IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

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Fukushima Daiichi nuclear accident
-
Groundwater under the site

Situation in January 2016

This document is based on publicly available information on the situation of the Fukushima Daiichi plant.

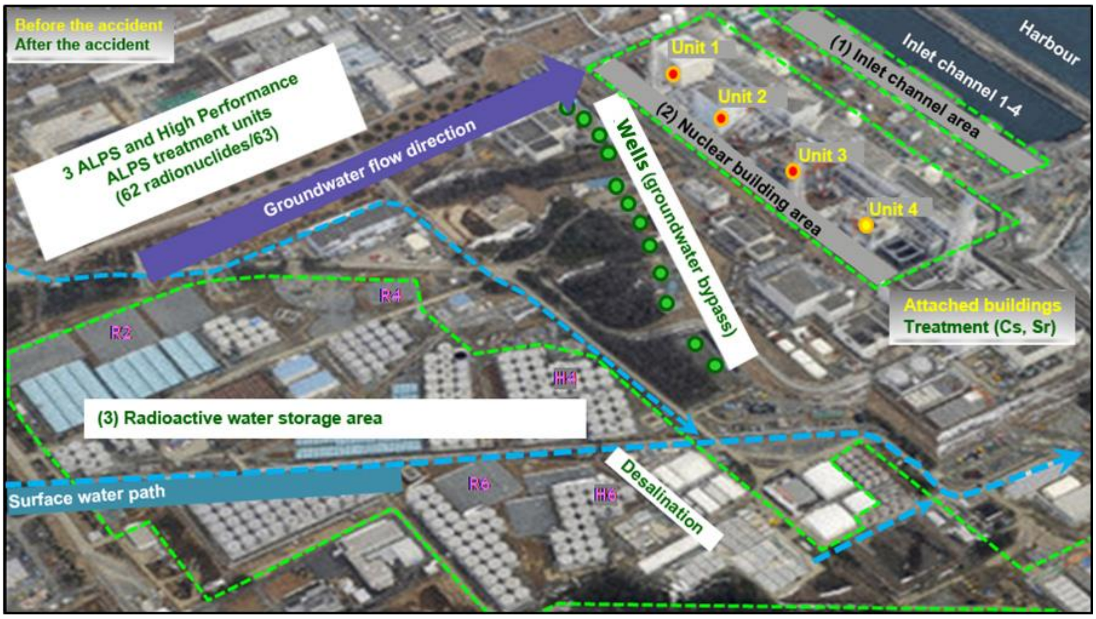
I. Background: three different areas to be considered

In order to understand the sources of radioactive contamination of the groundwater under the site, three different areas should be considered:

- The "inlet channel" area, known as “Turbine Building east side” on TEPCO website, is located next to the harbour and includes the water intakes of Units 1 to 4. Shortly after the accident, highly radioactive water from the reactors filled several trenches and passages and then spilled into the harbour;

- The "nuclear buildings" area, comprising in particular Reactors 1 to 4 and the related buildings housing the turbines. The basements of these buildings are filled with highly radioactive reactor cooling water (of the order of 70,000 m^3). In addition, they receive significant inflows of groundwater (about 200 m^3/day);

- The "storage" area, located upstream of the reactors. Created after the accident to manage the highly radioactive water pumped on the site[1], this tank installation area occupies a surface area 5 times larger than that of the nuclear buildings. To date, approximately 750,000 m^3 of radioactive water are stored there.

