Sustainable Water Use: Finnish Water Management in Sparsely Populated Regions

Piia Leskinen and Juha Kääriä

Abstract In Finland, 1 million inhabitants of the population (5.4 million) live in sparsely populated areas. Since 2004, the Finnish legislation requires that every house outside the municipal sewer networks must have a water purification system that meets the minimum purification requirements for phosphorus, nitrogen, and organic matter. Existing dwellings were given an adaptation period of ten years, during which they would have to make the necessary investments. In our study, we focused on making research on the functionality of small-scale purification systems in 30 different households and on dissemination of information about the purification systems and the legislation to concerned property owners. The purification performance of the plants was monitored by traditional sampling and continuous on-line water quality sondes. The study was focused at determining how much the fluctuations in the incoming wastewater quality affect the purification performance. The main results showed that the small-scale purification systems function generally well if they are properly installed and regularly maintained. Unfortunately, this is not often the case. Several recommendations on how to prevent faults in installation of the systems and how to encourage property owners to maintain their systems were made.

Keywords On-site wastewater treatment · Single-house package plants · Wastewater management · Sparsely populated areas

1 Introduction

Eutrophication, caused by excess input of phosphorus and nitrogen nutrients into the water bodies, has been identified as a major threat to the quality of coastal water resources in Europe (European Environmental Agency 2001). In 2000, the European Union set a directive to improve the water quality in all member states (EU 2000).

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This so-called Water Framework Directive set the ambitious goal of having all water bodies in the European Union area in a good state, as defined using ecological classification system. Finland has a reputation of being a sparsely populated country with thousands of lakes and a clean nature. In fact, the country has 5.4 million inhabitants in 300,000 km^2 of land and 60,000 lakes of surface over a hectare. One-third of classified lakes and half of the coastal areas are in a poor or satisfactory state (Putkuri et al. 2013). One million of Finns live in rural areas, without connection to municipal water management systems. In addition, there are approximately half a million summer residences in Finland, most of which are located by a lake or the Baltic Sea. Traditionally, the summer cottages were modest cottages with dry toilets, but during the last 20 years, there has been a strong trend of upgrading the commodity standards of summer houses to the level of permanent residencies. As the nutrient loading from municipal water treatment facilities and industrial sources has diminished significantly due to strict regulations and investments in treatment technologies, the emissions from rural dwellings have become the second largest source of phosphorus after agriculture (Putkuri et al. 2013). In addition, there is a risk of contamination of drinking water wells by untreated wastewaters.

In order to reduce the nutrient loads and hygienic risks from rural dwellings, the Finnish legislation was modified in the early 2000s. The most important addition was the Government Decree on Treating Domestic Wastewater in Areas outside Sewer Networks (542/2003), which came into force in the beginning of 2004, and set minimum standards for wastewater treatment and the planning, construction, use, and maintenance of treatment systems in rural areas. The Decree does not make a difference between permanent and holiday residences. Instead, the level of sanitary and water facilities is considered, meaning that no wastewater treatment is required only if the house has a dry toilet and no water pipe. The requirements of the decree were applied to all new houses immediately, but the existing houses were given a transition period of 10 years.

The decree was not welcomed by residents of rural areas, and it started a wide ranging public discussion that went on from internet discussion groups, newspapers, and markets all the way to the parliamentary sessions. The main points of criticism were that the performance of small-scale purification is questionable, the investments are too expensive, and the limits for purification are too strict. Further, many property owners seemed to be unaware of what they were expected to do. In 2009, it was estimated that only 10–15 % of properties had done the required improvements in their wastewater systems (Tarasti 2009).

Due to the debate, the Government Decree on Treating Domestic Wastewater in Areas outside Sewer Networks (hereafter wastewater decree) was modified and the new decree (209/2011) came into force on March 15, 2011, with lower purification requirements and extended transition period for upgrading the treatment systems in old houses.

In this article, we describe the results on the functionality of different systems. Our aim was to answer the following questions raised by the public debate:

1. Is the average load and reduction percentages a good way of defining the purification requirements?

2. Are the purification results of single-house purification plants affected by variations in the daily load or occasional exposure to strong household chemicals?

In this article, we also evaluate the impact of public debate and the modification of legislation on the willingness of property owners to comply with wastewater legislation.

