Interreg North-West Europe

Carbon Connects

European Regional Development Fund

THEMATIC PRIORITY

LOW CARBON

MONITORING REPORT

KWETSHAGE, BELGIUM
CARBON CONNECTS PILOT SITE

MONITORING PERIOD: SEPTEMBER 2020 - FEBRUARY 2022

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EDITION: MARCH 2022

Content

ACKNOWLEDGMENTS

This document is an output from the Interreg NWE Carbon Connects project, which has received European Regional Development Funding through the Interreg IVB NWE Programme.

1 Overall objective

In the pilot Kwetshage a rewetting of a total area of approximately 100 ha is being prepared. The purpose of the rewetting is the creation of a wetland within the Natura 2000 network.

An area of approximately 100 ha will be transferred from mainly agricultural land to wetland. A part of this area is involved within Carbon Connects.

The main question addressed within Carbon Connects is what amount of CO2-emission is avoided by means of the pilot's rewetting.

Due to a delay in getting the environmental permit it was not feasible to start the rewetting during the project period of Carbon Connects. However, an area within the pilot of approximately 12 ha is already rewetted, due to a lack of management of ditches during the last 10 to 15 years. This has resulted in surface water levels that are 20 to 30 cm higher than in the rest of the pilot area, particularly during winter and spring. In fact hydrological conditions in this restricted area are more or less the conditions aimed at for a large part of area after rewetting. This gives the opportunity to compare CO2-emission between rewetted and non-rewetted conditions.

In order to obtain data on the effect of the rise of the surface water level on groundwater levels an intensive monitoring was set up, from which data can be used to make conclusions on the influence of groundwater level on CO2-emission.

A time series of groundwater levels from different parts of the pilot is available. Additionally an extensive ecohydrological study has been performed in 2015 including the calculation of a total water balance of the area.

Collected data on C-emission, water quality and water quantity were used to estimate the total amount of avoided C-emission in the pilot Kwetshage after rewetting.

2 Monitoring setup in Kwetshage: methods

2.1. Plots

Three test areas were established in Kwetshage. The following monitoring equipment was installed:

The test areas were provided with 2 monitoring wells:

A deep well with filter under the peat (in Pleistocene sand) and a shallow well with filter in clay and peat.

Each monitoring well has diameter of 5 cm and is fitted with a filter of 1 m length.

Soil profile description was carried out when deep well was installed

Each monitoring well is equiped with a diver (In-Situ Rugged TROLL100). Start date of the measurements 12/11/2020.

x, y and z coordinates of the monitoring wells have been measured on 22/12/2020 (Flepos).

Characteristics of the monitoring wells:

Nr	X	Y	Top of the well	Δh	Surface level	Length of well	Basis of filter
			m TAW	m	m TAW	m	m TAW
CARP001X	62100,74	211360,06	2,79	0,86	1,93	2,96	-0,17
CARP002X	62100,00	211360,02	2,78	0,86	1,92	1,96	0,82
CARP003X	61614,27	211212,14	2,70	0,80	1,90	2,96	-0,26
CARP004X	61613,71	211211,97	2,91	1,01	1,90	1,96	0,96
CARP005X	61447,19	211124,35	2,96	0,93	2,03	2,96	0,00
CARP006X	61446,60	211124,09	2,72	0,70	2,02	1,96	0,76

2. In each plot a weather station was installed, which measures air temperature and precipitation. Sensors for measuring soil humidity are installed.

3. Installation of 3 rings per test area for measuring soil respiration

4. Surface of 64 m² is kept free for measuring biomass

Location of the test areas (plots) and monitoring wells (piezometers) are shown respectively on figure n° 1 and n° 2 in annex.

2.2 Measurements and sampling schemes

Water quantity

Divers in the piezometers have been measuring water levels continuously from 13/11/2020 untill 6/01/2022. Therefore for each plot there are two time series from nearly 14 months. For another piezometer there is a time series since 2015.

Water quality

✳ Ground water

Per test are samples are taken in the two monitoring wells for analysing: pH, EC, anions (chloride, sulphate, carbonate, bicarbonate, nitrate, nitrite, hydroxides, phosphate), cations (Ca, Mg, K, Na, Mn, Fe^{2+}, Fe^{3+}, NH_4, Al), total P, orthophosphate, total S, sulphate, total N, nitrate, ammonium, TOC dissolved (dissolved total organic carbon).

✳ Sampling scheme for water quality

In winter (November – April) samples were taken on a 2-monthly basis. During summer samples were taken on a 2-weekly basis. One day prior to the sampling, the well was emptied by means of manual pumping. So in total samples were taken on 16 different dates. For each date all parameters were analysed.

Table 1: Sampling scheme water quality

date	date
Emptying well by pumping	Taking the sample
7/12/2020	8/12/2020
17/02/2021	18/02/2021
14/04/2021	15/04/2021
28/04/2021	29/04/2021
10/05/2021	11/05/2021
26/04/2021	27/05/2021
9/06/2021	10/06/2021
23/06/2021	24/06/2021
14/07/2021	15/07/2021
28/07/2021	29/07/2021
11/08/2021	12/08/2021
25/08/2021	26/08/2021
15/09/2021	16/09/2021
29/09/2021	30/09/2021
13/10/2021	14/10/2021
15/12/2021	16/12/2021

Gas flux measurements

During winter (November – March) gas flux measurements were done on a monthly basis, whereas during summer the measurements were performed on a 2-weekly basis. Soil samples were taken on the same basis. Four times an extended soil analysis was performed by taken samples up to 1 m under surface level. So samples were taken on 20 different dates between 8/12/2020 and 14/12/2021.

Table 2 Sampling scheme CO_2 flux measurements

date	gasflux measurements	Soil analysis extended (0-100 cm under surface area)	Soil analysis restricted (0-30 cm under surface area)	Bulk density (use socket)	Peat sampling	Determining yield and CNP analyse vegetation
12/8/2020	x	5			1	
12/15/2020	x					
1/12/2021	x		3			
2/17/2021	x		3			
3/9/2021	x	5		x	1	1
4/13/2021	x		3	x (if too wet in March)		
4/27/2021	x		3			
5/10/2021	x		3			
5/25/2021	x		3			
6/8/2021	x	5			1	1
6/22/2021	x		3			
7/13/2021	x		3			
7/27/2021	x		3			
8/10/2021	x		3			
8/24/2021	x		3			
9/14/2021	x	5			1	1
9/28/2021	x		3			
10/12/2021	x		3			
11/8/2021	x		3			
12/14/2021	x	5			1	1

3 Results

3.1 Soil description

Plot 1045

Date: 12/11/2020

Groundwater level: -10 cm under surface level

Soil use: mown

Soil mapping (CVB): OU2: peat extracted soils, heavy profile; Soil mapping (VLM): B3f, profiel B3f

Test area plot 1045 8/12/2020

Soil profile

Table 3 Soil profile plot 1045

A	0-12 cm	Moist, 10YR 3/2 very dark greyish brown, humous, clay, weak crumble structure, very many very fine roots, randomly oriented, , 1-3 mm roots present, Ca-
B	12-50 cm	Moist, 2.5Y 4/1 tot 2.5Y 5/1 dark grey to grey , clay, 25% clear 10YR 5/6 yellowish brown oxido-reduction stains 3-5 cm, 2 mm border, many very fine roots vertically oriented,, 1 root of reed with 1 cm diameter, crushed roots of reed, Ca-
Cr	50-60	Moist, 2.5Y 3/1 very dark grey, clay, no rvk, fine roots present, washed peat, Ca-
2Vr	60-110	Moist to very moist, 7,5YR 2.5/1 tot 10YR 2/1 black, peat, no rvk, very fine roots present, some small wood fragments (< 1 cm), 60-80 cm larger fragments of peat, 80-110 cm amorfous peat, Ca-
3A	110-125	Muddy, 10YR2/1 black, sand, no rvk, no roots, Ca- (black buried surface horizont)
3Bc	125-140	Muddy, 10YR 3/2 very dark greyish brown, sand, no rvk, nog roots (browned horizon) Ca-
3C	140-200	Muddy, 2.5Y 4/2 dark greyish brown,sand no rvk,no roots, Ca-

Plot 1060

Date: 12/11/2020

Groundwater: -12 cm under surface level

Soil use: grazed by cattle, many stepwells

Soil mapping (CVB): OU2: peat extracted soils, heavy profile, Soil mapping (VLM): B2e, profile B3f

	
Test are plot 1060, 8/12/2020	Soil profile

Table 4 Soil profile plot 1060

A	0-30 cm	Slightly moist, 10YR 3/2 very dark greyish brown, humous, clay, crumble structure 1cm, very many very fine roots and many fine roots, bottom 25 cm 20% clear 7.5YR 4/6 strong brown rvk, Ca-
B(r)	30-40 cm	Moist, 10Y 4/1, heavy clay, 3% indistinct rvk, very many fine roots present, Ca-
2Vr	40-95	Very moist, 10YR 2/2 very dark brown 10YR 2/1 black, heavy clay, no rvk, very fine roots present, crushed reed root stems, wood fragments (Alnus), birch twig, from 70 cm more amorphous, Ca-
2A	95-105	Wet, 10YR 3/1 very dark grey, sand, no rvk, no roots, Ca-
3B	105-130	Wet, 10YR3/2 very dark greyish brown, sand no rvk, no roots, Ca-
3C	130-150	Muddy, 5Y 5/2 greyish brown, sand, no rvk, no roots, Ca-
4C (r)	150-215	Wet, 10GY 5/1 greenish grey sand to 5GY 5/1 greenish grey sandy loam, no rvk, no roots, Ca- (tertiary material)

Plot 1063

Date: 12/11/2020

Groundwater: shallow well -6 cm under surface level, deep well -13 cm onder surface level

Soil surface: grazed with cattle many stepwells

Soil mapping (CVB): OU2: peat extracted soils, heavy profile, Soil mapping (VLM): B2e, profiel B3f

Test are plot 1063, 8/12/2020

Soil profile 1063

Table 5 Soil profile plot 1063

A1	0-20 cm	Moist, 10YR 3/1 very dark grey, humou, clay, crumble structure 0,5 cm, very many very fine randomly oriented en fine roots present, Ca-
A2	20-25 cm	Moist, 10Y 4/1, dark grey, humous, clay 30% 7.5YR 4/6 dark yellowish brown rvk 1 cm large, very many very fine roots randomly oriented, Ca-
B1	25-40	Moist, 2.5Y 4/1 dark grey, heavy clay, 40% pronounced 7.5YR 5/4 brown rvk, very fine roots vertically oriented present, Ca+
B2	40-70	Moist, 2.5Y 5/1 grey, heavy clay, 20% clearly 2.5Y 5/6 light olive brown rvk, very fine roots vertically oriented present, Ca+
	68-70	Washed out layer of peat and clay
2Vr	70-110	Moist to very moist, 10YR2/2 very dark brown to 10YR 2/1 black, peat wood fragments, peaces of bark especially 70 – 90 cm, underneath more amorphous, crushed reed roots, no rvk, Ca-
3A	110-125	Very moist, 10YR 2/1 black, loamy sand, no rvk, no roots, Ca-
3B	125-135	Very moist, 10YR 2/2, very dark brown, sand, no rvk, no roots, Ca-
4C1	135-180	Muddy, 5Y 5/2 olive grey to 10Y 5/1 greenish grey, sand, reduced, Ca-, Tertiary
4C2	180-210	Muddy, 5G_5-4/2 greyish green, sandy loam to clay, grijsachtig groen, zandleem tot klei, fieldstone fragments to 8 cm, reduced, white spots – threadlike in the chunks, Ca+, Tertiary

3.2. Water quantity

Plot 1045 (CARP001X - CARP002X)

CARP001X and CARP002X are the wells in plot 1045, which are located within the rewetted area. Groundwater levels during the monitoring period are presented in figures 1 (absolute levels) and 2 (relative to surface level).

Untill the end of March water levels in the shallow well (CARP002X)are within 0,1 m under surface, with short periods of levels slightly above surface. Then water level drops to approximately 0,30 m under surface level by the end of April. This is due to a dry period in March and April. During a wetter period in May water level goes up to 0,1 m under surface level. During a dryer period in June water level drops again to approximately 0,1 m under surface. From mid June onwards a wet to very wet period starts, which lasts until the end of July. During this period groundwater fluctuates between 0,3 and 0,1 m under surface. From the end of July a drier period starts, whereby water level drops to 0,55 m under surface by the end of September.

By the beginning of October groundwater levels have again reached levels of less than 0,1 m under surface. This situation lasts during November and December.

During the measuring period (13/11/2020 – 6/01/2022) there seems to be a permanent infiltration to the groundwater as levels of the deep well CARP001X are generally lower than the shallow well CARP002X. This effect is even more pronounced during the summer period, where the mean difference in head between the two wells is 12 cm. Mean groundwater levels are 1,74 and 1,77 m TAW for respectively CARP001X and CARP002X. Surface level at this plot is 1,90 m TAW meaning mean groundwater levels of respectively 16 cm and 13 cm under surface level. Mean groundwater levels for the period April – September 2021 are respectively 1,63 and 1,66 m TAW, or 27 and 24 cm under surface level. Median groundwater levels in the periode April – September 2021 are respectively 1,67 and 1,69 m TAW, or 23 and 21 cm under surface level.

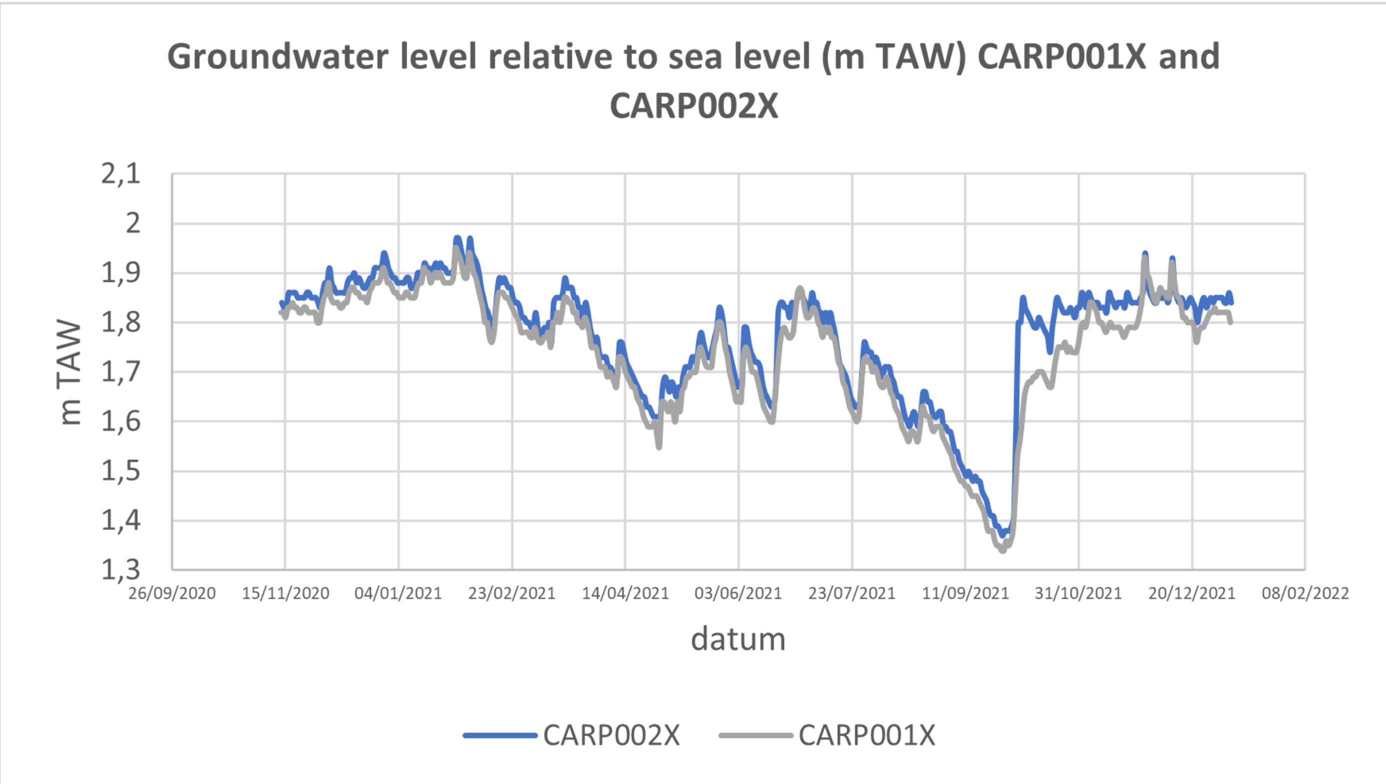


Figure 1 Groundwater level relative to sea level (m TAW) CARP001X and CARP002X

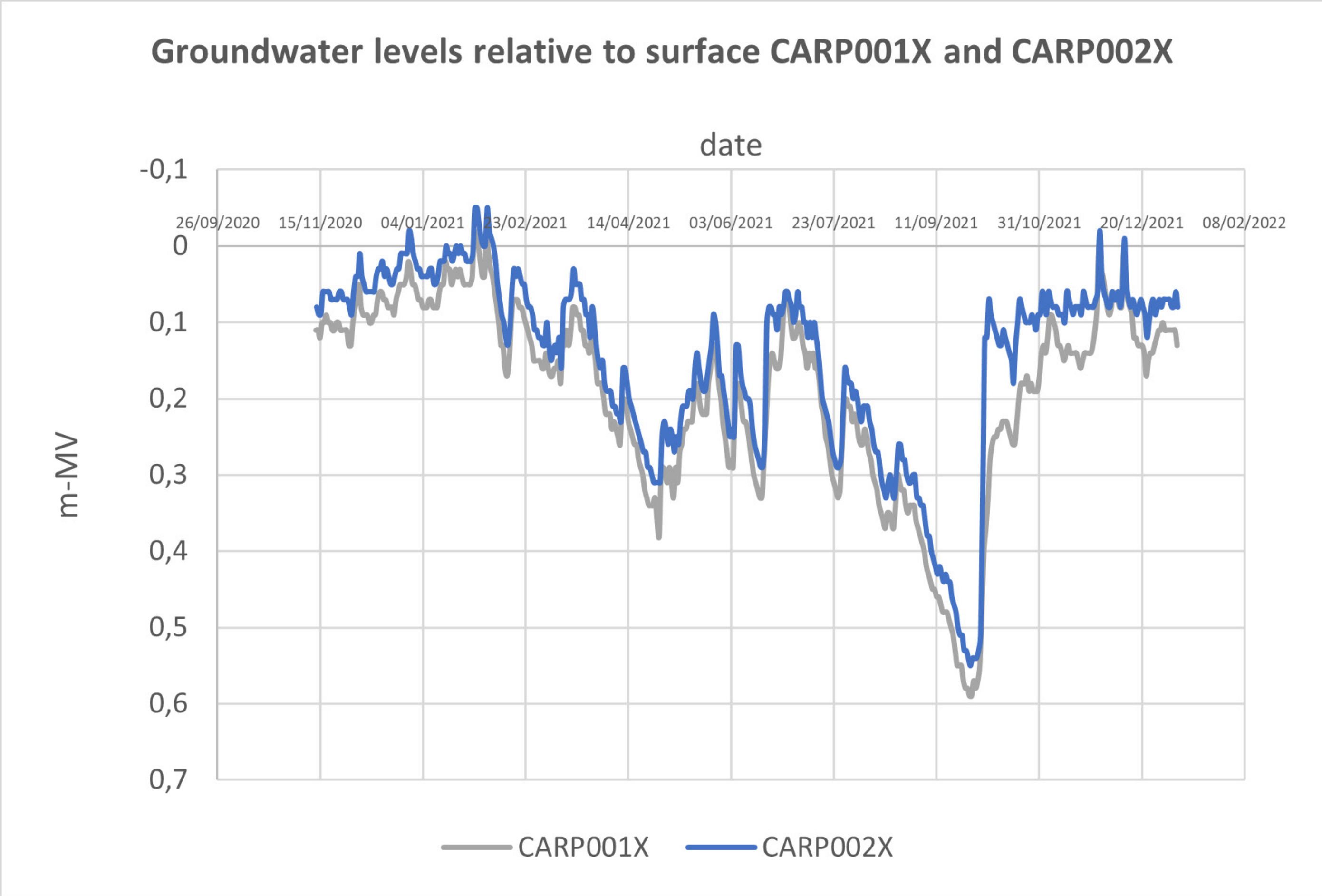


Figure 2. Groundwater level relative to surface CARP001X and CARP002X

Plot 1060 (CARP003X and CARP004X)

Water levels are lower during the period November – April in comparison with the shallow well of plot 1045 (CARP002X) (figures 5 and 6). The mean difference relative to sea level (m TAW) is approximately 8,6 cm. During the period May – September we see the reverse where groundwater levels in plot 1060 are approximately 4,5 cm higher in comparison with plot 1045. In the periode October – December mean water level relative to sea level (m TAW) level is 2,2 cm lower in comparison with plot 1045. Over the entire period November 2020 – December 2021 mean water level is 2,5 cm higher in plot 1045.

