FAME Fieldwork report

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General introduction to FAME

This report provides an overview of a three-month field campaign to the Mekong Delta of Vietnam, as part of the Deltares project 'FAME' (Freshwater availability in the Mekong Delta). The aim of the report is to provide a description of the visited field sites and activities performed at each site, discuss the first data obtained in the field and make suggestions for further research. We hope that this report will provide the necessary information for other researchers to continue work at these sites within the FAME project.

The Mekong Delta is key to the Vietnam national food security, with a large part of the agriculture being dependent on fresh water for food production[1]. Currently groundwater resources are being depleted and substantial parts of the delta are subject to subsidence[2]. This, combined with the increasing vulnerability to climate change and sea level rise, makes the implementation of water management and adaptation strategies - to reduce the over extraction of groundwater and help dealing with more saline conditions - of crucial importance. The project FAME is a collaboration with local Vietnamese partners (WACC and DWRPIS) and entails assessing the feasibility of different water management techniques in the region, at a 'farmer scale level'. In the current phase of the project the aim is to design, conduct and monitor a pilot of an Aquifer Storage and Recovery (ASR) technique in the coastal provinces of Ben Tre and Tra Vinh in relation to sustainable food production. In these provinces, old sand dune ridges can be found which serve as shallow aquifers supplying groundwater to the farmers living on or close to these dunes. ASR techniques that can be implemented at these sites consist of i.e. restoring phreatic fresh groundwater, deep well infiltration, and the construction of fresh (ground)water reservoirs[3].
Three field sites have been selected by Deltares and the local partners, one in Tra Vinh and two in Ben Tre. These three sites are tested for their suitability as a pilot location for the ASR-techniques. This report provides an overview of field activities performed in the months October to December 2019 by the students Sep Bregman (Wageningen University), Josh Shankel and Anne Kruijt (Utrecht University).

Location of the three field sites

[1] Delta Plan, Long-term vision and strategy, Vietnam-Netherlands, 2013. Mekong Delta Plan, Long-term vision and strategy.
[2] Minderhoud, P. S.J. 2017; Impacts of 25 years of groundwater extraction on subsidence in the Mekong delta, Vietnam

[3] Pauw, P.S., Van Baaren, E.S., Visser, M., De Louw, P.G.B., Oude Essink, G.H.P., 2015. Increasing a freshwater lens below a creek ridge using a controlled artificial recharge and drainage system: a case study in the Netherlands. Hydrogeology Journal

Field work

The three students have been selected to perform a geological and hydrogeological assessment of the sites together with an assessment of the water demand of farmers based on their agricultural activities. A general overview of field activities is given below, and site-specific information can be found further on in the report. Pictures of the different measuring devices can be found in appendix 1.

Geological work and well installation

The sedimentology of the shallow subsurface was determined with the use of hand operated coring devices. With a hand auger, sediments from the unsaturated zone could be brought to the surface and when the water table was hit a self-made suction corer was used to take out sediment further. The suction coring enabled us to go down to a depth of 3 to 4 meters. These coring devices were also used to create a hole in which a self-made observation well was placed. Pressure sensors were placed in these wells, to monitor the changes in groundwater level at each site. Since the suction corer could only be used until a depth of 4 meters, a professional drilling team was hired to perform deeper corings and install deep wells. This team was led by Dr. Hung, one of the Vietnamese collaborators of this project. They would drill until they hit the suspected bottom of the sand dune, and until a maximum of 15 meters depth. The purpose of these drillings and installations was to make sure that there is at least one well at each site that monitors groundwater changes year-round (without the danger of the well falling dry) and at the same time get an impression of lithologies at a depth greater than 4 m.

Hydrological work

Next to the monitoring of groundwater level variations, the water quality of both groundwater and surface water was tested with the use of a CTD-diver measuring electrical conductivity, nitrate strips and a ‘probe’. The CTD-diver could be attached to a ‘fishing rod’ to perform a continuous measurement of salinity changes in a ditch or canal. A rain gauge was installed at two of the three sites. This rain gauge measures precipitation by recording the number of tips of its ‘tipping bucket’.

Slug test and infiltration testing

To determine the infiltration rate and hydraulic conductivity of the sediments found at each field site, infiltration tests and slug tests were performed. For a proper infiltration test many conditions need to be met; the soil should be not too densely vegetated, not too affected by human activities, and for practical reasons there should be a water source nearby. It proved very difficult to find locations that met all the requirements. We are not sure about the correctness of all our results and thus if they are of use for the calculation of the infiltration capacity of the sand dunes at each site. The results will be presented and discussed in more detail in a later report.

Interviews

Information on water use and problems with water availability occurring in the region were gathered through interviews with local farmers. These were performed at each field site with the help of a local translator. These personal stories and experiences can serve as indicators of the scope of the problem and help in the identification of a suitable pilot site. The interviews will be processed by Sep Bregman and results presented in a later report.

TV02:

Introduction to the site

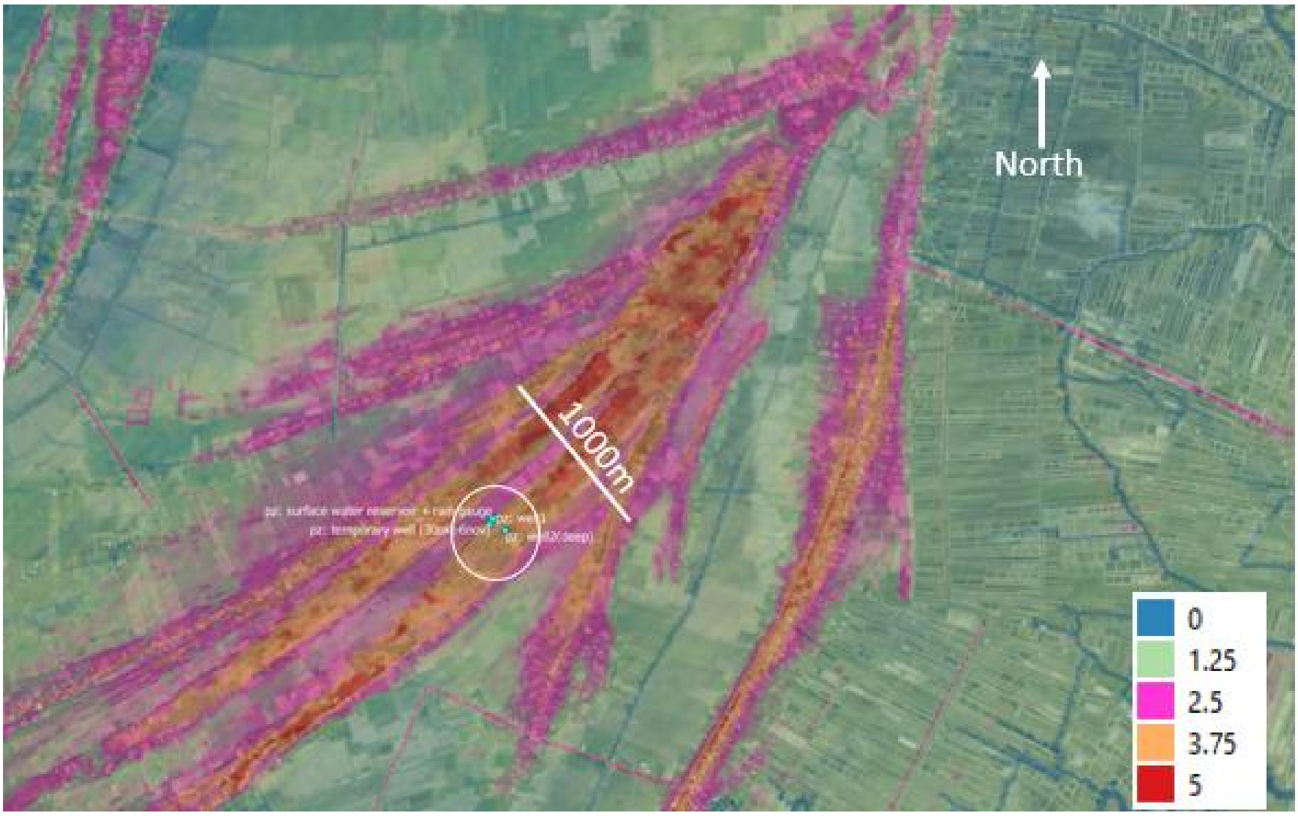
This field site is located in the eastern part of the Tra Vinh province. Farmers in this area live quite far apart from each other and often own a piece of land on the top of the dune as well as a rice or grass field further away, off dune. The sand dune system seems to be quite extensive and elevation differences are clearly visible in the field.

This province is known for its relatively large Khmer minority and you will find many Khmer temples along the way from Tra Vinh city as well as close by the field site. It is one of the poorest parts of the Mekong Delta and receives special attention from the government. The AMD project (*Adaptation in the Mekong Delta*, a Vietnamese project funded by the International Fund for Agricultural Development (IFAD)) has installed a surface water reservoir at this site. This reservoir is meant to improve the year-round availability of fresh water for farmers, but is not yet in full use. In the middle of November 2019 a pumping station has been placed next to the reservoir and several farmers have been selected to participate in a testing phase in which they can extract water from the reservoir.

Left upper and lower: farmland on top of the dune. Middle: Father of Mr. Hung, the farmer living right beside the AMD reservoir. Right upper: AMD reservoir. Right lower: house and children of Mr. Hung

Lithological characterization

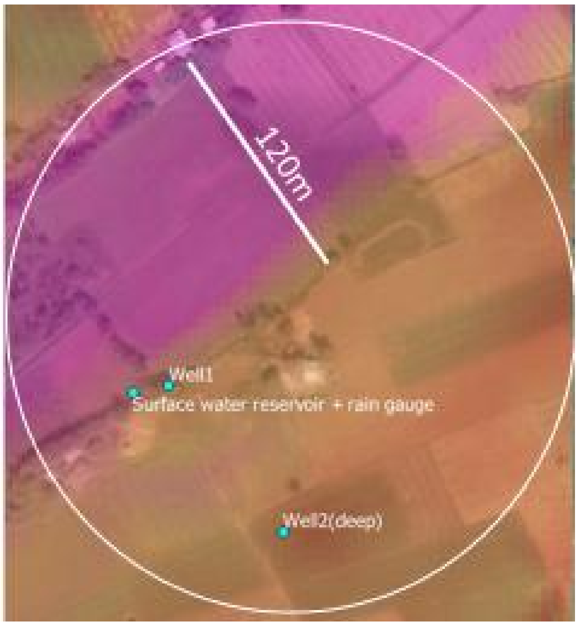
At this site we experienced some difficulties with the coring, meaning that often we did not manage to get very deep. The corings that were successful helped us determine the lithology of the upper 3 to 4 meters of the sand dune, but more and deeper corings are needed to get a more accurate estimate of the size of this dune system. A lithological transect and a map with coring sites is added in appendix 2. The results of our corings have been analysed by Josh Shankel, who has provided the short description below: '*This site is characterized by a largely, deep and uniform sand layer of well sorted very fine sand. This was observed across two dune structures spanning approximately 670m. Very few clay or sandy clay (maximum 20cm thick) deposits were found during the shallow coring (maximum 4m deep). These small layers do not appear to be significant or continuous across the dunes. The deep coring shows a thick clay layer, which is considered the continuous base of the dune and an aquitard. Based on this boundary and varied surface elevation, the sand layer is approximately 7.4m – 6.2m thick.*'



Digital elevation model of the area, with legend (showing height in meters). Installed measuring devices are indicated with blue dots.

Installed devices

At this site, two observation wells have been made containing pressure sensors (divers) that will monitor groundwater changes from the wet to the dry season. The first well is quite shallow and was installed by hand, the other was installed by the drilling team led by Dr. Hung. Besides this a diver has been temporarily installed in the AMD reservoir to monitor changes in surface water level between November and December. A rain gauge has been placed next to the reservoir to monitor the rain fall at this site. A short description of each monitoring device can be found below. Details on each observation well can be found in appendix 3.



Well1_TV02:

The diver was installed on the 3rd of October, in a self-made observation well. This well is located opposite the AMD reservoir next to a field and a small path. It is close to the house of the farmer who is our main contact at this site, Mr. Hung. We chose this spot because it wasn't on farmland and hence would not be in the way of farmers working on their land. We expect this well to be on the side of one of the sand dune ridges in this area. The screen of the well consists of 50 cm of small holes at the end of the tube.

Well1, hidden from sight by some old pieces of bamboo

Well2_D_TV02:

The installation of this well and diver was performed on the 16th of December. A detailed well schematic with descriptions of encountered lithologies can be found in appendix 4. We expect this location to be on top of the most eastern ridge of this sand dune complex. The well is located in the front garden of the farmer Mr. Nanh, next to the small path crossing the dune. The installation took place after our last field week, so we have not yet been able to inspect the data from the diver in this well.

Well2_D, installed in the front garden of the house on the left upper and lower photos

Surface_water_reservoir_TV02:

The AMD reservoir dimensions are not publicly available, meaning that we do not know exactly how the reservoir is connected to its surroundings. Drains at the side of the reservoir are told to discharge water from the surrounding groundwater system. A diver attached to a rope was hung in the reservoir from a self-made fishing rod like construction. It has been recording surface water level variations between the 30th of October and the 10th of December, after which it was deinstalled because the construction was quite fragile and not suitable to be left unattended for several months.

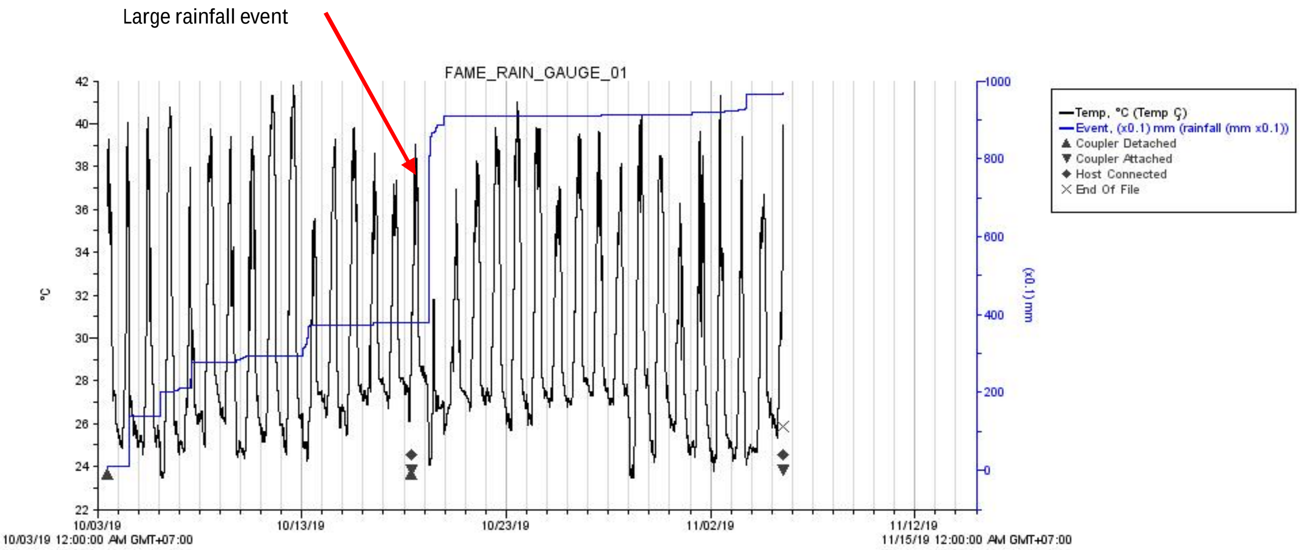
Rain_gauge_TV02:

The rain gauge has been installed on the 3rd of October. From October to the end of November the rain gauge has been measuring at an interval of 1 minute, but to save memory space in the months that no researchers will be available to download data, the measuring interval has been set to once every 5 minutes. Important to note is that the pumping station extracting water from the reservoir has been installed by the AMD right next to our rain gauge. We hope this installation will not influence the amount of rain fall registered by the rain gauge.

