Chloride, Calcium Carbonate and Total Soluble Salts Contents Distribution for An-Najaf and Al-Kufa Cities' Soil by Using GIS

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Abstract The main objective of the paper is to create geotechnical maps for three soil chemical properties in An-Najaf and Kufa cities' soil by utilizing of GIS tools. This properties are the chloride concentration, calcium carbonate (CaCO_3) and total soluble salts where they affect the durability of reinforced structural elements. This paper provides an easy accurate way to represent soil properties levels for different depths of soil and create reliable database that will help engineers and decision makers. The data included

in this paper were collected for (464) boreholes with depths up to 35 m distributed on residential areas in all of An-Najaf and Kufa cities. Arc-Map of GIS 10.2.1 was used to produce the maps. It has been concluded that chloride content in the soil of the study area range from – 0.01 to 0.99% and with an average of 0.5. The maximum value found in at depth 4–6 m while the minimum value found in location at depth 4–6, 8–10 and 14–16 m. The chloride content in most of An-Najaf province has exceeded the permissible limit and

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for all, this required taking percussions to protect foundations. While calcium carbonate content in the soil of the study area range from 53 to 0.18 and with an average of 26.6. The maximum and the minimum values found at depth 4–6 m. Calcium carbonate content is within the permissible limits in most locations except in some locations.

Keywords Chloride content · GIS · Calcium carbonate (CaCO_3) · Total soluble salts (TSS) · An-Najaf and Kufa cities · Geotechnical maps · Reinforced concrete

1 Introduction

For any project to be done a complete soil investigations must be carried out, these investigations are very hard, expensive and time-consuming work. That's why, a need appear to reduce them as much as possible. The corrosion of steel reinforcement is one of the most important aspects in the durability of reinforced structural elements (Oh and Jang 2005) in addition to the failure of the concrete itself.

Chloride attack is the main cause of structural damage in reinforced structural elements which is triggered by the propagation of the chloride ions through the pore solution to the reinforcement level (Mallick et al. 2018). The chloride ions may be redounded by the ingredients of concrete mixture, such as aggregates, mixing water, cement, and Additives for concrete mixtures. Alternatively, they may spread into the sclerotic concrete from the surrounding environment (Karthick et al. 2016). The diffusion of chloride ions from the external environment through concrete to the reinforcement steel's surface, leads to the erosion of the precautionary layer and finally to reinforcement corrosion (Hirao et al. 2005). One such case is the spread of chloride ions from the surrounding soil into the hardened concrete in foundations or substructures (Maslehuddin et al. 2007). There are no guidelines or threshold limits for the chloride concentration in the soil and its influence on reinforcement corrosion (Maslehuddin et al. 2007). That is because chloride effect is dependent upon many factors such as type of cement used in the concrete mixed. Chloride does not affect the concrete or the reinforcement in direct way but it does make deterioration of concrete

from cyclic freezing even worse if the concrete was so exposed (Niville 1995). The existence of chloride ions in concrete has the potential to boost erosion of reinforcement (Al-Amoudi et al. 2015). The major concern when dealing with reinforced structural elements exposed to soils containing chlorides is erosion of reinforcement bars. Concrete permeability will have a “time” effect, where if chlorides are founded in any but the smallest amounts and there is even a little moisture in the soil, then erosion of reinforcement steel will eventually occur (Ali 2017). With comparatively impermeable concrete, the start of erosion will only be belated, and that is all. When the ground water rose above the concrete foundations they will be affected by chemical effects associated with consecutive cycles of drying and moistening. At high water table the concrete saturate with water, and when it drops, part of the water evaporates from concrete causing salts crystallizing. A following water rise causes the concrete saturation again with water that contain higher salts concentration. The repetition of this process by time causes salts crystallization inside the concrete pores, if it is permeable, resulting in a swelling leading to develop cracks in concrete. There is an allowable size limit for these cracks for various types of exposure; these limits range from 0.1 mm for very extreme environment to 0.4 mm for moderate environment (Mallick et al. 2018).

Carbonation is another chemical process which leads to concrete degradation. This process is the interaction of calcium hydroxide $\text{Ca}(\text{OH})_2$, with carbon dioxide CO_2 existing in the air. At first, carbonic acid is engender by carbon dioxide dissolving in the pore water, and it in turn reacts with calcium hydroxide to form calcium carbonate (CaCO_3) (Bonic et al. 2015). The greater permeability and porosity of concrete, the easier it is gets corroded (Glasser et al. 2008). However, the main result for concrete carbonation is the reduction of alkaline nature of concrete, which is a very important precondition for reinforcement corrosion (Bonic et al. 2015). Total soluble salts TSS is defined as all soluble soil salts, where the solubility of these salts varies by its nature. The degree of solubility is affected by the temperature, the pH value and the quantity of the dissolved carbon dioxide CO_2 , as well as evaporation and moisture (Atyah and Muir 2013). The importance of this test is to estimate the proportions of salts that cause the erosion of concrete and pipes and reinforcing steel. When their

solubility is free in water, it has a significant impact on the degree of damage to the concrete (Emmanuel et al. 2012).