After a dry period in September 2021 water levels drop to 55 cm under surface level in plot 1045, whereas in plot 1060 water level does not drop under 40 cm under surface level.

The difference between the shallow well and the deep well is very limited, with the level in the shallow well slightly higher over the full period (mean 1 cm higher) (figures 3 and 4). Unlike plot 1045 infiltration to deeper groundwater seems much less pronounced in comparison with plot 1060. Mean groundwater levels are 1,74 and 1,75 m TAW for respectively CARP003X and CARP004X. Surface level at this plot is 1,92 m TAW meaning mean groundwater levels of respectively 18 cm and 17 cm under surface level. Mean and median groundwater level for the period April – September 2021 is 1,70 m TAW for both wells., or 22 cm under surface level.

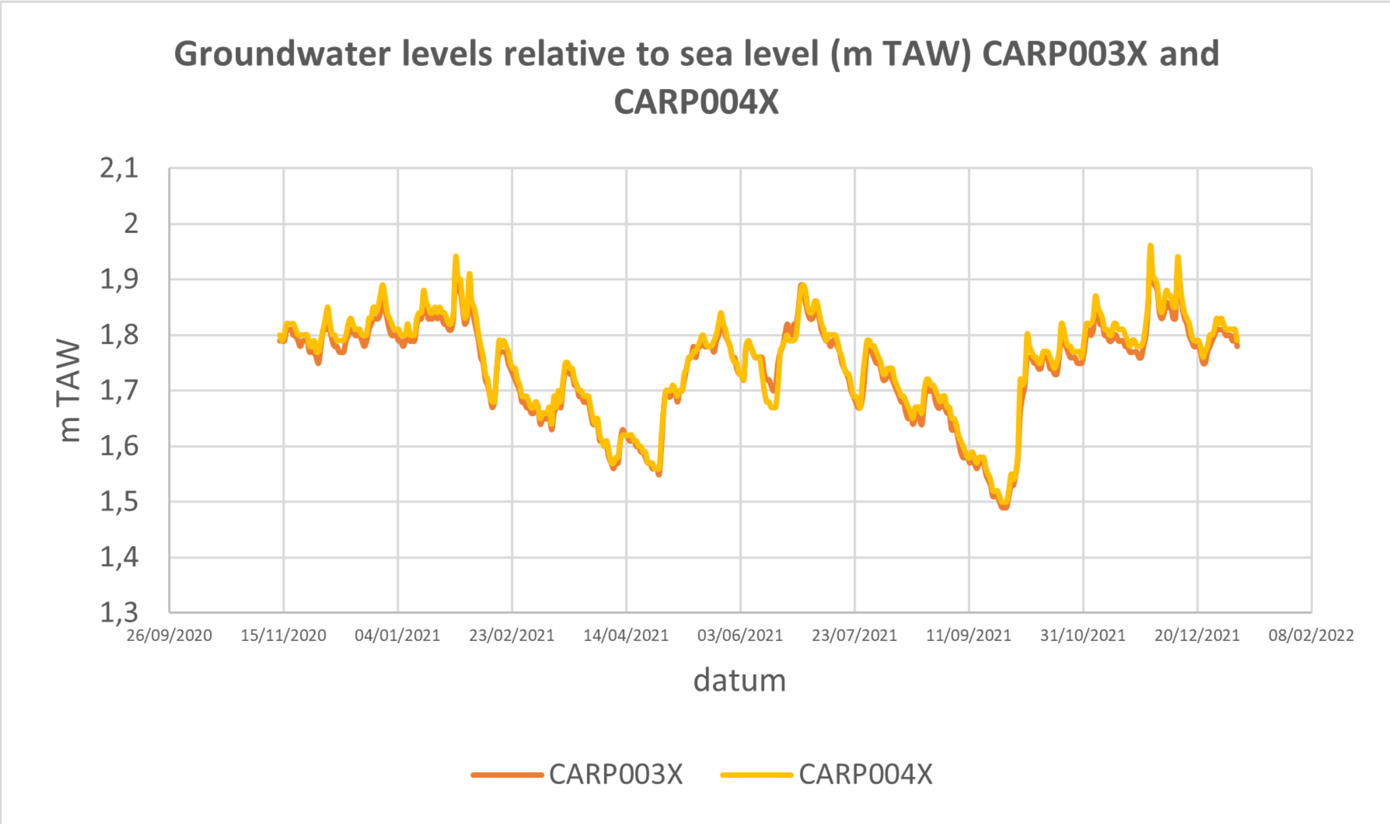


Figure 3 Groundwater level relative to sea level (m TAW) CARP003X and CARP004X

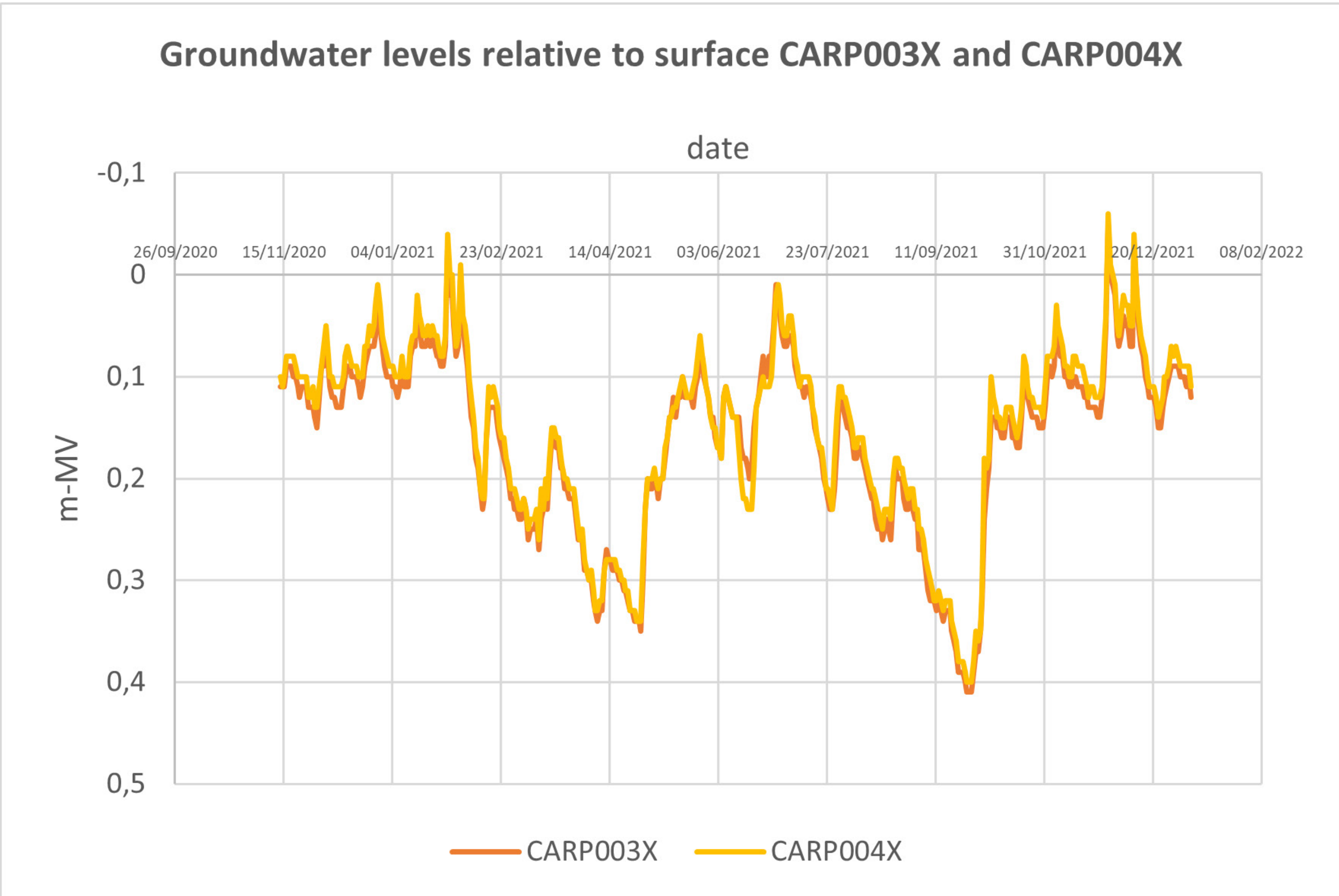


Figure 4. Groundwater level relative to surface CARP003X and CARP004X

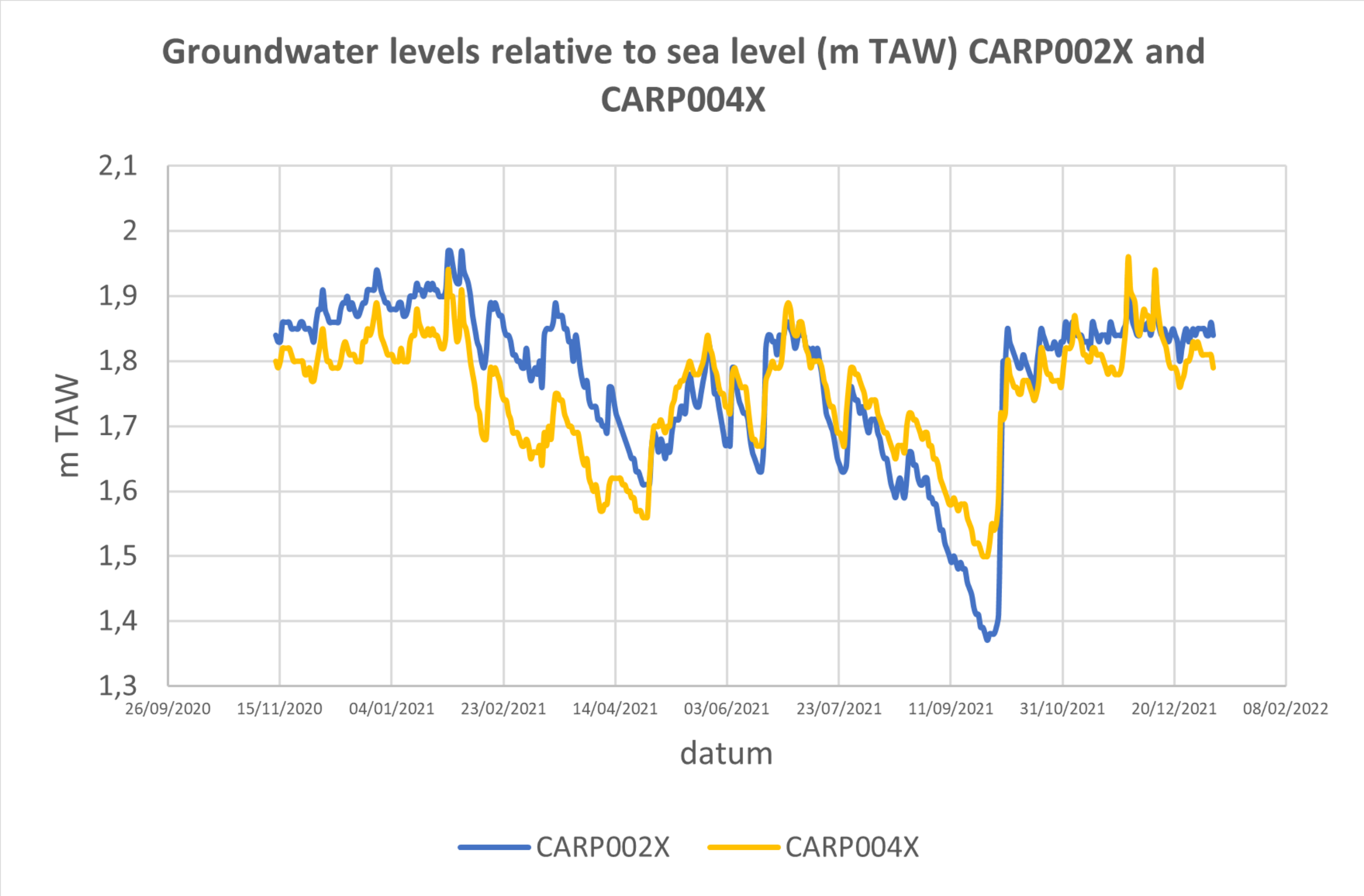


Figure 5. Groundwater levels relative to sea level (m TAW) CARP002X and CARP004X

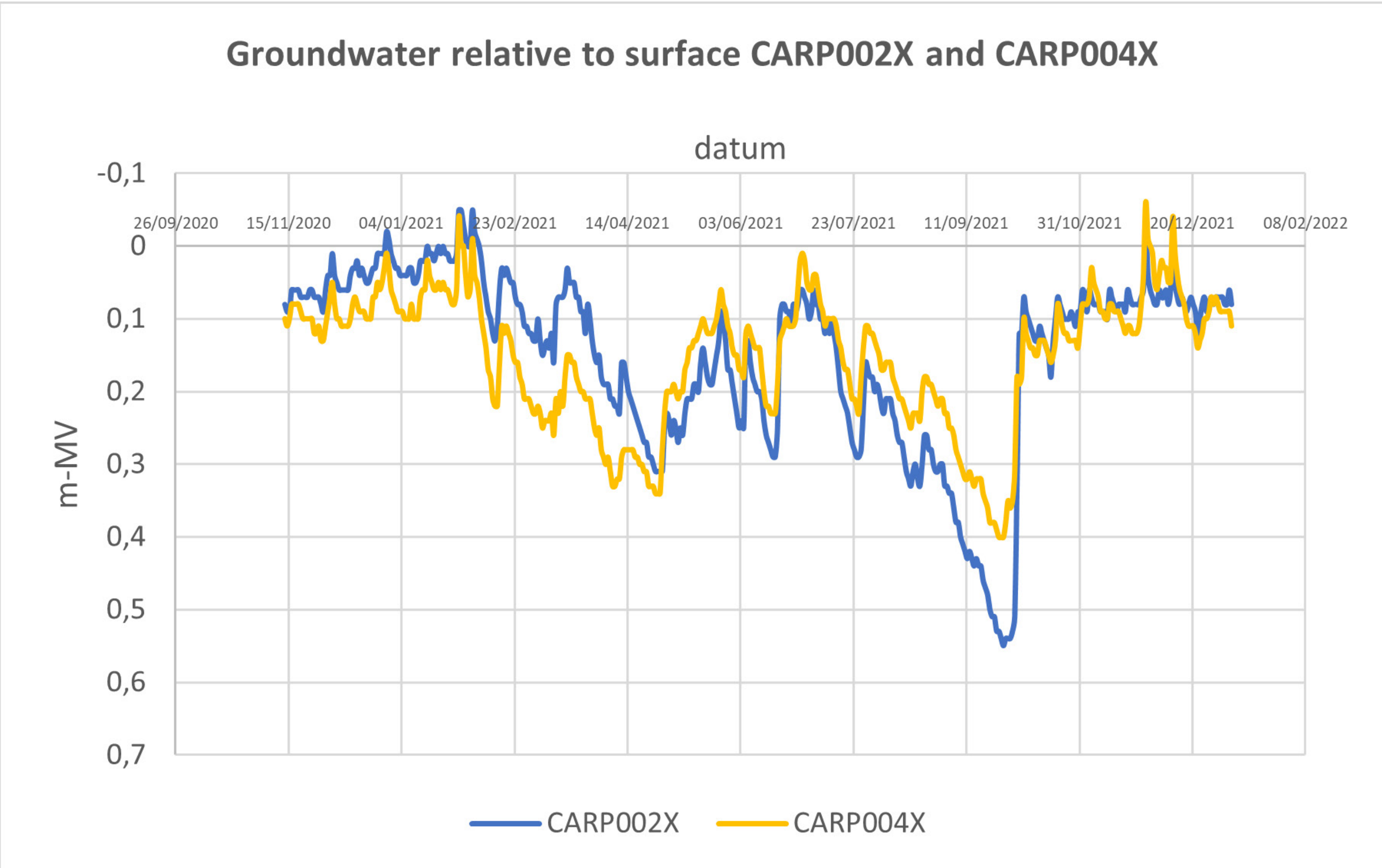


Figure 6. Groundwater levels relative to surface CARP002X and CARP004X

Plot 1063 (CARP005X and CARP006X)

The mean difference between the shallow well (CARP006X) and the deep well (CARP005X) during the period November 2020 – December 2021 is approximately 2 cm, where the deep well had the higher mean water level. This suggests that unlike the plots 1045 and 1060, there is a weak, but constant seepage from groundwater to the upper soil layers.

