ENVIRONMENTAL RISK ASSESSMENT AND CALCULATION OF THE DAMAGE'S MAGNITUDE IN WWTP

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1 of March 2012

Abstract

The dissertation's scope is related to the need for environmental risk assessment of WWTP and subsequent calculation of the magnitude of damage that may occur in the context of Directive No. 2004/35/CE of 21 April, known as Environmental Liability Directive. This law promotes the formation of financial guarantees by activities referred in Annex III, and therefore the responsibility of the operators and stakeholders, costs and implementation of measures to repair environmental vectors that have been disturbed. The transposition of the directive into national law by Decree-Law No. 147/2008 of 29 July established the legal regime of liability for environmental damage, and Portugal opted for mandatory financial guarantees for activities considered in Annex III.

The study of environmental risk assessment of the WWTP shows that bypass operations, organ rupture and pipes rupture are the main events that can occur with potential to cause environmental damage, and the events that address disruptions organs are those with the greatest magnitude of damage. Besides the magnitude of damage was also possible to determine the value of the insurance premium to be established by the head, as it is the option that is applied in the country.

KEYWORD: environmental liability directive, WWTP, financial guarantees, magnitude of damage, occupational activities.

1 Introduction

Talk about environmental liability was associated with damage to persons and things. Over the years, this concept has expanded, to include damage to nature itself, the natural heritage and the natural foundations of life. Environmental liability is the term used to represent the responsibility for the cost of damaging the environment, which is transferred back to those responsible for acts that caused (URSEspanha, 2010).

Thus, environmental responsibility seeks to blame the causer of environmental damage to pay compensation for damage caused by standards and procedures designed to preserve the environment. It is a theme that emerged in the middle of 80s in Europe when the European Union (EU) consisted of 10 Member States (MS) has been developed a system of responsibility for damage caused by waste.

The principles of response the polluter for the environmental damage caused an effect on prevention of risks and damage, and encourage investment in research and development to increase knowledge and improve technologies (Comissão, 2000).

However, with advancing decades, it was necessary to give new impetus to the issue of environmental liability due to the accumulation at European sites contaminated with significant risks both to health both the loss of biodiversity. Thus instruments were created based on the application of the polluter pays principle, in line with the principle of sustainable development, gaining expression through Directive No. 2004/35/CE of 21 April 2004, more commonly known as Environmental Liability Directive (ELD).

The ELD establishes a common framework for environmental liability on operators of some occupational activities listed in the community scheme in order to prevent and repair damage that can occur on water resources, species and natural *habitats* and soil, prompting traders to form a financial guarantee.

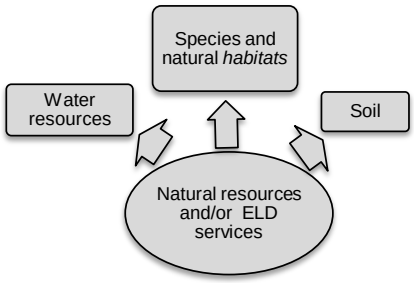

Figure 1 – Environmental vectors covered by the ELD.

However it is EU's MS that should encourage or even the constitution making it compulsory the establishment of financial mechanisms to ensure the implementation of preventive measures and repair in order to blame the operators, not just the payment of fines.

The ELD transposition's into Portuguese law takes place through the Decree-Law No. 147/2008 of 29 July, which establishes the Legal Framework for Environmental Liability for environmental damage requiring the establishment of a financial guarantee to the activities listed in Annex III.

The set of economic activities listed in this annex are highly heterogeneous, being necessary to identify the occurrences that

can cause an environmental damage. The waste water treatment plant (WWTP) is an activity which still requires risk assessment under ELD and one possible reason is the difficulty in materializing financially of risks.

The objectives of this study were precisely:

- To establish a methodology for assessing environmental risks in WWTP.
- To calculate the damage magnitude and financial guarantee to a WWTP, specifically for the Beirolas's WWTP.

The analysis of the risks focuses on a WWTP with tertiary treatment, UV disinfection and energy recovery through biogas production.

Note that this study was done with the agreement of SIMTEJO, manager of the Beirolas's WWTP and others plants.

2 Treatment and Identification of General Risks in WWTP

As said the analysis centers on WWTP with tertiary treatment and energy recovery through biogas production. Usually the plant's process has three phases: liquid, solid and gas phase.