This study included collect, sort and analyze the data of (464) boreholes in the study area and for depths from 0 to 35 m. The data were obtained from the National Center for Construction Laboratories & Researches (NCCLR 2016)/Babylon laboratory reports (NCCLR).

2 Methodology

The methodology of this work include the steps listed in the flow chart shown in Fig. 1.

2.1 The Study Area

An-Najaf governorate is located at the southwest of Iraq away from the capital Baghdad of about 161 km

Fig. 1 The work flow chart

Fig. 2 Location of An-Najaf province

Fig. 3 Location of study area

southwest (Fig. 1). It has an area of about 29,000 km² and comprise about 7.1% of the country total area (Mallick et al. 2018). It is located at the intersection of longitude 44°21'0" eastern and latitude 32°2'0" northern. This study involve parts of An-Najaf and Kufa cities that located between the coordinates 44°17'00" and 44°25'00" Eastwards and 32°7'0" and 31° [the researcher]. Figure 1 shows the location of An-Najaf province. Figure 2 show the of study area and locations of boreholes (Fig. 3).

Table 1 Neighborhoods numbering

Num.	Neighborhood	Num.	Neighborhood
1	Wadi Al Salam	42	Al Muthanna
2	Al Askari	43	Abu Khalid
3	Al Makrama	44	Al Mahdi
4	Al Nasr	45	Al Meelad Al Jadeed
5	Al Wafa'a	46	Al Radhawiea
6	Abu Talib	47	Al Rahma
7	Al Meelad	48	Najaf National Airport
8	Al Jam'iea	49	Scientific City
9	Al Urooba	50	Al Nida'a
10	Al Indiea	51	Najaf Technical Institute
11	Al Ghari	52	Kufa University
12	Al Jami'aa	53	Meesan
13	Al Salam	54	Kinda2
14	Al Salam Al jadeed	55	Maytham Al Tammar
15	Al Atibba'a	56	Kinda1
16	Al Ansar	57	Al Shurta
17	Al Harafieen	58	Al Mua'alimeen
18	Al Quds2	59	Al Askari
19	Al Quds1	60	Al Mutanabbi
20	Al Sina'ei	61	Al Jamia'a
21	Al Ameer	62	Al Jedaydat
22	Al Adala	63	Al Waqf
23	Al Hussien	64	Al Rashadiea
24	Al Furat	65	Al Jamhooriea
25	Al Ghadeer	66	Al Safeer
26	Civil Offices	67	Al Furat
27	Al Karama	68	Door Al Ma'amal
28	Al Hannana	69	Al Sadr Al Thalith
29	Al Sahha	70	Al Suhayliea
30	Al Ulama'a & Al Shuara'a	71	Al Sahla
31	Al Zahra'a	72	Al Jidayda 1
32	Al Qadissiea	73	Al Jidayda 3
6 + 33	Al Askan	74	Tourism Zone
34	Al Sa'ad	75	Al Jidayda 2
35	Adan	76	Commercial Zone
36	Al Mua'alimeen	77	Imam Ali Shrine
37	Al Shurta	78	Al Buraq
38	Al Jidayda 4	79	Al Mishraq
39	Al Hwoaysh	80	Al Emara
40	Al Hawra'a	81	Al Sooq Al Kabeer
41	Al Eshtiraki

Fig. 4 Chloride concentration at depths 0–2 m

2.1.1 An-Najaf City Soil Description

Generally, An-Najaf City Soil consist of sand about 50–85.1% of the soil components, with some layers of clay and silty clay soil at various depths. SPT test values that dominated on most of the region are high and exceeds 50 blows. the most existing soil conditions are dense to very dense sand, and cemented sand. Angle of Internal friction ϕ range between 26.3° and 41.2° in most of the region (Ali and Fakhraldin 2016). The bearing capacity form SPT values ranged between 5 and 20 Ton/m² in the studied region (Al-Maliki et al. 2018). Sulfate content in soil varies between 0.36 and 14% while in groundwater was between 84 and 239% (Al-Mamoori et al. 2017). Gypsum content is very high, it rang between 10 and 25% (Al-Mamoori 2017).

2.1.2 An-Najaf City Climate Description

The study area is characterized by desert climate, that is a hot dry summer and cold winter (Iraqi Ministry of Planning, Central Statistical Organization). Summer temperatures in the study area range between 41 in

Fig. 5 Chloride concentration at depths 2–4 m

June, 44 in July and 43.4 in August, while the temperatures diminish in winter to 5 in December, 4 in January, and 5.6 in February. Rainfall is limited from October to May and unevenly distributed. The total annual rainfall is 101, 112, 121 ml/cm² (Environmental Statistics Report, Iraqi Ministry of Planning). The climate is an important factor affecting the quality of soil, water and air. The increase in the amount of rain precipitation leads to the filtration of water through the soil layers, washing salts and then the rise of groundwater levels, in addition to the reduction of some elements in soil and groundwater. On the contrary the lack of rainfall and increase the temperature, especially in the summer, lead to water evaporation, soil dryness, lower ground water levels and increased crystallization of salts (Mahmoud and Jaafar 2017).