However, groundwater levels during dry periods in April and September 2021 drop to more than 60 cm under surface level (1,40 m TAW). During the dry period in April water levels in plot 1045 and 1060 drop to approximately 30 cm below surface level (resp. 1,62 m TAW and 1,55 m TAW). Plot 1060 and 1063 are only 190 m apart, with a difference in groundwater level of 15 cm in April. In plot 1063 groundwater level drops with 45 cm in two weeks time. Groundwater in plot 1045 drops with 27 cm in one month's time in the same period, whereas in plot 1060 the level drops 20 cm in 5 week's time.

In the dry period in September the difference (m TAW) between plot 1060 and 1063 is 15 cm. The difference in this period between 1063 and 1045 is only 2 cm. Relative to surface level the differences are much larger.

Mean groundwater levels are 1,80 and 1,78 m TAW for respectively CARP005X and CARP005X. Surface level at this plot is 2,02 m TAW meaning mean groundwater levels of respectively 22 cm and 24 cm under surface level. Mean groundwater levels for the period April – September 2021 are respectively 1,63 and 1,61 m TAW, or 29 and 41 cm under surface level. Median groundwater levels in the periode April – September 2021 are respectively 1,55 and 1,52 m TAW, or 47 and 50 cm under surface level.

Overall, variability in groundwater levels is much higher in plot 1063. This seems to contradict with the seepage which is present yearround.

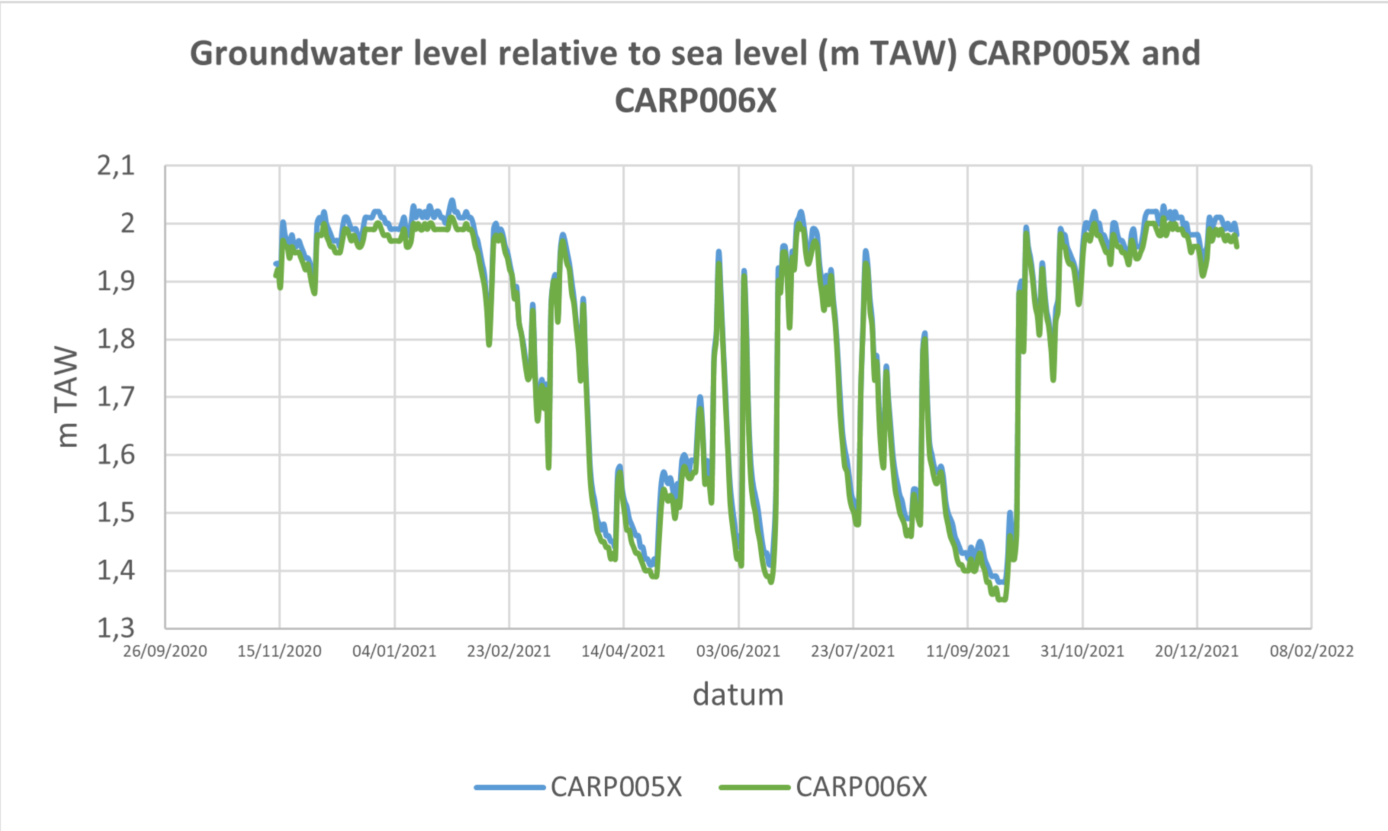


Figure 7. Groundwater levels relative to sea level (m TAW) CARP005X and CARP006X

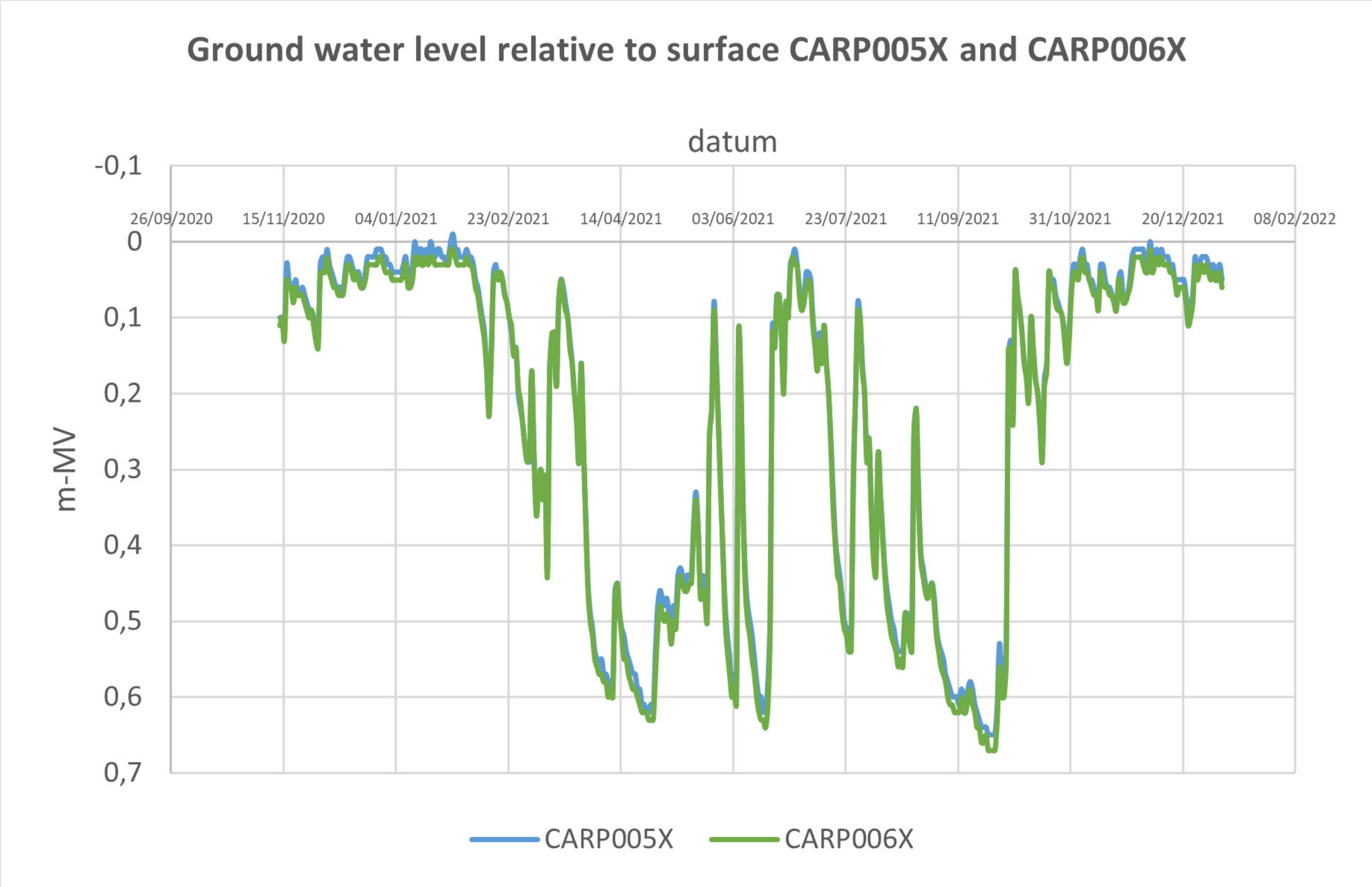


Figure 8. Groundwater levels relative to surface CARP005X and CARP006X

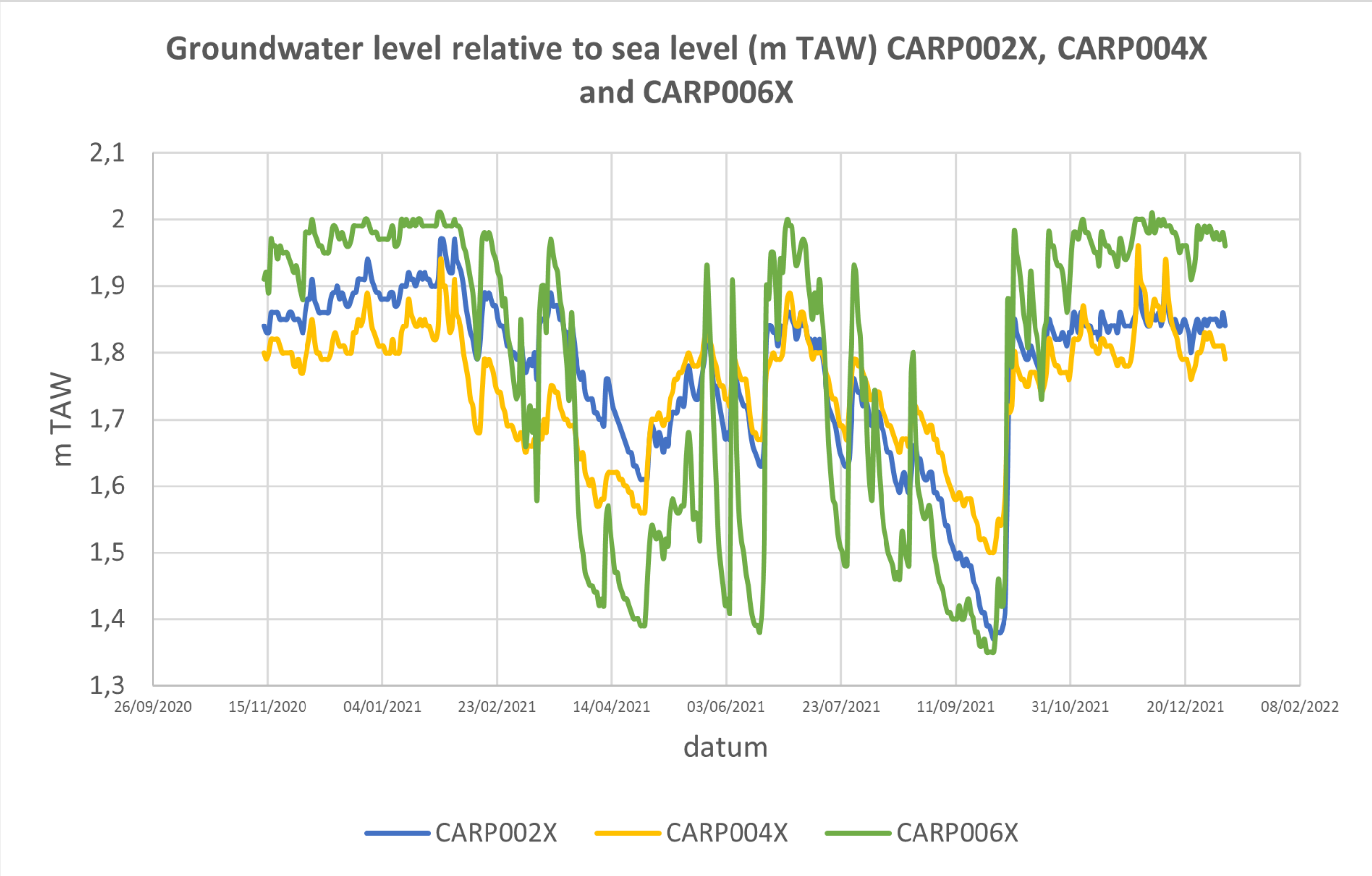


Figure 9. Groundwater levels relative to sea level (m TAW) CARP002X, CARP004X and CARP006X

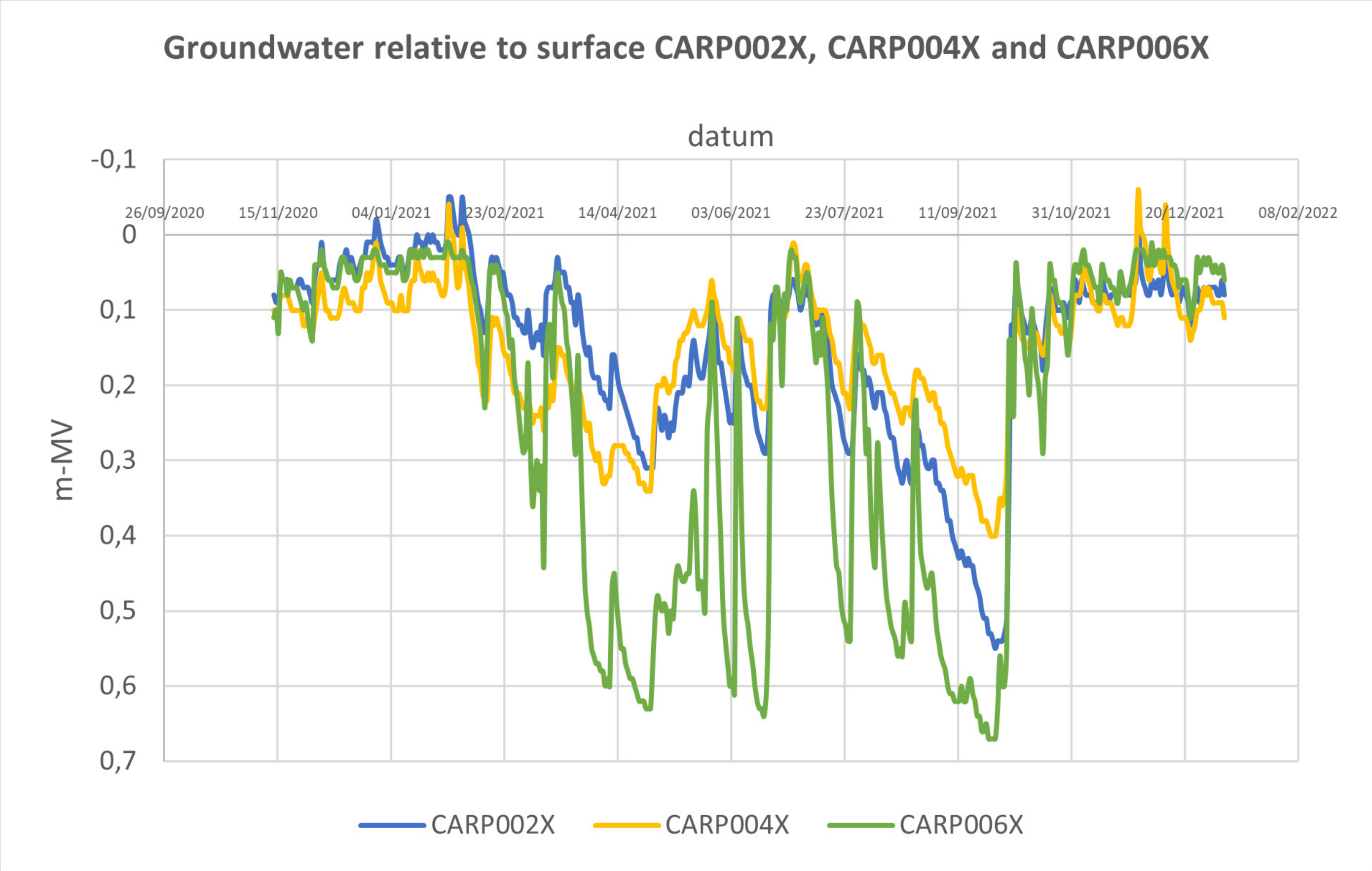


Figure 10. Groundwater levels relative to surface CARP002X, CARP004X, CARP006X

Table 6: Groundwater levels for the period 13/11/2020 – 6/01/2022 for the 6 monitoring well in the plots 1045, 1060 and 1063.

	Groundwater level (m TAW)			Groundwater level (m under surface level)		
	Annual mean	Mean April - September	Median April - September	Annual mean	Mean April - September	Median April - September
CARPO001X (deep)	1,74	1,63	1,67	0,16	0,27	0,23
CARP002X (shallow)	1,77	1,66	1,69	0,13	0,24	0,21
CARP003X (deep)	1,74	1,70	1,70	0,18	0,22	0,22
CARP004X (shallow)	1,75	1,70	1,70	0,18	0,22	0,22
CARP005X (deep)	1,80	1,63	1,55	0,22	0,39	0,47
CARP006X (shallow)	1,78	1,61	1,52	0,24	0,41	0,50

KWEP002A and KWEP005X

These piezometers are located near plot 1045 (CARP001X and CARP002X) (140 m apart). These are also located within the area that is presumed to be rewetted. A time series is available from 2015 onwards.