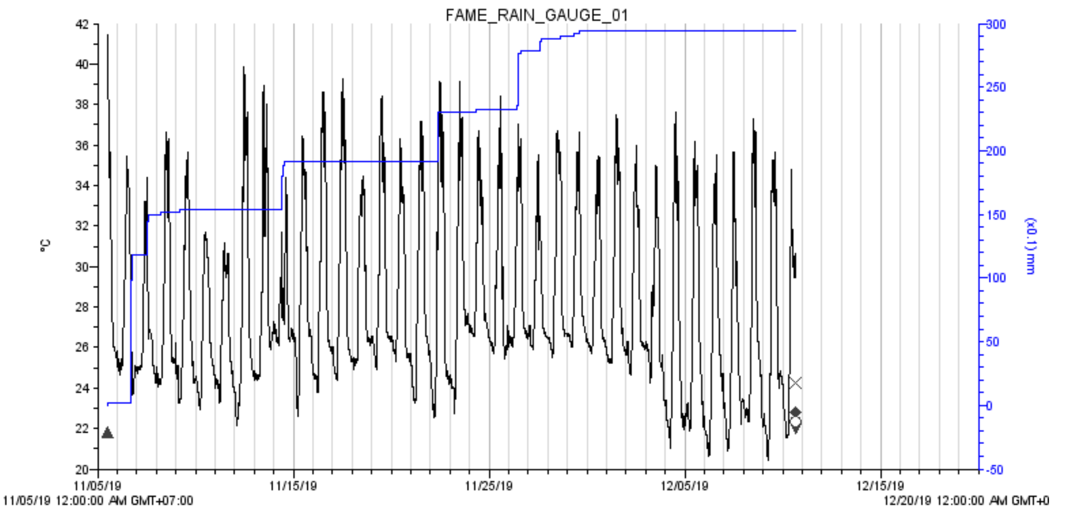
Rain gauge and surface water monitoring installation shown on the left. The photo on the right shows the pumping installation.

Rain gauge data

The graphs below show the cumulative rainfall for the months October to end of November and end of November to middle of December. Between the 3rd of October and the 5th of November, we can observe several small rainfall events and one larger event on the 19th of October. The rain gauge recorded a cumulative rainfall of 100 mm for the month of October, 50mm of which fell on the 19th of October. The rest of October, November and the start of December are much dryer; the rain gauge recorded a cumulative rainfall of 30 mm for this latter period.

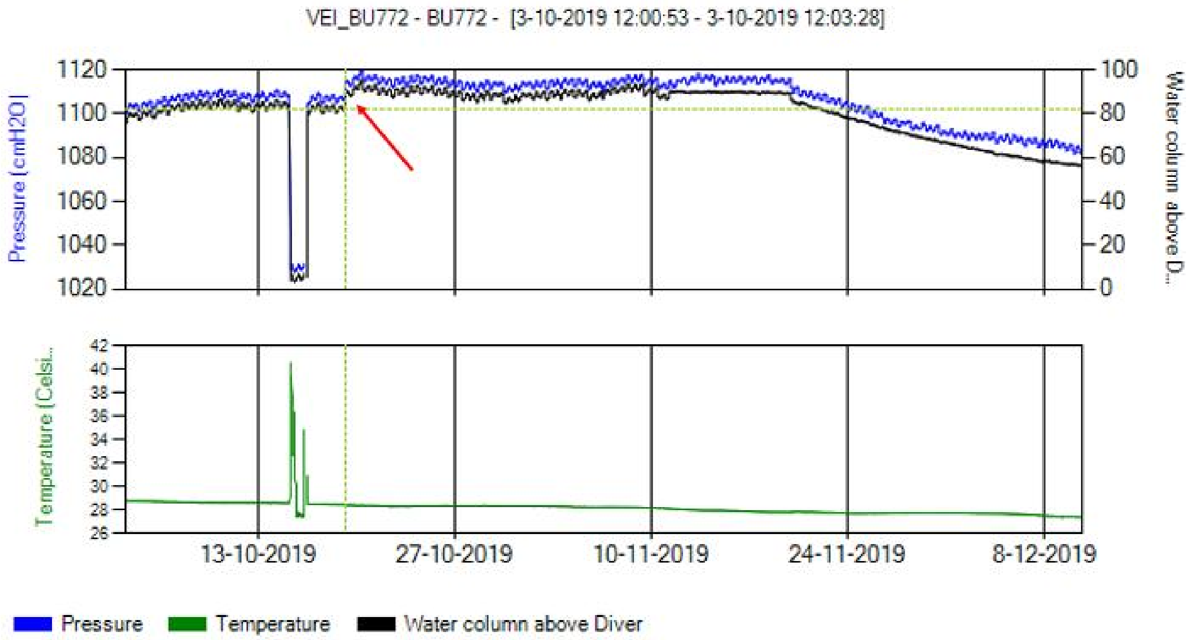


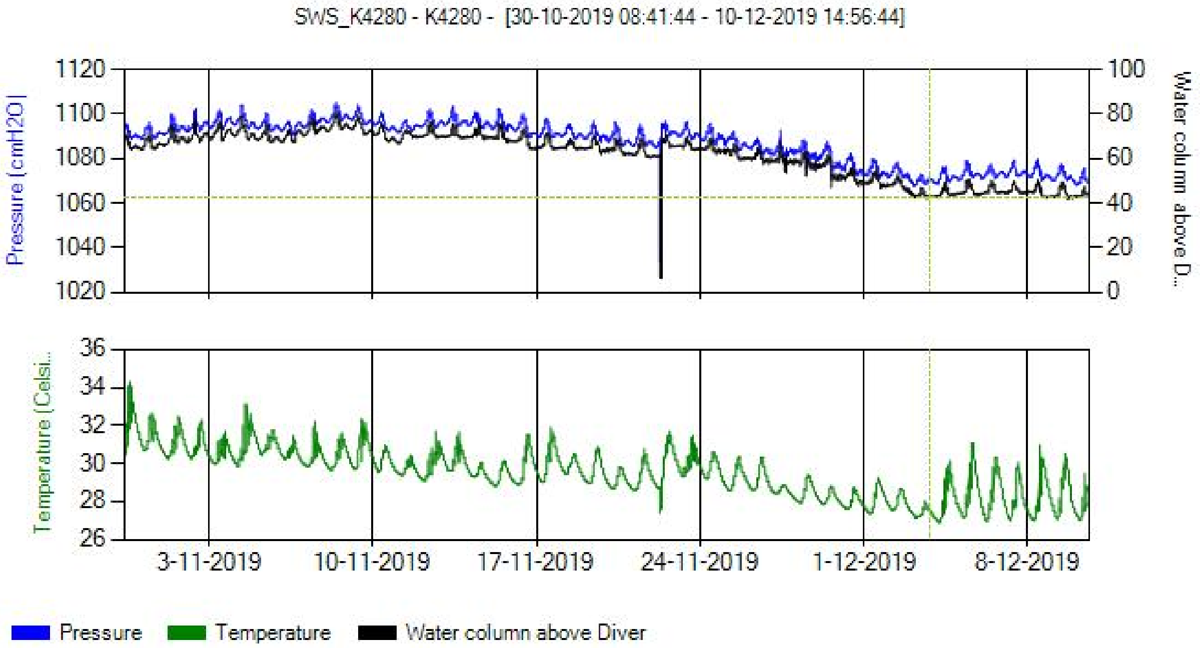
Data as presented by the HOBO-software that comes with the rain gauge. Graph above shows the cumulative rainfall from the 3rd of October to the 5th of November. Graph below shows the cumulative rainfall from the 5th of November to the 11th of December.



Groundwater monitoring

Measurements from the longest running diver at this site, located in Well1, are shown in the first graph below. We can observe a slight rise in groundwater level from the 3rd to 19th of October, with a short interruption between the 15th and 16th of October when the well was accidentally de-installed by the farmer Mr. Hung. There is a sudden rise on the 19th of October (indicated by the red arrow), and a steady decline from the 20th of November onward. In total there has been a drop of 27 cm in groundwater level over the months October to December. Since the rain gauge registered quite some rain fall in October and an especially large amount on the 19th of this month, this might explain the slight rise we observe during this period and the sudden rise in ground water level on the 19th.





Data from the diver as presented in the Diver-office software. The diver measures pressure and temperature of the water and the software can then calculate the water column above the diver, by compensating for atmospheric pressure. A barometer diver is installed at another field site (BT02) and the data used to compensate measurements at all field sites. The barometer was installed permanently on the 11th of November, meaning that for the first month only some single measurements of atmospheric pressure are available and compensation is not done correctly.

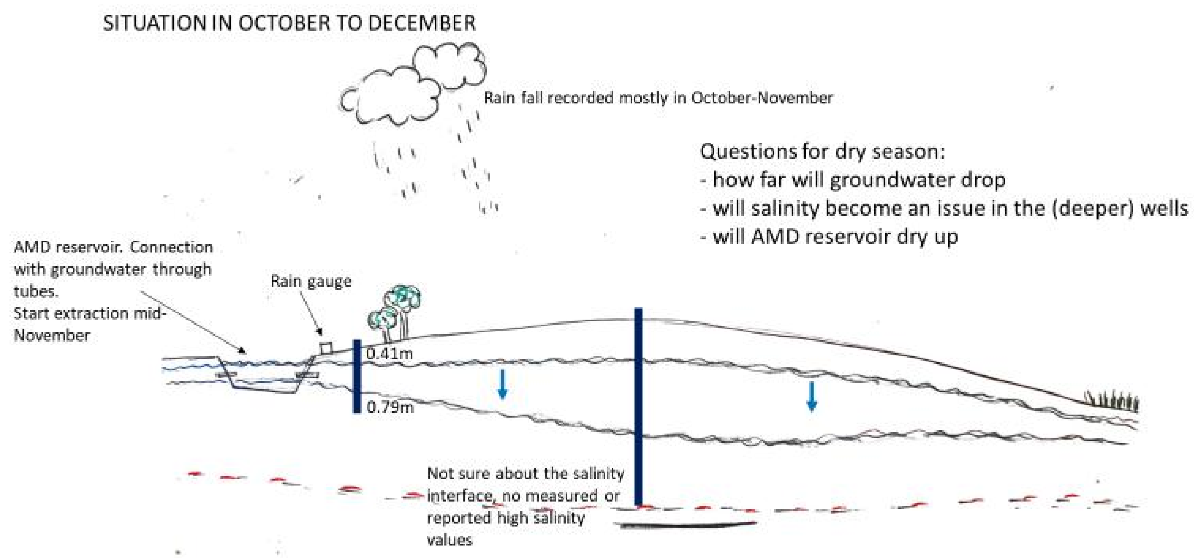
The second graph shows the surface water level in the AMD reservoir between the 30th of October and 10th of December. A steady drop in water level is observable between the 22nd of November and the 3rd of December, after which the water level seems to stabilize again. This drop, of approximately 26 cm, is similar in timing and magnitude to the drop observable in the groundwater, indicating that these two systems are indeed connected. The large sudden drop in the surface water level on the morning of the 22nd of November is caused by the piezometer briefly being taken out of the water, possibly due to construction works related to the installation of the pumping station. The steady decline in groundwater and surface water levels from the 20th of November onwards is possibly related to the onset of controlled extraction from the AMD reservoir. However, since we do not know when the controlled extraction from the AMD reservoir started exactly and how much water is extracted per day on average, it is hard to be certain about this.

Water quality and salinity measurements

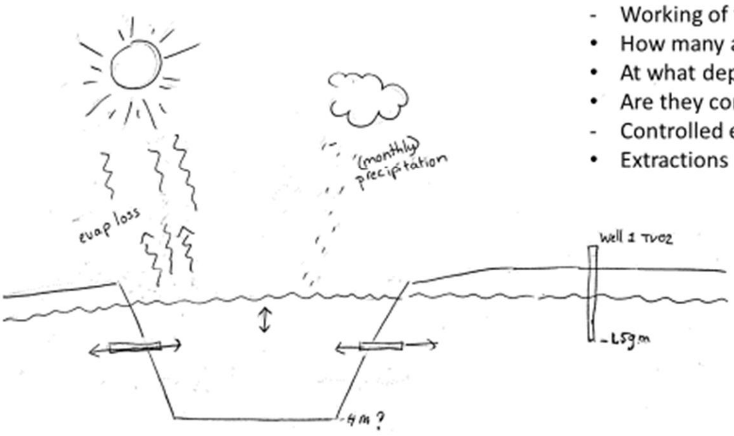
The sand dune complex at TV02 is quite extensive, meaning the area in the immediate vicinity of the field site is relatively high and sandy, with little to no surface water available. At this site our attention was focused on the lithological corings and only few water quality measurements were performed. The spots that were measured lie in a transect across the dune and consist of a small ditch and a dug-out pond to the west, the AMD reservoir and a dug-out pond on the east of the dune ridge. Besides this we measured the quality of two existing groundwater wells, one next to the AMD reservoir and one on the western side of the dune. A map with the locations is added as appendix 5.1. All spots were measured once, and at each spot the electric conductivity was between 300 and 500 µS/cm both in the surface water and in the wells. This suggests there is no real issue with salinity in this region, which fits with the impression we got from talking to farmers in the area.

System dynamics - a conceptual picture

The following images summarize our first findings in a conceptual way, but are also an 'artist impression' of the system, meaning that many of the lines are not backed up by measurements. All our activities took place during the end of the wet season. The first image contains some follow up questions to be answered through further activities at this site in the dry season. The second image shows an impression of the AMD reservoir. One of the initial aims of this project was to show the water balance of the reservoir, but not enough data is available yet. The problems that need to be overcome in order to make such a balance are listed on the side of the image.



Problems:
- The dimensions of the reservoir are not clear
• Depth, slope of the sides, surface area of the bottom
- Working of the tubes connecting reservoir to land not clear
• How many are there
• At what depths
• Are they controlled
- Controlled extraction has started in November
• Extractions rates not easily made available



Opportunities for this site

There is room in the sand lenses at this site to infiltrate fresh water in the months of October to December. Groundwater levels on the sand dune were already several tens of cm below ground surface at the beginning of October and started declining further from the end of November onwards. However, there are not many canals or ditches close to the field site that could serve as a water source for infiltration of freshwater into the sand lens. Furthermore, most farmers in the area report little to no problems with either quantity or quality of the groundwater during the dry season, suggesting there is no ‘freshwater availability problem’ that can be tackled here. However, we have only studied part of this extensive dune system and suggest more scouting of the surroundings might lead to the finding of a more suitable location closer to a canal. More careful scouting might also reveal sites close to our current site where farmers do experience problems with water availability.

Another interesting challenge for this site is to better understand the working of the AMD-reservoir and its connection to the groundwater system. A water balance of this reservoir could potentially show an estimate of the amount of water lost from the reservoir through evaporation and help determine whether this reservoir is a smart solution to storing freshwater in the area.

BT02:

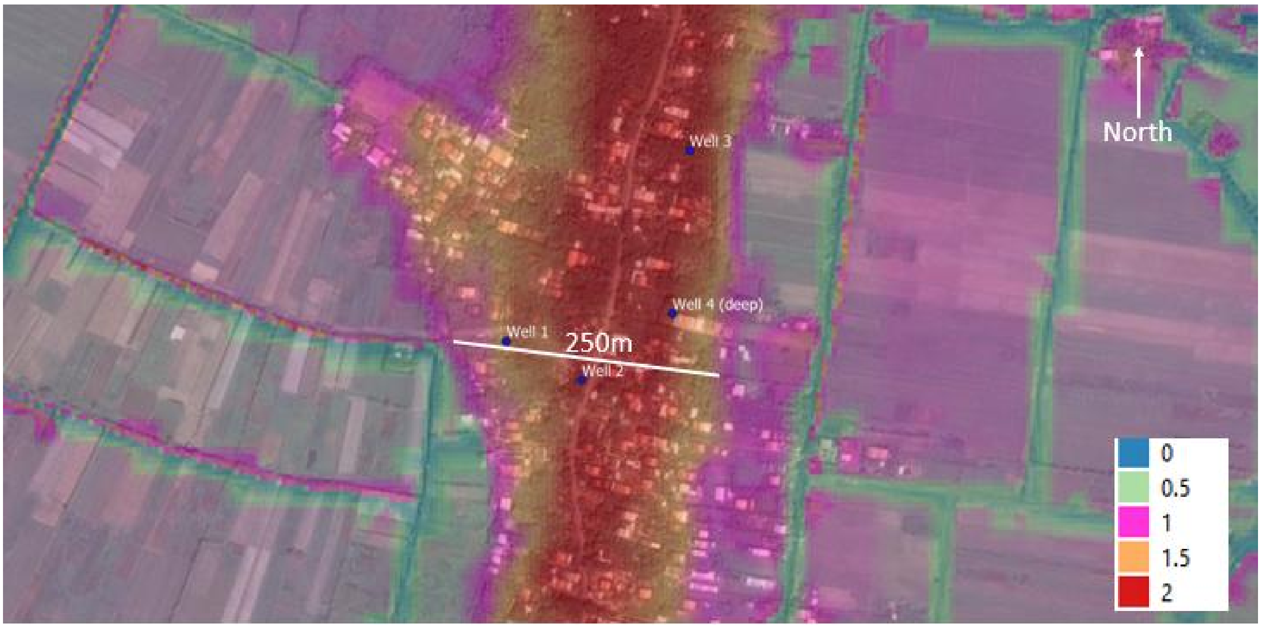
Introduction to the site

The field site is located south of the village Phú Ngãi. The sand dune here is quite narrow, only approximately 210 m across, and mostly occupied by the main road and houses and gardens directly on to or close to this road. Most farmers have (rice)fields off or on the side of the dune. There are several small communities of houses, accessible by little paths off the main road. Many houses have pump wells, but communities often also have an older, sometimes shared, open well. Groundwater from these wells is mostly used for domestic activities such as washing and cooking. Small canals can be found to the west and east of the dune, and their water is used for irrigation of the fields. Farmers in this area mainly produce rice, own cows and have orchards with fruit trees such as bananas.