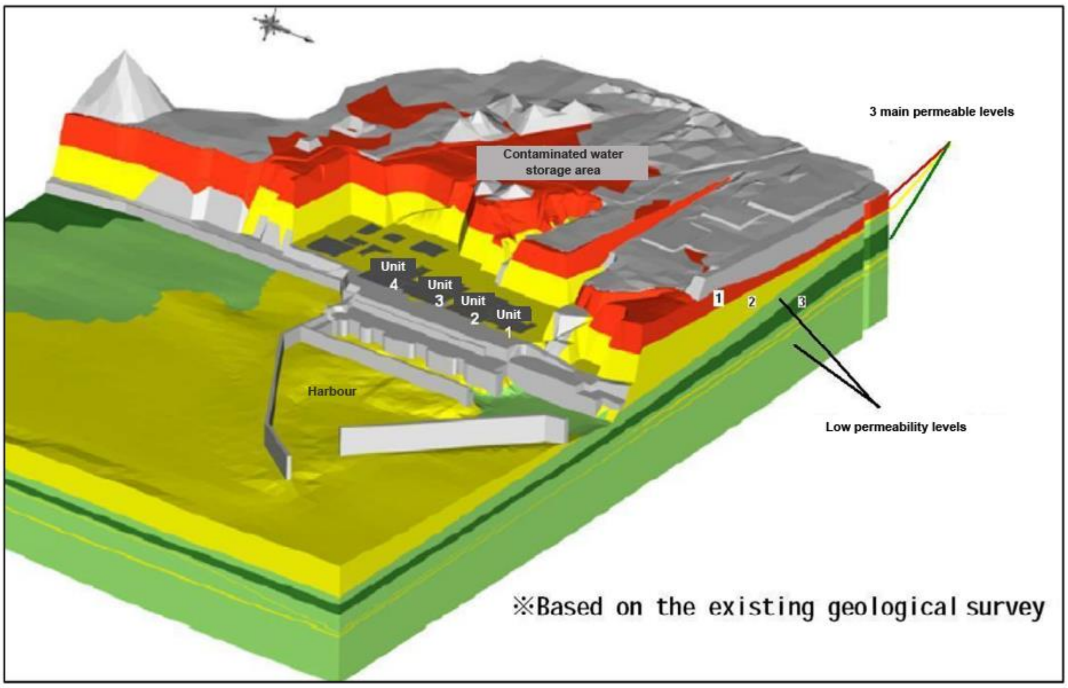


View of the various areas of the site

[1] See the information note on the management of radioactive water.

Groundwater flows naturally from the inland toward the ocean into 3 main sandstone layers. TEPCO estimates that around 1 000 m^3/day circulate under the nuclear buildings area. This flow is divided between the shallow aquifer (Permeable Levels 1 and 2 in the figure below) with 700 m^3/day and the confined aquifer (Permeable Level 3 in the figure below) with 300 m^3/day.

Thus, if no particular action is taken, any groundwater contamination at the Fukushima Daiichi site would eventually reach the ocean.



Source TEPCO – Geological context of the site

The distance between the contamination source and the sea is the main parameter in terms of time to reach the ocean. In addition, the rate of contamination migration in the groundwater depends on the radionuclides, since they may interact more or less strongly with the sandstone layers. Thus, tritium (^3H), which does not interact, travels at the groundwater velocity (1 m/day in order of magnitude). Strontium travels slower (1 m/month in order of magnitude) and caesium is even slower (a few cm/day or less).