A comparison for the period November 2020 – October 2021 shows that groundwater level in KWEP002A is year round higher than in CARP002X, with a mean difference of 10 cm. There is no clear explanation for this difference.

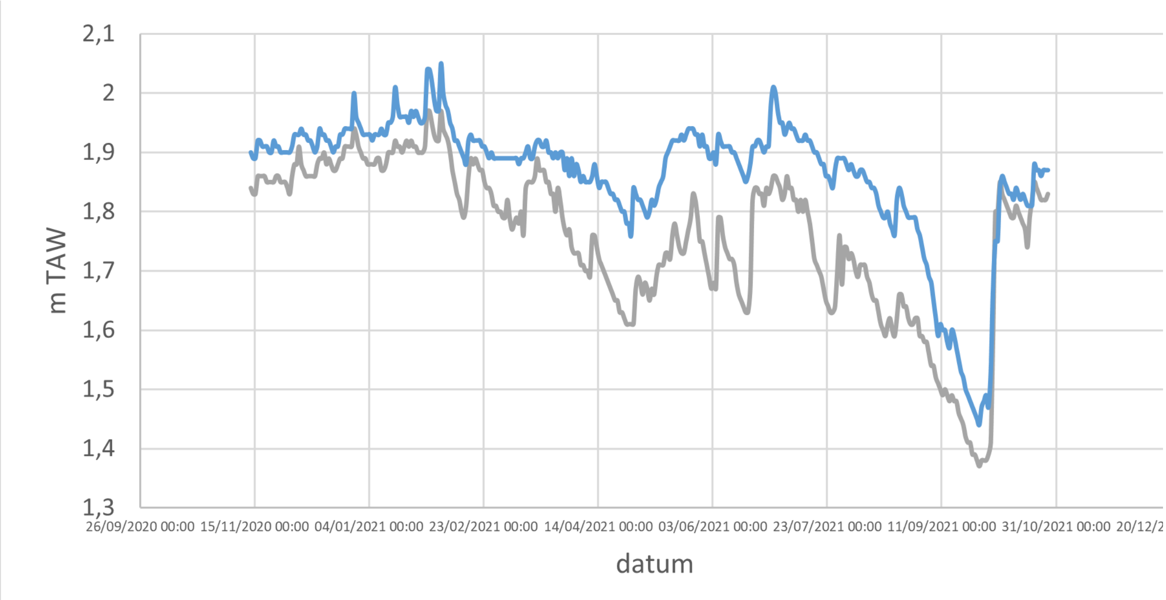


Figure 11. Groundwater levels relative to sea level (m TAW) CARP002X, KWEP002A

The time series of piezometer KWEP002A makes it possible to estimate the amount of rewetting that has already been established within the restricted area of the pilot.

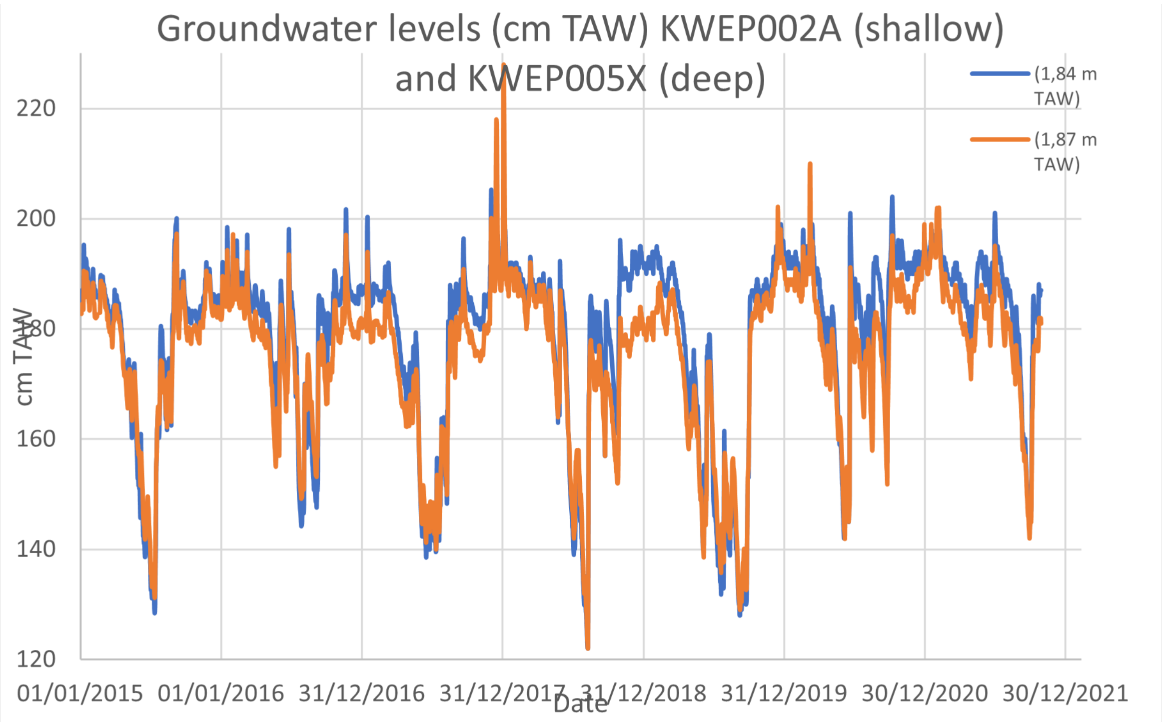


Figure 12. Groundwater levels (cm TAW) KWEP002A (shallow) and KWEP005X (deep)

In order to look for possible effects of rewetting, we calculated the mean annual groundwater level in KWE-P002A in the period 2015 – 2021.

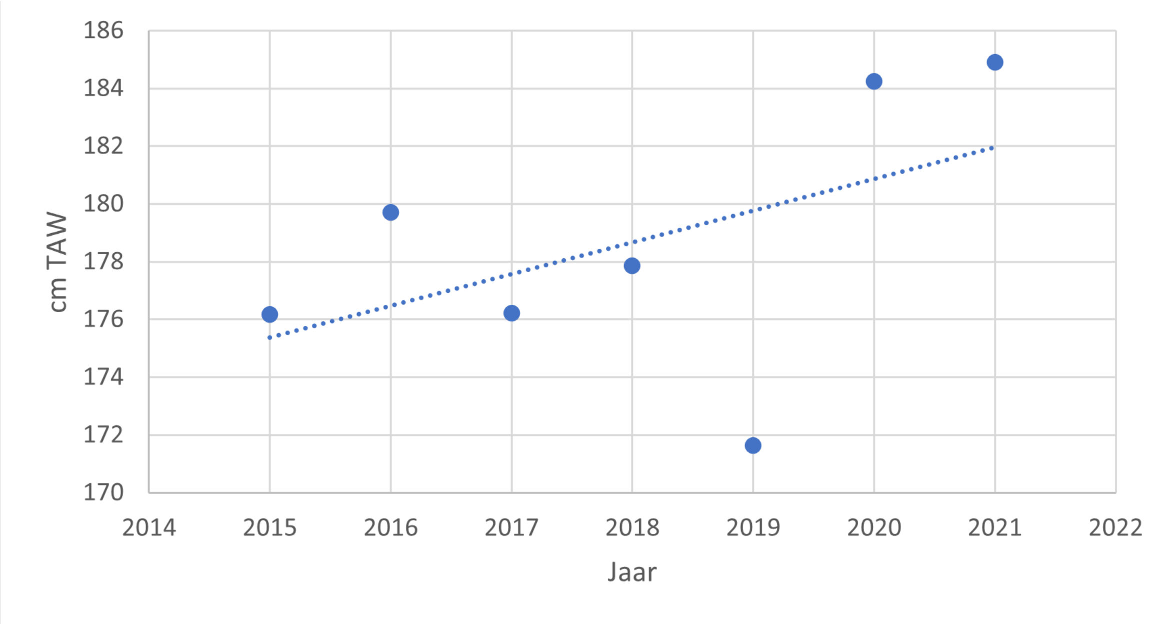


Figure 13. Mean annual groundwater levels KWEP002A (2015 -2021)

There are clearly indications of an upward trend of the mean groundwater level over the period 2015 - 2021. 2019 was an exceptionally dry year with prolonged very low groundwater levels in spring and summer. If we consider 2019 as an outlier and omit 2019 from the time series, we get a more clear linear relationship. Based on this relationship we estimate the mean anual increase of groundwater level as 1,45 cm/year. Mean annual groundwater level has risen with 8,7 cm during the period 2015 – 2021.

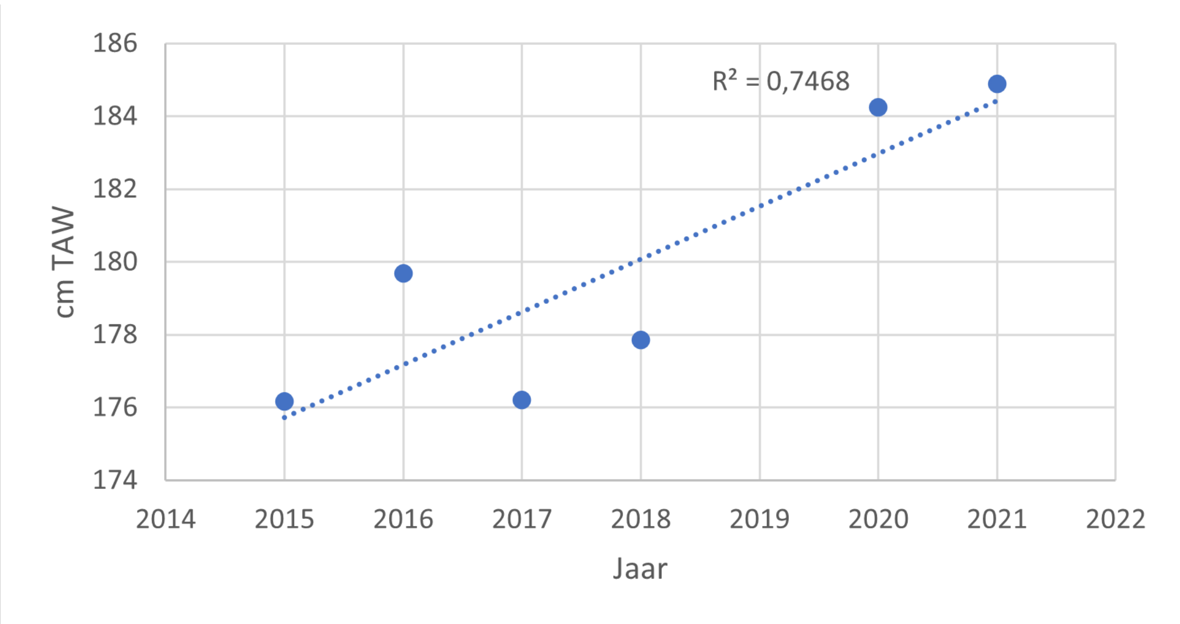


Figure 14. Mean annual groundwater levels KWEP002A (2015 -2021 excluding 2019)

It is expected that the rise of the groundwater level is largely attibutable to be achieved during the months with excess precipitation (October – March). The regression for these months clearly give a significant upward trend of groundwater level in the period October - March, with an increase of 8,2 cm over a period of 6 years.

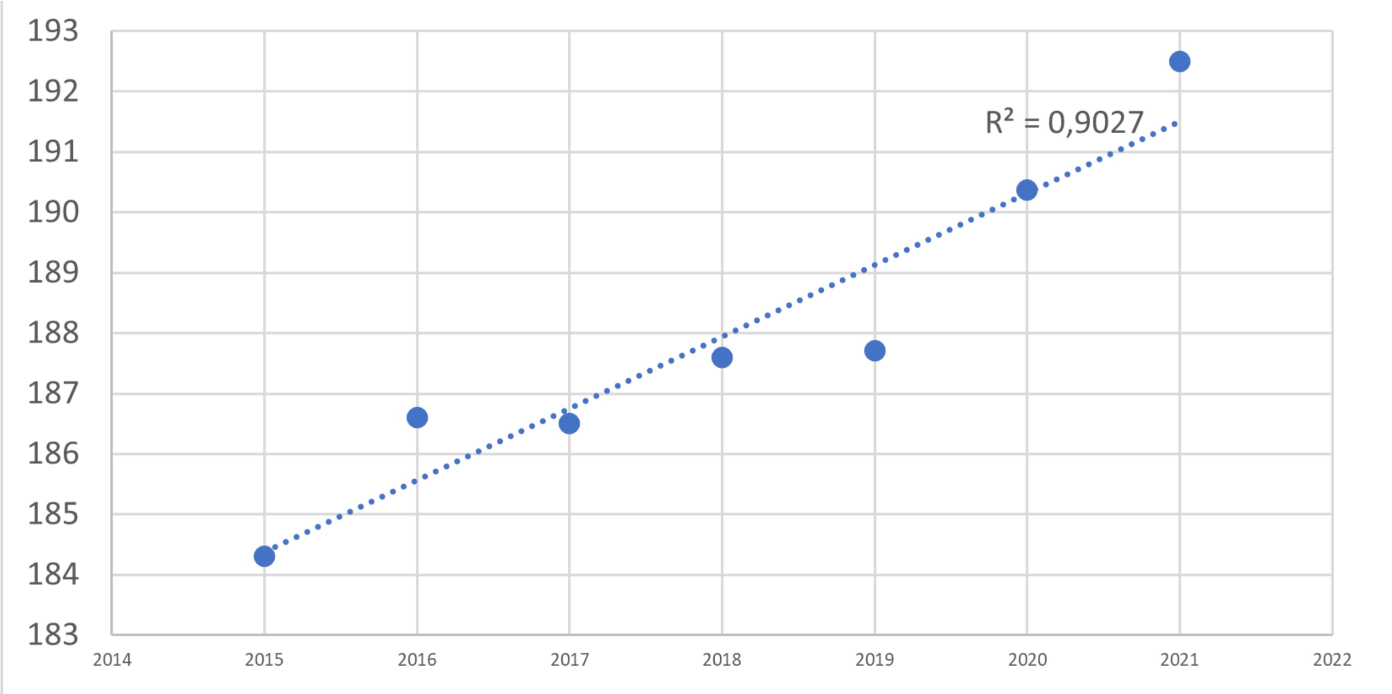


Figure 15. Evolution of mean groundwater levels in KWEP002A for the period October- March

Conclusion

Based on an existing time series there is evidence that a part of Kwetshage has gradually rewetted due to lack of management of ditches. This area is indicated in figure 1 and 2 in the annex. Mean annual groundwater level has raised by approximately 8 cm since 2015 (1,45 cm / year).

Groundwater level measurements on 3 different plots from December 2020 to December 2021 show a gradient towards drier conditions from plot 1045 to plot 1063, with mean annual groundwater levels in the shallow wells ranging from 13 cm under surface level (1045) to 24 cm under surface level (1063), with an intermediate level at plot 1060 (18 cm under surface level. This reflects the rewetting that has already occurred in the area around plot 1045.

In plot 1045 (wet) and 1060 (intermediate) there is an infiltration towards groundwater yearround, whereas in plot 1063 (dry) there is an slight seepage from groundwater up to the surface, particularly in summer.

Water quality

Analyses of groundwater quality is performed on samples form both the deep and shallow wells. As shown in previous section there is an infiltration towards deeper groundwater in plots 1045 and 1060. Upwards seepage occurs in plot 1063, but remains restricted.

Conductivity

In plot 1045 in the deep well (CARP001X) is somewhat higher than in the shallow well (CARP002X): a mean of 2823 µS/cm for the deep wel and 2226 µS/cm for the shallow well.

In plot 1060 conductivity is much higher with a mean of 4545 µS/cm for the deep well and 4550 µS/cm for the shallow well. This means that the influence of the brackish water in the underground is more prominent is this plot.

In plot 1063 there is a mean of 2421 µS/cm in the deep well and 2370 µS/cm in the shallow well. As in 1060 there is no real difference in conductivity between the deep and shallow well, but conductivity is much lower.

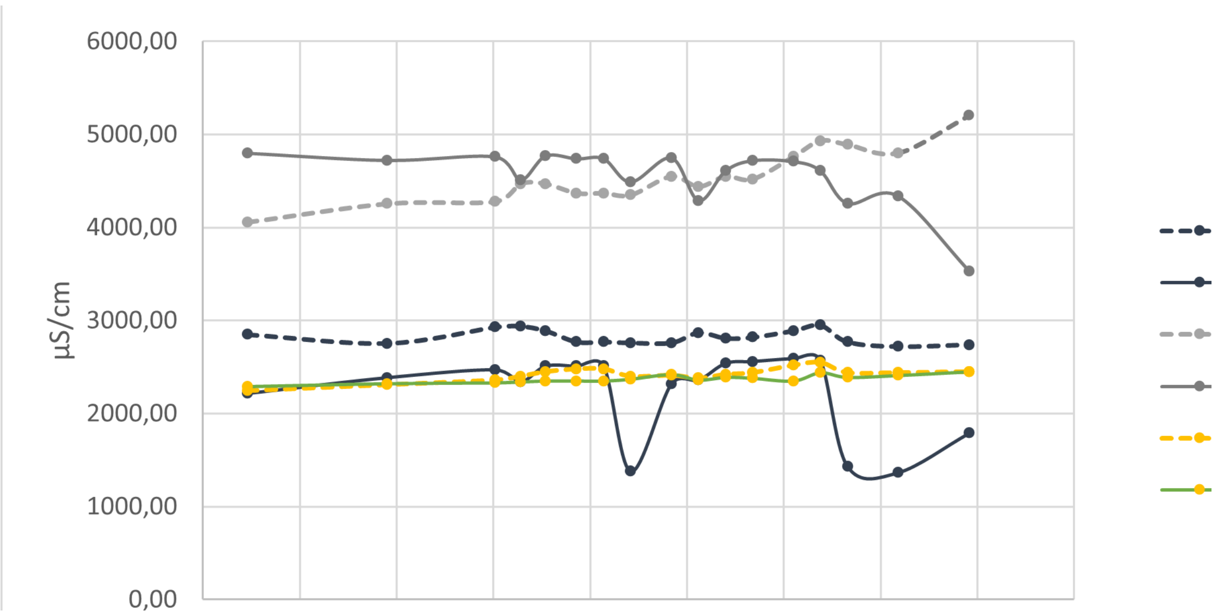


Figure 16. Conductivity (EC) in groundwater

Nitrogen

⁕ Nitrate and nitrite

Concentrations of NO_3^- and NO_2^{2-} are constantly very low with respectively < 0,44 mg NO_3^-/L and < 0,02 mg NO_2^{2-}/L. Only on 29/7/2021 concentrations of NO_2^{2-} are much higher for all 6 wells, with a maximum of 1,9 mg NO_2^{2-}/ L in well CARP001 and 3,6 mg NO_2^{2-} / L in well CARP003. Both are deep wells. Concentrations in de corresponding shallow wells are much lower: respectively mg NO_2^{2-}/L 0,21 and 0,26 mg NO_2^{2-}/L. But these values are also much higher than at other dates, where concentration is < 0,44 mg/L. Concentration of total N and $NH4^+$ in well CARP001 are similar to values at other dates: resp. 3,3 mg/L and 1,2 mg/L. It remains unclear if

Generally conclusion is that NO_3^- and NO_2^{2-} concentration are most of the time very low in all 6 wells.