Clockwise, from upper right: coring on the western side of the dune, a small communal field on dune, coring on dune, farmhouse, coring between the banana trees, interviewing farmer Mr. Phuoc

Lithological characterization

The corings at this site helped determine the lateral limits of the sand dune, with a thick layer of sand often found at sites close to the road and clay encountered almost immediately off the sides of the dune. Three lithological transects and a map with coring sites are added in appendix 2 of this report. The results of the corings performed at this site have been analyzed by Josh Shankel, who provided the short description below: '*This site is highly influenced by anthropogenic activity. A single small dune was studied on this site, across its width of approximately 200m. It is characterized by a layer of well sorted, fine sand bound by clay layers in the dune slacks and marine sand at approximately 2.0m-3.5m depth. The sides of the dune yielded significant amounts of clay. However, based on anthropogenic evidence (glass, trash, and plastics) often found in these areas the data does not reflect the natural environment. A deep coring yielded evidence of a shallow clay layer at 4m from the surface, followed by another large sand layer of 11m, both are considered continuous. The aquifer boundary is represented by a large clay layer at approximately 14m from MSL*.'



Digital elevation model of the area, with legend (showing height in meters). Installed measuring devices are indicated with blue dots.

Installed equipment

At this site, four observation wells have been made containing pressure sensors (divers) that will monitor groundwater changes from the wet to the dry season. The first three wells are quite shallow and were installed by hand, the fourth is much deeper and was installed by the drilling team led by Dr. Hung. A short description of each observation well can be found below. Details on each well can be found in appendix 3.

Well1_BT02:

The diver was installed on the 23rd of October, in a self-made observation well on the property of a farmer living off the main road (Mr. Phuoc). We chose this location because it seems to be slightly higher elevated (not in a rice field) and expect it to be part of the sand dune. Also, here it is under the protection of the farmer, and separated from the main road by a fence. The Baro-diver is also installed in this well, hanging just below the cap. It was placed in the well on the 11th of November. The screen of this well consists of 50 cm of small holes at the end of the tube and a mesh on the inside.

Well2_BT02:

The diver was installed on the 7th of December, in a self-made observation well on the property of Mr. Phuoc. This farmer owns a lot of land in this village (Well1 is located in his garden). This site is located directly next to the road and expected to be near- top of sand dune. The well is protected from sight by some bushes and situated next to a house of a farmer who will keep an eye on the well. The screen of this well consists of 60 cm of small holes on the bottom of the tube without an additional mesh on the inside, as the holes of the mesh were almost the same size as the holes in the tube, and the mesh was hampering propper attachement of the screen to rest of the tube. The installation of the well was a bit troublesome. Due to collapsing of the hole and the very fine sand present at depth, we could only get the tube down to about 3.5m below ground surface. When placing the diver it hit a sandy layer *inside* the tube, meaning fine sand must have passed trough the holes of the mesh when we pushed the pipe into the ground. We had to place the diver above this sandy layer for it to hang freely in the water column. We hope it is placed deep enough to be below the permanent water table and that the pipe will not become clogged further.

Well3_BT02:

The diver was installed on the 7th of December, in a self-made observation well on the property of Mrs Xeo. Her house is next to the main road, and the well is located behind the house, next to some large bamboo trees. We expect this location to be on the eastern side of the sand dune. The screen consists of 60 cm of small holes at the end of the tube, with no additional mesh inserted on the inside. Our concerns for this well are the same as for Well2; we experienced fast collapse of the hole while installing the tube, and there was some fine sand on the inside of the tube when we placed our diver.

Well2 (left) and Well3(right)

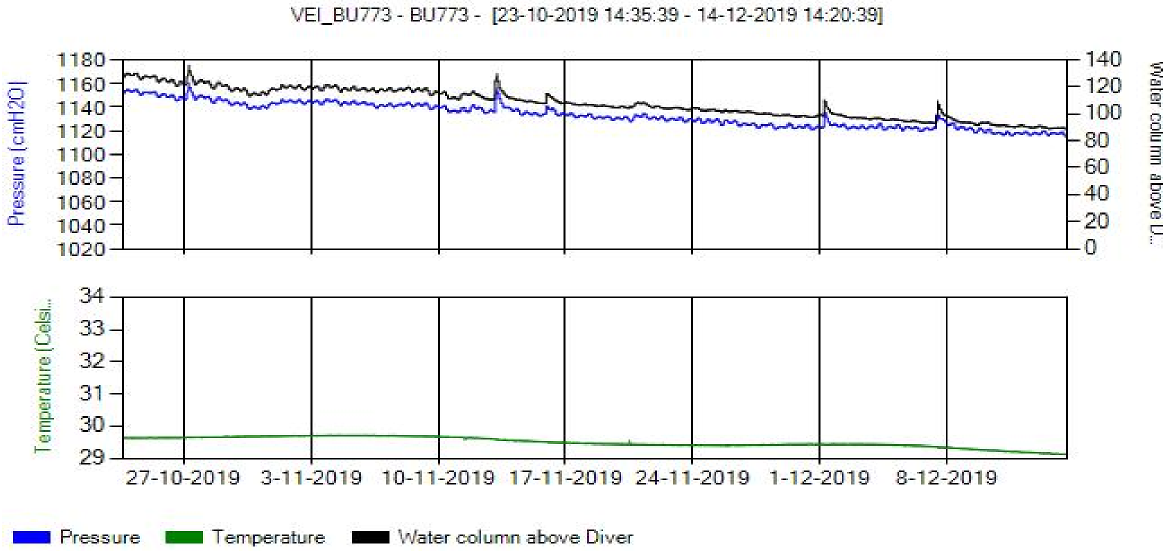
Well4_D_BT02:

The installation of this well and diver was performed on the 15th of December. A detailed well schematic with descriptions of encountered lithologies can be found in appendix 4. A small clay layer was encountered at approx. 10m depth and it was decided by the drilling team to place the screen below this clay layer, from 11.5 to 12.5m. We are not sure if this thin clay layer is continuous and thick enough to create a confined aquifer below, or if in fact the sand in which the screen is placed is part of the unconfined aquifer, in which case it might have been preferable to have a larger screen also connected to the sand above the clay layer. Since the installation took place after our last field week, we have not yet been able to inspect the data from the diver in this well.

Well4_D, located in the front garden of Mr. Lua

Groundwater monitoring

Measurements from the longest running diver at this site, located in Well1, are shown in the graph below. We can observe a steady decline in groundwater level, with some interesting spikes at: 27th of October, the 13th and 16th of November and the 1st and 7th of December. These might be due to heavy rainfall, but we have no measurements to back this up, since there is no rain gauge on site. Because rain fall in this region can be very local, data from the rain gauges at the other two sites might not be representative. Another possibility is that human activity in the garden in which this piezometer is located has caused these momentary higher water levels. From the interview with Mr. Phuoc we know that the trees and grass in this garden is watered regularly. In total the water level has dropped approximately 40 cm over the months October to December.



Well1_BT02, diver placed 190 cm below ground surface

Water quality and salinity measurements

Groundwater in wells

Measurements were performed with both a CTD-diver and the probe in open wells and water pumped up by pump wells. Measuring sites are spread out across the study area, on both sides of the main road (map 1 in appendix 5.2). The sites were all visited once, and measurements performed in the months of November and December. Measured values range from approximately 600 to 5800 µS/cm, with one extreme value of 15000 at location 11 in the map. Salinity values measured in wells on both sides of the dune are higher than those measured on top of the dune. Wells on the western side, especially in a small group of houses slightly off the main road, show slightly higher salinities than on the eastern side. More measurements on top of the dune and on the eastern side might be needed, but measuring is hampered by lack of permission to trespass on people's property and the lack of a permanent translator on site. Furthermore, not all houses in the area seem to have wells or use groundwater.

To determine the depth of the interface between saline and fresh groundwater, ideally one should measure water from different depths. We have made a first attempt at doing so by inquiring after the depth of the wells we measured, but there often was no clear answer. In future work this inquiry could be further pursued, in combination with perhaps installing several observation wells of different depths to use as measuring points. Our measurements were performed at the end of the wet season. Ideally these measurements should be carried out at least every two months, to get a better understanding of the salinity intrusion in the groundwater wells. At present pressure sensors are installed in four observation wells across the dune. These could be replaced at a later stage by CTD divers, to measure salinity changes in the groundwater.

Surface water in ditches, ponds and small canals

Measurements were performed with the probe in a few canals, ditches and ponds surrounding the field site, on both sides of the road. A larger canal is located east and south of our field site, and smaller canals both west and east of our field site seem to be fed by water from this canal. These smaller systems of ditches are close enough to potentially serve as fresh water source for infiltration.

The sites (map 2 in appendix 5.2) were all visited once, and measurements performed in the months November and December. Measured values range from approximately 1100 to 5200 µS/cm, with no clear trend observable. The high (5000 µS/cm,) values were measured in ponds, most likely resembling groundwater rather than surface (canal) water.

More measurements at different locations along the ditches are needed to identify any change in salinity or direction of surface water salinity intrusion. However, at present the lowest salinity value was measured in the main canal south of the field site (location 5 in map 2) suggesting that salinization is not yet occurring in the large canals at this time of the year. To monitor the onset of salinization in the canals, a CTD-diver could be installed in one of the larger branches of the canal, potentially at the bridge located at location 5 in the map. Measuring salinity changes with the 'fishing rod' at this site was problematic, since there are often paths along the side, slopes are steep or highly overgrown, and access roads are often private property. We suggest a boat trip should be arranged to perform a continuous measurement of salinity along the canals.

Small system of ditches west of dune (location 1 in map 2)

Small canal east of dune (location 9 in map 2)

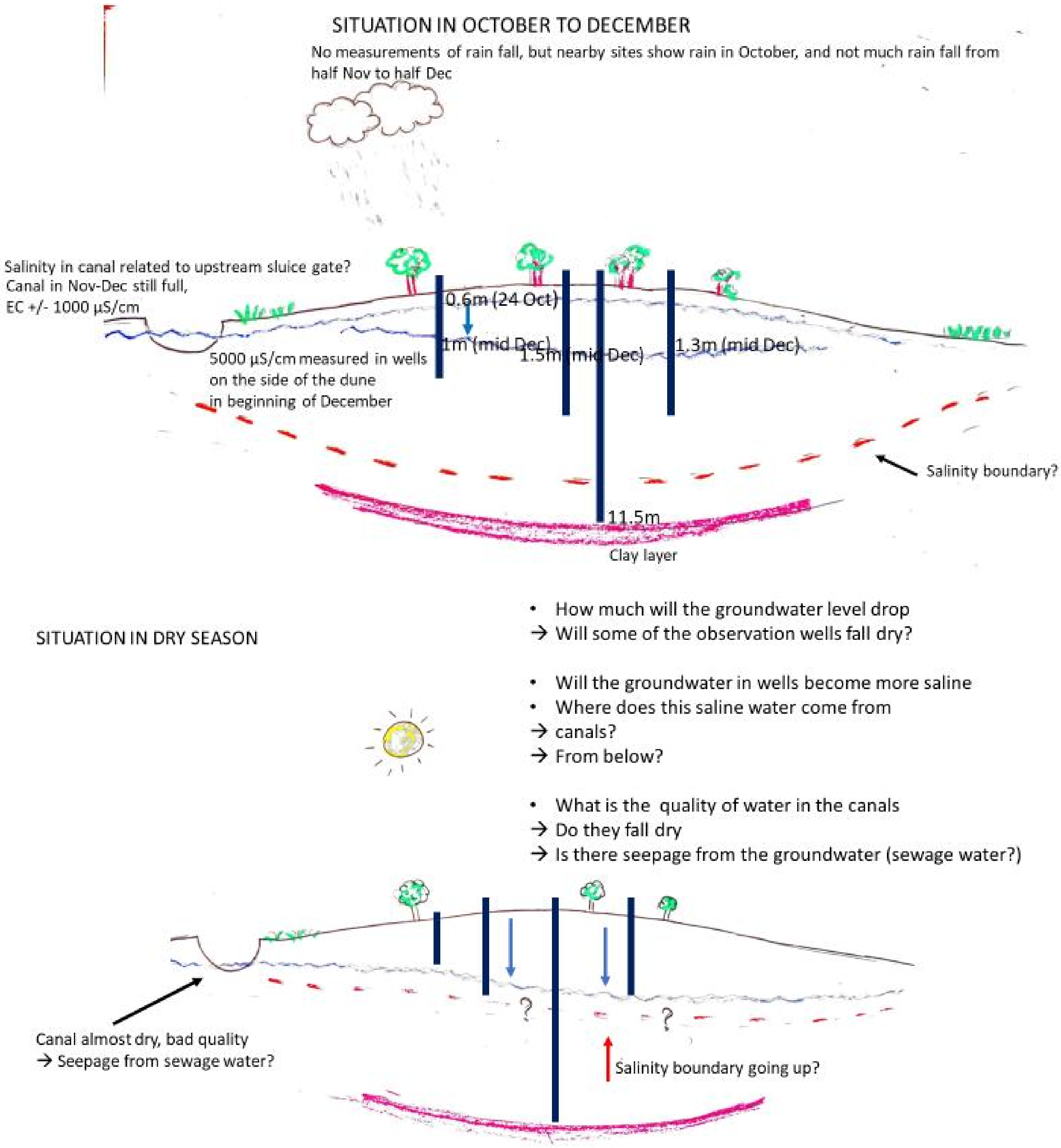
(same canal)

Example of a pump well (location 15 in map 1)

Example of an open well (location 19, in map 1)

System dynamics – a conceptual picture

The following image summarizes our first findings in a conceptual way, but is also an 'artist impression' of the system, meaning that many of the lines are not backed up by measurements. All our activities took place during the end of the wet season. The image contains some follow up questions to be answered through further activities at this site in the dry season.



Opportunities for this site

In the months October to December 2019 there has been a steady decline in groundwater level while at the same time water levels in the nearby canal are still high and salinity levels low. This means there is a window of opportunity at this site to infiltrate fresh surface water into the dune during these months, thereby enlarging the freshwater availability in the dry season. However, the dune is quite narrow and is densely populated, most of its surface covered by houses, gardens and the main road. This might make finding a suitable spot for the installation of ASR complicated. From the interviews we know that farmers at present do not use groundwater for agricultural purposes. For their domestic activities there is enough groundwater available year-round. Some farmers do report problems with availability and quality of surface water they use for irrigation in the dry season, so it would be interesting to explore the possibilities of making more groundwater available for agriculture in these months.