2 The Purification Requirements and Measured Wastewater Quality

The modified Government Decree on Treating Domestic Wastewater in Areas outside Sewer Networks in Finland (from 2011) requires that all properties must remove 70 % of phosphorus (P), 30 % of nitrogen (N), and 80 % of organic matter (BOD7) in their treatment systems. In especially sensitive areas, such as those near water bodies or ground water areas, the requirements are 85 % P, 40 % N, and 90 % BOD7. The purification requirements are counted from estimated average loading, which is defined in the same decree, 2.2 g P, 14 g N, and 50 g BOD_7 per person per day. Purification requirements are defined as reduction percentages from initial load in Finland and for example in Norway, whereas in some countries the purification requirements are expressed as maximum concentrations in outgoing wastewater. The actual wastewater concentrations that can be measured and reduction percentage from average load can be compared using the following equation:

$$\text{concentration} = \left(1 - \left(\frac{\text{reduction requirement}}{100}\right)\right) \times \frac{\text{average load } \left(\frac{g}{d}\right)}{\text{water consumption } (L/d)}$$

For example, for phosphorus, the maximum allowed concentration in purified wastewater can be calculated:

$$\text{concentration} = \left(1 - \left(\frac{70}{100}\right)\right) \times \frac{2.2\left(\frac{g}{d}\right)}{128\left(\frac{L}{d}\right)} = 5.2\,\text{mg/L}$$

Above it can be seen that the water consumption needs to be known in order to resolve the equation. Most properties in rural areas get their water from an own well, and the water consumption is not measured, so the information on the actual water consumption in rural areas is scarce. In centralized water distribution systems, the average water consumption rate of households in Finland was 128 L/day in 2010 (Vesihuoltolaitosyhdistys 2012). During our studies, we measured water consumption in a number of properties and the consumption rates varied from 70 L to 150 L/day, the average being 110 L.

To our knowledge, there is not much measured data on wastewater production in individual properties, and all estimates are based on data collected from municipal wastewater treatment plants. The sampling of nonpurified wastewater in an individual property is technically challenging, and the quality and quantity of wastewater produced in an individual property have large daily and weekly

Table 1 The measured wastewater load in four properties compared to standard load in the decree

		BOD7 mg/L	Ntot mg/L	Ptot mg/L	Water consumption L/day/person
Property 1	Mean standard (n)	322 58.8 (17)	101 16.1 (17)	16.3 6.3 (17)	74
Property 2	Mean standard (n)	318 89.7 (13)	110 22.4 (13)	16.7 5.4 (13)	115
Property 3	Mean standard (n)	520 195 (10)	122 45.9 (10)	23.3 6.4 (10)	80
Property 4	Mean standard (n)	399 107 (20)	94.6 19.2 (20)	20.1 6.25 (20)	120
Decree standard		*391*	*109*	*17.2*	*128*

variations. Thus, estimating the average load is difficult. We attempted to address this question by installing sampling devices in four different properties. The unpurified wastewater samples were collected in a container in a 24-h period, and the samplers were equipped with a disintegrator. The samples of purified wastewater were taken from the inspection wells of the purification plants. The results are summarized in Table 1. According to our data, in these four properties, the decree standard values corresponded quite well to the measured wastewater load. Our results are in line with the few other studies (Lowe et al. 2009; Nieminen et al. 2013) where wastewater production in individual properties has been measured.

3 Treatment Systems Overview

Traditionally, rural dwellings in Finland get their drinking water from an own well and dispose their waste water into the environment, after one or two sedimentation tanks. In many properties, there are also septic tanks where either only toilet water or both washing and toilet waters are led. In a long term, this is a very expensive solution and the cost of the tanker truck visit may lead the property owners to emptying the tanks in the nature. Many of these systems have been installed 20–30 years ago, and not maintained since, apart from eventual emptying of the tanks.

In order to meet the requirements of the current wastewater legislation, a property must have an advanced purification system, including two to three sedimentation tanks followed by a filtering field or a small-scale purification plant. In properties that have a dry toilet or where toilet water is lead to a septic tank, a simple filtering system is sufficient for washing water treatment. The wastewater decree is based on the idea that no system is better than another, as long as the purification requirements are met. The choice of the treatment system depends on local conditions and the property owners should seek for advice from an expert in order to make the right choice (Lehtoranta et al. 2014). The water using habits and personal preferences of the system users should be taken into account when

planning a system, as well as the soil type and dimensions on the property. For example, soil filtering systems can be only used in areas where groundwater is not near the soil surface, in properties that are large enough to allow construction of a filtering field of about 30 m^2.