The liquid phase has three levels of treatment whose aims are to remove substances that have negative effects on the environment. The purification of the effluent follows a line of treatment in which each step proceeds to the removal of a specific parameter (Figure 2) (Spellman, 2000).

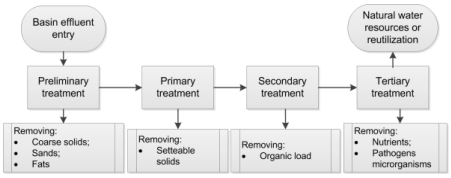

Figure 2 – Line of wastewater treatment

The solid phase consists of the treatment of sludge produced in primary and secondary level of the liquid phase. The continuous purification of waste water originates sludge that may subject to recovery or disposal. Any option taken for the sludge's treatment the final aim will always be the conversion of these forms for viable economic and environmental. As you can see in Figure 3 the primary and secondary sludge treatment can be made aerobic or anaerobic form.

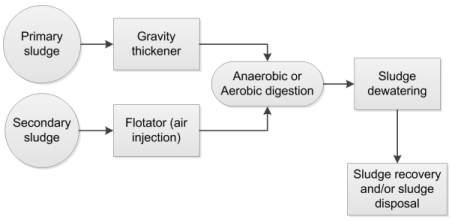

Figure 3 – Treatment of solid phase in WWTP.

The treatment of primary and secondary sludge goes through a process comprising the following stages: thickening and flotation of primary and secondary sludge, respectively; the mixture of sludge digestion and sludge dewatering.

As mentioned, the ELD environmental vectors are water resources, species and natural *habitats* and soil, if this last creates a significant risk to human health (Comissão, 2004; Sá, 2011)

The growth of industrial activities and the tourism's development have introduced

pressures on coastal and estuarine areas, with the inevitable increase in production of urban and industrial effluents (INAG, 2001). These facts can be minimized with an efficient treatment in the WWTP, although problems can occur in the treatment's line that can produce effluents that pollute the water resources with high concentrations in Phosphorus (P), Nitrogen (N), Solids Suspends (SS) and pathogenic microorganisms. High concentrations in nutrients like P and N can produce eutrophication and the water resource stay in an anoxic stage. One of the most typical cases of water resources contamination it is a WWTP bypass operation as well as effluent discharges with chemical and biological characteristics not allowed by law.

At the level of soil contamination, the WWTP exploration phase carries with possible environmental consequences. In Portugal there is no legal framework on soil contamination, with frequent use of the Dutch standard for soils and the *"Guidelines for Use at Contaminated Sites in Ontario"*, Canadian law. The main environmental risks that the soil may suffer arising out of the sludge production and spreading sludge in agriculture. However, the sludge applied in agriculture may have high amounts of heavy metals and pathogenic microorganisms that can cause serious environmental problems to plants and soil microorganisms, including nitrogen fixing bacteria *Rhizobium* (Gonçalves e Castro, 2004). Most of the production of sludge treatment plant focuses exclusively on the processes of primary and secondary treatment, which somehow are considered factually phases of treatment where sludge is produced. The groundwater contamination and the contamination of WWTP soil are other risks that can occur. During the operation of a WWTP but with low probability, there may be cracks, structural breaks and bleeds in the organs of treatment. These conditions can cause possible contaminations derived from leaking into the soil of WWTP within the installations and surrounding areas that is not waterproof.

As environmental risks considered for the soil and water resources, species and protected *habitats* are also covered by the ELD. Certain events associated with the exploration phase of a WWTP may affect the ecological dynamics of surrounding the plant and the water resources that receive de effluents. In fact the environmental impacts that this vector can be eventually suffer indirect impacts that are associated with environmental damage in the other two natural services enshrined in ELD.

Table 1 - Actions subject to environmental impacts in the exploration phase of a WWTP within the environmental liability.

Typical actions during the exploration phase in the environmental liability context	Production of treated wastewater discharge into water resources with parameters not allowed by the law.
	Reuse of treated wastewater (if applicable).
	Production of waste (including sludge).
	Agricultural development of the sludge produced.
	Movement of vehicles especially with the transport of sludge and reagent.
	Bypass operations due emergencies and breakdowns.