BT03:

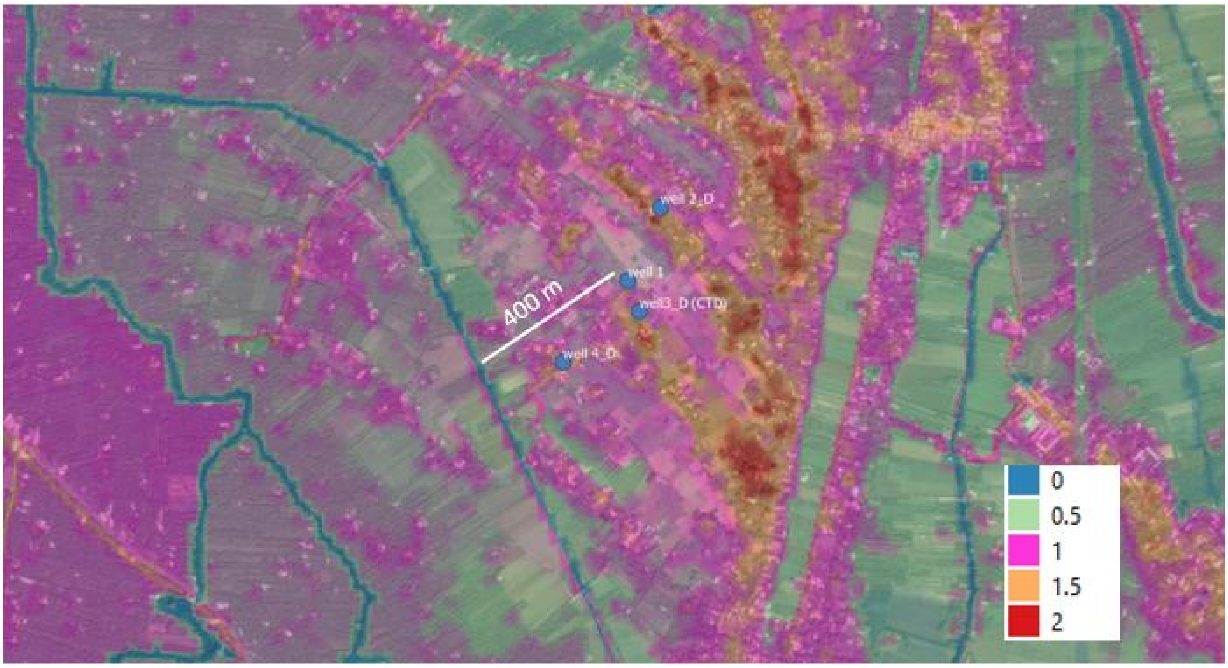
Introduction to the field site

This site is located in the middle of the Ben Tre province, which is quite densely forested and contains a lot of small rivers branching off the main canal near Ben Tre city. The sand dune system at this site is quite wide (more than 600 m across) but not clearly observable in the field, since elevation changes are small and houses and trees obstruct lines of sight. The area is densely populated and small fields are alternated with groups of trees, houses and little roads. To the west and east of the field site we find canals, but there are no continuous ditches crossing through the field site. Most farmers use a combination of groundwater and water from dug out 'water holes' to irrigate their crops. Coconut plantations and rice fields can be found close to the canals, and slightly higher up on the dune the farmers alternate between e.g. rice, peanuts, cucumber, citrus fruits and cassava.

Clockwise, from upper left: Farmer Mr. Hieu on his front porch, cassava on the dune, fields to the side of the dune, small ditches between coconut trees, a dug-out water hole on the dune, field bordering Mr. Hieu's farm, farmers harvesting peanuts in the field.

Lithological characterization

To identify the lithology of the subsurface we performed several corings using a hand auger and self-made suction corer, enabling us to go down to 4m depth. A lithological transect and a map with coring sites is added in appendix 2. The results of these corings have been analysed by Josh Shankel, who has provided the short description below: '*This site was studied in the highest detail, with the most deep and shallow coring completed. The site covers two dunes over a span of 500m. This layer is characterized by well sorted fine sand with intermittent layers of clayey/loamy sands and few clay layers (maximum 30cm thick). These layers appear to be significant enough to have an effect on hydraulic conductivity but are likely not fully continuous across the system. Three deep cores were completed on this site yielding a reliable aquifer boundary at approximately 6.5m below MSL. The sand layer from the surface is approximately 7.5m thick. Cores taken from this site show a very reliable reduction zone boundary which denotes the lowest average ground water level in the dry* *season. This boundary appears to be affected by groundwater extraction in some areas, but allows observation of low water levels to compare with water levels observed during the study of the site in a reliable way. '*



Digital elevation model of the area, with legend (showing height in meters). Installed measuring devices are indicated with blue dots, the rain gauge is installed at the location of well1.

Installed equipment

At this site, four observation wells have been made containing pressure sensors (divers) that will monitor groundwater changes from the wet to the dry season. The first well is quite shallow and was installed by hand, the other three were installed by the drilling team led by Dr. Hung. A detailed well schematic of these deeper wells, with descriptions of encountered lithologies can be found in appendix 4. A short description of each observation well can be found below. Details on each well can be found in appendix 3.

Well1_BT03:

A CTD-diver was installed on the 24th of October, in this self-made observation well on the property of the farmer Mr. Hieu. We chose this location because it is under the protection of the farmer, and slightly off the main road. The screen consists of 50 cm of small holes at the end of the tube and a mesh on the inside. We suspect this well to be located close to the top of the sand dune, based on the sandy subsurface present and its location on the DEM. On the 14th of December, the CTD-diver was placed in a different well (Well3_D_BT03) and replaced by a normal diver measuring only temperature and waterlevel.

Well1 on the property of Mr. Hieu

Well2_D_BT03:

The installation of this well and diver was performed on the 13th of December. This well is located on top of the sand dune in the front garden of Mr. Bay, next to a field of fruit trees. One meter of screen was placed at a depth of 7.3 to 8.3 meters and the diver hung just above the screen.

Well3_D_BT03:

The installation of this well and the diver was performed on the 13th of December. This well is located on top of the sand dune in the back garden of Mr. Phuong, behind the house. One meter of screen was placed at a depth of 5.5 to 6.5 meters and a CTD-diver was hung just above the screen.

Well2_D (left) and landowner (upper middle) and Well3_D (lower middle) and location of Well3_D (right)

Well4_D_BT03:

The installation of this well and diver was performed on the 14th of December. We expect this location to be more towards the side of the sand dune. It is located next to a junction between two small roads and quite close to a water hole, in a small grass field belonging to Mr. Tha. A layer of sandy clay was encountered from 5.7 to 6.8 m and it was decided by the drilling team to interpret this as an aquitard layer and place a small screen of 40 cm in the sand below this layer, interpreted as a confined layer. We are not sure if this interpretation is correct and the clay encountered above this sand is indeed creating a confined layer, or if in fact the sand in which the screen is placed is part of the unconfined aquifer, in which case it might have been preferable to have a larger screen also connected to the sand above the clay layer. Since the installation took place after our last field week, we have not yet been able to inspect the data from the diver in this well.

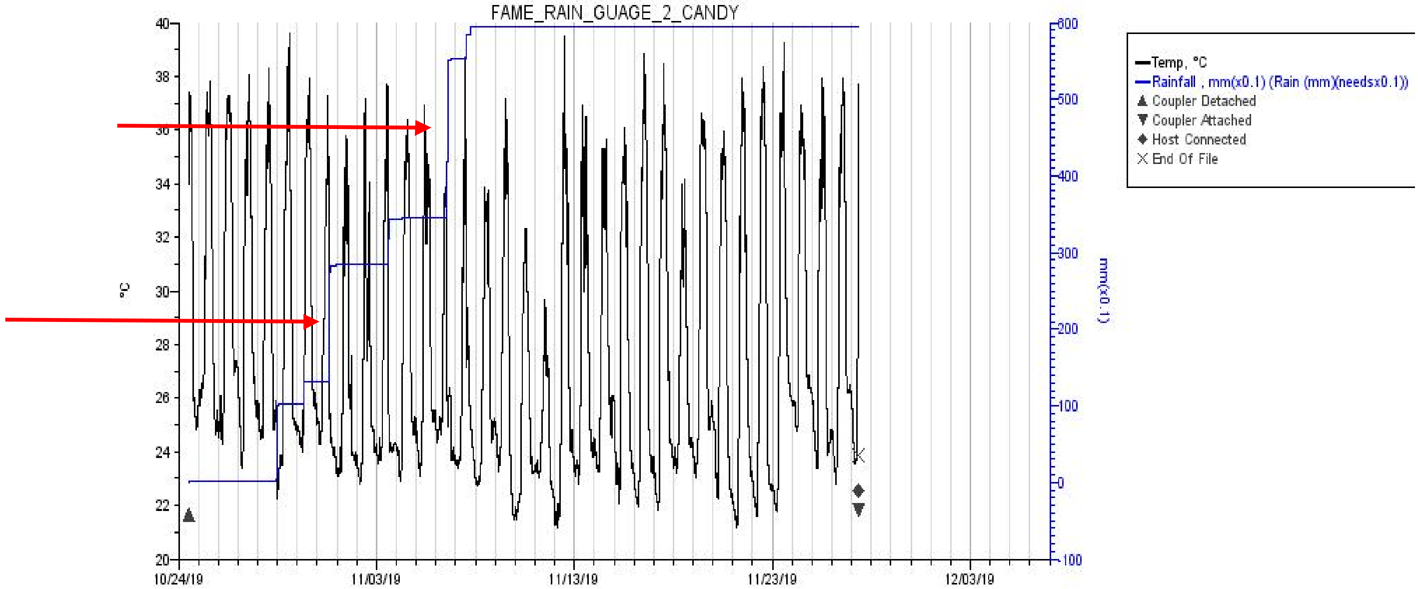
Well4_D, located in a small field next to a water hole and a road.

Rain_gauge_BT03:

The rain gauge has been installed on the 24th of October, on the property of Mr. Hieu. From October to the end of November the rain gauge has been measuring at an interval of 1 minute, but to save memory space in the months that no researchers will be available to download data, the measuring interval has been set to once every 5 minutes.

Rain gauge data

The graph below shows the cumulative rainfall for the months October to end of November and end of November to middle of December. Between the 24th of October and the 8th of November, we can observe approximately six rainfall events, the largest on the 31st of October (15mm in one day) and the 6th of November (20mm in one day), and a cumulative rainfall of 60 mm for this period. The rest of November and the start of December is much dryer. The rain gauge recorded a cumulative rainfall of 12 mm for this latter period, but since the ‘rainfall’ events coincide with coupling and decoupling of the logger, we expect these measurements to be incorrect, caused by the accidental tipping of the measuring cup while handling the logger and the graph is not shown here.

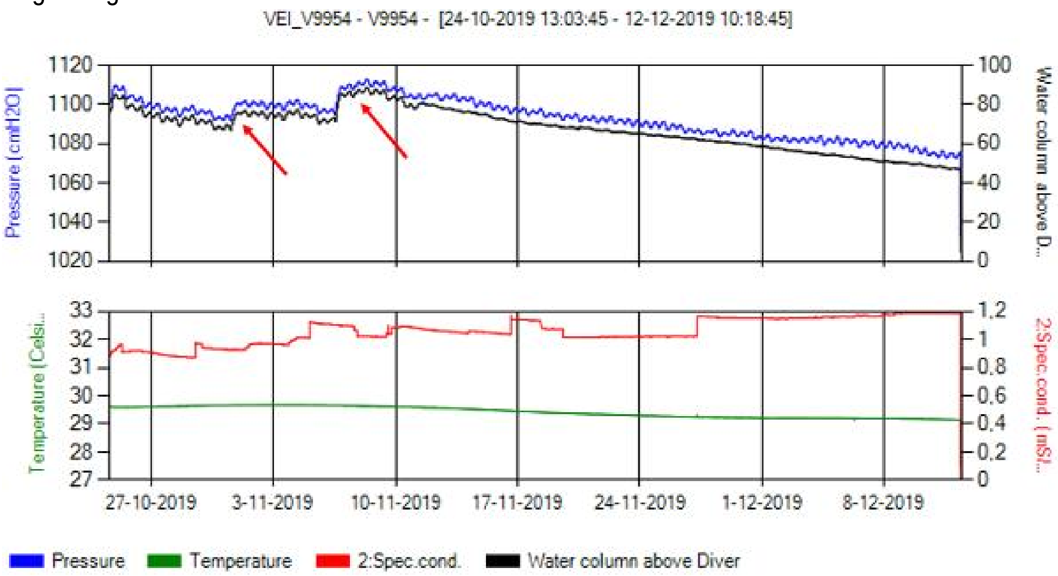


Cumulative rainfall for the 24th of October to the 27th of November. Red arrows indicate the above-mentioned large rainfall events.

Groundwater monitoring

Measurements from the longest running diver at this site, located in well1, are shown in the graph below. We can observe a decline in groundwater level from the 24th of October to the 6th of November, interrupted by a sudden rise on the 31st of October, probably related to the rainfall event observable in the rain gauge data. A second large rise occurs at the 6th of November, related to another large rainfall event. After this second rise, the groundwater starts to steadily drop again from the 10th of November onwards. There has been a total drop in groundwater level of 30 cm over this entire period. The bottom graph shows the salinity of the groundwater in the well. There is a small increase in salinity over the months, from 880 to 1200 µS/cm.

Important to mention is that when this site was first visited in the beginning of October, water levels were high, water holes almost full and water present in the rice fields. At the time of the installation of the diver, at the end of October, the groundwater level had already dropped significantly. Rice fields had dried up and the water level in the water holes was about a meter lower than at the beginning of October.



Groundwater level (top) and salinity (bottom) in well1, red arrows indicating timings of two large rain fall events

Water quality and salinity measurements

Groundwater in wells

Measurements were performed with both a CTD-diver and the probe in open wells and water pumped up by pump wells. Measuring sites are spread out across the study area (see map 1 in appendix 5.3) on and next to both dunes. The sites were all visited once, and measurements performed in the months November and December. Measured values range from approximately 600 to 2000 µS/cm. Salinity values seem to be lowest on top of the most western dune, and highest on the sides of both dunes, but other than that there is no very clear pattern observable.

The measured Ph is around 6.8 and 7.8 for all wells. Nitrate was not always measured but when measured is often 0. At one location (13 in map 1) it was very high (a value of 44), but this is likely related to the well being directly next to the cow shed.

Surface water in ditches, ponds and small canals:

Many small dug out irrigation ponds are present at this site. These most likely resemble the groundwater, but results are described here. A small canal is located to the west of the field site, which is connected to the larger river system in this part of the province. A system of smaller ditches is connected to this small canal, but there are no ditches crossing the field site. Interesting to note is that water level in the irrigation ponds dropped significantly, whereas water level in the canal did not visibly drop much over the months November to December.

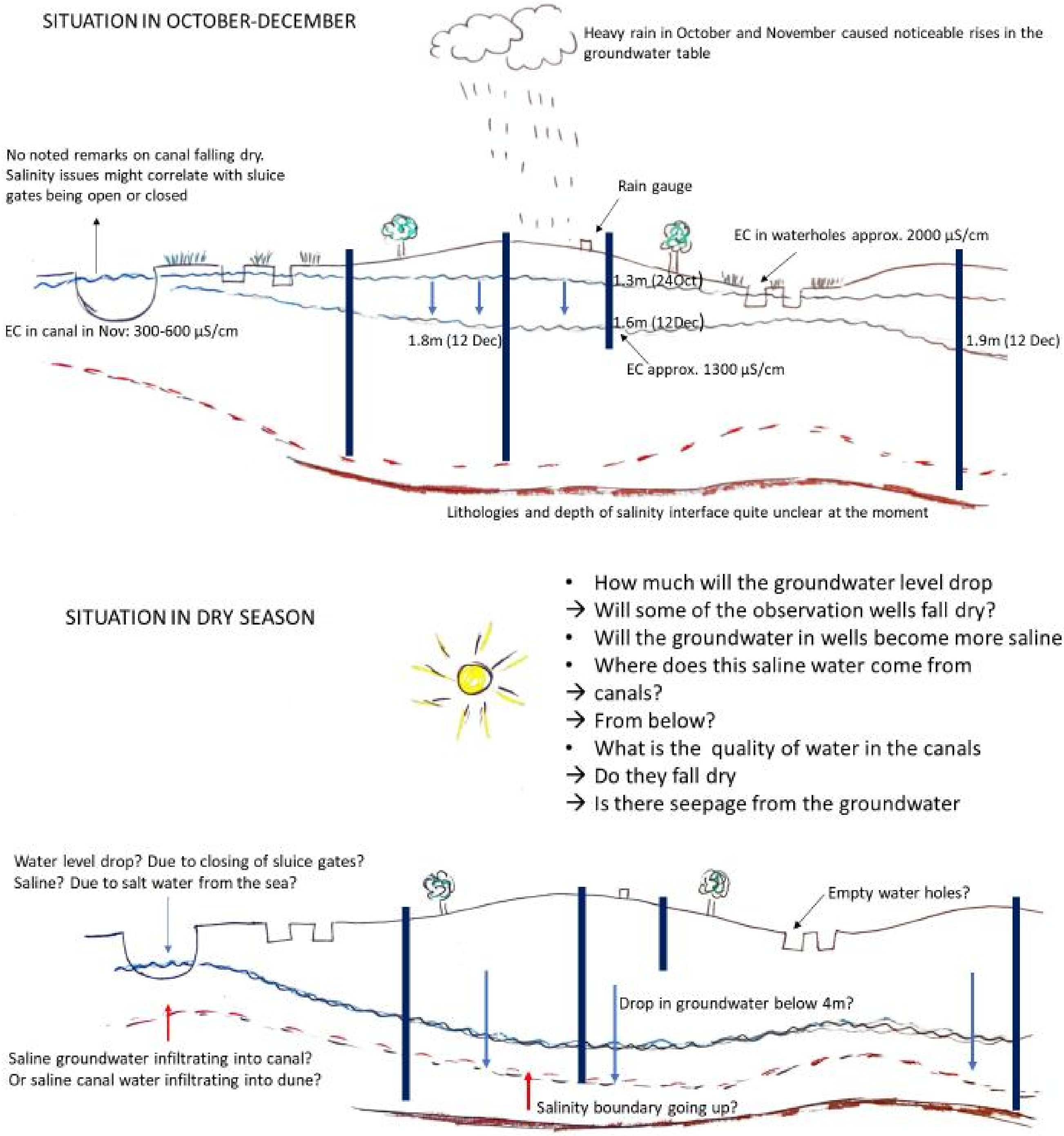
The measuring spots (see map 2 in appendix 5.3) were all visited once, and measurements performed in the months November and December. Measured salinity values in the ponds are highest and range between 1000 and 2000 (µS/cm). These ponds are mostly located on the sides of the sand dunes. Lowest salinity values of between 300 and 600 µS/cm, were measured in the small canal and ditches attached to the canal. This suggests that salinization is not (yet) occurring in the canals at this time of the year. To monitor the onset of salinization in the canals, a CTD-diver could be installed in the small canal, potentially at location 42 or 13 in map 2.