2.2 Research Method

In order to achieve the objective of the study, the following steps were taken

Fig. 6 Chloride concentration at depths 4–6 m

1. The used data were obtained from the National Center for Construction Laboratories & Researches (NCCLR)/Babylon laboratory reports. Babylon laboratory is a department that attached to the National Center for Construction Laboratories & Research (NCCLR), that is part of the Ministry of Construction and Housing authority. The laboratory is effective since its emergence in 1977. Therefore; information about the province of An-Najaf and all areas are available in this center.
2. After collecting the data, the exact locations for each borehole were obtained using GPS (see “Appendix”).
3. The data obtained was arranged in tabular format within the Excel program including the borehole location and concentrations for each depth.
4. Position the boreholes sites on the latest administrative map of the study area.
5. In order to facilitate and simplify the produced maps each *Neighborhood* was replaced by a certain number. Neighborhood’s names and numbers are listed in Table 1.

Fig. 7 Chloride concentration at depths 6–8 m

This research data were obtained from 464 boreholes spread in An-Najaf and Al-Kufa cities and for depths from 0 to 35 m.

2.3 Software Program

The Geographic Information System (GIS) is an integrated geographic information system published by the Environmental Systems Research Institute (ESRI). Arc Map is the central part of the program that has many tasks, such as mapping, editing, displaying, present digital data, working with layers, add elements to the maps such as scale and map legend. This research included sorting and categorizing the collected data in Excel program, the sorted data include the names of the sites and the sites’ features, as well as tables containing the data that we will use in the analysis process. Then the Excel file imported to the GIS program to analyze and produce maps using Inverse Distance Weighted (IDW) tool for this aspect. IDW is an interpolation method that use points with

Fig. 8 Chloride concentration at depths 8–10 m

known values or sample points to estimate values at other unknown points. In GIS program there are eight interpolation methods. Inverse Distance Weighting IDW is one of these methods which assumes that each input point has a local influence that diminishes with distance. The reason of using this method is because it can estimate extreme changes in terrain such as: Cliffs, Fault Lines, dense evenly space points are well interpolated (flat areas with cliffs) and can increase or decrease amount of sample points to influence cell

Fig. 9 Chloride concentration at depths 10–12 m

values. Finally geotechnical maps were prepared for each soil property. In this paper the version GIS (10.2.1) of the program was used.

The Geographic Information System (GIS) have tools that can help make, manage, analyze, and visualize any data specially these related to civil and urban infrastructures. It helps engineers and decision maker to transform the geotechnical data into practicable information that are useful for the reliable and

Fig. 10 Chloride concentration at depths 12–14 m

safe working with infrastructures during their lifecycle (Shahrour et al. 2007).

3 Results and Discussion

Figures 4, 5, 6, 7, 8, 9, 10, 11 and 12 show the produced maps for chloride concentrations.

From these maps it's found that chloride content in the soil of the study area range from -0.01 to 0.99%

Fig. 11 Chloride concentration at depths 14–16 m

and with an average of 0.5 . The maximum value found in at depth 4–6 m while the minimum value found in location at depth 4–6, 8–10 and 14–16 m. The maximum, minimum and average values for chloride content ranges in addition to the dangerous zone for each depth are listed in Table 2.

The high values of chloride salts content can be attributed to the rise in the groundwater levels in the region, As well as evaporation and drought factors. It is noted that the chloride content in most locations

Fig. 12 Chloride concentration at depth 35 ms

exceed the permissible value that effect on the soil engineering behavior which is 0.1%, and that poses a danger to the foundations and reinforcing steel. Increasing chloride content leads to a decrease in Atterberg limits and an increase in the value of the maximum dry density. And affect the properties of compression resistance of concrete as the resistance decreases with increasing the chloride content, especially in the early age of concrete.

The produced maps for calcium carbonate content are listed in Figs. 13, 14, 15, 16, 17, 18, 19, 20 and 21.

From these maps it's found that calcium carbonate content in the soil of the study area range from – 53 to 0.18 and with an average of 26.6. The maximum and the minimum values found at depth 4–6 m. The maximum, minimum and average values for calcium carbonate content ranges in addition to the dangerous zone for each depth are listed in Table 3.

It is noted that the soil of the study area contains a high percentage of calcium carbonate in some locations. This may be due to the geological nature of Najaf, which contains large quantities of limestone, the dry climate contributes to the deposition of carbon materials from groundwater (Allen 2005) and its union with the calcium ion form calcium carbonate. In general, calcium carbonate content in most locations and for all depths has exceeded the permissible limit

Table 2 Chloride content ranges for all depths

Depth	Chloride content %			
	Min.	Max.	Average	Dangerous areas > 0.1%
0–2	0.017	> 0.025	0.163	2, 22, 28, 36, 73, 37
2–4	0.016	> 0.25	0.158	2, 25, 29, 48, 80
4–6	0.01	> 0.25	0.5	1, 2, 76, 79, 78, 75, 72, 74, 80, 39, 38
6–8	0.014	0.23	0.122	2, 7, 1, 80, 25, 3, 45
8–10	0.01	> 0.25	0.45	2, 1, 80, 74, 39, 75, 38, 48, 20, 21, 32, 31, 17, 40, 16, 19
10–12	0.014	0.175	0.095	80
12–14	0.017	0.21	0.114	2, 3, 10, 53, 80
14–16	0.01	0.195	0.102	1, 76, 79
16–36	0.017	> 0.25	0.4	25, 1, 74, 80, 39, 78, 75, 38