As it can be seen in Table 1 the actions that can lead to environmental impacts within the ELD are primarily related to bypass operations that can be performed throughout the process, procedural flaws in the treatment of wastewater effluent discharges contaminants that originate in the water resources and occurrences as the agricultural value of sludge with heavy metals concentrations above the permissible by law. Most of these actions are due to failures of mechanical equipment and/or electro that make up the WWTP treatment's line.

To determine the value of financial guarantee of all occurrences identified is necessary to use probabilities. The environmental risk value is a function of probability of occurrence and their magnitude (Levy, 2011).

The set of possible discrete distributions obtaining a financial guarantee will be determined with the use of Poisson distribution used to model on of the main objectives of the dissertation, the calculated value of financial guarantee to be incorporated. The function of the Poisson probability distribution is given by:

$$P(X = x) = \begin{cases} e^{-\lambda}\dfrac{\lambda^x}{x!}, se\ x \geq 0 \\ 0, \quad c.c. \end{cases}$$

where λ is the mean of binomial distribution and x represents the number of events occurring in a limited time (Silveira, 2009).

Risks associated with events identified as causing environmental damage are determined by the product of damage's magnitude with the probability of occurrence matching, that is:

$$\begin{cases} \chi_t(ID_1) = \chi_1 \times MD_{ID_1} + \cdots + \chi_n \times MD_{ID_1} \\ \chi_t(ID_2) = \chi_1 \times MD_{ID_2} + \cdots + \chi_n \times MD_{ID_2} \\ \vdots \\ \chi_t(ID_N) = \chi_1 \times MD_{ID_N} + \cdots + \chi_n \times MD_{ID_N} \end{cases}$$

where $\chi_t(ID_N)$ represents the total environmental risk associated with the likelihood of occur n times per year and MD_{ID_N} corresponds to the value of the magnitude of the damage in €, associated with the occurrence ID_N (Levy, 2011).

Thus, it is possible to determine the value of financial guarantee that the operator responsible for operating activities included in Annex III of ELD is subject to form and proceed with the sum of environmental risks of each occurrence verified or will be possible to exist.

$$Financial\ guarantee = \sum_{ID=1}^{N} \chi_t(ID),\ in\ €$$

In Figure 6 it is possible to observe the process of calculating the overall risk of environmental damage of a WWTP. Through the flowchart, it is possible to estimate the value of financial guarantee that should be set up under the ELD.

As referred, the ELD establishes that if occur any damage on water resources, species and *habitats* and soil, the occupational activity has responsibility to repair. This way it was necessary to define the costs remediation for the three natural resources services.

Remedial measures to the soil were estimated between 160 and 210 €/m^3. These costs concerns to a repair method *in situ*, protecting the soil through vertical and horizontal barriers, not being necessary remove soil. If this method does not work, is

usual remove the contaminated soil by other soil with same characteristics. The costs associated fixes between 100 and 300 €/m^3 (Varennes, 2011). The remedial measures of surface water resources derived from bypass operations or wastewater characteristics that exceed the limit. For these events it was established a uniform magnitude of damage of about 29.000,00 €.

This value was determined as follows:

- 4 employees to perform the remediation works in a month (1000,00 €/month.employee).
- Pipelines, reagents, other material (5.000,00 €).
- Monitoring system (10.000,00 €).
- Clean margins (10.000,00 €).

3 Case Study – WWTP of Beirolas

The WWTP of Beirolas belongs to SIMTEJO that it is a company with public funds. It is responsible for managing the *Sistema Multimunicipal do Tejo e Trancão Multimunicipal* and covering the municipalities of Amadora, Lisbon, Loures, Mafra, Odivelas and Vila Franca de Xira. Currently Beirolas subsystem integrates one WWTP, eight pumping stations and 10 km of interceptor pipelines, which is expected to come into operation by 2013 the remaining infrastructure provided in the configuration of the subsystem.

The WWTP of Beirolas begun the process treatment in 1989 but between 1998 and 2000 was drawn up plans for the extension. It was planned a project horizon of 20 years, with a capacity of 215,000 eq.hab and a procedural design flow of 54,500 m^3 of waste water in order to absorb the increase flow of loads and estimated.

The WWTP is located in Parque das Nações near the Vasco da Gama bridge, in the municipality of Loures. Distance of about 350 m in a straight line of the Tejo river, which is the receiving environment for treated wastewater from the WWTP.