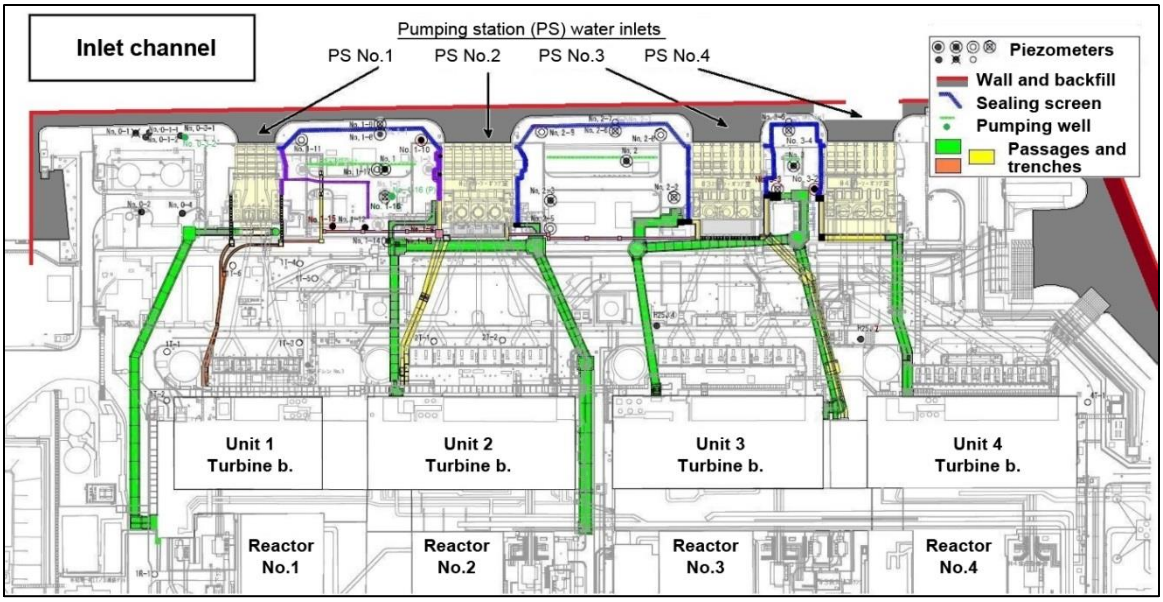
Under these conditions, the presence of one or more of these radionuclides in the groundwater gives an indication of the proximity of the radioactive water leaks into the ground. Closer to the source of contamination, high concentrations of caesium, strontium and tritium are detected. Further downstream, concentrations decrease and only strontium and tritium are detected, and then only tritium.

II. The inlet channel area (east side of Turbine Building Units 1 to 4)

Shortly after the accident in March 2011, the reactor cooling water flowed into the turbine building, filled several trenches (underground tunnels and vertical shafts containing pipes [green] in the figure below, power cables trenches [yellow] in the figure below), reached the water intakes and was released directly into the harbour. This highly radioactive water contaminates the harbour sediment and water, as well as contaminating the soil and groundwater near the water intakes.

In order to limit direct releases into the ocean, TEPCO blocked the mains trenches vertical shafts with crushed stones and concrete in April-May 2011. The releases into the harbour then continued diffusely with the natural flow of contaminated groundwater, particularly between the water intakes of Units 1 and 2.

As from December 2012, TEPCO started to install piezometers to characterise the groundwater contamination between the reactors and the sea. In the second half of 2013, this network was densified and contamination monitoring was set up. Around 50 piezometers were thus installed downstream from the reactors, thirty of which are monitored at least once per week.



Source TEPCO – Top view of the seaside trenches, between Units 1 to 4 and the inlet Channel - View of the piezometers - State in September 2015

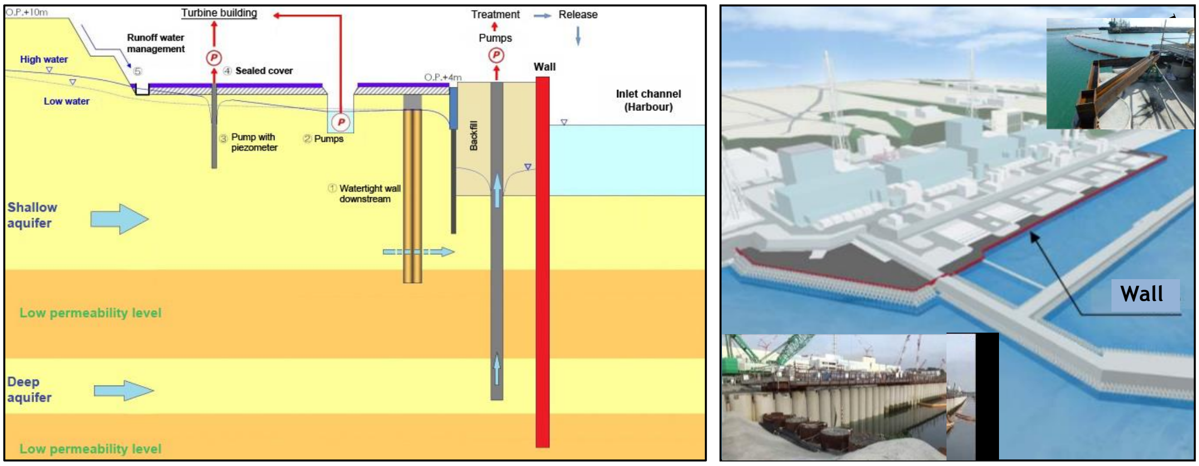
This monitoring has confirmed the local source of the contamination of this area. The simultaneous presence of caesium, strontium and tritium in the groundwater indicates the proximity of the leak locations, with the highest concentrations of caesium (not very mobile) being measured in the vicinity of the trenches. Thus, since 2013 TEPCO has been conducting a work programme spread over time (emergency measures and then management measures) to limit the contamination of groundwater (1) and eliminate diffuse releases into the harbour (2).