Fig. 13 Calcium carbonate content at depths 0–2 m

Fig. 15 Calcium carbonate content at depths 4–6 m

Fig. 14 Calcium carbonate content at depths 2–4 m

Fig. 16 Calcium carbonate content at depths 6–8 m

Fig. 17 Calcium carbonate content at depths 8–10 m

Fig. 19 Calcium carbonate content at depths 12–14 m

Fig. 18 Calcium carbonate content at depths 10–12 m

Fig. 20 Calcium carbonate content at depths 14–16 m

Fig. 21 Calcium carbonate content at depth 35 m

Fig. 22 TSS content at depths 0–2 m

Table 3 Calcium carbonate content ranges for all depths

Depth	Calcium carbonate content %			
	Min.	Max.	Average	Location
0–2	0.5	46.75	23.6	50, 1, 14, 13, 12, 26
2–4	0.5	46	23.25	1, 28, 26
4–6	0.18	53	26.6	50, 12, 41, 40, 35, 28
6–8	0.5	52	26.25	50, 12, 1, 74, 80, 79
8–10	0.5	50	25.5	1, 74, 80, 79, 26, 9
10–12	0.5	52.5	26.5	12, 80, 1, 23, 28, 29, 41, 40, 35
12–14	0.5	44	22.25	1, 74, 80
14–16	0.5	35.5	18	1, 74, 80
16–36	0.5	49.5	25	1, 74, 21, 32

that affect the soil engineering behavior which is 30%. So this pose a risk and lead to engineering problems such as cracks, buildings differential settlement and soil weakening. As for total soluble salts (TSS) the produced maps included in Figs. 22, 23, 24, 25, 26, 27, 28 and 29.

4 Conclusions

1. Geographic Information System a helpful way to predict soil properties in non-Spatial data locations.
2. Geotechnical maps created by this work illustrate a powerful database and visual display of the data.
3. Using such maps help saving time, expenses and potentials.
4. Eventual maps created by this research will be used as a guidance for engineers and decisions makers to decide the safety of the site soil to build any project and type of suitable treatment needed.
5. The chloride content in the soil of the study area range from -0.01 to 0.99% and with an average of 0.5 . The maximum value found in at depth

Fig. 24 TSS content at depths 4–6 m

Fig. 23 TSS content at depths 2–4 m

Fig. 25 TSS content at depths 6–8 m

Fig. 26 TSS content at depths 8–10 m

Fig. 28 TSS content at depths 12–14 m

Fig. 27 TSS content at depths 10–12 m

Fig. 29 TSS content at depths 12–36 m

- 4–6 m while the minimum value found in location at depth 4–6, 8–10 and 14–16 m.
6. The chloride content in most of An-Najaf province has exceeded the permissible limit in most locations and for all and this required taking percussions to protect foundations.
 7. Calcium Carbonate content in the soil of the study area range from – 0.18 to 53 and with an average of 26.6. The maximum and the minimum values found at depth 4–6 m.
 8. Calcium Carbonate content is within the permissible limits in most locations except in some locations.
 9. The results show that the salinity of soil in the governorate is true but not absolute because

salinity is unequal for all locations and depths. This salinity is liable to increase and decrease over time according to the geological and environmental factors affecting it.

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Appendix: Boreholes Coordinates of Wells