✳ Total nitrogen

In figure 17 mean concentrations of total N is depicted for each well. In plot 1045 there is a higher mean concentration of 6,1 mg/L in de deep well CARP001 in comparison to 2,5 mg/L fort he shallow well CARP002. In plot 1060 concentration is highest in de shallow well CARP004. Concentration here is nearly as high as in de deep well of plot 1045 (5,8 mg/L). The deep well CARP03 at plot 1060 has a concentration of 4 mg/L. Concentration total N is lowest in plot 1063, with little difference between deep well and shallow well (2,6 and 2,4 mg/L).

There is a large difference (2,5 x) in mean total N concentration between the lowest (plot 1063) and highest (plot 1045, deep) values. There is no consistency in differences between deep and shallow wells.

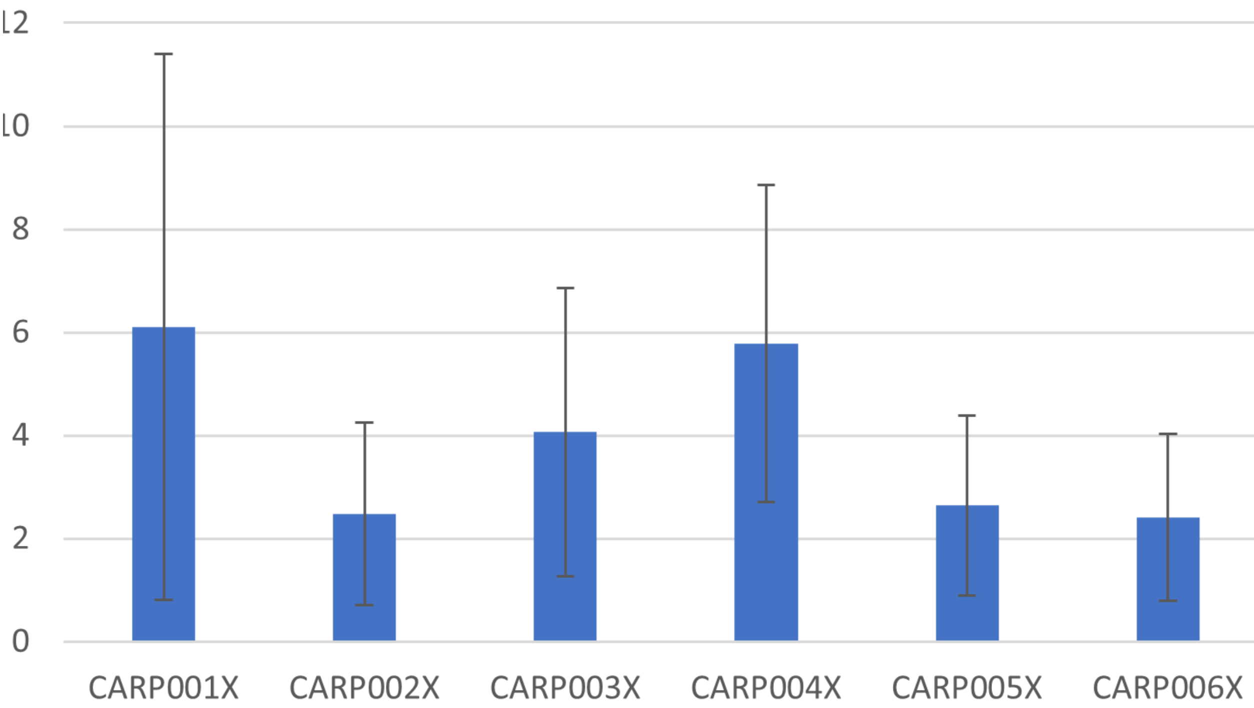
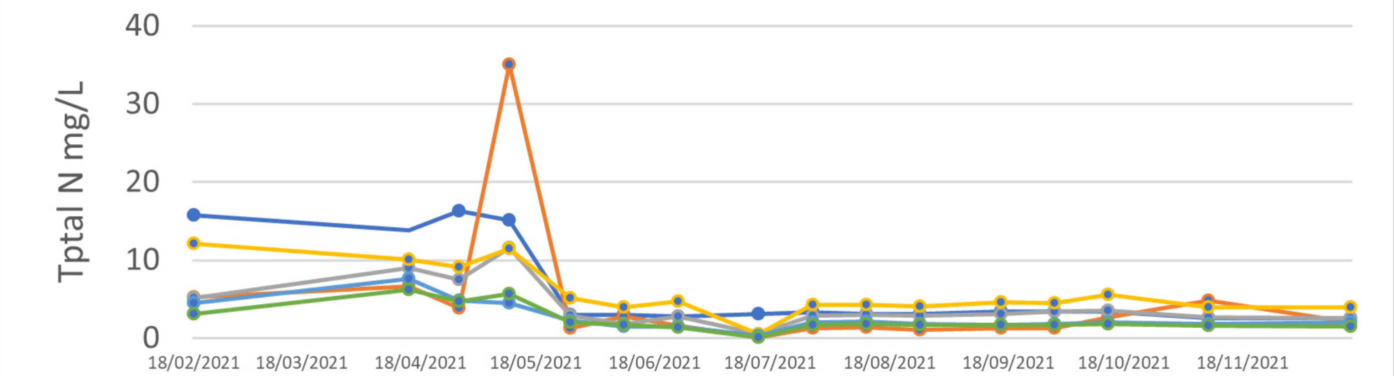


Figure 17. Mean concentration total N

Figure 18 shows the evolution of the total N-concentration. Concentrations are higher in the beginning of the monitoring period (winter and spring) in all wells, relative to the rest of the monitoring period.



	18/02/2021	15/04/2021	28/04/2021	11/05/2021	27/05/2021	10/06/2021	24/06/2021	15/07/2021	29/07/2021	12/08/2021	26/08/2021	16/09/2021	30/09/2021	14/10/2021	09/11/2021	16/12/2021
CARP001X	15,7	13,8	16,3	15,1	3,04	2,99	2,79	3,05	3,3	3,08	3,1	3,4	3,4	3,4	2,61	2,51
CARP002X	5,2	6,6	3,8	35	1,31	2,74	1,54	0,1	1,32	1,43	1,03	1,22	1,31	2,67	4,8	2,04
CARP003X	5,1	9	7,5	11,6	2,88	1,78	2,74	0,48	2,92	2,95	2,88	3,09	3,4	3,5	2,65	2,57
CARP004X	12,1	10,1	9,1	11,5	5,1	4	4,7	0,56	4,3	4,3	4,1	4,6	4,5	5,6	3,9	4
CARP005X	4,5	7,6	4,8	4,5	2,26	1,51	1,53	0,31	1,99	2,11	1,77	1,72	1,83	2,06	1,82	1,99
CARP006X	3,1	6,2	4,7	5,7	2,07	1,68	1,41	0,13	1,66	1,82	1,74	1,73	1,72	1,83	1,58	1,53

Figure 18. Total nitrogen

✱ Ammonium

In plot 1045 NH_4^+ mean concentration is very high in the deep well (2,20 mg/L) (CARP001). In the shallow well of plot 1045 (CARP002) concentration is much lower (0,45 mg/L). So there is nearly a 5x difference in mean NH_4^+ concentration at plot 1045 between the deep and shallow well.

In plot 1060 concentration is high in both the deep (CARP003) and shallow (CARP004) well (1,82 and 1,38 mg/L resp.). In plot 1063 concentrations in both deep and shallow well are under 0,5 mg/L.

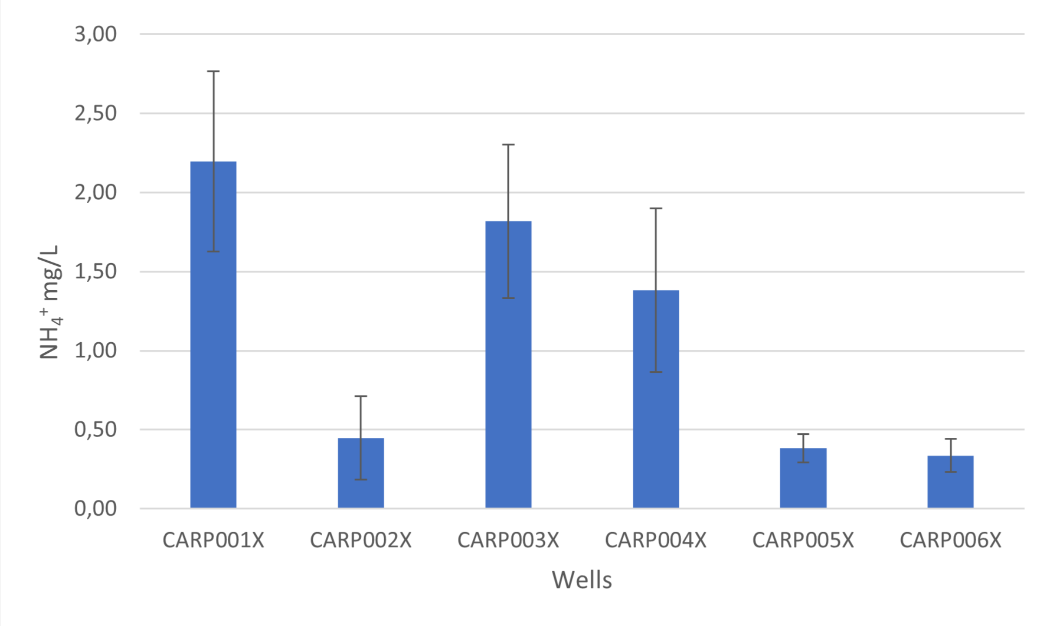
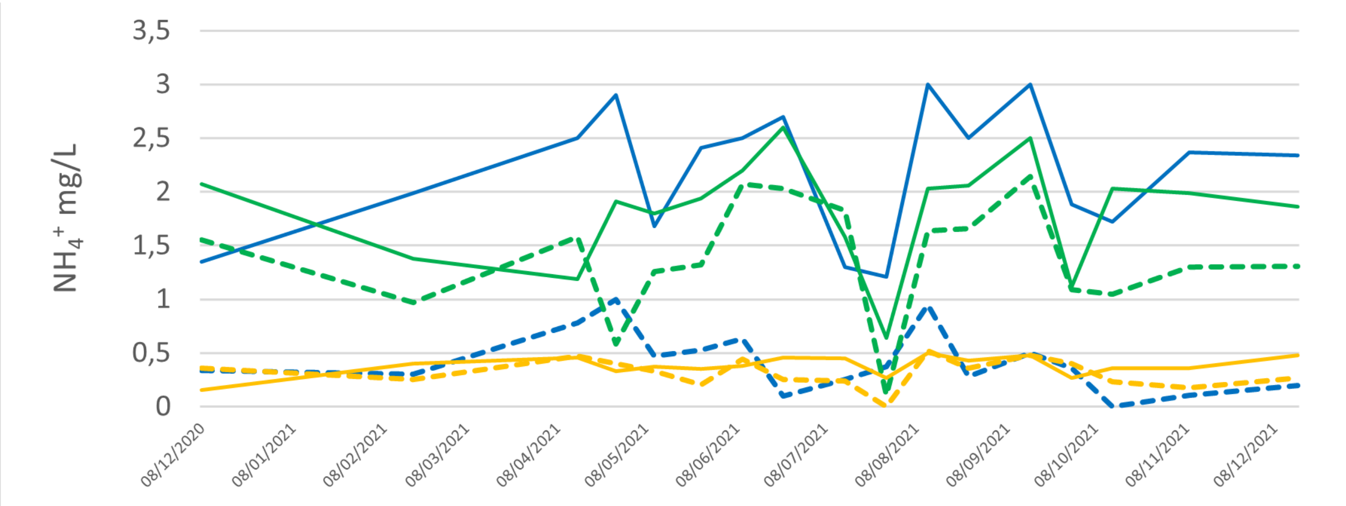


Figure 19. Mean concentration total NH4⁺

Variability in NH_4^+ concentration is reflected in the relative standard deviation (RSD). This is highest in the shallow well of plot 1045 (CARP002) with an RSD of 59%. Lowest variability occurs in the deep wells with an RSD of 23% (1063), 26% (1045) and 27% (1060).



	08/12/2020	18/02/2021	15/04/2021	28/04/2021	11/05/2021	27/05/2021	10/06/2021	24/06/2021	15/07/2021	29/07/2021	12/08/2021	26/08/2021	16/09/2021	30/09/2021	14/10/2021	09/11/2021	16/12/2021
CARP001X	1,35	1,99	2,50	2,90	1,68	2,41	2,50	2,70	1,30	1,21	3,00	2,50	3,00	1,88	1,72	2,37	2,34
CARP002X	0,34	0,30	0,78	1,00	0,47	0,53	0,63	0,10	0,25	0,37	0,95	0,28	0,50	0,36	0,00	0,11	0,20
CARP003X	2,07	1,38	1,19	1,91	1,80	1,94	2,20	2,60	1,58	0,64	2,03	2,06	2,50	1,12	2,03	1,99	1,86
CARP004X	1,55	0,97	1,58	0,58	1,26	1,32	2,07	2,03	1,83	0,11	1,64	1,66	2,14	1,09	1,05	1,30	1,31
CARP005X	0,157	0,40	0,46	0,33	0,37	0,35	0,38	0,46	0,45	0,27	0,50	0,43	0,48	0,27	0,36	0,36	0,48
CARP006X	0,36	0,25	0,47	0,40	0,33	0,20	0,44	0,25	0,24	0,00	0,52	0,36	0,48	0,40	0,23	0,17	0,27

Figure 20. NH4⁺ conentration in groundwater

Phosphorus

⁕ Orthophosphate (PO_4^{3-})

The deep wells in all three plots have the highest mean concentration PO_4^{3-}, ranging from 1,15 mg/L for plot 1045 to 0,57 mg/l for plot 1060. The shallow plots have lower concentrations: 0,38 mg/L for plots 1060 and 1063, and 0,36 mg/l for plot 1045.

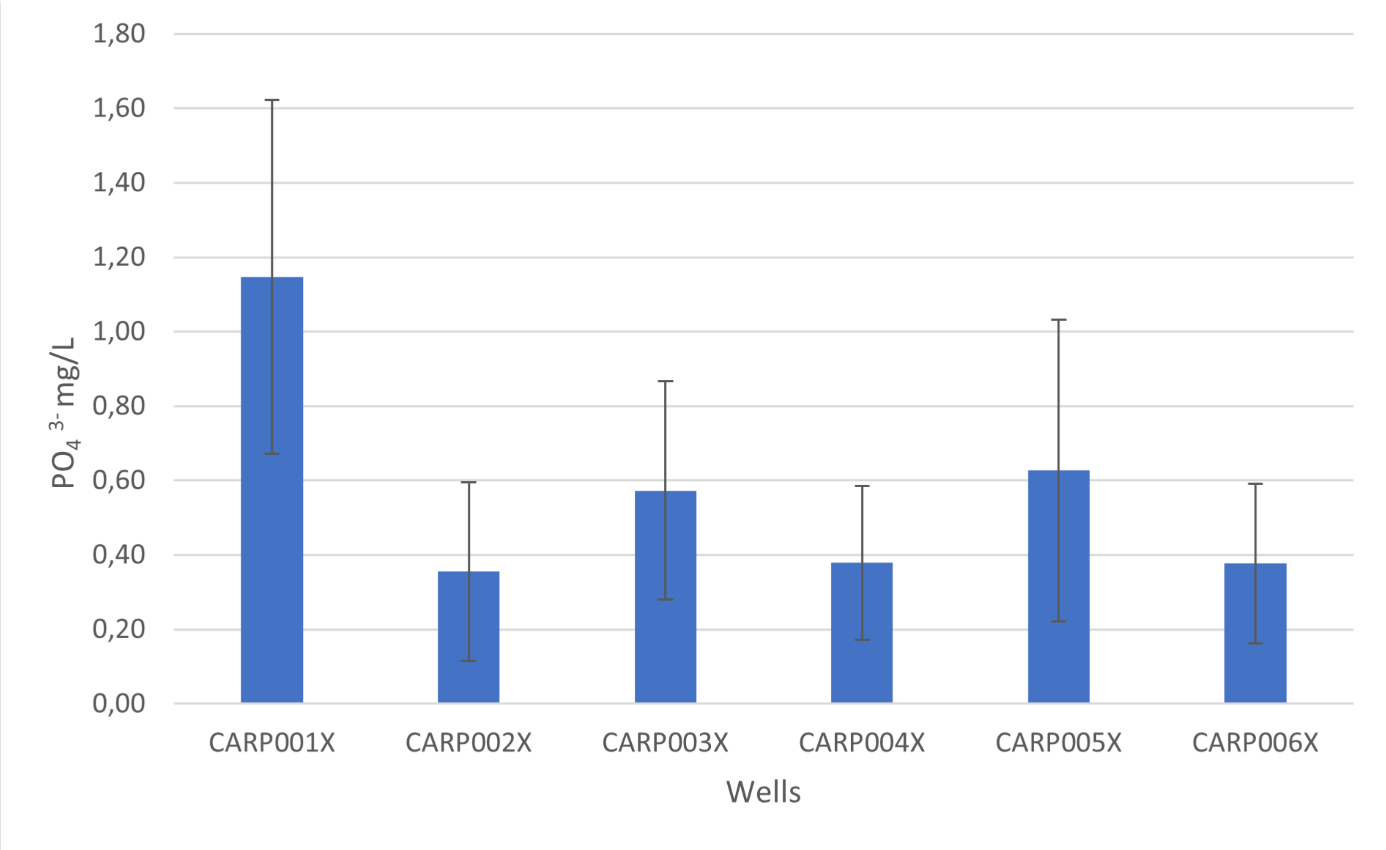
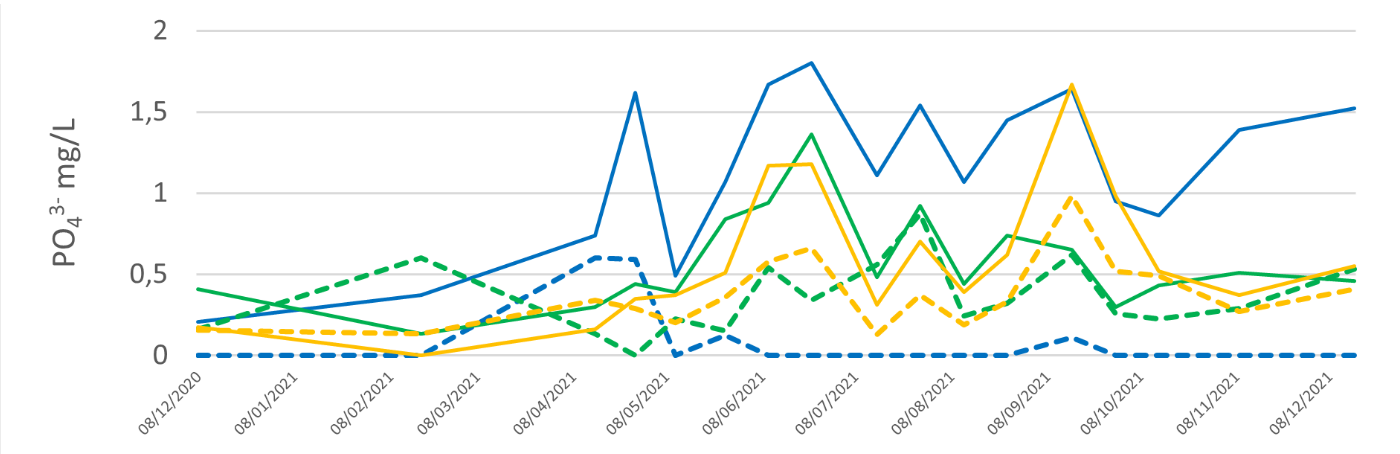