(1) To eliminate contamination sources, TEPCO has injected sealants into the ground to prevent leakages from the seaside trenches, and covered the ground to protect it from rain water infiltration. After trying to freeze the connections of main trenches to the turbine buildings (Units 2, 3 and 4) to stop water exchanges (April-November 2014), TEPCO proceeded to water collection by a step by step cement filler injection (tunnels, vertical shafts and finally the shafts-turbine buildings connections) during the 1st half of 2015. These operations led to the pumping and transfer to the turbine buildings of 11,000 m^3 of highly radioactive water. The Unit 1 main trench, which contains less radioactive water, was left as it was. TEPCO continues its pumping work in the secondary trenches network and in the water intake buildings.

(2) To prevent outflow of contaminated water into the harbour, TEPCO has set up additional provisions for capturing groundwater near the bank:

- Three local devices, consisting of a sealing screen made by chemical injection (“ground improvement”) associated with wells for pumping contaminated groundwater, were implemented during the second half of 2013 between water intakes of Units 1 and 2, 2 and 3, and 3 and 4. North of the Unit No. 1 water intake, only one well is used for pumping. Thus, the progression of the contamination towards the harbour was halted in late 2013, limiting the diffuse releases. Pumping is being continued, in order to reduce the local contamination of groundwater;
- A second sealing barrier ("sea-side impermeable wall") was established in the harbour, along the bank from April to December 2013. Nearly 900m long and about 35m high, the wall is made of metal tubes built in the land from the harbour. It should enable the flows in the shallow and deep aquifers downstream from the site as a whole to be controlled. In 2014, the space between the wall and the bank was backfilled and 5 pumping wells (“pits”) were drilled in it and then tested in August and October 2015 (“groundwater drains”). The closing of the wall was completed in October 2015 after the commissioning of the pumping, treatment and release

device for the groundwater arriving upstream of the wall was announced. However, the rise of the groundwater behind this wall, now closed, led to a slight tilting of the latter in November 2015. TEPCO then carried out strengthening work and increased the pumping to counteract this phenomenon.



From TEPCO data - harbour side sealing barriers (design views, photos of the wall after closing and reinforcements installed following its tilting)

After two years of continuous pumping in local devices, the changes in the groundwater contamination near the harbour are summarized in the following table.

Sector	Changes in the *maximum* readings by sector			Means implemented
	Measurement	Maximum observed[2]	1st fortnight of 2016	
North of PS No. 1	Tritium Overall β Caesium 137	76,000 Bq/L 330 Bq/L 81 Bq/L	26,000 Bq/L 140 Bq/L 53 Bq/L	1 well discharging approximately 1 m^3/day
Between PS No. 1 and 2	Tritium Overall β Caesium 137 Other	630 000 Bq/L 9,300,000 Bq/L 200 000 Bq/L ^{54}Mn, ^{60}Co, ^{106}Ru, ^{125}Sb	69,000 Bq/L 660 000 Bq/L 33,000 Bq/L ^{54}Mn, ^{60}Co, ^{125}Sb	Sealing screen and 28 wells discharging several tens of m^3/day
Between PS No. 2 and 3	Tritium Overall β Caesium 137	13,000 Bq/L 560 000 Bq/L 110 Bq/L	3700 Bq/L 560 000 Bq/L 23 Bq/L	Sealing screen and 29 wells discharging several tens of m^3/day
Between PS No. 3 and 4	Tritium Overall β Caesium 137	10,000 Bq/L 8900 Bq/L 520 Bq/L	7900 Bq/L 4400 Bq/L 100 Bq/L	Sealing screen and 7 wells discharging approximately ten m^3/day

These results show that the groundwater decontamination is slow, because of the different migration velocity of the radionuclides through the sandstone layers and the likely continued inflows from the main trenches until their drainage by TEPCO in the 1st half of 2015. Moreover, an increase in the readings remains possible, as was found in the vicinity of the Unit No. 2 water intake in November 2015, since the pumping work in the secondary trenches networks and in the water intake buildings is not yet finished.