If the distance to the neighboring houses is short, it is recommended that the possibility of putting up a shared or a community-based system is inspected first. If situated reasonably close to the cities, the communities may put up a cooperative for the construction of a water and sewage network that will then be connected to an existing municipal treatment plant. An own treatment plant can be put up by those community-based cooperatives that are situated in remote areas. Shared and community-based systems are recommended due to easier maintenance, better performance, steadier wastewater flow, and financial advantages. However, the Finns traditionally like to have their own space and typically houses are built far apart. In these cases, an individual system for the property is the only option.

A factory designed package plant with a combined active sludge and chemical treatment process is generally chosen in properties that are limited in space. In Finland, there are several manufacturers of such plants and new package plants came into the markets upon the enforcement of wastewater decree in 2004. Although some of the plants are working on a continuous flow principle, most of them have a sequencing batch reactor that start the purification process either at a certain time of a day or when the amount of wastewater reaches the preset level. The reactors typically have an aerobic mixing period during which a compressor feeds pressurized air into the reactor resulting in degradation of organic matter and nitrification of ammonium. This is followed by a settling period, during which the oxygen is rapidly consumed from the reaction tank creating anaerobic conditions that are favorable for denitrification (conversion of nitrates into elementary nitrogen gas). The phosphorus precipitation using aluminum or ferric salts is done either in the aerobic process tank or in a separate tank after the biological process. A part of the sludge from the process tank is used to maintain the process stability, but the excess sludge is stored in a separate container or a tank, from where it should be emptied regularly and transported for treatment to an authorized treatment plant.

4 Impact of Incoming Wastewater Quality on Treatment Efficiency of Single-House Package Plants

From the beginning, the Finnish wastewater debate raised many critical questions on the functionality of biological process of the package plants over cold winter periods and on their ability to deal with large fluctuations in wastewater quality. Several studies show that although the performance of on-site systems varies greatly, they generally work well if they are properly maintained (Hellström and Jonsson 2003; Vilpas and Santala 2007). Garcia et al. (2013) found that the purification results of aerobic on-site treatment systems were similar to those of municipal wastewater treatment plants. However, previous studies have been carried out by taking samples from purified wastewater only. In our study, we addressed the

impact of varying wastewater quality on the purification results of the package plants by taking samples from the raw and purified wastewater in three different package plants during a period of about one month. All plants were in normal use during the study. The results are presented in Fig. 1. According to these results, it seems that the fluctuations in the quality of incoming wastewater are generally not reflected in the quality of outgoing wastewater. Rather, when the purification plant is functioning well, it can treat even high concentrations of nutrients.

In order to reveal short-term variance in the purification efficiency, we installed continuous sensors in eight different purification plants and followed their functioning over a test period of 6–8 weeks, during which we also took samples from

