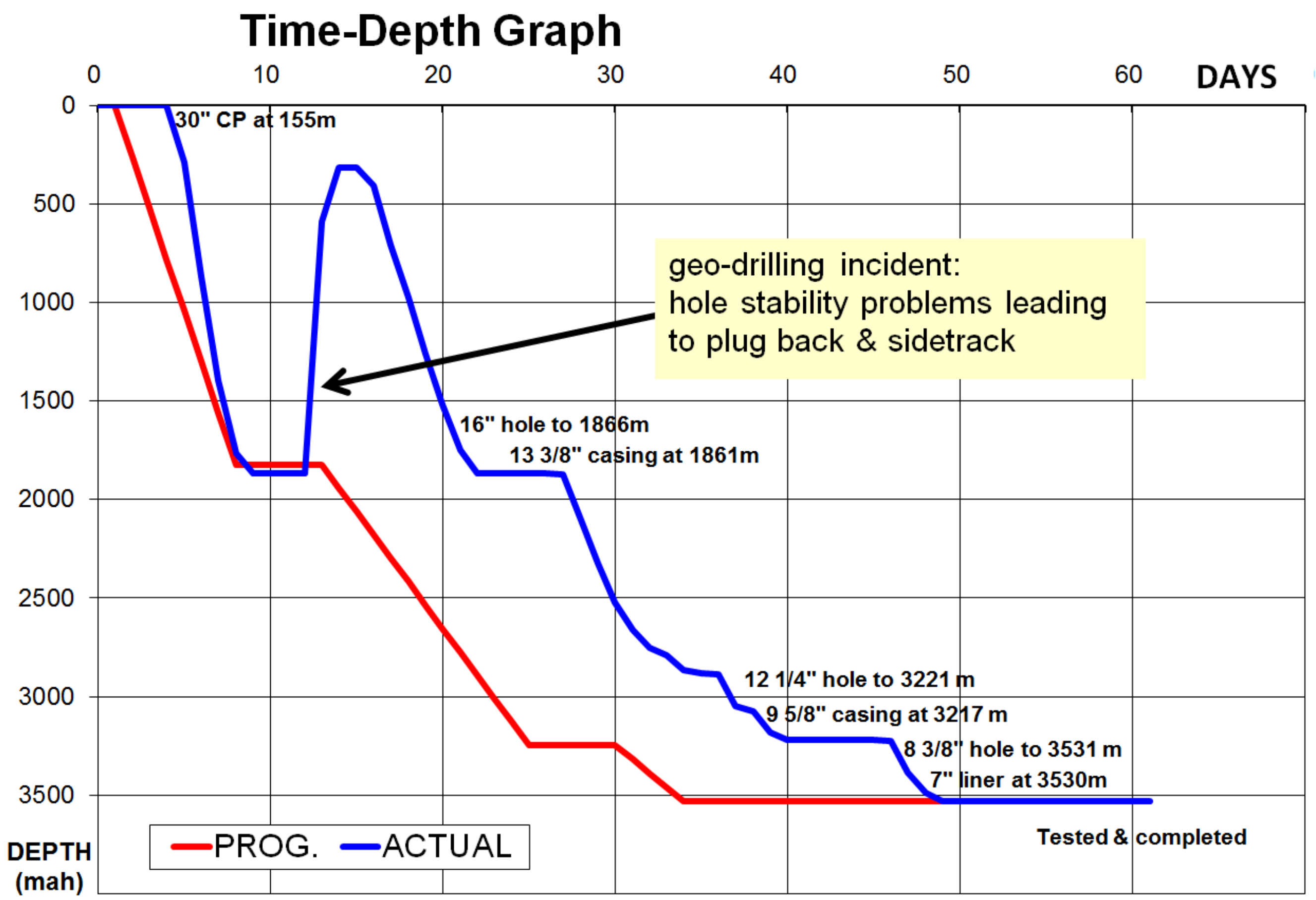

Fig. 3: Schematic Time depth curve (TZ curve) depicting bit depth against time.
Where the bit takes longer than planned, a drilling incident has likely occurred. Not all of these incidents do have a geological component.