The area surrounding the treatment plant is limited to the north by a landfill sealed. The south area is occupied by an urban green areas and west by residential area and services, reclassified under the Urbanization Plan of Parque EXPO.

Currently the WWTP of Beirolas performs tertiary treatment with final disinfection, also making energetic use of biogas produced in anaerobic digestion. Each treatment phase of the WWTP has environmental risks that are set out in Attachment II, the main events identified in the case study focus on bypass operations, ruptured organs, ruptured pipeline and effluent discharges with parameters not allowed by law. Should be noted that was not possible to access the historical record of failures. It was necessary to develop a literature search about the failures frequency of mechanical equipment, organ structures thus able to determine damage magnitude value.

Calculated the damage magnitude and the global value of financial guarantee from the WWTP of Beirolas it was interesting to determine the value of the insurance premium because this is option with more demand in Portugal regarding the ELD.

Typically when designing insurance contract is established premium value and the franchise between the insurer and the insured. The quantity sold is intended to not overload the amount of insurance to small claims and essentially reduce the premium value. Thus, the operator provides the insurer with which the value of the quantity sold that operational activity agrees to pay in case of any environmental damage.

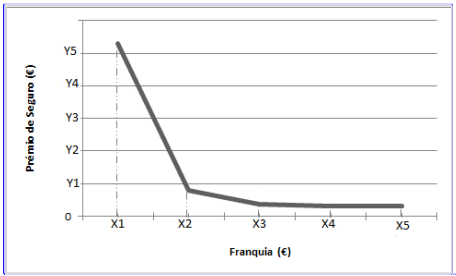

Figure 4 – Relation between the insurance premium and deductible in the preparation of a contract. Adapted from: (Freeman e Kunreuther, 1997).

As can be seen in Figure 4, the value of the premium varies depending on the deductible stipulated, that is, if the activity's operator decide that all risks are fully covered by insurance, the deductible corresponding to value X1 and the premium paid by the insured will be equal to Y5.

Table 2 – Total value of the damage's magnitude and the associated risk.

ID Insured		Total Environmental Damage Magnitude (€)	Total Risk Associated (€/year)
Option A	All occurrences	9.224.153,33	26.619,57
Option B	Occurrence above 30.000,00 €	8.490.986,67	7.512,20
Option C	Occurrence above 70.000,00 €	8.390.986,67	2.635,54

(*continued*)

As shown in the table above, the value of risk varies significantly depending on the maximum monetary value of occurrences. As expected, the value of the highest insurance premium payable by the WWTP responsible corresponds to the option of the insurance policy include all events that have been identified.

Option C which corresponds to include in the insurance policy environmental damage events with magnitudes greater than 70.000,00 € is the option that represents a value of insurance premiums of less value. The intermediate option provides that the operator shall be responsible for supporting the events that have a value of magnitude less than 30.000,00 €. It should be noted that most of the occurrences that have magnitudes below the value of option B are also events that are most likely to occur. It is also clear that the events that discuss of organ failure are those that have greater weight in the value of risk and the total magnitude value.

The following figure graphically represents the variation of the insurance premium with the increase in quantity sold, i.e. as can be seen between option A, B and C. increasing the quantity sold value takes a decrease in premium policy.

Comentário [FP1]: Alterar para ingles

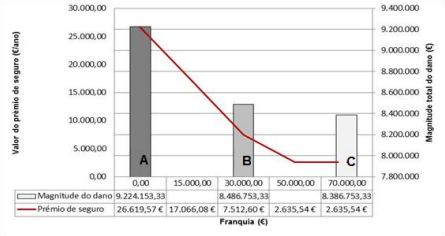

Figure 5 – Variation of the insurance premium and deductible insurance policy.

The total magnitude of the damage insured by the insurance policy, which in Figure 5 is in columns, presents a variation of about 10% between option A and option C, that drive the value of premium's insurance to be established. The small difference observed between the totals magnitudes of the options is around 23.984,00€ of annual insurance premium payable by the responsible of the WWTP.

The intermediate option lowers the value of the insurance premium by about 19.106,00€/year, standing at 7.512,00€/year of insurance, being an operation that excludes the occurrence of that have magnitude of damage less than 30.000,00€. The choice of insurance policy to be selected by SIMTEJO depends on the availability of funds and the insurer to present products that match the solutions obtained in this work. Also as previously noted, the financial guarantee may also be a combination of two different mechanisms in order to meet the requirements of the ELD.