Contaminated water pumped by the local devices is returned to the turbine buildings and thus processed with all of the highly radioactive water.

Groundwater pumped from the land-side of the sea-side impermeable wall, about 100 m^3/day (from the deep aquifer), is to be mixed with groundwater pumped around the nuclear buildings (see the

[2] TEPCO suspects an overassessment of the highest values for β and Caesium 137, due to the presence of contaminated suspended solids (SS) in the samples. The role of the SS has been highlighted by the significant differences depending on whether the measurements are performed with or without prior filtering of the samples.

next paragraph) for treatment and release into the harbour as long as it is within the permitted limits[3].

With the draining of the trenches, the installation of sealing barriers and pumping wells, TEPCO considers that it has managed to minimise diffuse releases of contaminated groundwater into the harbour.

III. The nuclear building area

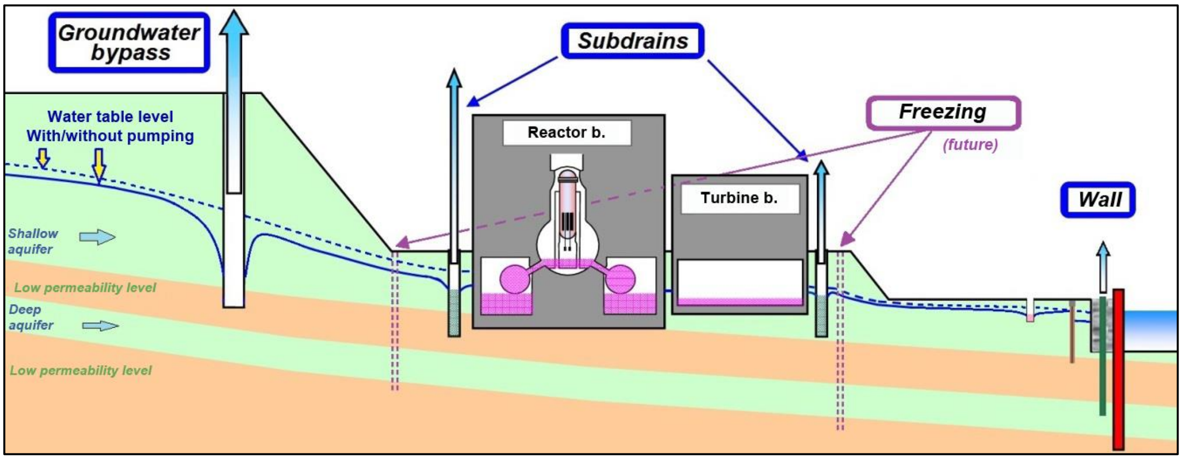
TEPCO's primary goal is to maintain the cooling of the damaged reactors by injecting about 325 m^3/day of water, which becomes contaminated upon contact with the fuel and then spreads to the lower parts of the buildings. Given that the March 2011 earthquake affected the watertightness of these buildings, TEPCO is forced to keep the level inside the buildings lower than that of the water table, in order to avoid contaminating the latter. Groundwater thus seeps into the basement (about 200 m^3/day) and mixes with contaminated water.

Outside the buildings, monitoring of the water samples taken from the drainage system installed around them shows a very moderate contamination of the groundwater (around 5000 Bq/L for tritium downstream from Unit No. 4 and 200 to 500 Bq/L for caesium around Unit No. 2) compared to the water inside the buildings (of the order of 10^6-10^7 Bq/L for caesium and 10^6 Bq/L for tritium). Thus, there are signs of leaks possibly resulting from the level reached in 2011 by radioactive water in the nuclear buildings, but no signs of any significant current leak. This finding was confirmed downstream from the turbine buildings of Units No. 1 to 3 after the installation of 11 piezometers.