No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.
1	1001	44 20'56"	32 0'6"	56	2019	44 18'48"	31 59'43"	111	1033	44 20'3"	31 59'37"
2	2001	44 20'56"	32 0'6"	57	3019	44 18'41"	31 59'44"	112	2033	44 20'3"	31 59'37"
3	1002	44 20'51"	32 0'25"	58	1020	44 19'22"	31 59'49"	113	1034	44 22'50"	31 58'36"
4	2002	44 20'50"	32 0'25"	59	2020	44 19'22"	31 59'49"	114	2034	44 22'52"	31 58'40"
5	3002	44 20'49"	32 0'25"	60	1021	44 18'38"	31 59'41"	115	3034	44 22'53"	31 58'37"
6	1003	44 20'40"	32 2'39"	61	2021	44 18'38"	31 59'41"	116	4034	44 22'54"	31 58'36"
7	2003	44 20'40"	32 2'39"	62	1022	44 21'6"	31 59'26"	117	5034	44 22'57"	31 58'36"
8	1004	44 19'43"	32 0'15"	63	2022	44 21'6"	31 59'29"	118	6034	44 22'55"	31 58'33"
9	2004	44 19'42"	32 0'17"	64	1023	44 22'48"	31 59'28"	119	1035	44 20'15"	32 2'19"
10	1005	44 20'0"	32 0'44"	65	2023	44 23'49"	31 59'28"	120	2035	44 20'14"	32 2'19"
11	2005	44 19'57"	32 0'47"	66	3023	44 24'15"	31 58'51"	121	3035	44 20'15"	32 2'19"
12	1006	44 19'13"	32 4'11"	67	4023	44 23'28"	31 59'56"	122	1036	44 18'29"	31 59'41"
13	2006	44 19'14"	32 4'10"	68	5023	44 23'53"	31 59'29"	123	2036	44 18'29"	31 59'39"
14	1007	44 18'34"	31 59'45"	69	6023	44 23'57"	31 59'28"	124	3036	44 18'28"	31 59'40"
15	2007	44 18'33"	31 59'44"	70	7023	44 23'51"	31 59'29"	125	4036	44 18'28"	31 59'41"
16	3007	44 18'33"	31 59'45"	71	8023	44 23'51"	31 59'29"	126	5036	44 18'27"	31 59'41"
17	1008	44 18'39"	31 59'28"	72	9023	44 23'50"	31 59'29"	127	1037	44 18'47"	31 59'42"
18	2008	44 19'4"	31 59'29"	73	10023	44 23'55"	31 59'28"	128	2037	44 18'48"	31 59'42"
19	1009	44 17'32"	32 0'25"	74	11023	44 23'54"	31 59'29"	129	1038	44 18'36"	31 59'41"
20	2009	44 17'36"	32 0'29"	75	12023	44 23'22"	31 59'41"	130	2038	44 18'36"	31 59'41"
21	3009	44 17'34"	32 0'31"	76	1024	44 21'3"	32 0'40"	131	1039	44 18'43"	31 59'42"
22	4009	44 17'29"	32 0'28"	77	2024	44 21'3"	32 0'39"	132	2039	44 18'44"	31 59'41"
23	5009	44 17'23"	32 0'30"	78	1025	44 18'33"	31 59'49"	133	1040	44 18'57"	32 3'42"
24	6009	44 17'29"	32 0'37"	79	2025	44 18'33"	31 59'49"	134	2040	44 18'59"	32 3'42"
25	7009	44 17'21"	32 0'32"	80	3025	44 18'32"	31 59'48"	135	3040	44 19'0"	32 3'43"
26	8009	44 17'19"	32 0'34"	81	4025	44 18'32"	31 59'48"	136	4040	44 18'59"	32 3'43"
27	9009	44 17'21"	32 0'37"	82	1026	44 16'46"	32 1'12"	137	1041	44 21'19"	32 0'41"
28	10009	44 17'15"	32 0'37"	83	2026	44 16'41"	32 1'12"	138	2041	44 21'20"	32 0'41"
29	1010	44 18'24"	32 3'55"	84	1027	44 19'52"	31 59'59"	139	3041	44 21'18"	32 0'41"