4 Closing Remarks

Comentário [FP2]: Alterar para ingles

The main theme of this article is intimately related with the need to establish financial guarantee to environmental risks that can happen in a WWTP.

The results obtained shows that the events identified involving rupture of treatment's organs are those with the greatest magnitude that mark most of the financial security and their insurance premium. This is due to the huge volume of effluent still under treatment and in extreme cases of collapse the same volume can to infiltrate the soil. As mentioned, the Tejo river is the

The limitations found along this study were mainly centered in the gathering of data about the natural receptor of discharges of waste water from the WWTP but close enough of the Trancão river which receives effluents from WWTP of Frielas and S. João da Talha as industries that are located in the area.

Where there is in an environmental damage is necessary to establish the casual link between the act causing the damage and have caused the negative impact. However, in situations of multiple causes and it is possible do identify the causes of environmental damage, the responsibility to implement remedial measures to be allocated among the indicted charge of activities

One of the limitations found in this work focused on obtaining frequency's data of the sets of events identified and the unavailability of a database of common procedural problems in WWTP. This limitation has affected the present study,

since not possible to establish the failures rates corresponding to the equipment installed in the WWTP, it was necessary to carry out a research at literature with information on equipment failure rates. It should be noted that due to lack of data on the frequency of bypass operations, which provide an annual basis, it was established that they occur with a timeline of one occurrence in 20 years.

Another limitation found involves the publication of the ELD and its subsequent transposition into national law and national environmental news that brought the level of environmental legislation in the sense that does not quantify what it see as damage has significant adverse effects, thus dependent the personal perspective of each person responsible for drawing up the list of events with the possibility of causing environmental damage. Regarding the subjectivity present in the degree of environmental liability, was considered all occurrences that may result in environmental damage and is therefore not exclude any events.

In this context, it would be necessary to collect and compile the historical record of failures, ruptures of the WWTP that belong to SIMTEJO.

The present study revealed that the ELD in Portugal is still in a phase in which insurers companies have difficulties in developing insurance products that respond effectively and covering the events identified. Besides this problem, operators of the activities listed in Annex III also show difficulties in acceptance of juridical regime of environmental liability because this legislation brings more charges. The WWTP responses reveal economic difficulties to support the costs related of environmental liability.

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Attachment I – Flowchart of the set of calculations to obtain the financial guarantee.