Canal to the east of the field site (locations 42 (top) and 13 (bottom) in map 2)

Measuring in a waterhole (e.g. locations 35, 34, 33 and 3, 4, 5 in map 2)

System dynamics – a conceptual picture

The following image summarizes our first findings in a conceptual way, but is also an 'artist impression' of the system, meaning that many of the lines are not backed up by measurements. All our activities took place during the end of the wet season. The image contains some follow up questions to be answered through further activities at this site in the dry season.



Opportunities for this site

Similar to the site BT02, in the months October to December 2019 there has been a steady decline in groundwater level while at the same time water levels in the nearby canal are still high and salinity levels low. This means there is a window of opportunity at this site to infiltrate fresh surface water into the dune during these months, thereby enlarging the freshwater availability in the dry season.

In BT03 farmers depend in part on the groundwater from their wells for the irrigation of their crops. They do not report any problems with saline groundwater in the dry season but do report that the availability of groundwater decreases, with some of the shallower wells even falling dry. This means that the installation of the ASR-technique at this site will potentially benefit the farmers by increasing the water availability for irrigation during the drier months.

More attention needs to be paid to existing and necessary infrastructure to install this ASR-technique. The nearest canal is approximately 400 m away from the top of the dune system and the area in between is quite intensively used. More information on the subsurface across the dune might be needed before deciding on the most suitable location to infiltrate surface water.

Acknowledgements

The work described in this report was performed together with my fieldwork partners Sep Bregman and Josh Shankel. We had an amazing time together in Vietnam and I am grateful that I got to do this fieldwork with them. I am also grateful for the continuous support of my supervisors Dr. Philip Minderhoud, Dr. Gualbert Oude Essink and Geoff Zimmel from Deltares. Dr. Wim Hoek and Tim Winkels from Utrecht University are thanked for introducing Josh and me to suction coring and providing us with the necessary equipment and training to build our own suction corers in the field. Dr. Quan and Dr. Quang from the WACC are thanked for their support in the field. Their enthusiasm for the project and efforts to support us wherever they could made work a lot easier. I thank all the farmers at the three field sites for their hospitality, for letting us work in their fields and inviting us for tea, sweets and sometimes even delicious lunches. It was an experience I wouldn't have missed for a lifetime.

Appendix

1. Field equipment

Hand auger

Suction corer

CTD-diver

Measuring in a pond with the probe


Fishing rod


Infiltration rings


Professional drilling team


Sediment cores delivered by drilling team

2. Lithological cross sections

This section contains maps with coring locations for each field site, and cross sections made with LLG software. The location codes in the maps correspond to the codes on top of each individual borelog in the cross section. Maps, borelogs and cross sections were made by Josh Shankel and will be described in more detail in a different report.

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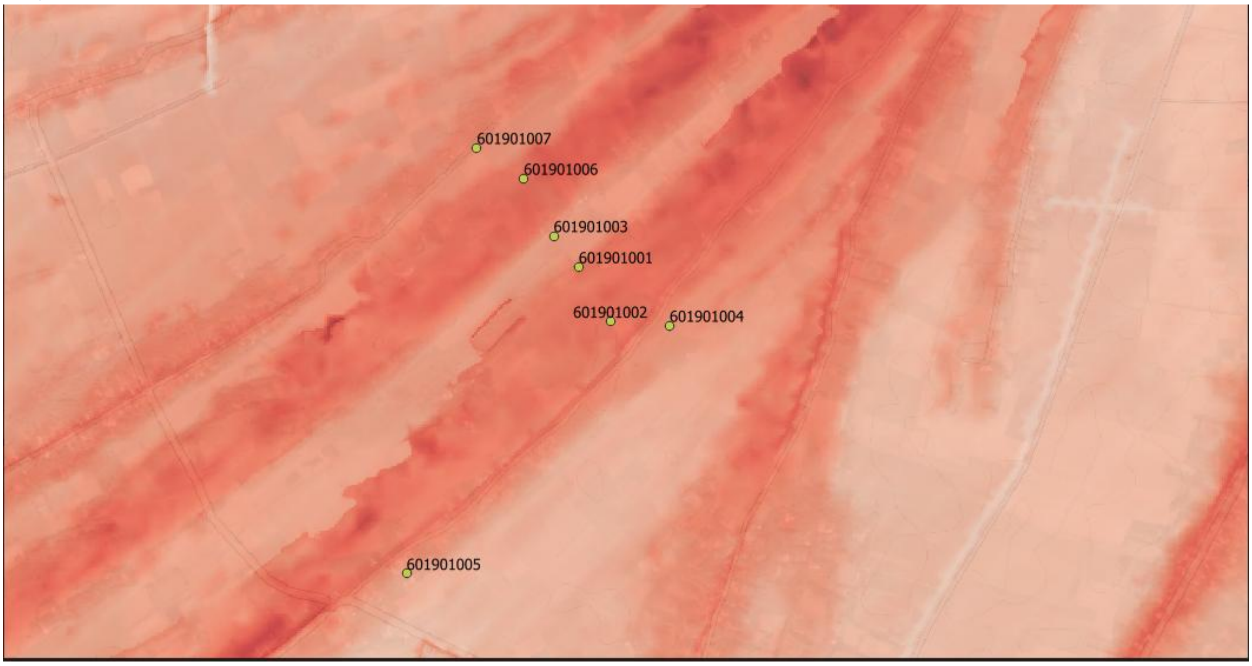

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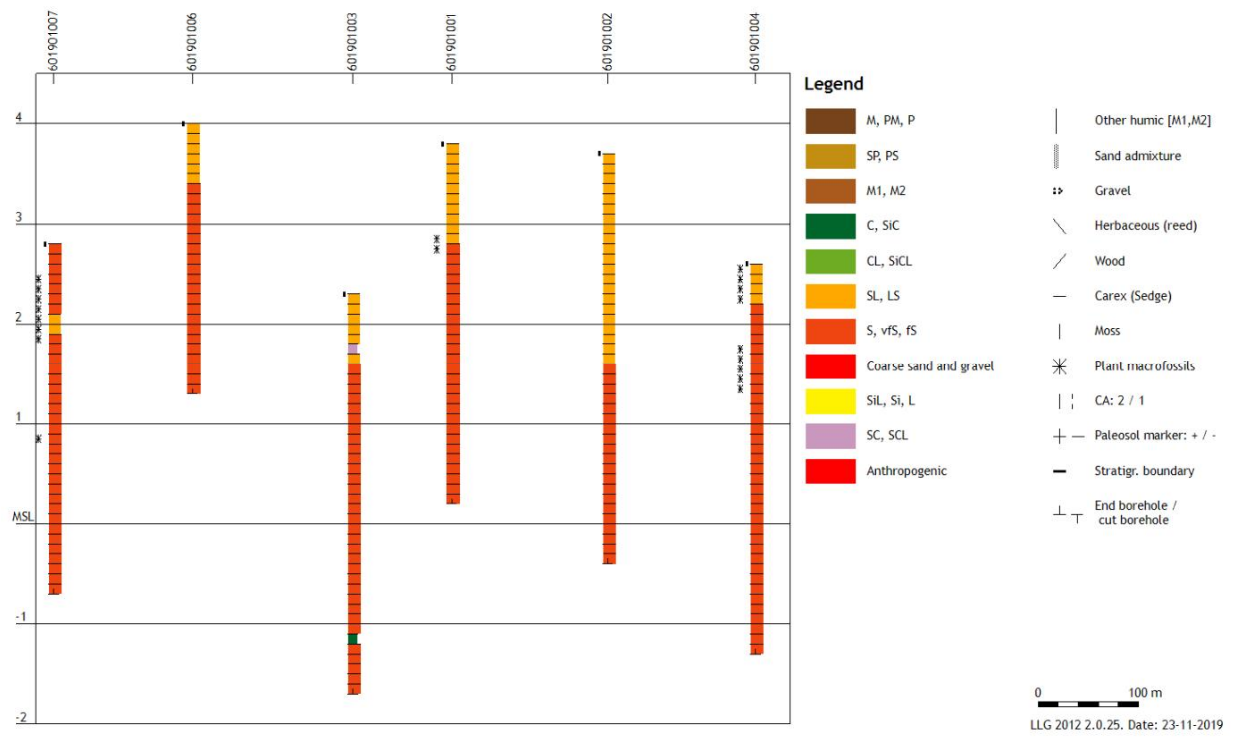

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4
3
2
1
MSL
-1
-2
Legend
M, PM, P
SP, PS
M1, M2
C, SiC
CL, SiCL
SL, LS
S, vfS, fS
Coarse sand and gravel
SiL, Si, L
SC, SCL
Anthropogenic
Other humic [M1,M2]
Sand admixture
Gravel
Herbaceous (reed)
Wood
Carex (Sedge)
Moss
Plant macrofossils
CA: 2 / 1
Paleosol marker: + / -
Stratigr. boundary
End borehole / cut borehole
0
100 m
LLG 2012 2.0.25. Date: 23-11-2019