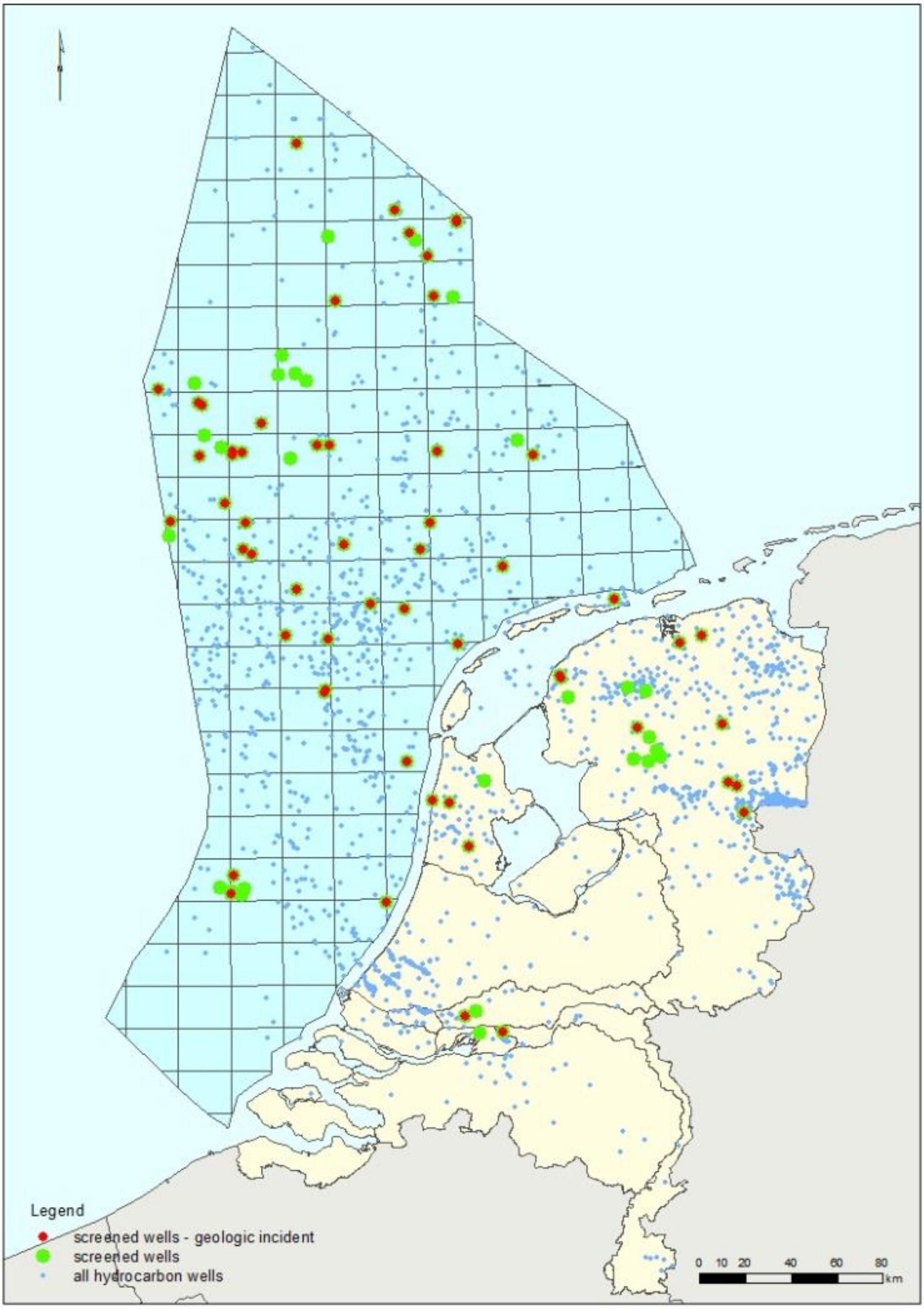

Fig. 4: Map of the Netherlands showing all hydrocarbon wells. The wells screened for geo-incidents in this pilot are indicated in green. Screened wells with a geo-incident encountered are highlighted in red. Around half of the wells investigated in this pilot had an incident with a geological component.