continued											
No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.
30	2010	44 18'25"	32 3'54"	85	2027	44 19'52"	31 59'59"	140	4041	44 21'20"	32 0'42"
31	1011	44 22'40"	32 1'4"	86	1028	44 19'11"	31 59'42"	141	1042	44 19'31"	32 3'44"
32	2011	44 22'44"	32 1'3"	87	2028	44 19'11"	31 59'42"	142	1043	44 21'12"	32 1'59"
33	3011	44 22'42"	32 1'5"	88	1029	44 19'56"	32 0'2"	143	2043	44 21'13"	32 2'0"
34	1012	44 18'37"	31 59'40"	89	2029	44 19'54"	32 0'2"	144	3043	44 21'13"	32 1'59"
35	2012	44 18'36"	31 59'40"	90	3029	44 19'56"	32 0'3"	145	1044	44 20'18"	32 3'59"
36	1013	44 19'53"	32 0'44"	91	4029	44 19'56"	31 59'58"	146	2044	44 20'16"	32 4'0"
37	2013	44 19'53"	32 0'43"	92	5029	44 19'57"	31 59'59"	147	1045	44 18'47"	32 0'29"
38	3013	44 19'56"	32 0'43"	93	6029	44 19'59"	32 0'2"	148	2045	44 18'52"	32 0'37"
39	4013	44 19'56"	32 0'44"	94	7029	44 19'59"	32 0'0"	149	3045	44 19'1"	32 0'32"
40	5013	44 19'54"	32 0'44"	95	1030	44 19'48"	32 0'4"	150	4045	44 18'34"	32 0'34"
41	6013	44 19'54"	32 0'45"	96	2030	44 19'51"	32 0'2"	151	5045	44 18'38"	32 0'37"
42	7013	44 20'2"	32 0'44"	97	3030	44 19'51"	32 0'4"	152	6045	44 18'41"	32 0'37"
43	1014	44 21'17"	32 0'27"	98	4030	44 19'50"	32 0'5"	153	7045	44 18'37"	32 0'41"
44	2014	44 21'18"	32 0'26"	99	1031	44 21'22"	31 58'42"	154	1046	44 21'19"	32 0'41"
45	1015	44 21'29"	32 0'48"	100	2031	44 21'16"	31 58'46"	155	2046	44 21'20"	32 0'41"
46	2015	44 21'14"	32 0'57"	101	3031	44 21'10"	31 58'47"	156	3046	44 21'18"	32 0'41"
47	1016	44 21'27"	32 1'4"	102	4031	44 21'20"	31 58'45"	157	4046	44 21'20"	32 0'42"
48	2016	44 21'30"	32 0'43"	103	5031	44 21'13"	31 58'48"	158	5046	44 18'49"	31 59'43"
49	1017	44 23'29"	31 59'34"	104	6031	44 21'26"	31 58'46"	159	6046	44 18'45"	31 59'43"
50	2017	44 23'43"	31 59'30"	105	7031	44 21'17"	31 58'48"	160	7046	44 18'40"	31 59'43"
51	3017	44 24'2"	31 59'26"	106	8031	44 21'12"	31 58'51"	161	8046	44 18'37"	31 59'43"
52	4017	44 24'18"	31 59'23"	107	1032	44 21'28"	32 0'42"	162	9046	44 18'51"	31 59'48"
53	1018	44 18'46"	31 59'40"	108	2032	44 21'28"	32 0'42"	163	10046	44 18'54"	31 59'48"
54	2018	44 18'46"	31 59'40"	109	3032	44 21'29"	32 0'41"	164	11046	44 18'55"	31 59'44"
55	1019	44 18'47"	31 59'46"	110	4032	44 21'29"	32 0'42"	165	12046	44 18'54"	31 59'43"
No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.
166	13046	44 18'52"	31 59'42"	222	1064	44 17'32"	32 8'13"	278	2091	44 21'19"	32 0'42"
167	1047	44 21'28"	32 0'42"	223	2064	44 13'11"	32 8'17"	279	3091	44 21'20"	32 0'42"
168	2047	44 21'29"	32 0'42"	224	1065	44 17'54"	32 7'43"	280	4091	44 21'18"	32 0'42"
169	3047	44 21'28"	32 0'41"	225	1066	44 18'57"	31 59'44"	281	5091	44 18'48"	31 59'42"
170	4047	44 21'28"	32 0'42"	226	2066	44 18'58"	31 59'44"	282	6091	44 18'36"	31 59'29"
171	5047	44 21'29"	32 0'41"	227	1067	44 20'59"	32 2'44"	283	7091	44 18'40"	31 59'54"
172	6047	44 21'29"	32 0'42"	228	2067	44 21'0"	32 2'43"	284	8091	44 18'39"	31 59'45"
173	1048	44 19'42"	32 0'28"	229	1068	44 21'31"	32 1'16"	285	9091	44 18'50"	31 59'49"
174	2048	44 19'42"	32 0'28"	230	2068	44 21'33"	32 1'17"	286	1092	44 19'52"	31 59'58"
175	1049	44 20'37"	32 0'28"	231	1069	44 19'5"	31 59'43"	287	2092	44 19'52"	31 59'58"
176	2049	44 20'36"	32 0'27"	232	2069	44 19'5"	31 59'43"	288	3092	44 19'52"	31 59'58"
177	3049	44 20'35"	32 0'29"	233	1070	44 19'10"	31 59'38"	289	1093	44 18'54"	31 59'54"
178	4049	44 20'36"	32 0'29"	234	2070	44 19'10"	31 59'39"	290	2093	44 18'54"	31 59'54"
179	5049	44 20'36"	32 0'28"	235	1071	44 19'2"	31 59'44"	291	1094	44 21'48"	32 0'43"
180	1050	44 20'47"	32 0'26"	236	2071	44 19'3"	31 59'45"	292	2094	44 21'40"	32 1'11"
181	2050	44 20'47"	32 0'26"	237	1072	44 19'9"	31 59'38"	293	1095	44 18'42"	32 2'17"