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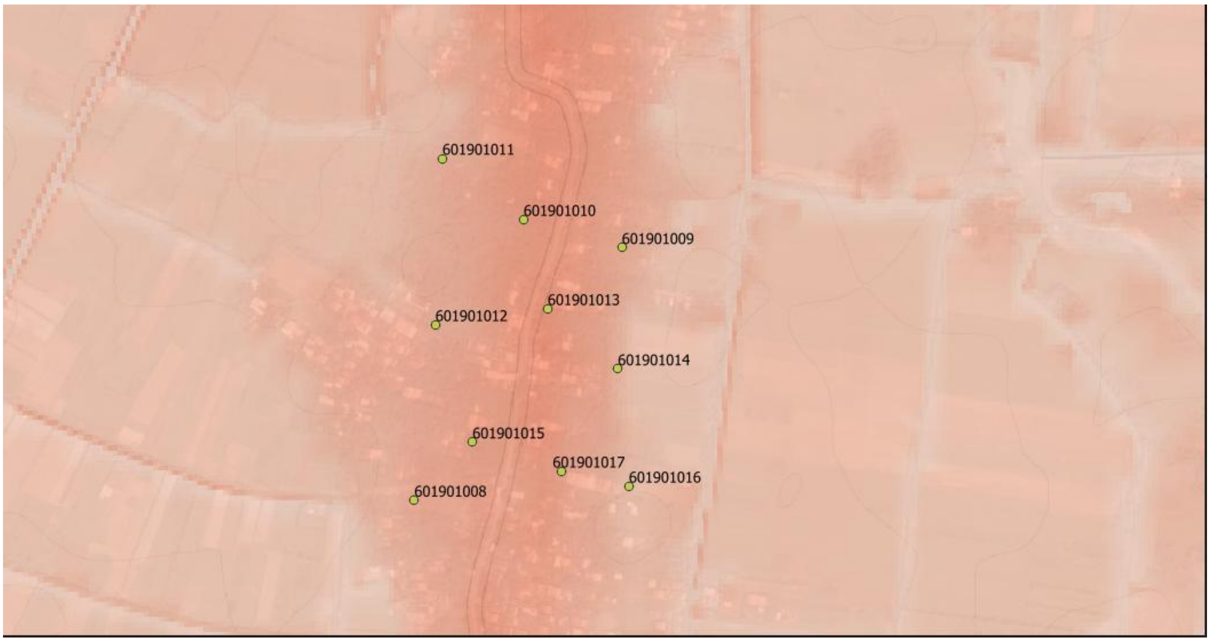
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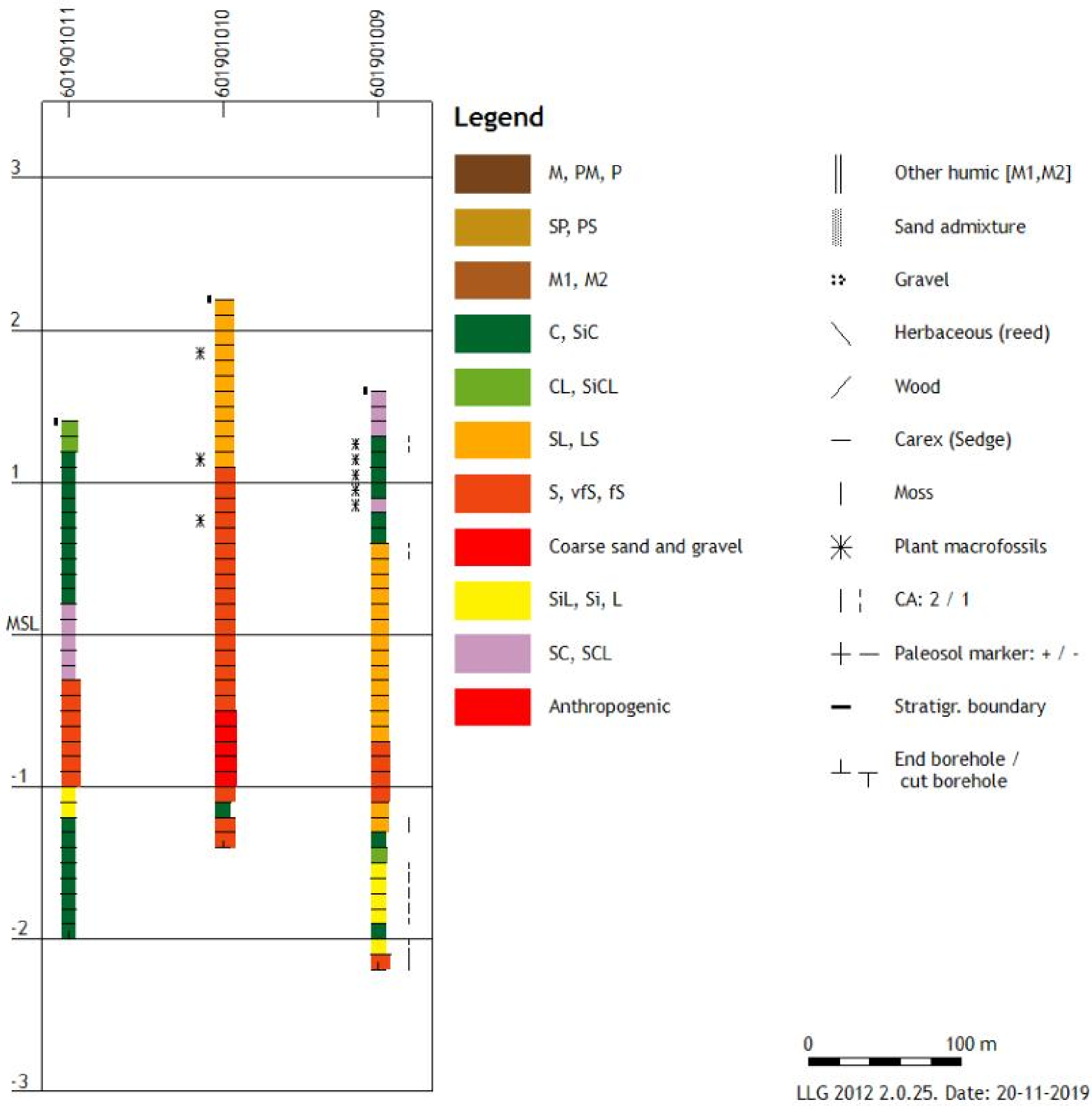
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-2
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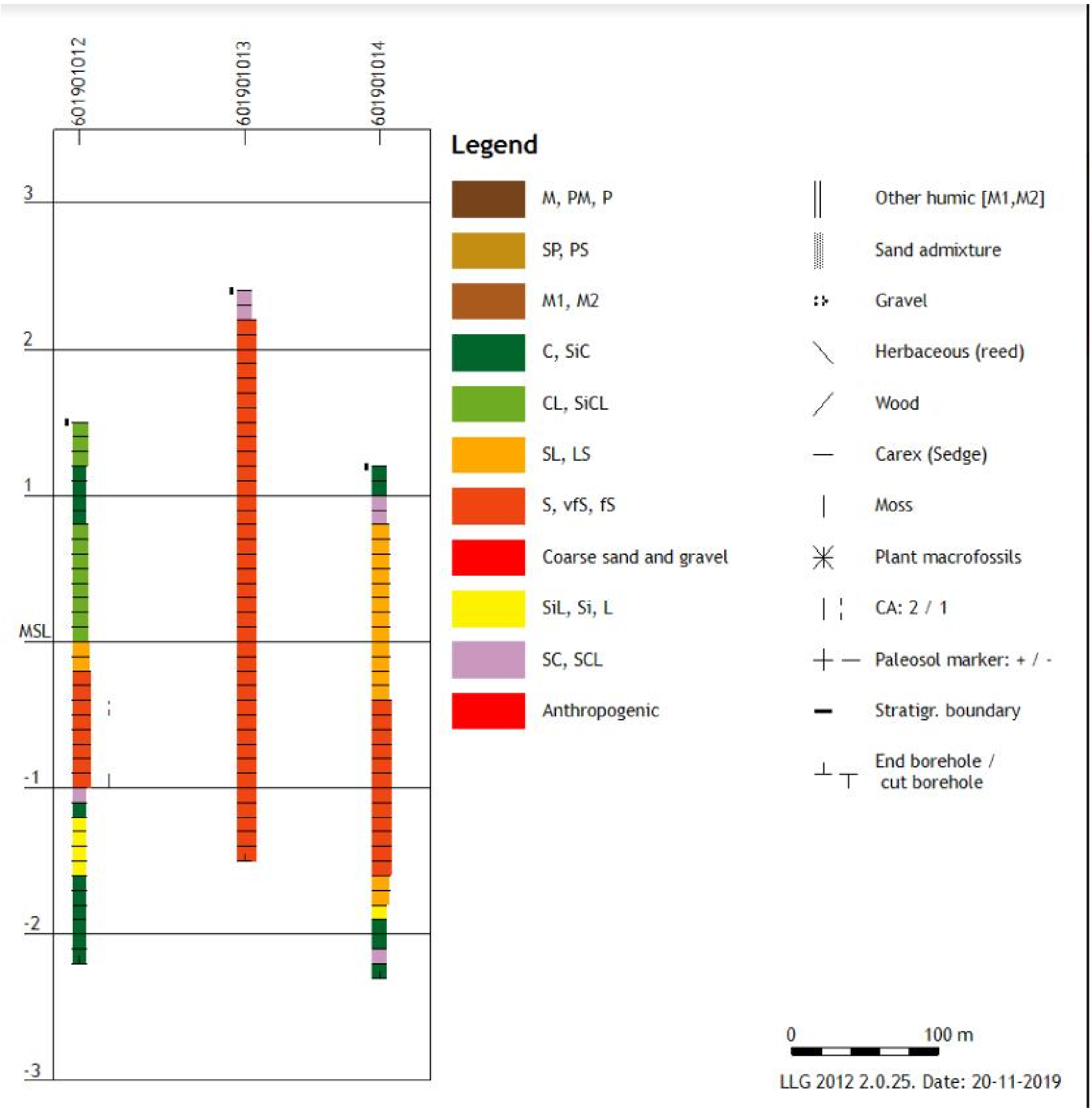
SP, PS
M1, M2
C, SiC
CL, SiCL
SL, LS
S, vfS, fS
Coarse sand and gravel
SiL, Si, L
SC, SCL
Anthropogenic
Other humic [M1,M2]
Sand admixture
Gravel
Herbaceous (reed)
Wood
Carex (Sedge)
Moss
Plant macrofossils
CA: 2 / 1
Paleosol marker: + / -
Stratigr. boundary
End borehole /
cut borehole
0
100 m
LLG 2012 2.0.25. Date: 20-11-2019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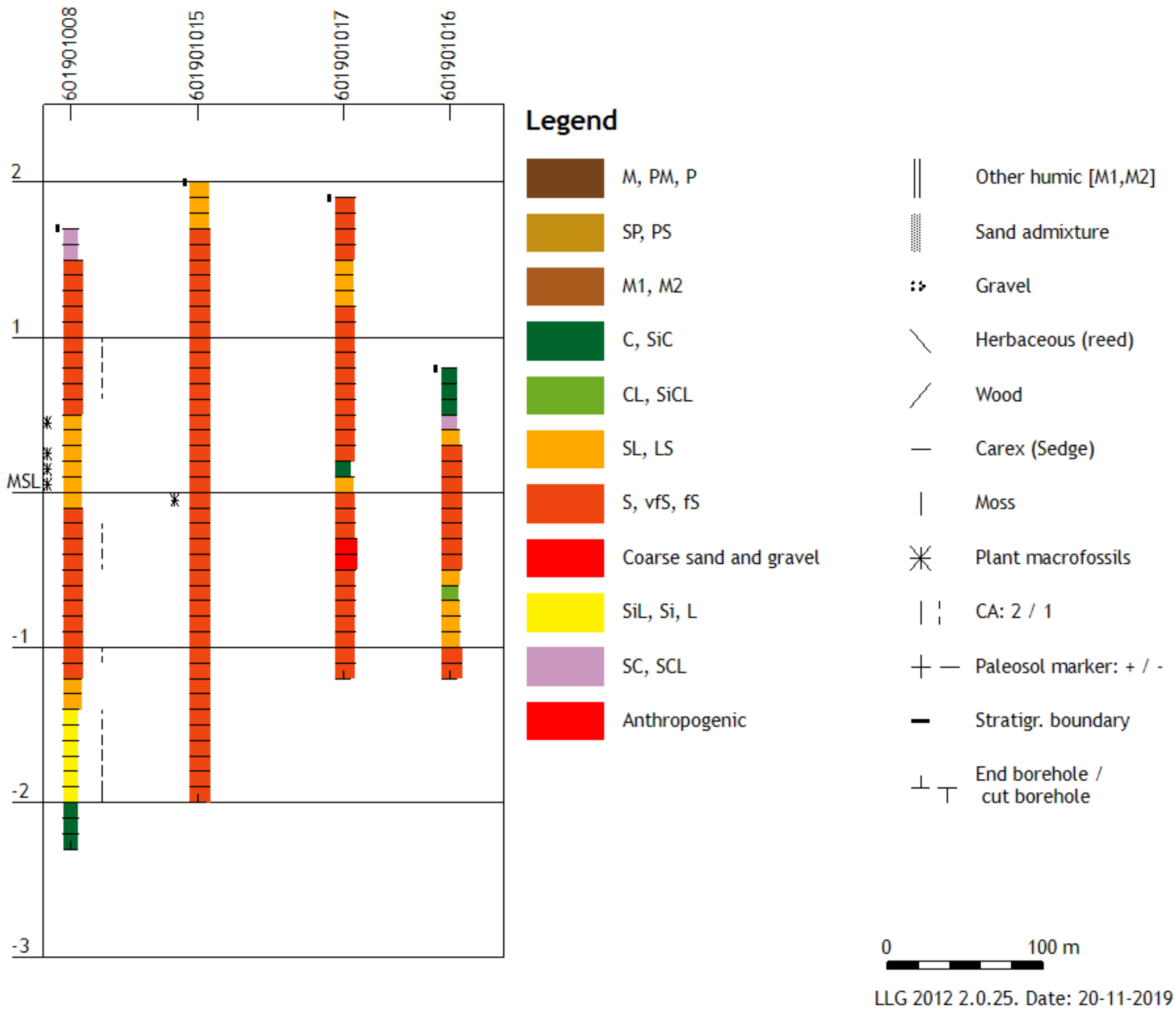
SP, PS
M1, M2
C, SiC
CL, SiCL
SL, LS
S, vfS, fS
Coarse sand and gravel
SiL, Si, L
SC, SCL
Anthropogenic
Other humic [M1,M2]
Sand admixture
Gravel
Herbaceous (reed)
Wood
Carex (Sedge)
Moss
Plant macrofossils
CA: 2 / 1
Paleosol marker: + / -
Stratigr. boundary
End borehole /
cut borehole
0
100 m
LLG 2012 2.0.25. Date: 20-11-2019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C, SiC
CL, SiCL
SL, LS
S, vfS, fS
Coarse sand and gravel
SiL, Si, L
SC, SCL
Anthropogenic
Other humic [M1,M2]
Sand admixture
Gravel
Herbaceous (reed)
Wood
Carex (Sedge)
Moss
Plant macrofossils
CA: 2 / 1
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Stratigr. boundary
End borehole /
cut borehole
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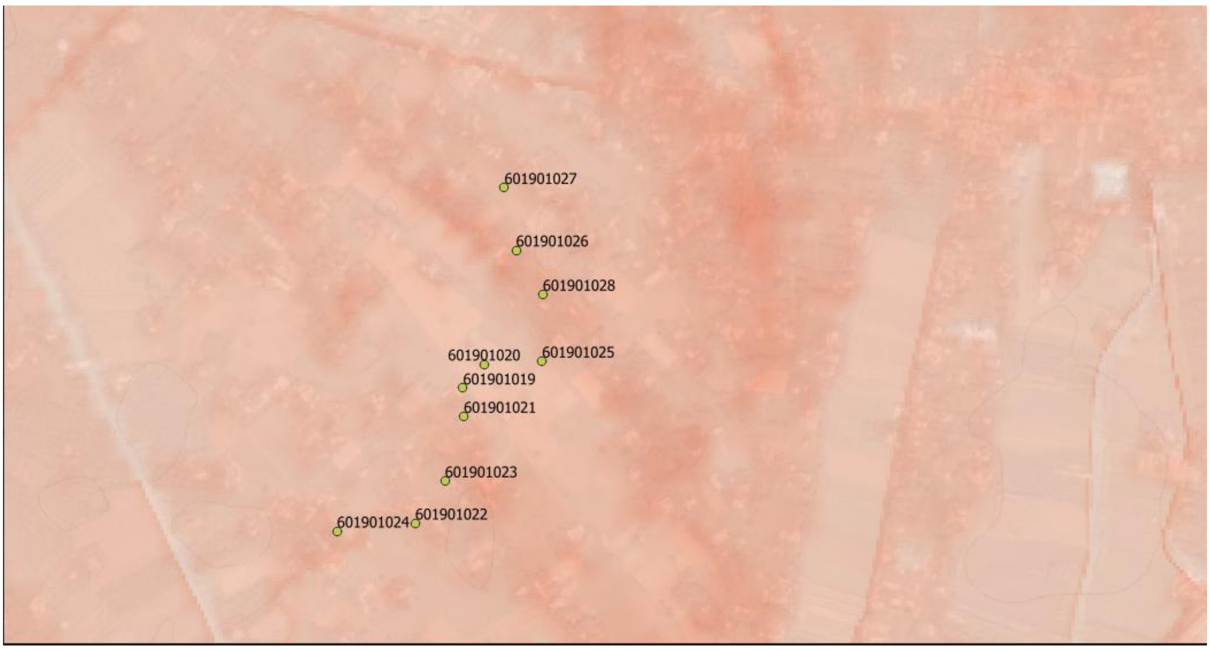
100 m
LLG 2012 2.0.25. Date: 20-11-2019

BT03: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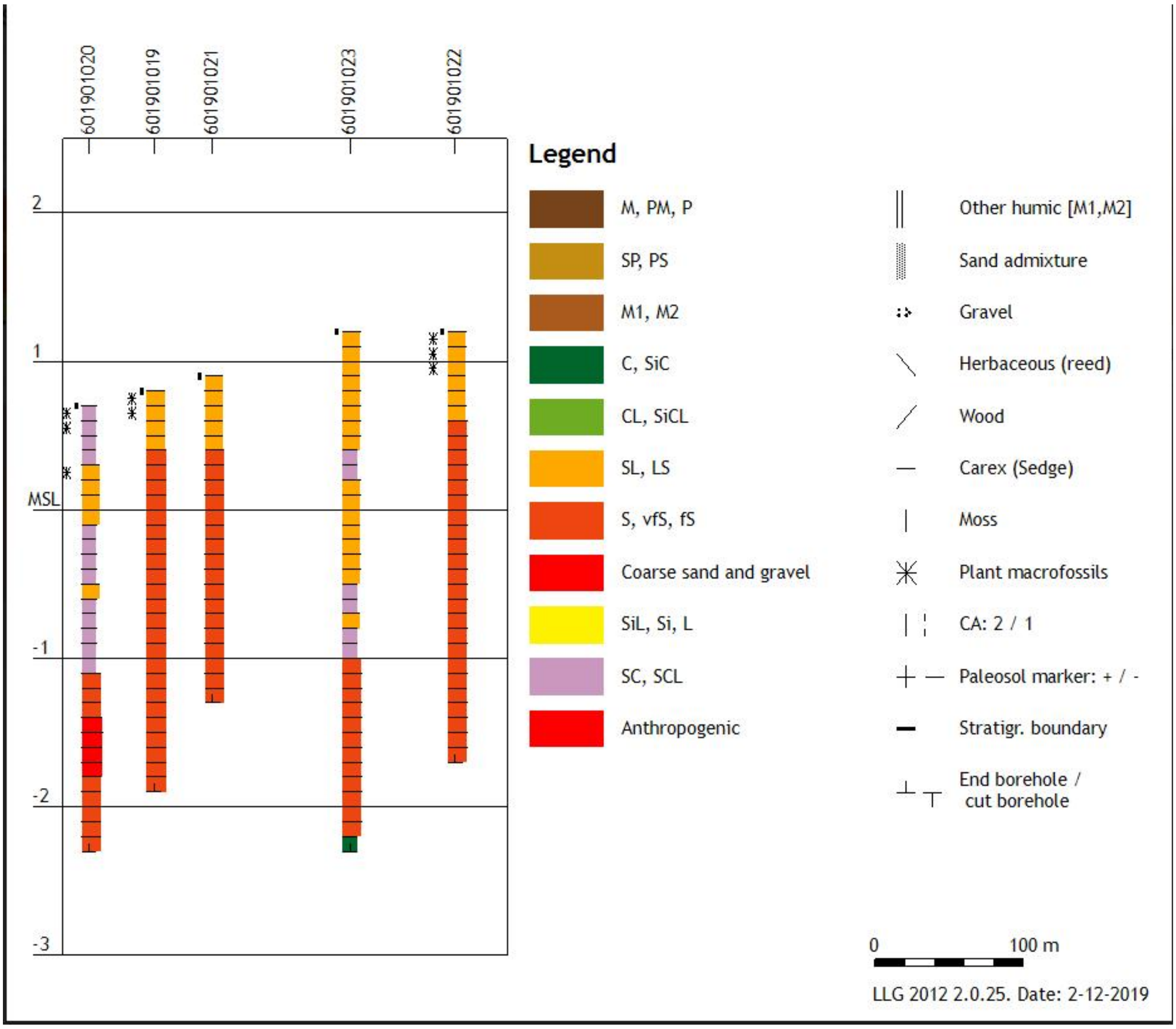