Figure 21. Mean concentration PO_4^{3-}



	08/12/2020	18/02/2021	15/04/2021	28/04/2021	11/05/2021	27/05/2021	10/06/2021	24/06/2021	15/07/2021	29/07/2021	12/08/2021	26/08/2021	16/09/2021	30/09/2021	14/10/2021	09/11/2021	16/12/2021
KWET 1	0,206	0,37	0,74	1,62	0,49	1,07	1,67	1,8	1,11	1,54	1,07	1,45	1,64	0,95	0,86	1,39	1,52
KWET 2	0	0	0,6	0,59	0	0,122	0	0	0	0	0	0	0,109	0	0	0	0
KWET 3	0,41	0,132	0,3	0,44	0,39	0,84	0,94	1,36	0,48	0,92	0,44	0,74	0,65	0,3	0,43	0,51	0,46
KWET 4	0,16	0,6	0,133	0	0,224	0,151	0,54	0,34	0,56	0,87	0,245	0,32	0,62	0,259	0,226	0,29	0,53
KWET 5	0,176	0	0,163	0,35	0,37	0,51	1,17	1,18	0,31	0,7	0,39	0,62	1,67	0,98	0,52	0,37	0,55
KWET 6	0,155	0,132	0,34	0,288	0,2	0,36	0,58	0,66	0,13	0,37	0,189	0,33	0,98	0,52	0,49	0,272	0,41

Figure 22. PO_4^{3-} concentration in groundwater

✳ Total P

The concentration of total P has the same pattern as the concentration of PO_4^{3-} in the three plots: higher concentrations in de the deep wells, with the highest concentration in plot 1045.

There are however very high values of total P in the deep wells of all three plots on 8/12/2020, with values ranging from 10,5 mg/l for plot 1045, 5,1 mg/L for plot 1063 and 2,5 mg/L for plot 1060. On 18/2/2021 values have dropped, but only from 27/5/2021 onwards concentrations reach values that remain more or less constant during the rest of the monitoring period. It is unclear what causes these high values. Measurement errors are unlikely as we don't have these high values for the shallow wells.

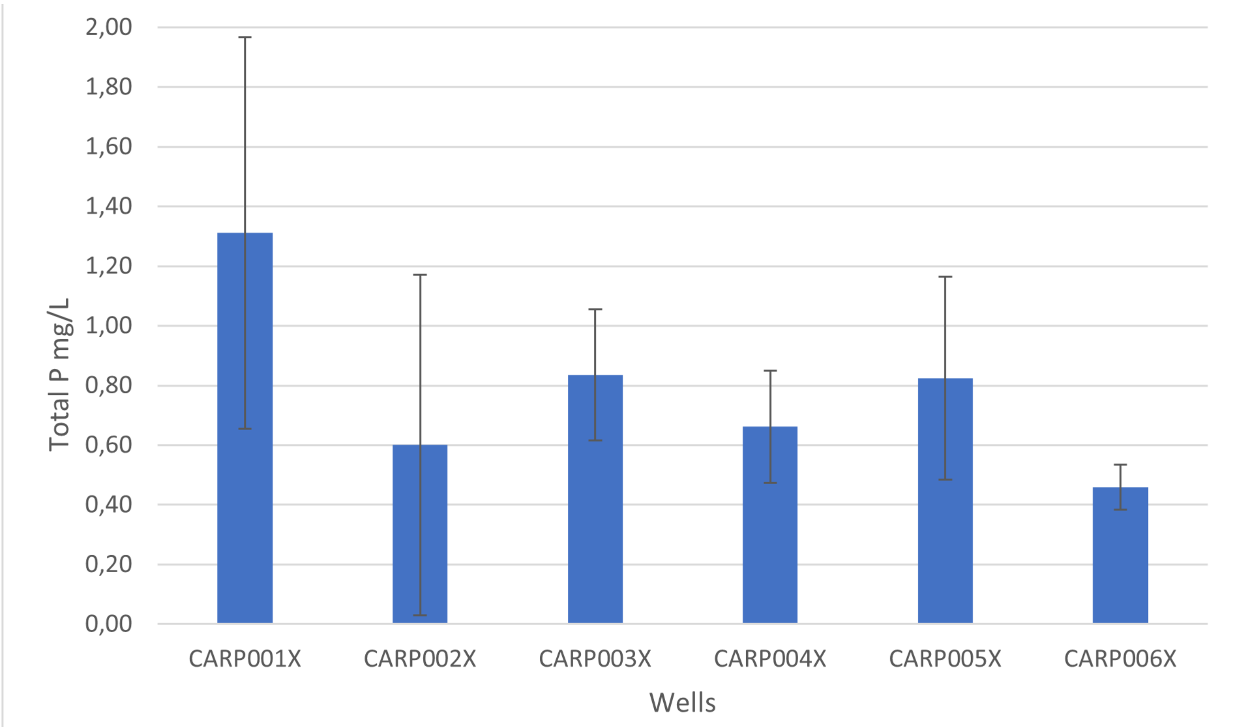
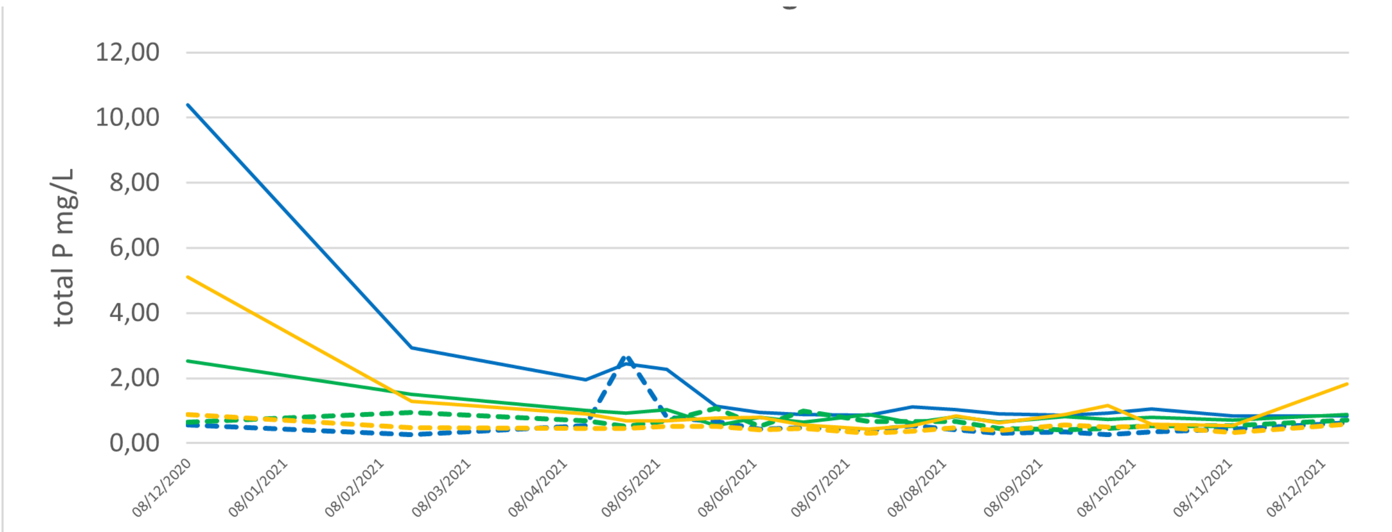


Figure 23. Mean concentration total P



	08/12/2020	18/02/2021	15/04/2021	28/04/2021	11/05/2021	27/05/2021	10/06/2021	24/06/2021	15/07/2021	29/07/2021	12/08/2021	26/08/2021	16/09/2021	30/09/2021	14/10/2021	09/11/2021	16/12/2021
KWET 1	10,40	2,92	1,95	2,44	2,27	1,13	0,94	0,88	0,86	1,12	1,04	0,91	0,85	0,93	1,05	0,84	0,84
KWET 2	0,57	0,26	0,54	2,74	0,79	0,67	0,43	0,47	0,40	0,55	0,42	0,31	0,35	0,26	0,35	0,44	0,62
KWET 3	2,52	1,51	1,00	0,92	1,04	0,54	0,79	0,64	0,89	0,62	0,82	0,64	0,82	0,73	0,79	0,72	0,88
KWET 4	0,64	0,95	0,68	0,53	0,69	1,07	0,52	0,99	0,66	0,67	0,67	0,46	0,42	0,45	0,55	0,55	0,72
KWET 5	5,10	1,29	0,90	0,70	0,69	0,78	0,80	0,57	0,44	0,54	0,83	0,63	0,88	1,16	0,59	0,55	1,83
KWET 6	0,88	0,48	0,45	0,45	0,53	0,52	0,42	0,45	0,31	0,38	0,48	0,39	0,56	0,50	0,51	0,33	0,58

Figure 24. Total P concentration in groundwater

Iron

In figure 25 both Fe^{2+} and Fe^{3+} are presented as mean concentrations for each well. Mean concentration in the shallow well of plot 1045 is more than twice the concentration in the other wells.

In alle wells iron is predominantly present as Fe^{3+}. Only in the shallow well of plot 1060 (CARP004) mean concentration of Fe^{2+} tends towards the concentration of Fe^{3+}. Redox potential is this well is such that Fe3+ is partly reduced to Fe2+. Mean ratio Fe^{3+}/Fe^{2+} for CARP004 is 1,68±1,57. For the other wells the ratio Fe^{3+}/Fe^{2+} ranges from 7,1 to 65.

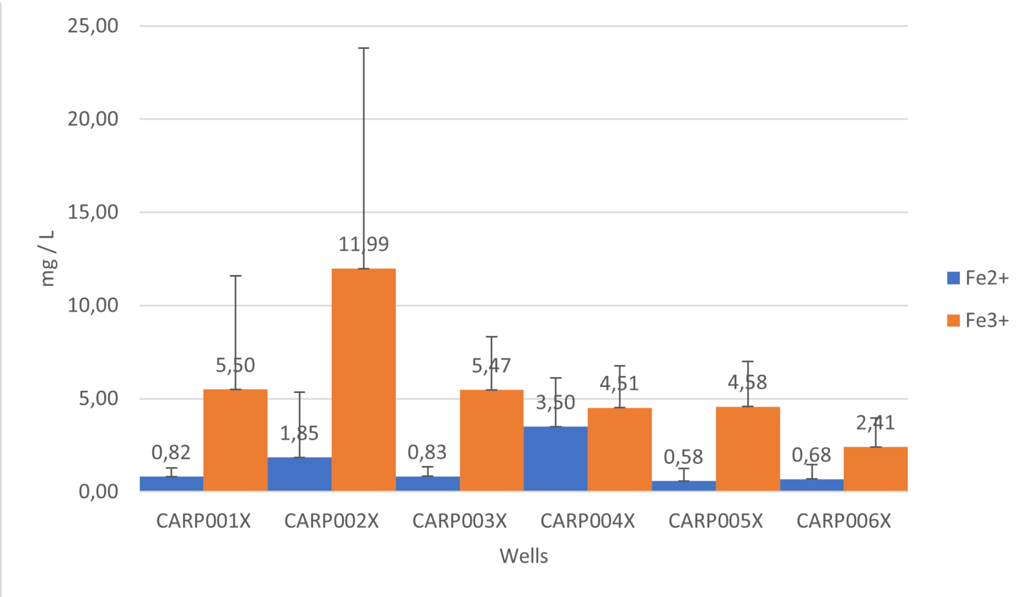


Figure 25. Fe^{2+} / Fe^{3+} mean concentration in groundwater

Sulphur

Mean $SO4^{2-}$ concentration is highest in the shallow well of plot 1060 (CARP004). Concentration in this well is 2,7x to 7x higher than in the other wells. Within plot 1060 $SO4^{2-}$ concentration in the deep well (CARP003 is 3,7x lower than in the shallow well. In fact we also see this difference between deep and shallow well in plot 1045, but with concentrations substantially lower than in plot 1060. In plot 1063 difference between the deep and shallow well is small.

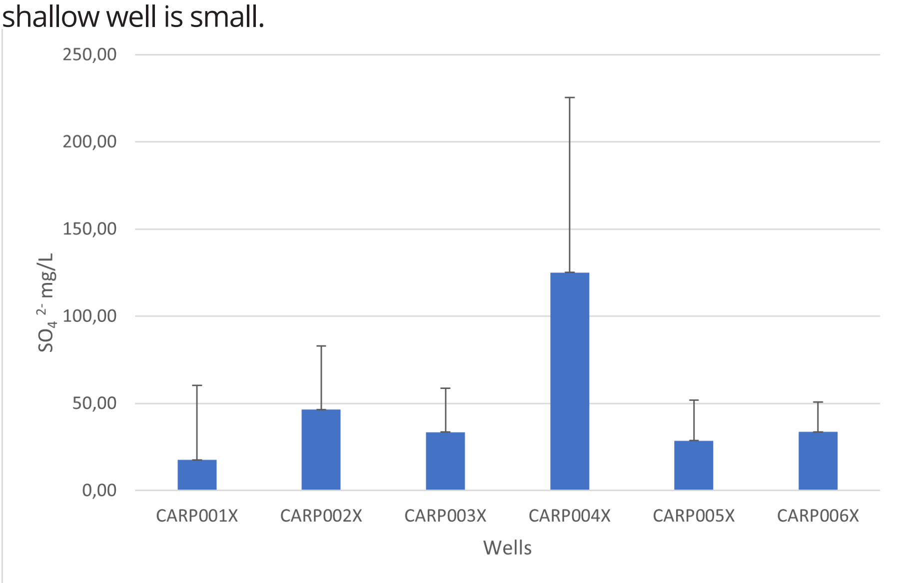
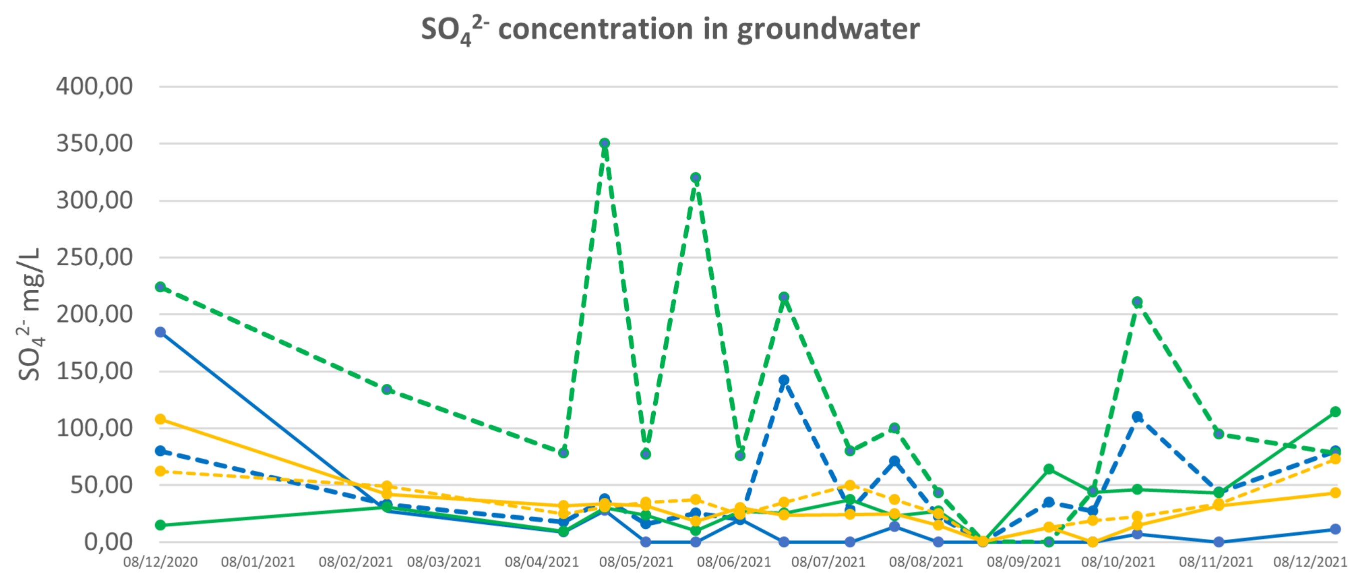


Figure 26. Mean concentration SO_4^{2-}



	08/12/2020	18/02/2021	15/04/2021	28/04/2021	11/05/2021	27/05/2021	10/06/2021	24/06/2021	15/07/2021	29/07/2021	12/08/2021	26/08/2021	16/09/2021	30/09/2021	14/10/2021	09/11/2021	16/12/2021
CARP001X	184,00	27,00	8,80	28,00	0	0	20,00	0	0,00	14	0	0,00	0,00	0,00	7	0,00	11
CARP002X	80,00	33,00	18,00	38,00	16,2	25	19,80	142	28,00	71	23	0,55	35,00	27,00	110	44,00	80
CARP003X	15,00	31,00	9,30	30,00	23,8	10	27,00	25,2	37,00	23	27	0,54	64,00	44,00	46	43,00	114
CARP004X	224,00	134,00	78,00	350,00	77	320	76,00	215	80,00	100	43	0,26	0,00	45,00	211	95,00	78
CARP005X	108,00	42,00	32,00	34,00	32	18	30,00	23,4	24,40	25	15	0,31	12,90	0,00	15	32,00	43
CARP006X	62,00	49,00	24,70	31,00	35	37	24,40	35	50,00	37	25	0,51	13,10	18,70	23	34,00	73

Date

Figure 27. SO_4^{2-} concentration in groundwater

Total Organic Carbon (TOC) dissolved

Mean concentration dissolved TOC (total organic carbon) is highest in the shallow well of plot 1060. In plot 1045 the deep well has a higher concentration than the shallow well. As in most of the other quality parameters there is little difference in TOC between the deep and shallow well of plot 1063.