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No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.
182	1051	44 19'6"	31 59'45"	238	2072	44 19'10"	31 59'37"	294	2095	44 18'43"	32 2'17"
183	2051	44 19'5"	31 59'45"	239	1073	44 18'40"	31 59'41"	295	1096	44 18'57"	31 59'48"
184	1052	44 19'1"	31 59'45"	240	2073	44 18'40"	31 59'40"	296	2096	44 18'58"	31 59'48"
185	2052	44 19'1"	31 59'44"	241	1074	44 19'8"	31 59'39"	297	3096	44 18'57"	31 59'48"
186	1053	44 19'14"	31 59'47"	242	2074	44 19'8"	31 59'40"	298	4096	44 18'57"	31 59'49"
187	2053	44 19'14"	31 59'47"	243	1075	44 19'9"	31 59'39"	299	1097	44 18'40"	31 59'53"
188	1054	44 19'0"	31 59'44"	244	2075	44 19'9"	31 59'39"	300	2097	44 18'42"	31 59'54"
189	2054	44 19'0"	31 59'45"	245	1076	44 19'9"	31 59'40"	301	3097	44 18'41"	31 59'54"
190	1055	44 18'4"	31 59'28"	246	2076	44 19'9"	31 59'40"	302	1098	44 22'18"	31 59'37"
191	2055	44 22'40"	31 58'14"	247	1077	44 19'3"	31 59'46"	303	2098	44 22'18"	31 59'38"
192	3055	44 22'30"	31 58'43"	248	2077	44 19'4"	31 59'46"	304	3098	44 22'17"	31 59'38"
193	4055	44 18'56"	31 59'45"	249	1078	44 19'9"	31 59'41"	305	1099	44 21'28"	32 0'41"
194	1056	44 21'4"	31 59'41"	250	2078	44 19'9"	31 59'41"	306	2099	44 21'4"	32 0'41"
195	2056	44 21'5"	31 59'43"	251	1079	44 21'12"	32 0'29"	307	3099	44 21'28"	32 0'41"
196	1057	44 20'21"	32 3'52"	252	2079	44 21'11"	32 0'29"	308	4099	44 21'35"	32 0'42"
197	2057	44 20'23"	32 3'51"	253	1080	44 21'12"	32 0'54"	309	5099	44 19'3"	31 59'42"
198	3057	44 20'20"	32 3'52"	254	2080	44 21'13"	32 0'52"	310	1100	44 19'26"	32 4'2"
199	4057	44 20'22"	32 3'52"	255	1081	44 19'0"	31 59'46"	311	2100	44 19'28"	32 4'2"
200	1058	44 20'40"	32 0'28"	256	2081	44 18'59"	31 59'46"	312	1101	44 18'30"	32 2'30"
201	2058	44 20'41"	32 0'28"	257	1082	44 19'5"	31 59'46"	313	2101	44 18'30"	32 2'31"
202	3058	44 20'43"	32 0'29"	258	2082	44 19'5"	31 59'46"	314	3101	44 18'31"	32 2'32"
203	4058	44 20'44"	32 0'29"	259	1083	44 21'13"	32 0'35"	315	1102	44 18'33"	31 59'53"
204	5058	44 20'42"	32 0'27"	260	2083	44 21'12"	32 0'36"	316	2102	44 18'35"	31 59'51"
205	6058	44 20'43"	32 0'28"	261	3083	44 21'12"	32 0'36"	317	1103	44 16'59"	32 1'0"
206	7058	44 20'41"	32 0'26"	262	4083	44 21'12"	32 0'36"	318	2103	44 16'54"	32 0'57"
207	8058	44 20'43"	32 0'27"	263	1084	44 18'58"	31 59'46"	319	3103	44 16'52"	32 1'4"
208	9058	44 20'45"	32 0'28"	264	2084	44 18'57"	31 59'46"	320	1104	44 23'33"	32 0'13"
209	10058	44 20'42"	32 0'26"	265	1085	44 19'1"	31 59'46"	321	2104	44 23'32"	32 0'14"
210	12058	44 20'46"	32 0'28"	266	2085	44 19'0"	31 59'46"	322	3104	44 23'32"	32 0'13"
211	14058	44 20'43"	32 0'25"	267	1086	44 18'38"	31 52'54"	323	1105	44 20'35"	32 1'37"
212	1059	44 18'36"	31 59'24"	268	2086	44 18'38"	31 21'53"	324	2105	44 20'37"	32 1'37"
213	2059	44 18'36"	31 59'28"	269	1087	44 19'0"	31 59'46"	325	1106	44 20'42"	31 59'26"
214	1060	44 20'12"	32 2'43"	270	2087	44 18'59"	31 59'46"	326	2106	44 20'42"	31 59'26"
215	2060	44 20'8"	32 2'43"	271	1088	44 18'38"	31 59'40"	327	1107	44 21'9"	32 0'29"
216	1061	44 18'59"	31 59'44"	272	2088	44 18'38"	31 59'40"	328	2107	44 21'9"	32 0'28"
217	2061	44 18'58"	31 59'44"	273	1089	44 18'40"	31 59'40"	329	1108	44 18'46"	32 2'34"
218	1062	44 21'11"	32 1'11"	274	2089	44 18'43"	31 59'40"	330	2108	44 18'47"	32 2'20"
219	2062	44 21'14"	32 1'7"	275	1090	44 21'48"	32 2'15"	331	1109	44 20'32"	31 59'4"
220	1063	44 19'4"	31 59'45"	276	2090	44 21'48"	32 2'14"	332	2109	44 20'29"	31 59'0"
221	2063	44 19'3"	31 59'44"	277	1091	44 21'20"	32 0'40"	333	1110	44 23'38"	32 1'33"