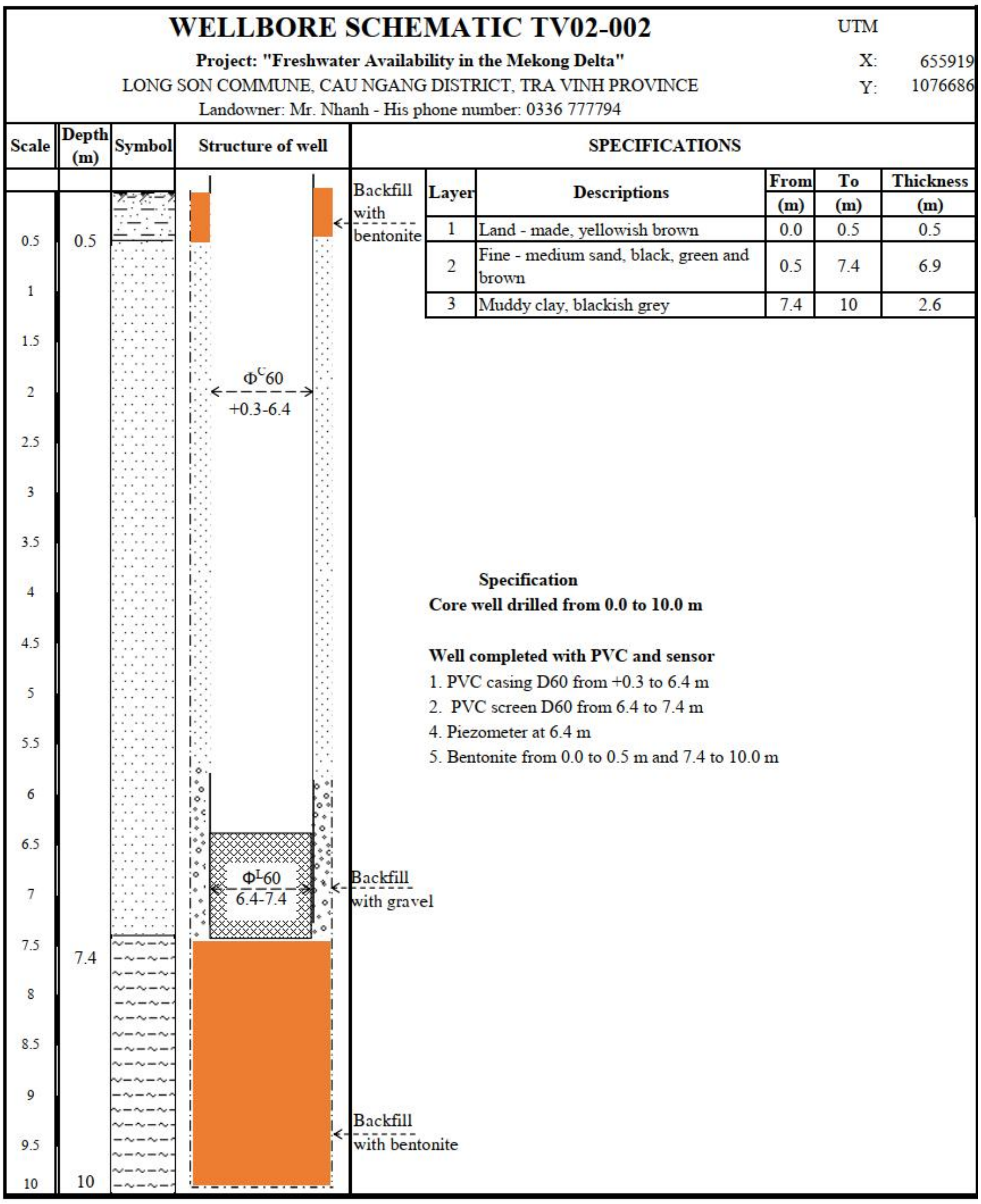
3. Overview of the installed devices

Field site	Well number	Coordinate	Depth well (cm)	Depth sensor (cm)	Name sensor	Name downloaded files	measuring interval	Installation date sensor	Name land owner	Phone number land owner
TV02	Well 1	N09.73785, E106.420910	159	135	VEI_bu772	Well1_TV02_*date*	15 min	3-10-2019	Mr. Hung	0084 (0)35716003
TV02	Well 2 (Deep)	N09.737220, E106.421411	1000 --> filled up with bentonite from 740 to 1000	640	VEI_AV204	Well2_D_TV02_*date*	""	16-12-2019	Mr. Nanh	0336 777794
BT02	Well 1	N10.06356, E106.62990	240	190	VEI_bu773	Well1_BT02_*date*	""	23-10-2019	Mr. Phuoc	091 9369875
BT02	BARO in well 1	N10.06356, E106.62990	240	20	sws_jo127	BARO_well1_BT02_*date*	""	11-11-2019	Mr. Phuoc	""
BT02	Well 2	N10.06323702, E106.63053474	350	260 --> 250*	vei_au747	Well2_BT02_*date*	""	7-12-2019	Mr. Phuoc (and his brother)	""
BT02	Well 3	N10.06514280, E106.63144423	360	250--> 240*	pb_28_105	Well3_BT02_*date*	""	7-12-2019	Mrs. Xeo	0389 605717
BT02	Well 4 (Deep)	N10.063789, E106.631300	2000 --> filled up with bentonite from 1350 to 1350	1150	sws_k4280	Well4_D_BT02_*date*	""	15-12-2019	Mr. Lua	0396 933545
BT03	Well 1 *	N10.12887, E106.48813	268	210	VEI_av354	Well1_BT03_*date*	""	24-10-2019	Mr. Hieu	091 7422969
BT03	Well 2 (B2: Deep)	N10.13053313, E106.48887160	1000 --> filled up from 860 to 1000	730	VEI_av358	Well2_D_BT03_*date*	""	13-12-2019	Mr. Bay	0386 148082

BT03	Well 3 (A1: Deep)	N10.12816015, E106.48838801	1000 --> filled up with bentonite from 680 to 1000	550	VEI_v9954	Well3_D_BT03_*date*	""	13-12-2019	Mr. Phuong	0989 247969
BT03	Well 4 (A2: Deep)	N10.12694465, E106.48662060	970--> filled up with bentonite from 720 to 970	680	VEI_au635	Well4_D_BT03_*date*	""	14-12-2019	Mr. Tha	097 6770178
Field site	Measuring device	Coordinate	Name sensor	measuring interval	Installation date	Name downloaded files	Name landowner	Phone number landowner		
TV02	Rain gauge	N09.73782, E106.42075	FAME_RAIN_GUAGE_1_TVAMD	5 min	3-10-2019	FAME_RAIN_GAUGE1_TVAMD_*date*	Mr. Hung	0084 (0)35716003		
BT03	Rain gauge	N10.12887, E106.48824	FAME_RAIN_GUAGE_2_CANDY	5 min	24-10-2019	FAME_RAIN_GUAGE_2_CANDY_*date*	Mr. Hieu	091 7422969		

4. Well schematics of deep wells

All wellbore schematics presented here were made by Dr. Hung and his drilling team and originally presented in their report.



Well2_D_TV02

WELLBORE SCHEMATIC BT02-015

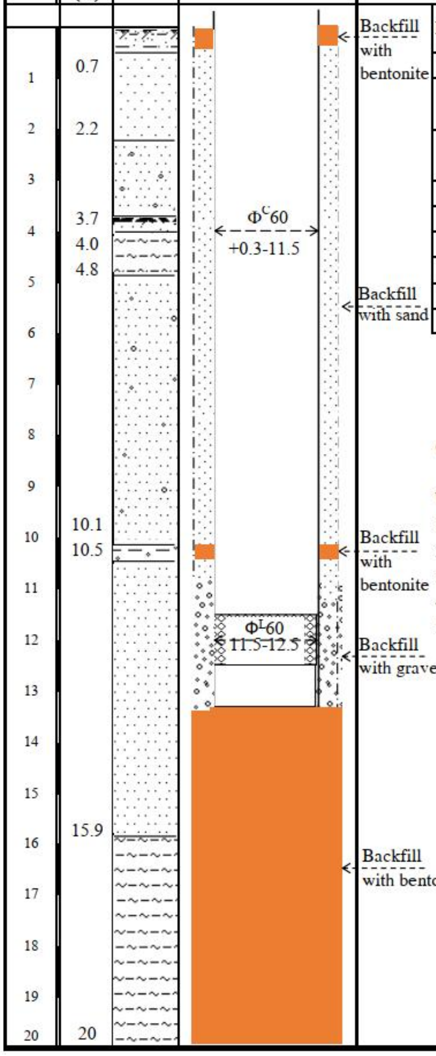
Project: "Freshwater Availability in the Mekong Delta"

PHU NGAI COMMUNE, BA TRI DISTRICT, BEN TRE PROVINCE

Landowner: Mr. Lua - His phone number: 0396 933545

UTM
X: 678771
Y: 1112910

Scale | Depth (m) | Symbol | Structure of well



SPECIFICATIONS

Layer	Descriptions	From (m)	To (m)	Thickness (m)
1	Land - made, yellowish brown	0	0.7	0.7
2	Medium sand, yellowish brown, reddish brown	0.7	2.2	1.5
3	Medium sand with seashell, brownish grey	2.2	3.7	1.5
4	Plant mud	3.7	4.00	0.3
5	Muddy clay, blackish grey	4.0	4.8	0.8
7	Fine - medium sand with seashell,	4.8	10.1	5.3
8	Clay with sand, blackish grey	10.1	10.5	0.4
9	Fine - medium sand, blackish grey	10.5	15.9	5.4
10	Muddy clay, blackish grey	15.9	20	4.1

Specification

Core well drillled from 0.0 to 20.0 m

Well completed with PVC and sensor

1. PVC Casing D60 from +0.3 to 11.5 m
2. PVC screen D60 from 11.5 to 12.5 m
3. PVC Casing D60 from 12.5 to 13.5 m
4. Piezometer at 11.5 m
5. Bentonite from 0.0 to 0.5 m, 10.1 to 10.5 m, and 13.5 to 20.0 m

Well4_D_BT02

WELLBORE SCHEMATIC BT3-A1

Project: "Freshwater Availability in the Mekong Delta"

TAN THANH COMMUNE, GIONG TROM DISTRICT, BEN TRE PROVINCE

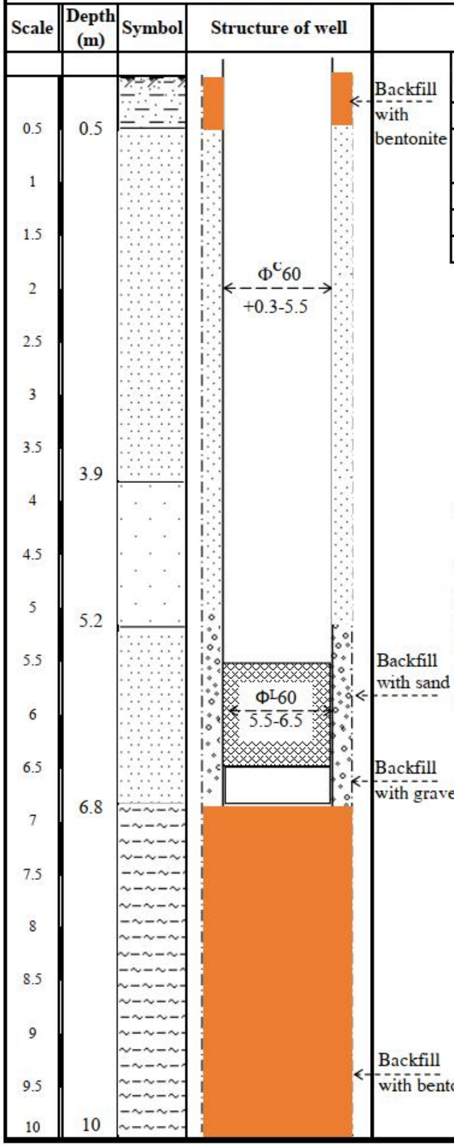
Landowner: Ms. Phuong - His phone number: 0989 247969

UTM

X: 663072

Y: 1119961

SPECIFICATIONS



Layer	Descriptions	From (m)	To (m)	Thickness (m)
1	Land - made, yellowish brown	0.0	0.5	0.5
2	Fine - medium sand, yellowish brown, reddish brown	0.5	3.9	3.4
3	Coarse sand, blackish grey	3.9	5.2	1.3
4	Fine - medium, blackish grey	5.2	6.8	1.6
5	Muddy clay, blackish grey	6.8	10	3.2

Specification

Core well drilled from 0.0 to 10.0 m

Well completed with PVC and sensor

1. PVC casing D60 from +0.3 to 5.5 m
2. PVC screen D60 from 5.5 to 6.5 m
3. PVC casing D60 from 6.5 to 6.8 m
4. Piezometer at 5.5 m
5. Bentonite from 0.0 to 0.5 m and 6.8 to 10.0 m

Well3_D_BT03

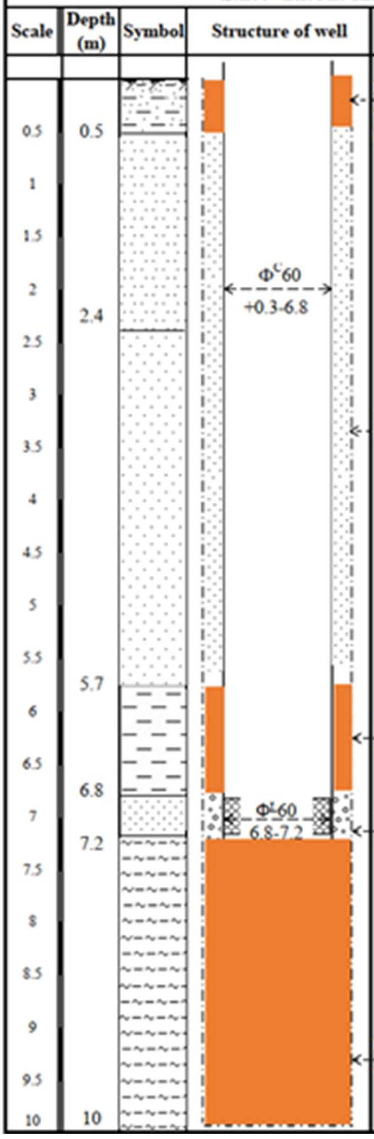
WELLBORE SCHEMATIC BT3-A2

Project: "Freshwater Availability in the Mekong Delta"

TAN THANH COMMUNE, GIONG TROM DISTRICT, BEN TRE PROVINCE

Landowner: Mr. Tha - His phone number: 0976 770178

UTM
X: 662878
Y: 1119830



SPECIFICATIONS

Layer	Descriptions	From (m)	To (m)	Thickness (m)
1	Land - made, yellowish brown	0.0	0.5	0.5
2	Fine - medium sand, yellowish brown, reddish brown	0.5	2.4	1.9
3	Medium sand with seashell, brownish grey	2.4	5.7	3.3
4	Clay with sand, blackish grey	5.7	6.8	1.1
5	Fine sand, blackish grey	6.8	7.2	0.4
6	Muddy clay, blackish grey	7.2	10	2.8

Specification

Core well drilled from 0.0 to 10.0 m

Well completed with PVC and sensor

1. PVC casing D60 from +0.3 to 6.8 m
2. PVC screen D60 from 6.8 to 7.2 m
3. Piezometer at 6.8 m
4. Bentonite from 0.0 to 0.5m, 5.7 to 6.8m, and 7.2 to 10m

Well4_D_BT03

WELLBORE SCHEMATIC BT3-B2

Project: "Freshwater Availability in the Mekong Delta"

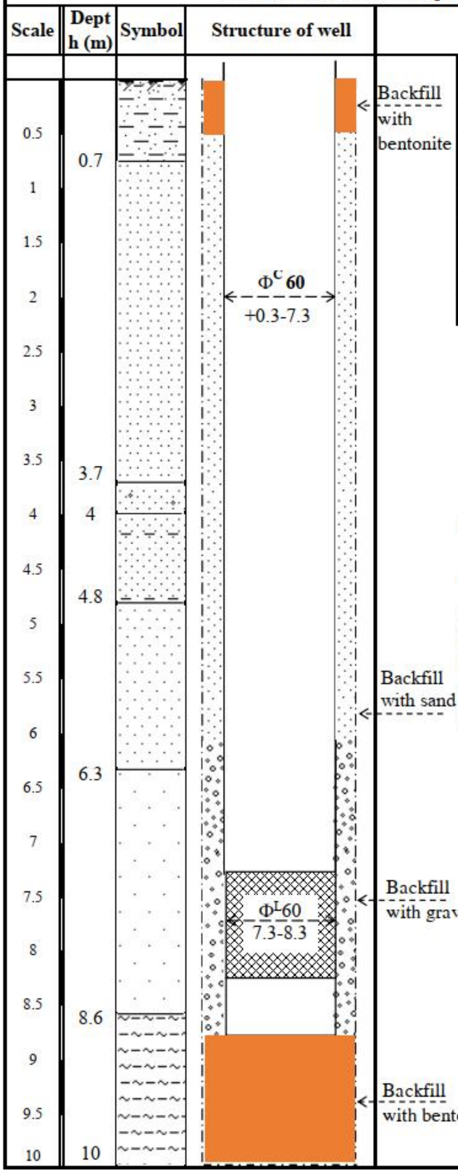
TAN THANH COMMUNE, GIONG TROM DISTRICT, BEN TRE PROVINCE

Landowner: Ms. Chi - Her phone number: 0367 964740

UTM

X: 663123

Y: 1120216



SPECIFICATIONS

Layer	Descriptions	From (m)	To (m)	Thickness (m)
1	Land - made, yellowish brown	0.0	0.7	0.7
2	Fine - medium sand, yellowish brown, reddish brown	0.7	3.7	3.0
3	Fine sand with seashell, blackish grey	3.7	4	0.3
4	Fine sand with organic, blackish grey	4	4.8	0.8
5	Medium sand, blackish grey	4.8	6.3	1.5
6	Coarse sand, blackish grey	6.3	8.6	2.3
7	Muddy clay, blackish grey	8.6	10	1.4