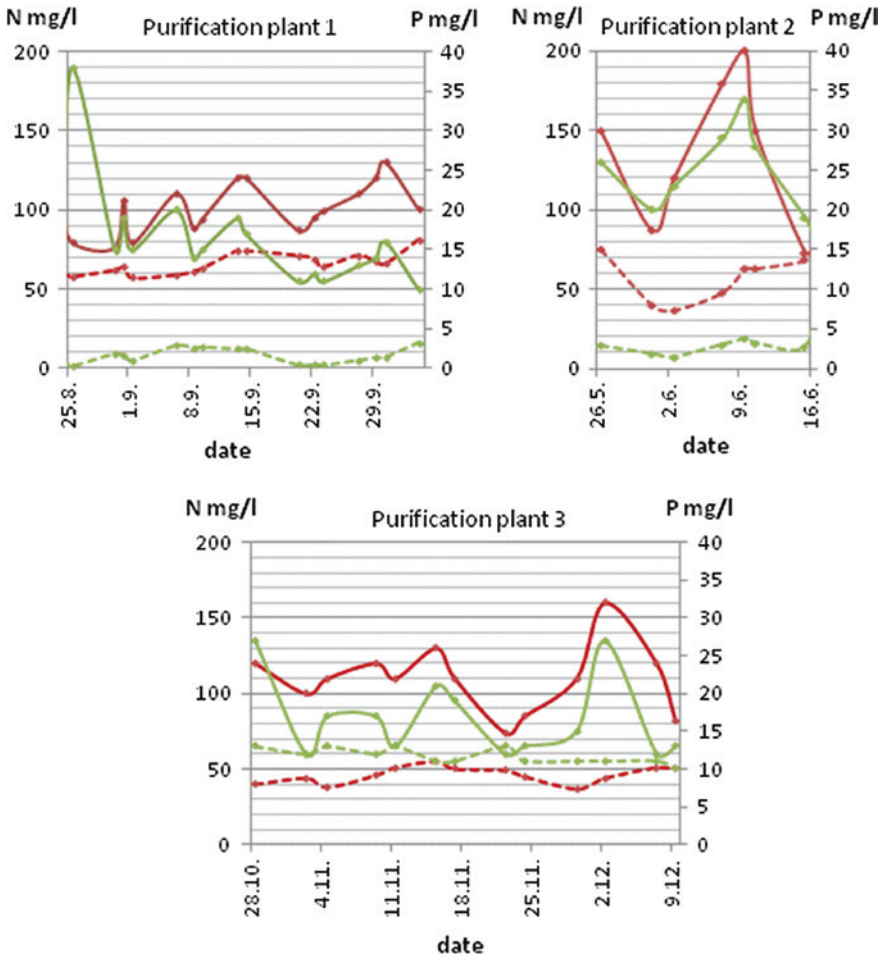

Fig. 1 The fluctuation in the quality of incoming (*solid lines*) and outgoing (*dashed lines*) wastewater in three different single-house purification plants in normal household use. Total nitrogen concentrations in *red* and total phosphorus concentrations in *green*

purified wastewater twice a week. According to our results, those purification plants that were correctly installed and regularly maintained met the purification requirements during the whole monitoring period, without significant variations in purification efficiency.

Flushing toxic chemicals, such as solvents or chlorine, is forbidden in the user manual of all package plants, and property owners generally are aware of this. However, commonly used cosmetics and household cleaning products often contain toxic chemicals that go down the drain. In order to find out how well the single-house purification plants could stand occasional loads of strong chemicals, we did two tests in five different purification plants. In the first one, we flushed two packets of hair coloring products into the drain and in the second one, we asked the owners of the purification plants to change their usual washing powder into a stronger one that contains phosphates and solvents. We monitored the effect of these chemicals with an YSI6600—series continuous turbidity/pH/oxygen/temperature sensor installed in the process tank of the purification plants and by taking the samples from the purified water after the chemical additions. Figures 2 and 3 show how the addition of hair coloring chemicals affected the process and purification performance in two different reactors. Although the pH and oxygen balance was disturbed during 3 days in the purification plant number 1, the perturbations do not significantly affect the purification results of nitrogen and phosphorus. In summary, the tested purification plants seemed to tolerate well the addition of strong household chemicals.

5 Servicing and Maintenance Issues

The servicing and maintenance emerged as one of the major issues in the functionality of different purification systems. Although the ease of maintenance is one of the major selling arguments of system providers, no purification plant can go on without regular maintenance. The required maintenance steps depend on the design of the treatment plant, but at least checking of pumps and air diffusers, adding of precipitation chemicals, and emptying of excess sludge are required for almost all plants. One common reason to low purification performance are problems with dosing of phosphorus precipitation chemical, which can be at too low level, if the settings are made in factory. The dosage amount should be adjusted based on number of users and their using habits to reach good phosphorus removal level.

Some property owners carry out these tasks regularly, and many have made a contract with a servicing company. However, many treatment plants in our study were found nonfunctional due to lack of maintenance or because of an installation fault. There is no data available in Finland on how many percentages of single-house purification plants are maintained properly. There is a large difference between the theoretical amount of sludge that should be produced in rural areas (based on the number of residents) and the actual amount of sludge received