In order to prevent groundwater from flowing into the basements of the buildings, without risk of contaminating the groundwater, TEPCO conducted the following actions:

- Installation of a system of 12 wells to pump up groundwater flowing from the mountain side upstream of the buildings ("*Groundwater bypass*"). This system, which has been operational since the summer of 2013, was implemented in April 2014. It leads to regularly releasing water (about 250 m^3/day) after contamination controls[3].
- Restoration of 27 drainage pits and construction of 15 new pits around the buildings (" *subdrains*") to complete the drawdown. Before the accident, this drainage network enabled the drawdown of the water table in contact with Units No. 1 to 4 by pumping 850 m^3/day. After a test phase carried out on 14 wells in August 2014, the commissioning of this system and the treatment and release of water into the harbour were approved by the Japanese regulatory authority in early 2015 and then by local authorities and associations in September 2015. Approximately 350 m^3/day are pumped from around the buildings and then treated, and must meet the same release criteria as the pumped water upstream of the sea-side impermeable wall mentioned in the previous chapter[3];
- Search for groundwater seepage areas inside the buildings to carry out sealing work. This long process will require a systematic examination of some 800 existing passageways through the outer walls of Units No. 1 to 4;
- Deployment of a soil freezing device down to a depth of around thirty meters around Units No. 1 to 4 ("land-side impermeable walls"), following the work of a group of experts mandated by the authorities and several experimental phases. Between June 2014 and October 2015, TEPCO completed 1552 freezing boreholes and 332 soil temperature monitoring boreholes. Since April 2015, TEPCO has been testing the process at 18 locations (58 holes), on the hill side.

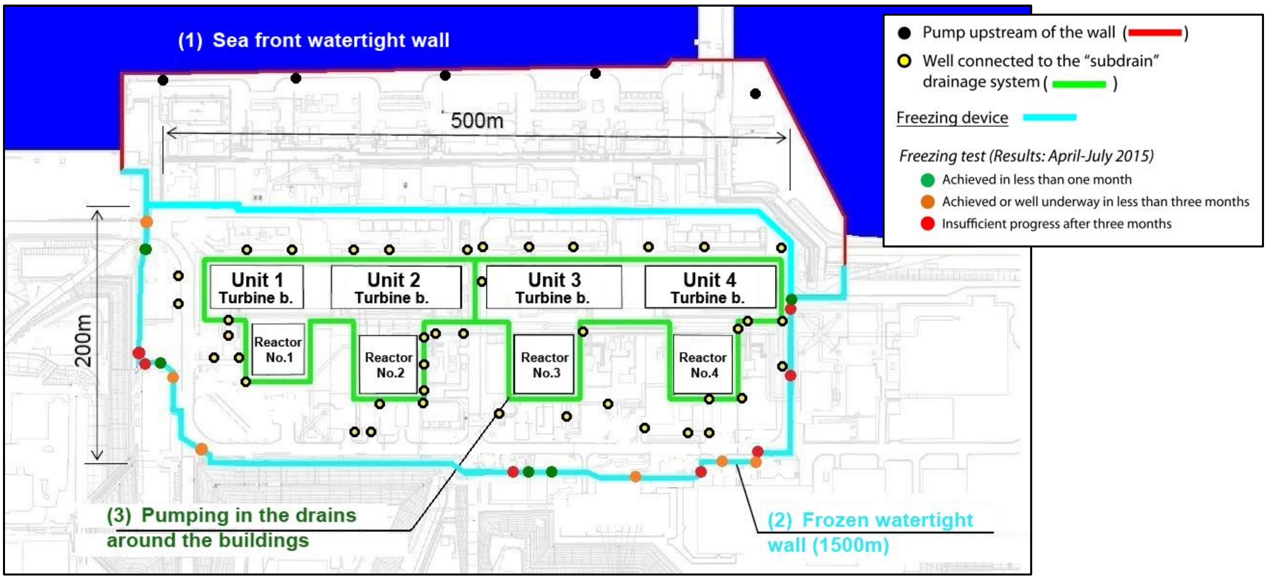
[3] TEPCO has set itself, in agreement with the authorities and fishing associations, contamination limits below the legal discharge values set forth in the regulations: less than 1 Bq/L for caesium 137, less than 1500 Bq/L for tritium and less than 3 Bq/L or 5 Bq/L for overall b (essentially strontium) depending on the device. Releases are allowed after TEPCO and a third-party organization have confirmed that its quality meets operational targets.