Specification

Core well drilled from 0.0 to 10.0 m

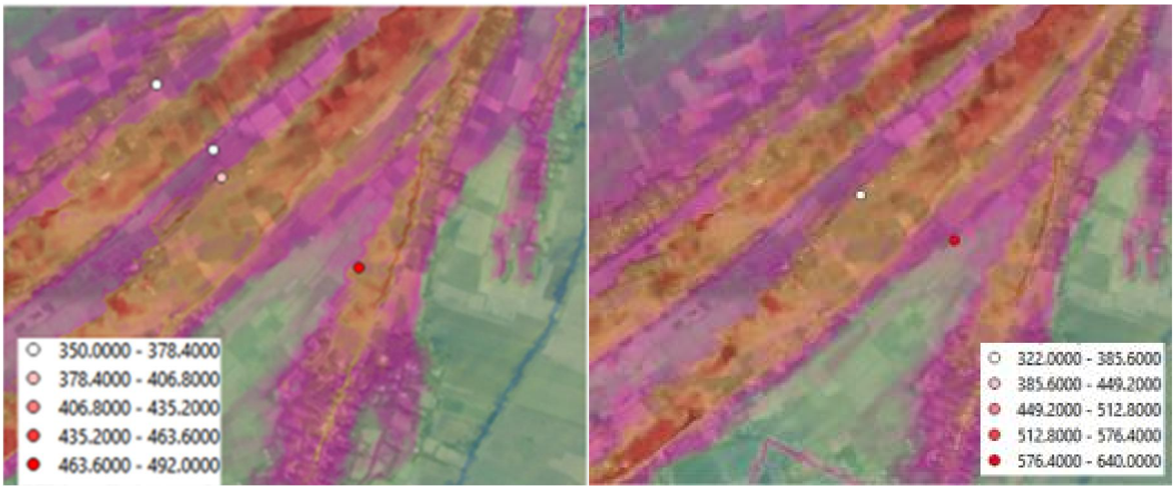
Well completed with PVC and sensor

1. PVC casing D60 from +0.3 to 7.3 m
2. PVC screen D60 from 7.3 to 8.3 m
3. PVC casing D60 from 8.3 to 8.6 m
4. Piezometer at 7.3 m
5. Bentonite from 0.0 to 0.5 m and 8.6 to 10.0 m

Well2_D_BT03

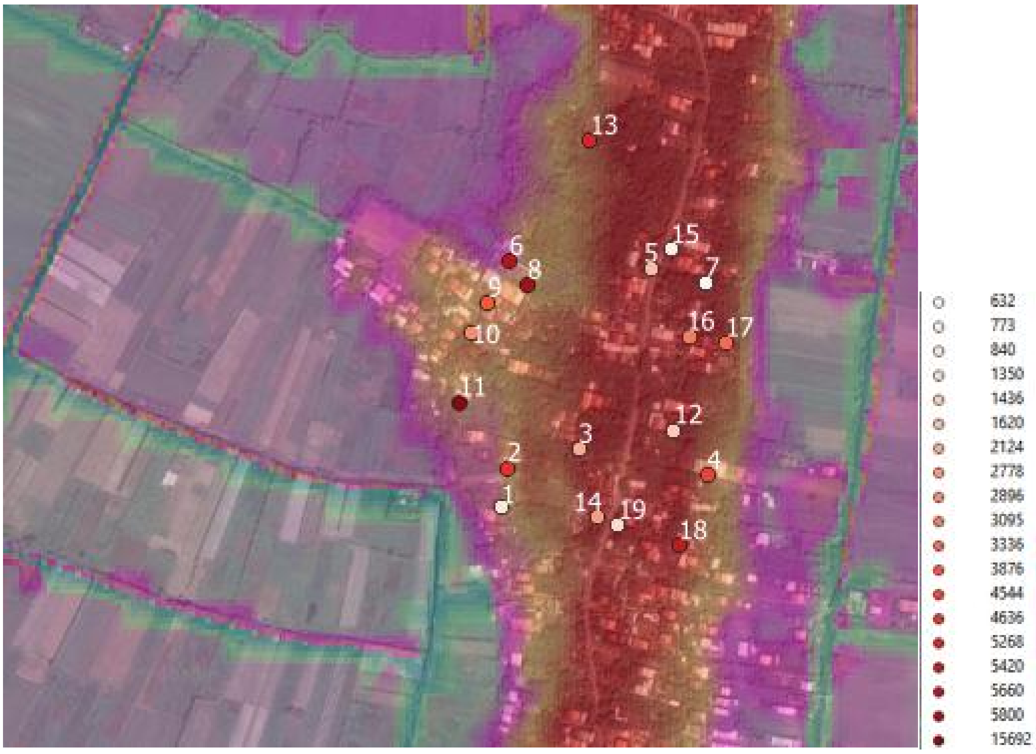
5. Maps of water quality measurements

5.1 TV02

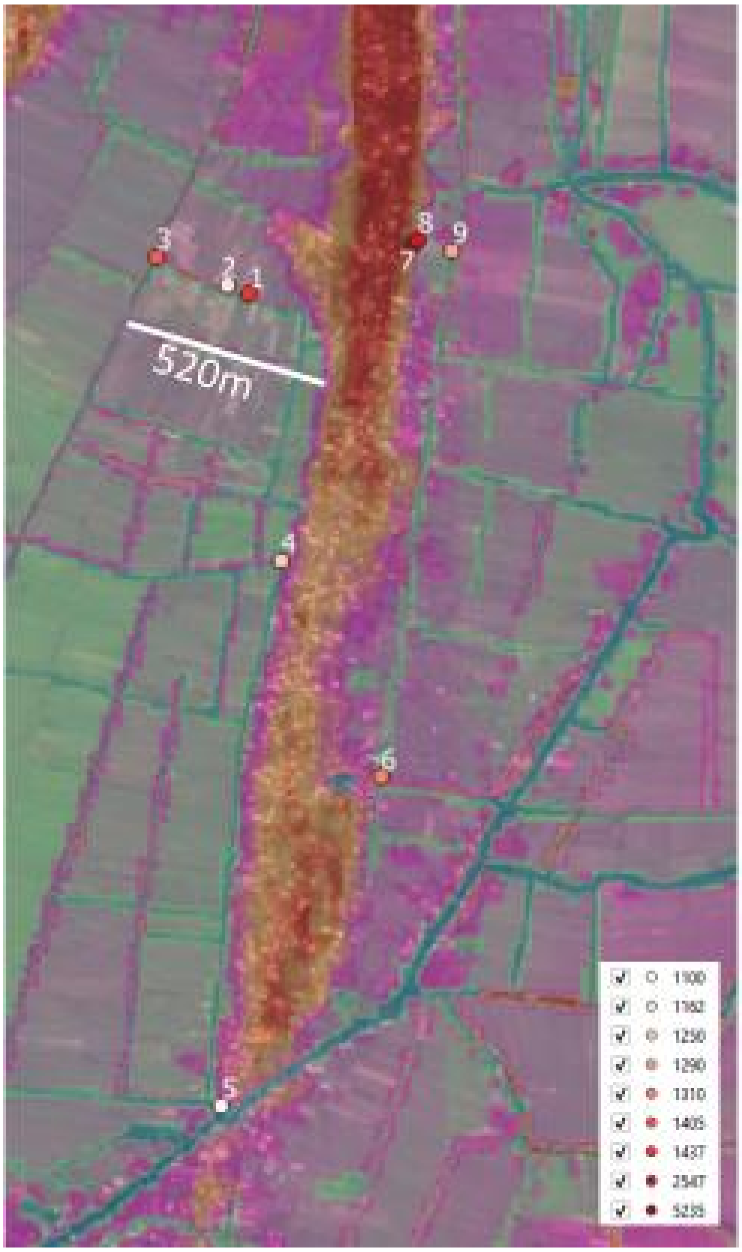


Surface water quality measurements (left) and salinity measurements in groundwater wells (right), legend showing the measured EC values in µS/cm

5.2 BT02

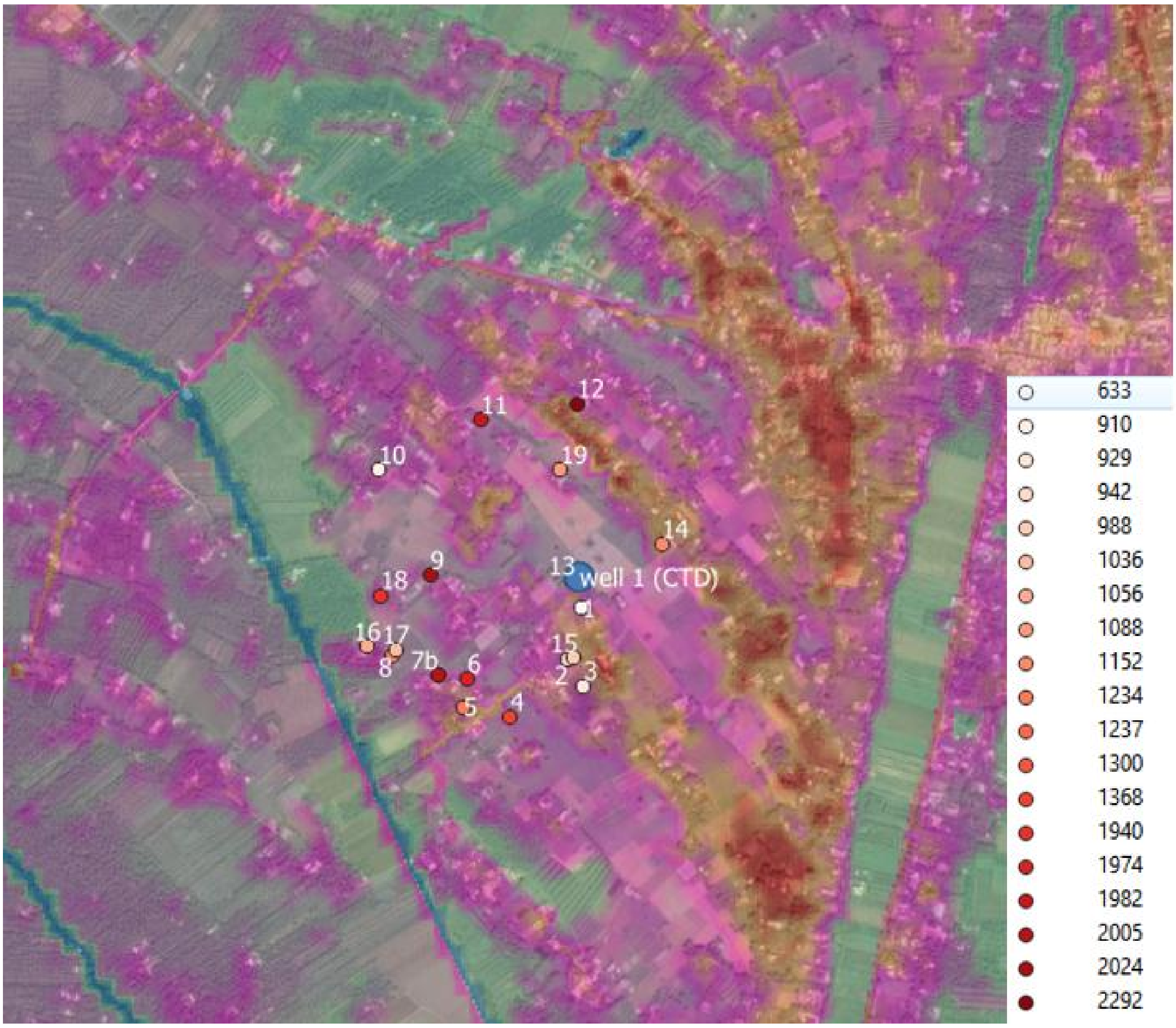


Map1: Salinity measurements in groundwater wells, legend showing the measured EC values in µS/cm

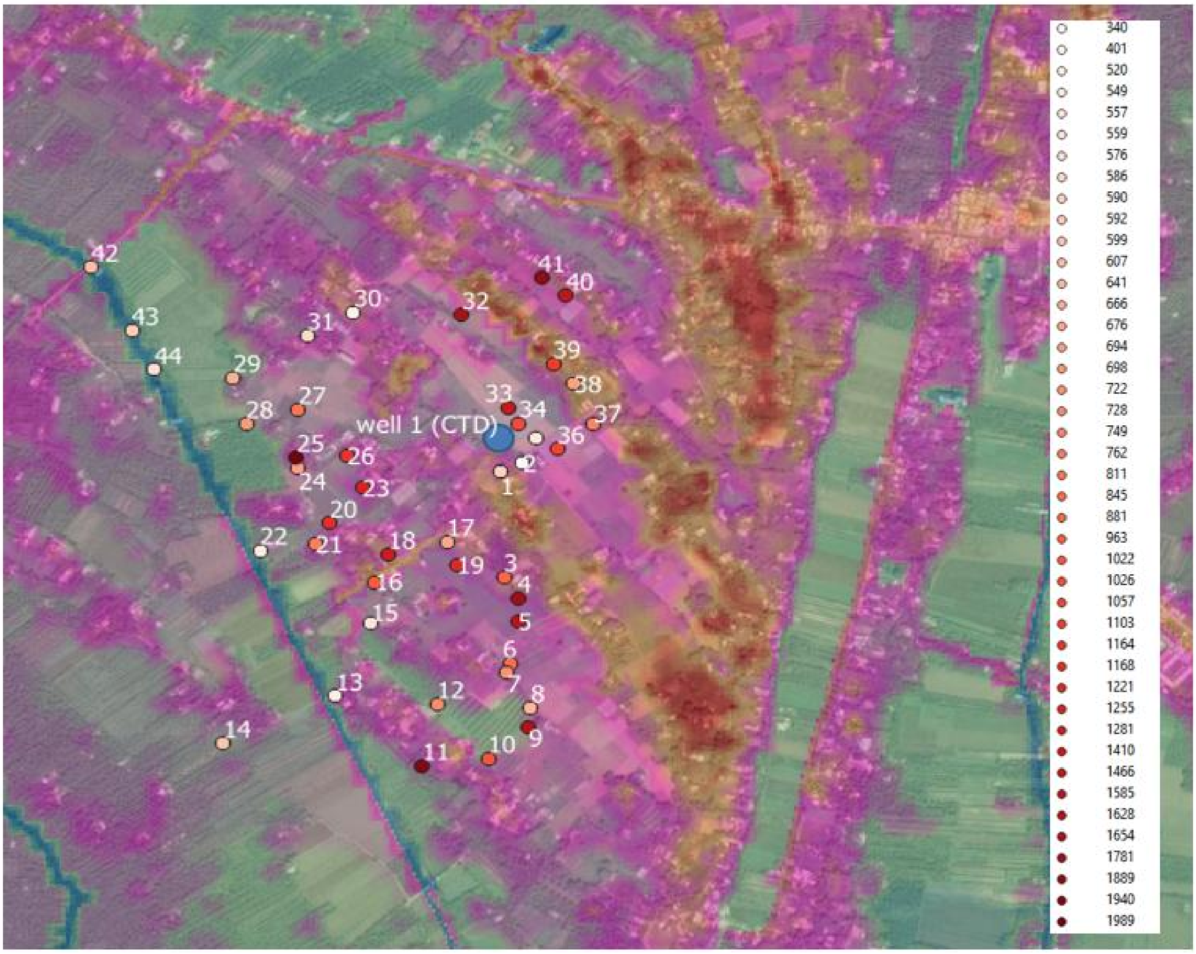


Map2: Surface water quality measurements, legend showing the measured EC values in µS/cm

5.3 BT03



Map1: Salinity measurements in groundwater wells, legend showing the measured EC values in µS/cm



Map2: Surface water quality measurements, legend showing the measured EC values in µS/cm