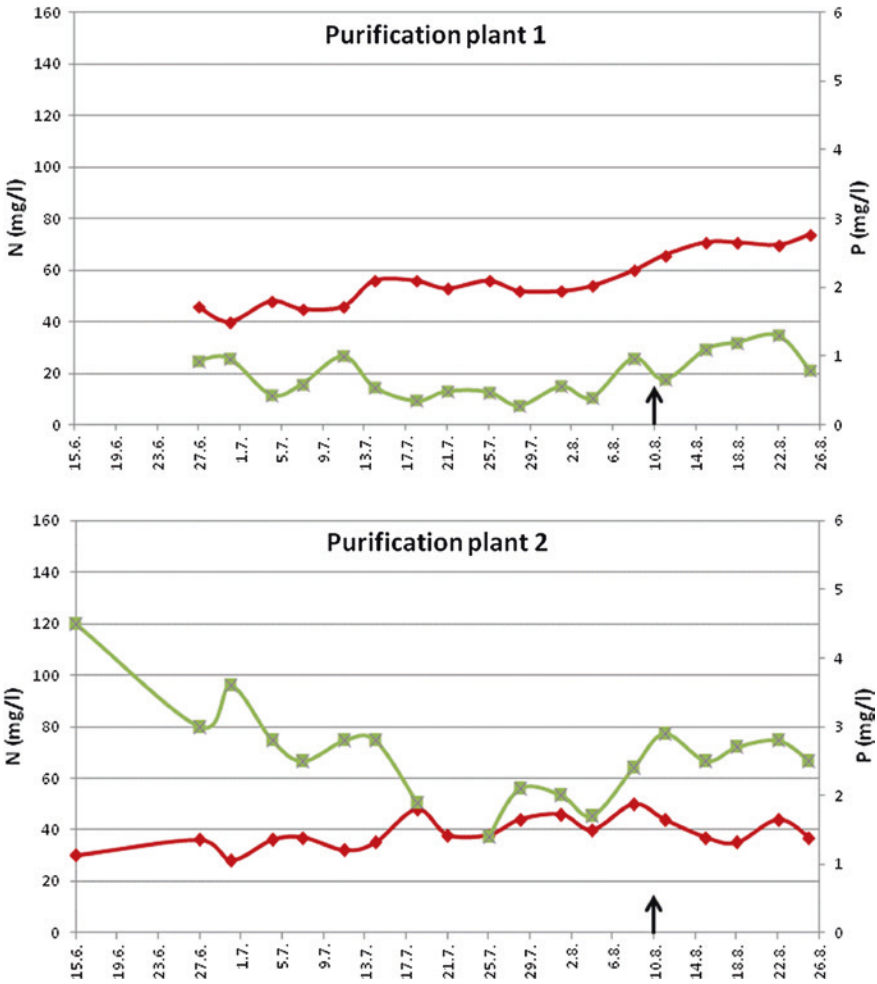

Fig. 2 The total phosphorus (*green*) and total nitrogen (*red*) concentrations in the purified wastewater of two different single-house purification plants. The *arrows* show the time of flushing of hair coloring products in the drain

by authorized treatment plants. This indicates that emptying of the sludge—the most basic step of maintenance—is not carried out properly in the majority of properties. In our study, we carried out a questionnaire where treatment plant owners were asked if they felt they had had sufficient information on wastewater legislation, purification systems, and maintenance issues. When the results of the questionnaire were compared to data on the maintenance level and purification performance of the same treatment plants (Table 2), it was clear that proper maintenance was the crucial factor in purification performance of the reactors. Interestingly, we found out that even though some property owners felt they had got sufficient information, they still did not take proper care of their treatment

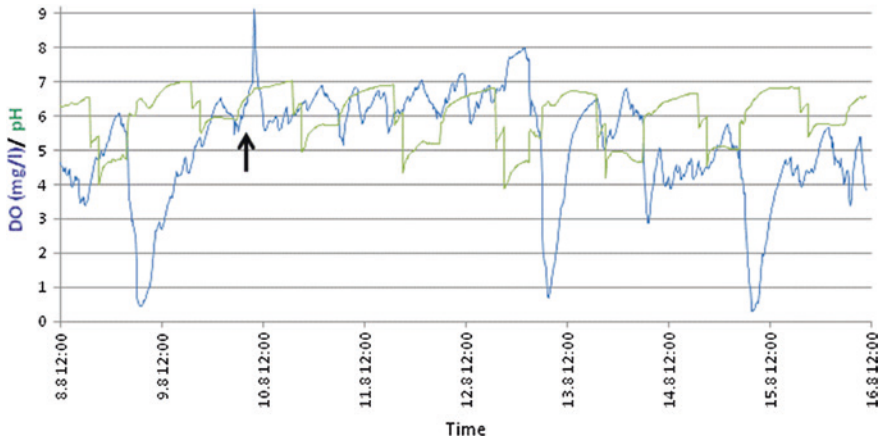

Fig. 3 The oxygen concentration (*blue line*) and pH (*green line*) in the reactor of a single-house purification plant during exposure to strong hair coloring products. The *arrow* shows the time of flushing of hair coloring products into the drain