Source TEPCO – Effect of the "groundwater bypass" and "subdrains" pumping devices before the commissioning of the soil freezing device.

The results to date of these various devices is detailed below.

- In the case of the *"groundwater bypass"*, there are tritium readings in the pumped water due to leaks from the storage areas (see the next paragraph) and TEPCO has suspended the pumping of the well exceeding 1500 Bq/L. In addition, bacterial growth in the boreholes causes stoppages for cleaning. After more than a year of pumping, TEPCO considers that this device has enabled seepage to be reduced in the buildings from 400 to 300 m^3/day (findings in the summer of 2015).
- Pumping was thus commissioned in the drainage pits ("*subdrains")* around buildings to reduce seepage into the buildings from 300 to 200 m^3/day (findings at the end of 2015 by TEPCO). However, maintaining a stable water table level around the buildings is made difficult by rainwater infiltrations. In addition, TEPCO expected a reduction in the groundwater flows into the harbour area, which has not yet been the case.
- In order to freeze soils around the Units 1 to 4, the test phase showed encouraging results. However, since the month of August and the beginning of the rainy season, increased groundwater flows have led to a rise of soil temperature in most of the boreholes.



From TEPCO data - soil freezing devices and "subdrains" location.

IV. The storage area

Since June 2011, TEPCO has been storing highly radioactive water in tanks installed progressively upstream of the nuclear buildings. Water treatment enabled TEPCO to reduce their radiological content[4].

In 2013 and 2014, several incidents led to releases of highly radioactive water that reached the shallow aquifer.

TEPCO thus carried out work to limit the occurrence of new spills, reduce their consequences by containing leaks or rainwater around the tanks and restoring and monitoring the rainwater collection network.

After several years of monitoring, the changes in the groundwater contamination in the storage area are summarized in the following table.

Storage Sector	Changes in the *maximum* readings by sector			Means implemented
	Radionuclide detected	Maximum observed	1st fortnight of 2016	
Tank R4	Tritium	3,400 Bq/L	570 Bq/L	None considered necessary. Collection downstream by the *Groundwater bypass*
Tank R6	Tritium	3,800 Bq/L	130 Bq/L	
Tanks H4	Tritium Overall β	790,000 Bq/L 710,000 Bq/L	24,000 Bq/L 9,900 Bq/L	Local pumping between October and December 2013. Collection by the *Groundwater bypass*
Tanks H6	Tritium Overall β	7,000 Bq/L 260 Bq/L	990 Bq/L undetectable	None considered necessary
Groundwater bypass (Downstream from R4, R6 and H4)	Tritium	3,100 Bq/L	880 Bq/L (*No. 10>1,500 Bq/L*)	Pumping since April 2014

The levels have fallen significantly, but the closest piezometers still show sharp fluctuations in the readings after heavy rain periods. Downstream from these areas, only tritium is detectable and disrupts the functioning of the *"groundwater bypass"* wells. With levels exceeding 1500 Bq/L, Well No. 12 was shut down twice between May and August 2014 and Well No. 10 has been shut down since July 2015 (in November 2015, the readings were still 3,100 Bq/L).

Following the highly radioactive water leaks that occurred in the storage area in 2013 and 2014, only tritium is detected downstream. Since the commissioning of the "*groundwater bypass*" in April 2014, most contaminated groundwater from this area is captured by this device.

As a conclusion, it appears that the provisions implemented by TEPCO enable the bulk of the groundwater contamination to be contained within the Fukushima Daiichi plant.

[4] See the information note on the management of radioactive water.