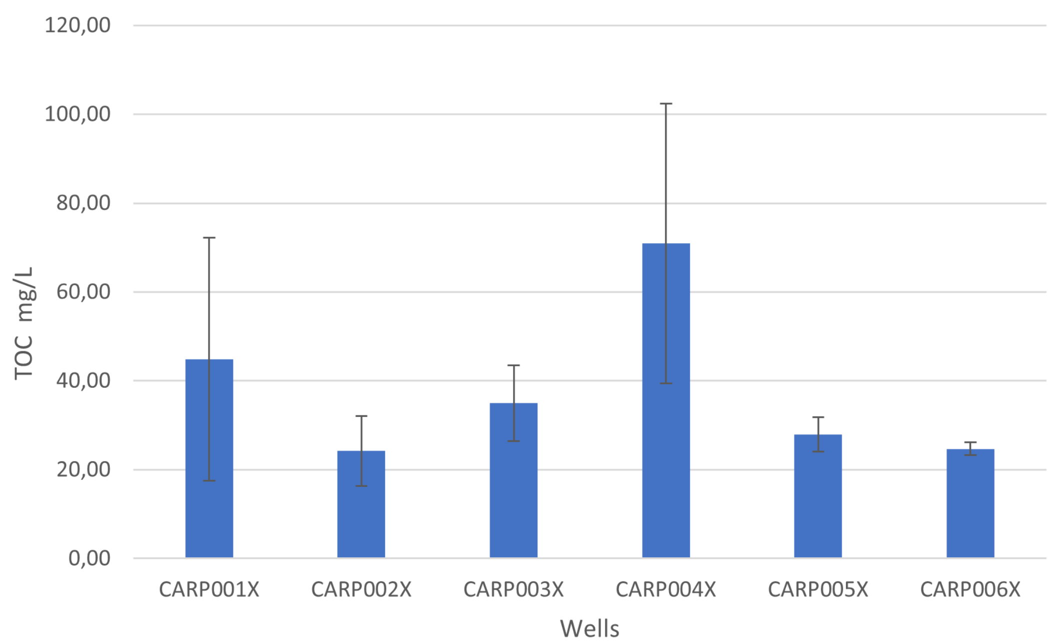
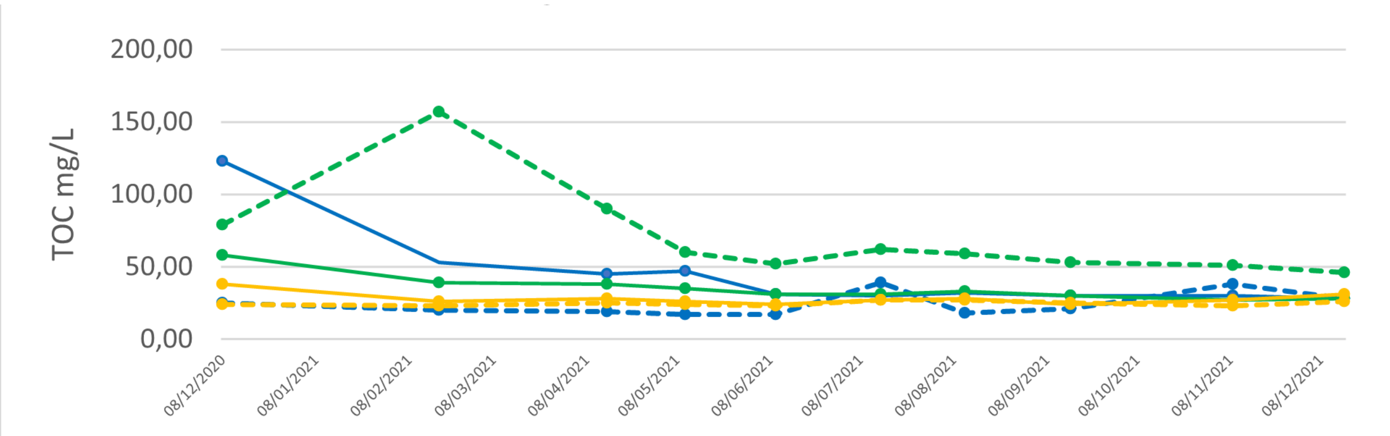


Figure 28. Mean concentration Total Organic Carbon (TOC)



	08/12/2020	18/02/2021	15/04/2021	11/05/2021	10/06/2021	15/07/2021	12/08/2021	16/09/2021	09/11/2021	16/12/2021
CARP001X	123,00	53,00	45,00	47,00	31,00	30,00	32,00	30,00	30,00	28,00
CARP002X	25,00	20,00	19,00	17,00	17,00	39,00	18,00	21,00	38,00	28,00
CARP003X	58,00	39,00	38,00	35,00	31,00	31,00	33,00	30,00	27,00	28,00
CARP004X	79,00	157,00	90,00	60,00	52,00	62,00	59,00	53,00	51,00	46,00
CARP005X	38,00	26,00	28,00	26,00	24,00	27,00	28,00	24,00	27,00	31,00
CARP006X	24,00	23,00	25,00	24,00	23,00	27,00	27,00	25,00	23,00	26,00

Figure 29. Total Organic Carbon (TOC dissolved)

Soil organic carbon

In the following bar graph the 3 different plots are transcribed as:

* Plot 1045 : wet
* Plot 1060: medium
* Plot 1063: dry

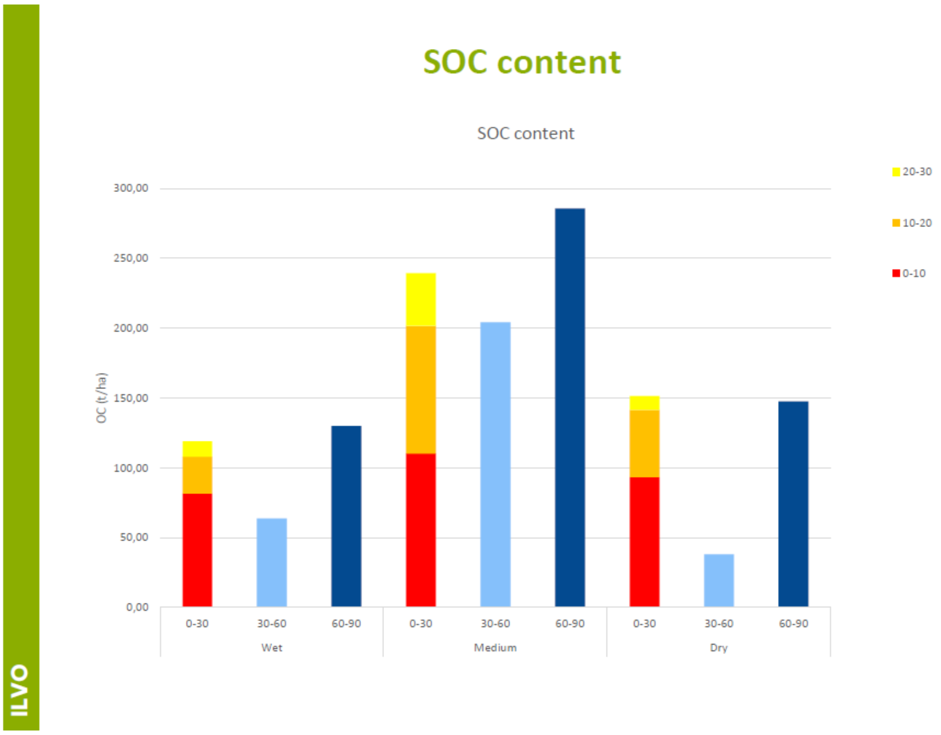


Figure 30: Soil organic content in upper 90 cm of soil in the three plots.

The medium plot has the highest soil organic content in all three layers (0 - 30, 30 – 60, 60 – 90). This is in agreement with the measurements of the concentration of TOC (dissolved).
Total amount of organic carbon in the soil up to a depth of 90 cm ranges from ± 350 to ± 700 tons C / ha. The upper 30 cm of the soil account for ± 120 to ± 240 tons C / ha.

Data on GHG measurements are from the period 8/12/2020 up to 13/07/2021. Measurements were conducted by ILVO (Flemish Institute of Agriculture, Fisheries and Food Research).

CO_2 emission

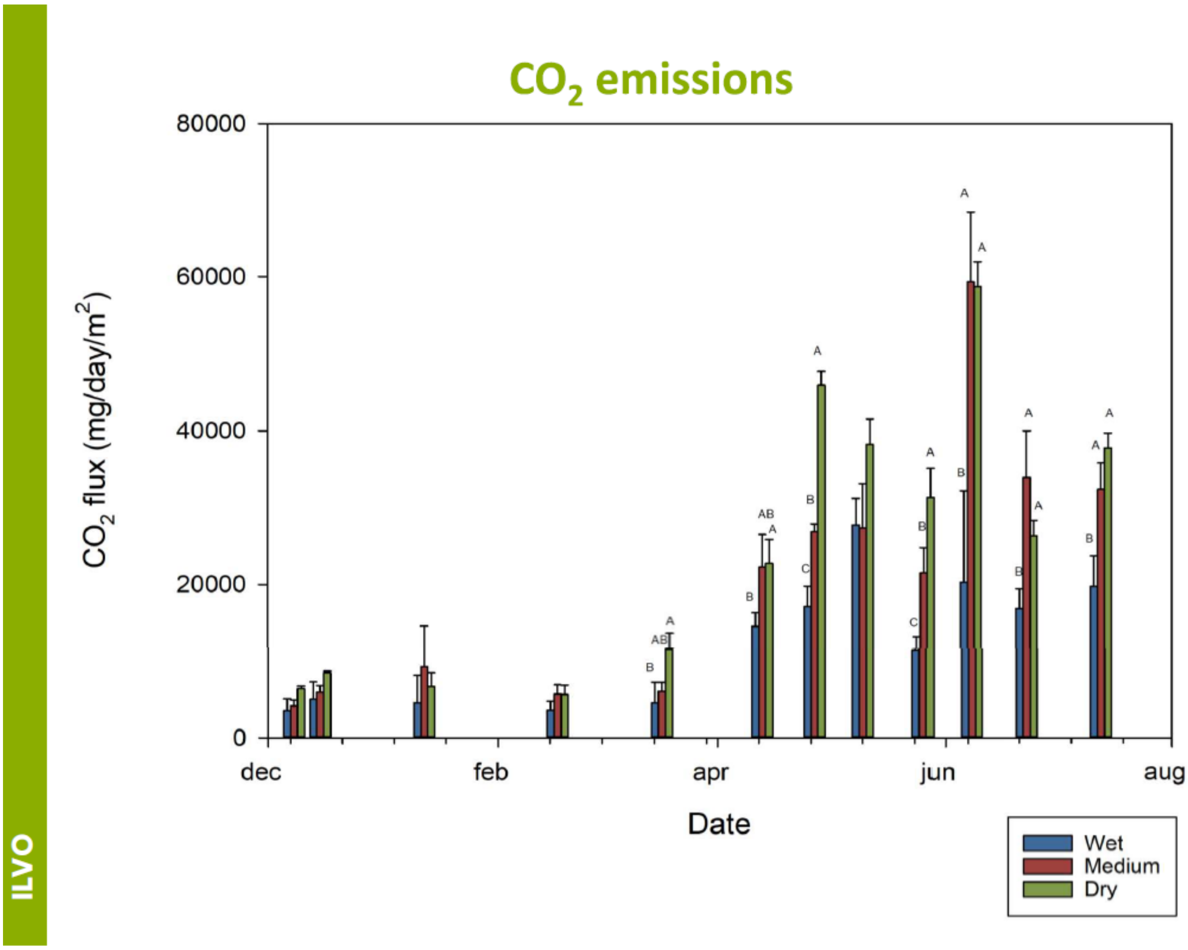


Figure 31. CO2 emissions

Shown data are restricted to the period December 2020 up to July 2021. From the histogram it is clear that CO_2 emission during the colder period of the year (December – April; < 10°C) is much lower with emission levels ranging from 3,5 to 11,6 g CO_2 /day /m^2. In spring and summer emission levels go up to 59,5 g CO_2 /day /m^2. Although the differences in emission between the three plots during the colder period is restricted, these are much more pronounced in the period from April to July.

The period December – March has lower temperatures and thus less CO_2-emission because of lower bacterial activity in the soil. From April onwards CO_2-emissions are much higher, with however a high variability in the plots 1060 and 1063. Variability is less in plot 1045.

These differences are presented as a time series in figure 31.

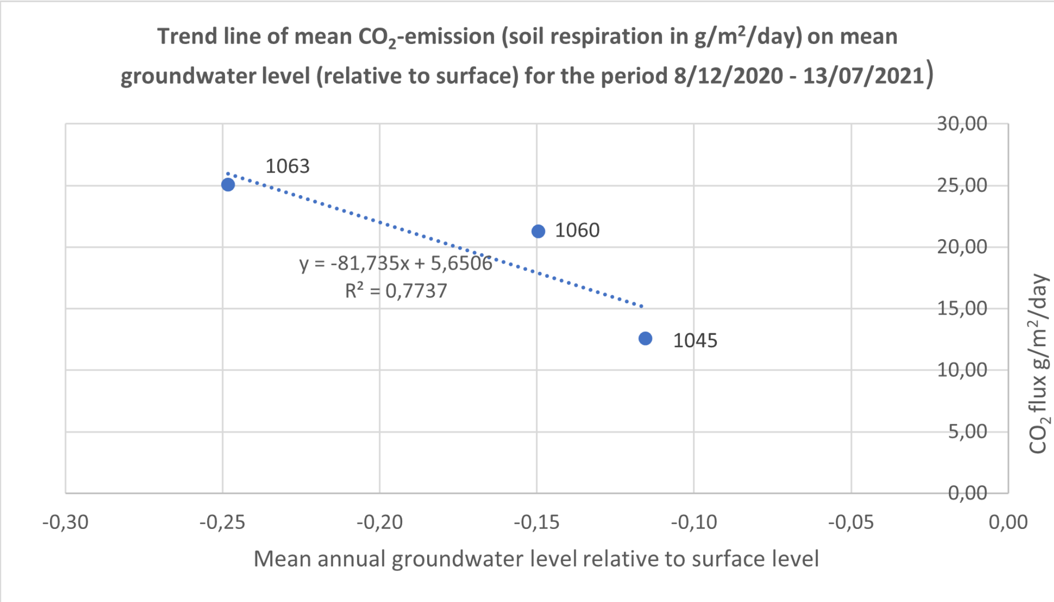


Figure 32: CO_2 emission on the three plots 1063, 1045 and 1060.

Emission in plot 1045 is lower with a maximum of 27 g CO_2 /m²/day (May 10th). On June 8th emission in plot 1045 is 20 g CO_2 /m²/day, whereas the plots 1060 and 1063 reach nearly 60 g CO_2 /m²/day (3 x higher). Mean CO_2-emission for each plot over the entire monitoring period, with corresponding mean groundwater level is given in table 7.

Table 7.

	CO_2-emission (g/m²/day)	Groundwater level (m)
1045 / CARP002	12,56	-0,12
1060 / CARP004	21,26	-0,15
1063 / CARP006	25,07	-0,25

CO_2 flux and groundwater level

With the data in table 7 we can generate a trend line representing the relationship between CO_2 flux and groundwater level. This trend line is presented in figure 32.

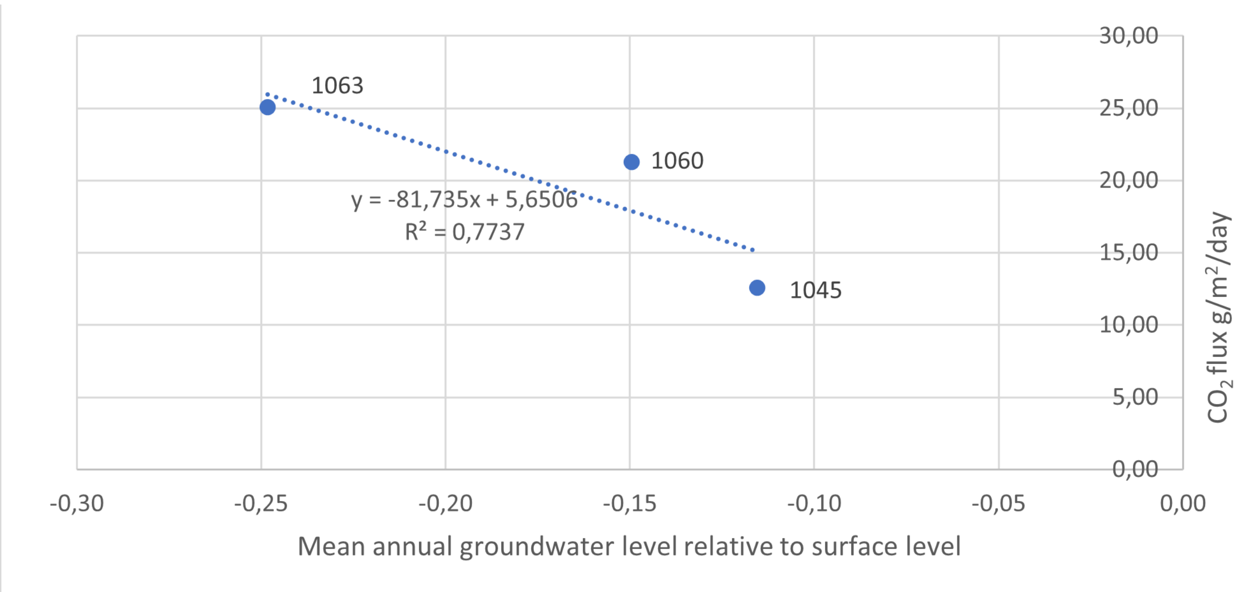


Figure 33. trend line of mean CO_2 emission (soil respiration in g/m&/day) on mean groundwater level (relative to surface) for the period 8/12/2020 - 13/07/2021

From figures 31 and 32 it is however clear that CO_2 emission is much higher from April onwards. Most probably temperature plays a major role in the amount of CO2 emission during the colder months, whereas groundwater levels are highest during these months. Therefore it is probably better to use the median groundwater level of the period April – July in order to create a trend line of CO_2 emission in relation to groundwater level. This is presented in figure 33.