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No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.
334	2110	44 23' 24"	32 1'33"	393	1137	44 18' 47"	32 3'12"	452	2160	44 22' 2"	32 0'37"
335	1111	44 20' 11"	31 59'21"	394	2137	44 18' 47"	32 3'11"	453	1161	44 20' 14"	32 45'28"
336	2111	44 20' 10"	31 59'21"	395	1138	44 21' 12"	32 1'55"	454	2161	44 20' 17"	32 33'1"
337	1112	44 21' 16"	32 1'11"	396	2138	44 21' 12"	32 1'54"	455	3161	44 20' 19"	32 36'58"
338	2112	44 21' 16"	32 1'4"	397	1139	44 20' 57"	32 1'7"	456	4161	44 20' 16"	32 23'14"
339	1113	44 22' 55"	31 58'35"	398	2139	44 20' 56"	32 1'8"	457	1162	44 22' 17"	32 0'3"
340	2113	44 22' 54"	31 58'36"	399	1140	44 18' 36"	31 59'50"	458	2162	44 22' 16"	32 0'4"
341	3113	44 22' 53"	31 58'36"	400	2140	44 18' 36"	31 59'49"	459	3162	44 22' 17"	32 0'4"
342	1114	44 22' 7"	32 3'34"	401	1141	44 18' 35"	31 59'49"	460	4162	44 22' 17"	32 0'4"
343	1115	44 18' 33"	31 59'40"	402	2141	44 18' 35"	31 59'49"	461	1163	44 20' 3"	32 2'32"
344	1116	44 22' 32"	31 58'31"	403	1142	44 18' 47"	32 3'12"	462	2163	44 20' 3"	32 2'32"
345	2116	44 22' 31"	31 58'29"	404	2142	44 18' 47"	32 3'11"	463	1164	44 21' 29"	32 0'42"
346	1117	44 19' 40"	32 1'58"	405	1143	44 20' 53"	32 2'14"	464	2164	44 21' 28"	32 0'41"
347	2117	44 19' 40"	32 1'58"	406	2143	44 20' 52"	32 2'14"				
348	3117	44 19' 40"	32 1'58"	407	1144	44 19' 2"	31 59'52"				
349	4117	44 19' 40"	32 1'58"	408	2144	44 19' 2"	31 59'51"				
350	5117	44 19' 40"	32 1'58"	409	1145	44 18' 51"	32 3'13"				
351	6117	44 19' 40"	32 1'58"	410	2145	44 18' 51"	32 3'12"				
352	7117	44 19' 40"	32 1'58"	411	1146	44 18' 46"	31 59'49"				
353	8117	44 19' 40"	32 1'58"	412	2146	44 18' 46"	31 59'50"				
354	1118	44 20' 14"	32 2'51"	413	1147	44 19' 56"	32 1'49"				
355	2118	44 20' 14"	32 2'50"	414	2147	44 19' 56"	32 1'51"				
356	1119	44 20' 57"	32 0'2"	415	1148	44 18' 59"	32 3'58"				
357	2119	44 20' 58"	32 0'1"	416	2148	44 18' 58"	32 3'40"				
358	1120	44 22' 13"	32 0'1"	417	3148	44 19' 0"	32 3'46"				
359	2120	44 22' 14"	32 0'1"	418	1149	44 19' 36"	32 5'14"				
360	1121	44 20' 21"	32 0'19"	419	2149	44 19' 42"	32 5'13"				
361	2121	44 20' 22"	32 0'19"	420	3149	44 19' 39"	32 5'14"				
362	1122	44 18' 59"	31 59'43"	421	1150	44 19' 36"	32 3'19"				
363	2122	44 18' 57"	31 59'28"	422	2150	44 19' 37"	32 3'18"				
364	1123	44 18' 44"	32 6'4"	423	3150	44 19' 35"	32 3'18"				
365	2123	44 18' 36"	32 7'14"	424	1151	44 21' 44"	32 2'24"				
366	1124	44 18' 6"	32 11'28"	425	2151	44 21' 42"	32 2'23"				
367	2124	44 19' 50"	32 0'5"	426	3151	44 21' 45"	32 2'22"				
368	1125	44 19' 31"	32 0'53"	427	4151	44 21' 47"	32 2'23"				
369	2125	44 19' 32"	32 0'56"	428	5151	44 21' 45"	32 2'26"				
370	1126	44 20' 20"	31 59'51"	429	6151	44 21' 43"	32 2'26"				
371	2126	44 20' 21"	31 59'51"	430	1152	44 21' 8"	32 2'45"				
372	1127	44 20' 32"	32 1'34"	431	2152	44 21' 0"	32 1'15"				
373	2127	44 20' 32"	32 1'33"	432	3152	44 21' 28"	32 1'16"				
374	1128	44 18' 57"	31 59'30"	433	4152	44 19' 5"	31 59'44"				
375	1129	44 19' 16"	31 59'19"	434	5152	44 19' 4"	31 59'42"				
376	2129	44 19' 17"	31 59'18"	435	1153	44 19' 8"	31 59'38"				
377	1130	44 19' 18"	32 3'56"	436	2153	44 19' 11"	31 58'52"				

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No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.	No.	Borehole codes	Long.	Latt.
378	2130	44 19' 18"	32 3'55"	437	1154	44 23' 37"	32 1'36"				
379	1131	44 19' 51"	31 59'6"	438	2154	44 23' 36"	32 1'37"				
380	2131	44 19' 50"	31 59'5"	439	1155	44 22' 48"	31 58'35"				
381	1132	44 21' 41"	32 0'41"	440	2155	44 22' 48"	31 58'38"				
382	2132	44 21' 40"	32 0'40"	441	3155	44 22' 51"	31 58'39"				
383	1133	44 19' 11"	31 59'56"	442	4155	44 22' 52"	31 58'37"				
384	2133	44 17' 28"	32 0'35"	443	1156	44 18' 50"	32 2'24"				
385	3133	44 17' 29"	32 0'31"	444	2156	44 18' 49"	32 2'23"				
386	1134	44 19' 6"	31 59'50"	445	1157	44 18' 43"	32 1'30"				
387	2134	44 19' 6"	31 59'50"	446	2157	44 18' 43"	32 1'32"				
388	1135	44 4' 34"	31 6'11"	447	1158	44 20' 0"	32 0'5"				
389	2135	44 4' 10"	31 6'47"	448	2158	44 19' 59"	32 0'5"				
390	3135	44 3' 7"	31 11'20"	449	1159	44 19' 57"	31 58'56"				
391	1136	44 18' 42"	31 59'51"	450	2159	44 19' 57"	31 58'56"				
392	2136	44 18' 42"	31 59'51"	451	1160	44 22' 3"	32 0'36"				

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