Table 2 Links between information, action, and purification performance

Purification plant	1	2	3	4	5	6
Did you feel that you had got sufficient information on...						
...wastewater legislation?	No	Yes	Yes	Yes	Yes	Yes
...different purification systems?	Yes	Yes	Yes	Yes	Yes	No
...your own purification plant?	No	Yes	Yes	Yes	Yes	Yes
...maintenance of the purification plant?	No	Yes	Yes	Yes	No	No
Was the purification plant						
...properly installed and fixed?	No	No	Yes	Yes	Yes	No
...serviced regularly?	No	Yes	No	Yes	Yes	No
Did the purification plant meet the purification requirements over the whole monitoring period?	No	Yes	No	Yes	Yes	No

systems. A wastewater treatment system seems to be something that people rather forget, until it becomes for some reason unavoidable to do something. A study carried out in the Republic of Ireland found that many inhabitants of sparsely populated areas were unaware of what type of on-site wastewater system they had in their own property (Naughton and Hynds 2013).

It is of crucial importance that the package plant is correctly installed. Based on this study, it seems that different kinds of problems in installation are common. Property owners should make sure that they get competent contractors to install wastewater treatment systems. After installation, package plants must be monitored by their owners to ensure that treatment process has started to work properly. A sample from purified wastewater should be taken and analyzed few months

after installation to ensure that the process has started functioning. Some of the manufacturers already provide sampling service and a guarantee of functionality after installation.

6 From Legislation to Action

Since the enforcement of the rural wastewater legislation, numerous projects financed by European Union and national funds have offered consulting for citizens who need to update the wastewater treatment systems in their properties. The consulting has been given through e-mail and telephone services, happenings and work demonstrations. In each district, there is an office responsible for consulting of the public. The Finnish Environment Institute hosts web pages where research information, environmental justifications for improved wastewater treatment, as well as clear and concise instructions for choosing and maintaining a purification system, are displayed. As a result, information on different wastewater systems is now available for those who are willing to modify their wastewater systems and are actively looking for information on different systems. Initial questions about the functionality of single-house purification plants have been addressed by independent studies, which have showed that the single-house purification plants generally work efficiently when they are properly maintained and installed. However, still it is estimated that more than half of the properties have not taken action to update their systems to meet the requirements of current legislation. Thus, it seems that either information is still not reaching concerned property owners, or then knowledge of the legislation and environmental reasons is not sufficient for making people to act. Rather, it seems like many people are expecting that the legislation will be changed again and that they may not need to do anything finally.

7 Conclusions

While working properly, package plants reached purification requirements easily. To achieve requirements, package plants need proper maintenance and regular observation from users. Regular observation helps to notice problems early and avoid expensive maintenance costs. Variation in purification results is typical for biochemically functioning package plants. If the treatment plant is well maintained, purification results meet the requirements despite the natural variation of biological process and the process recovers faster from occasional disturbance.

The purification results are not automatically similar in same kind of purification plants when they are installed in different households. The purification result depends significantly on how the package plant is used and maintained. Main reason for bad purification results are incorrect installation or wrong settings and lack

of maintenance as this study demonstrates. Owners of package plants need more information about the maintenance procedures, and they need to be encouraged to look after their treatment plants by emphasizing advantages they gain by doing so.

Based on experiences of Finnish wastewater legislation, we conclude that it is more important to set requirements for purification plant manufacturers to test and develop their purification systems and for property owners in rural area to correct installation and maintenance than to set strict quantitative purification requirements. This is because a well designed purification system, when correctly installed and properly maintained, is likely to significantly reduce loading of nutrients and organic matter, whereas numeric values for purification requirements may cause confusion in general public and the fact that they are not monitored can give a misleading idea of the legislations' obligations.

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