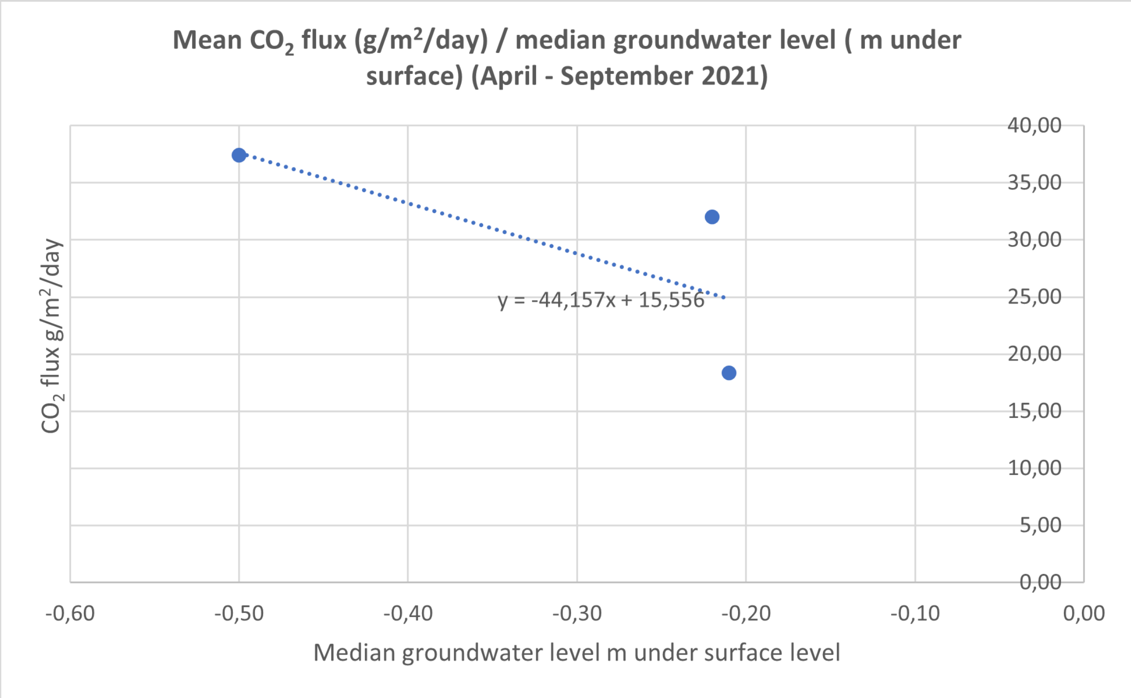


Figure 34. Mean CO_2 flux (g/m²/day) / median groundwater level (m under surface) (April - September 2021)

The trend line gives us the opportunity to get an estimate of the impact of groundwater level on CO_2-emission. It should be stressed that these results are based on measurements during a restricted period without taking into account other parameters. Extrapolations should therefore be handled very cautiously..

The current hydrological conditions of plot 1045 can be regarded as the objective for a large part of the pilot area. Thus, the distance to target is the difference of the current mean groundwater level at a specific location within the pilot with those of plot 1045.

The increase of mean groundwater level corresponds to a reduction of CO_2-emission. In case we use the mean groundwater level July (trend line figure 33), 1 cm increase of mean groundwater level gives a decrease of CO_2-emission of 0,81 g/m²/day. In case we use the median groundwater level (figure 34), 1 cm increase of groundwater level gives a decrease of 0,38 g/m²/day. As already indicated the latter is probably a better estimate of the decrease of CO_2 emission through increase of groundwater level.

CO_2 flux and soil humidity

The trend line on the scatter plot of soil humidity (cm^3 / cm^3) on CO_2-emission ($g/m^2/day$) (figure 35) clearly shows a similar relationship as the one between groundwater level and CO_2-emission. Higher soil humidity in the upper soil layer gives lower CO_2-emission.

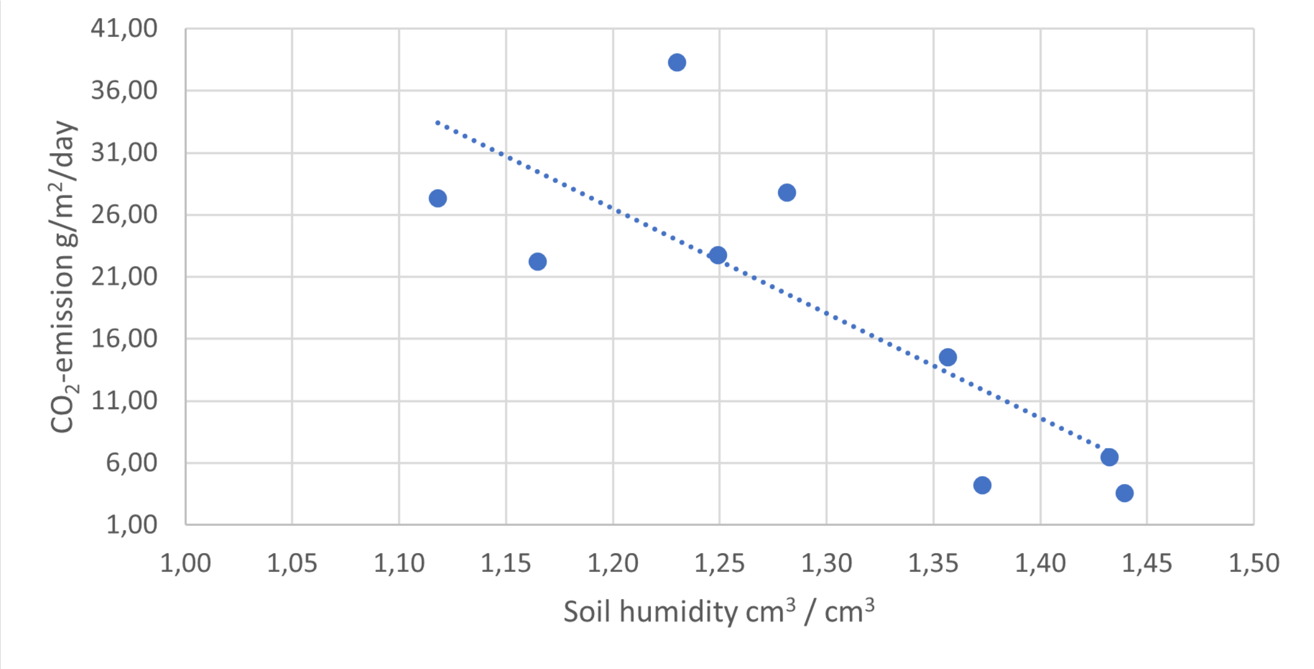
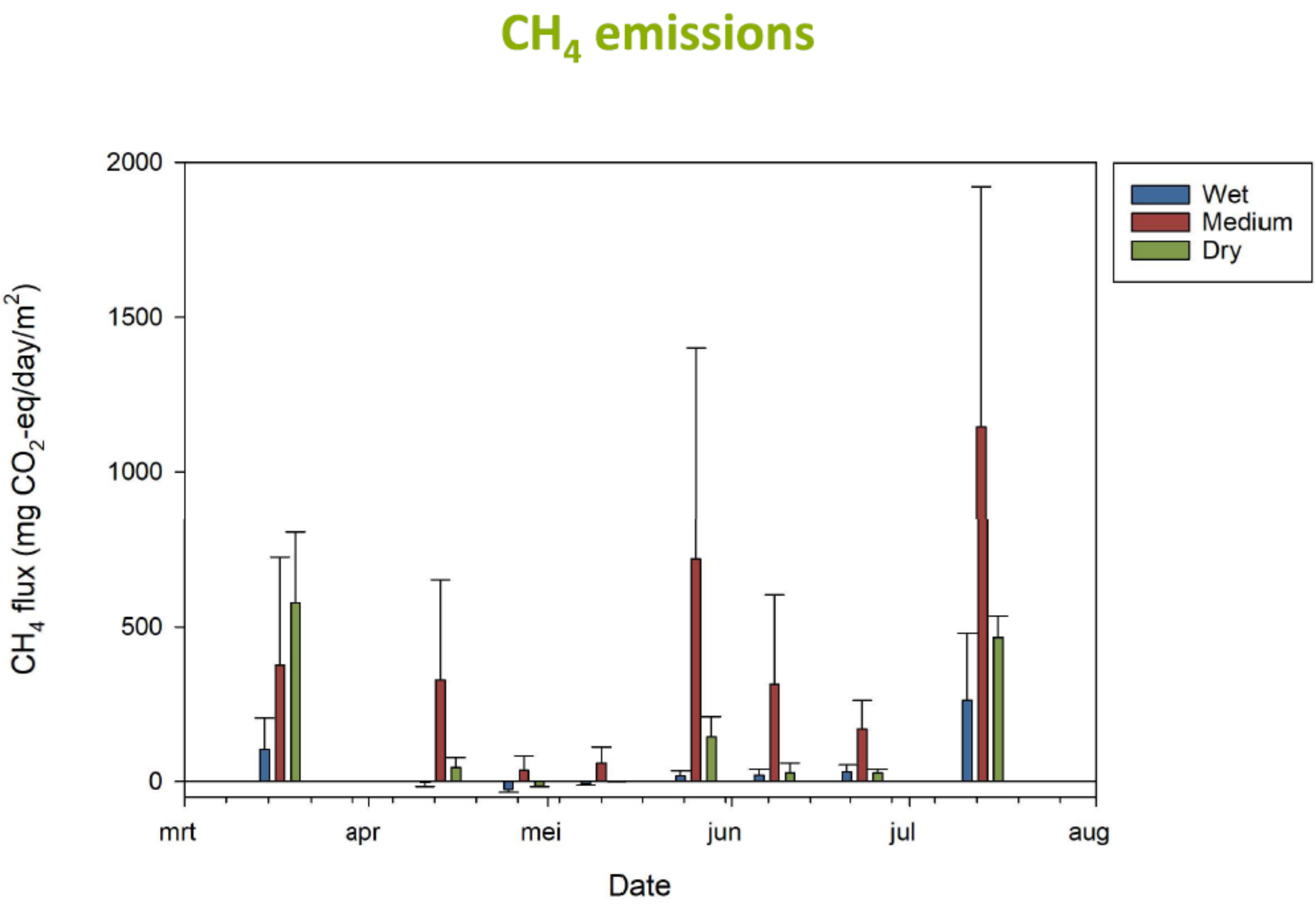


Figure 35. CO_2 emission / soil humidity

CH_4 emission

In figure 34 CH_4 emission is shown for the three plots. CH_4 emissions are an order of magnitude 50 lower than CO_2 emission (in CO_2 equivalents as GWP). From these data it can be estimated that the GWP of the CH_4-emission ranges from 0,17 to 1,43 CO_2 eq / ha/year. This agrees with CH_4 emissions of 7 to 57 kg CH_4/ha/a. This shows that in comparison, with CO_2 , CH_4 emission currently plays a minor role in total C-flux in plots 1045 and 1063. CH_4 -emission is much higher in plot 1060 (medium) in comparison with the other 2 plots. Especiallly plot 1045 has low CH4 emission. Plot 1063 shows intermediate values. It is however clear that groundwater level is not the sole determining factor for CH_4 emission, meaning that there is no clear relation between groundwater level and CH_4 emission. Possibly the higher concentration of TOC (dissolved) in plot 1060 and the amount of soil organic carbon, which is more than twice this in plots 1045 and 1063 generates a carbon source much more prone to methanogenesis. In this respect it is remarkable that soil organic carbon content at plot 1063 is intermediate between 1045 and 1060.



ILVO

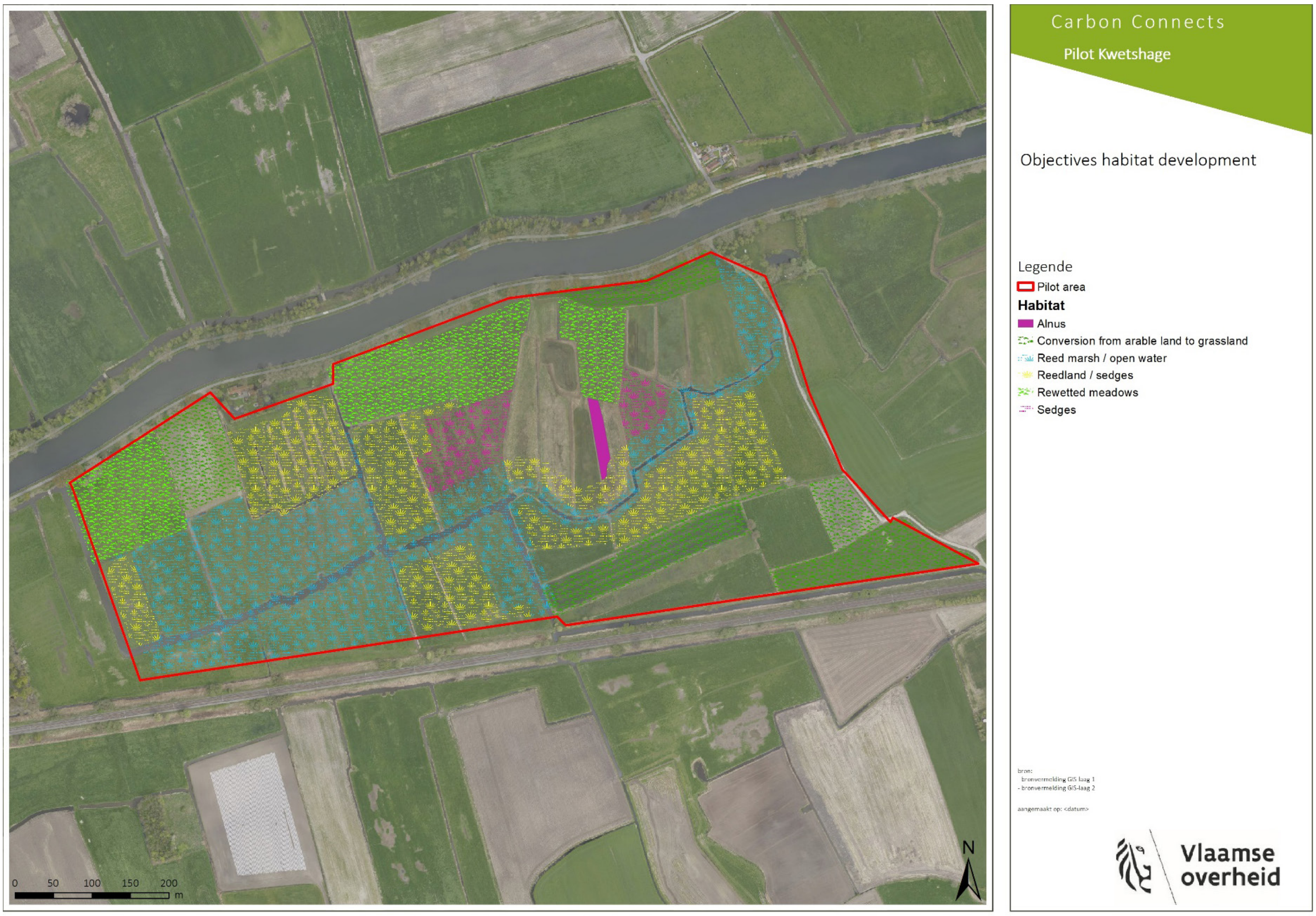
Figure 36. CH_4 flux in CO_2 equivalents / day / m^2 for the three plots.

4 Conclusion

1. Mean annual groundwater levels in Kwetshage are already low ranging from 0,13 m to 0,24 m under surface level
2. Mean groundwater levels in spring and summer range from 0,22 m to 0,41 m under surface level
3. Soil organic carbon content in the upper 0,90 m of the soil range from 350 to 700 t C / ha.
4. Mean CO_2 – flux measured in the period December 2020 – July 2021 ranges from 12,5 to 25 g CO_2 /m^2/ day
5. There is a linear relationship between mean groundwater level and CO_2 flux. Based on this relationship it is estimated that 1 cm of groundwater level rise gives a decrease in CO_2 emission of 0,8 g CO_2/m^2/day
6. The linear relationship between median groundwater level in the period April – July and CO_2 flux, gives an estimate of decrease of CO_2 emission of 0,38 g CO_2/m^2/day for each cm rise of the groundwater level.
7. Current CH_4 emission varies highly between locations ranging from 47 mg CO_2eq/m^2/day to 391 CO_2eq/ m^2/day.


Carbon Connects
Pilot Kwetshage
Monitoring
Map 1: Location of plots
C-emission measurements
Legende
Plot
Rewetted area
Pilot_Kwetshage
1045
1060
1063
0
250
500
750
1.000
N
Interreg
North-West Europe
Carbon Connects
Vlaamse
overheid


Carbon Connects
Pilot Kwetshage
Monitoring
Map 2: Location of piezometers
Legende
Peilbuizen_Kwetshage
Rewetted area
Pilot_Kwetshage
CARP001XCARP002X
KWEP002a1KWEP005x1
CARP004XCARP003X
CARP006XCARP005X
250
500
750
1.000
m
N
Interreg
North-West Europe
Carbon Connects
Vlaamse
overheid



Carbon Connects
Pilot Kwetshage
Objectives habitat development
Legende
Pilot area
Habitat
Alnus
Conversion from arable land to grassland
Reed marsh / open water
Reedland / sedges
Rewetted meadows
Sedges
bron:
bronvermelding GIS laag 1
- bronvermelding GIS-laag 2
aangemaakt op: <datum>
Vlaamse
overheid
0 50 100 150 200 m
N