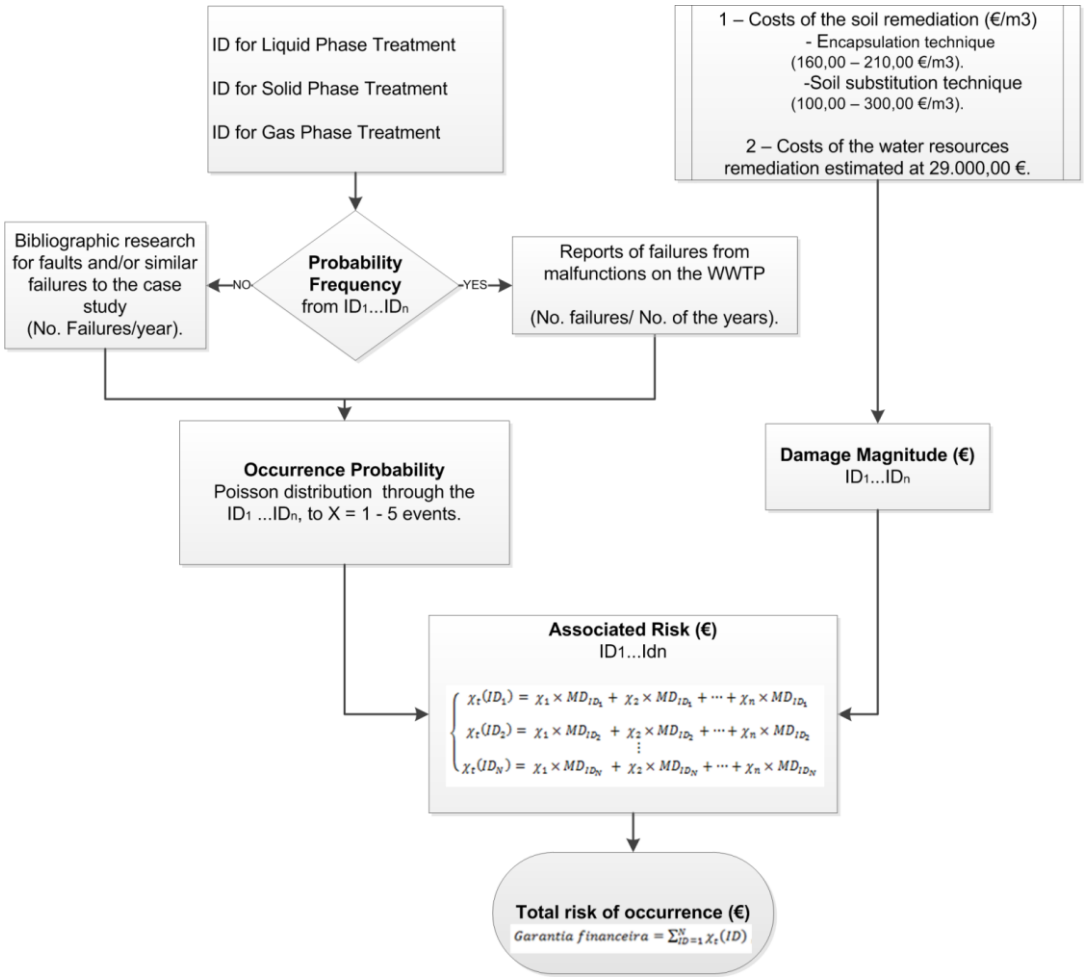

Figure 6 - Flowchart of the set of calculations to obtain the financial guarantee.

Attachment II – Environmental risks list identified in WWTP of Beirolas

Table 3 – List of the all risks identified in WWTP of Beirolas.

	Ocurrence ID	P(X)	Damage Magnitude (€)	Total Risk of Ocurrence		Ocurrence ID	P(X)	Damage Magnitude (€)	Total Risk of Ocurrence		Ocurrence ID	P(X)	Damage Magnitude (€)	Total Risk of Ocurrence
Pre Treatment	1	0,00E+00	0,00 €	0,00 €	Primary Treatment	27	3,00E-02	29.000,00 €	857,08 €	Tertiary Treatment	53	1,75E-03	6.666,67 €	11,67 €
	2	5,00E-02	29.000,00 €	1.414,35 €		28	1,00E-04	1.636.800,00 €	163,67 €		54	8,76E-03	29.000,00 €	252,93 €
	3	5,00E-02	29.000,00 €	1.414,35 €		29	1,75E-03	401.600,00 €	702.99 €		55	2,05E-02	29.000,00 €	589,81 €
	4	6,72E-04	29.000,00 €	19,49 €		30	2,74E-15	29.000,00 €	0,00 €					
	5	1,22E-02	29.000,00 €	350,97 €	Secondary Treatment	31	1,00E-04	624.000,00 €	62,40 €	Gas and Solid Phase Treatment	56	1,00E-04	0,00 €	0,00 €
	6	0,00E+00	0,00 €	0,00 €		32	1,00E-04	624.000,00 €	62,40 €		57	1,75E-03	23.600,00 €	41,31 €
	7	1,75E-03	0,00 €	0,00 €		33	1,75E-03	363.333,33 €	636,00 €		58	5,00E-04	0,00 €	0,00 €
	8	1,30E-03	0,00 €	0,00 €		34	5,00E-02	29.000,00 €	1.414,35 €		59	1,75E-03	7.666,67 €	13,42 €
	9	5,00E-02	29.000,00 €	1.414,35 €		35	1,22E-02	29.000,00 €	350,97 €		60	5,00E-04	0,00 €	0,00 €
	10	4,38E-03	29.000,00 €	126,74 €		36	1,22E-02	29.000,00 €	350,97 €		61	5,00E-04	0,00 €	0,00 €
	11	4,38E-03	29.000,00 €	126,74 €		37	3,00E-02	29.000,00 €	857,08 €		62	1,75E-03	4.233,33 €	7,41 €
	12	1,22E-02	29.000,00 €	350,97 €		38	3,00E-02	29.000,00 €	857,08 €		63	5,00E-07	0,00 €	0,00 €
	13	5,00E-02	29.000,00 €	1.414,35 €		39	1,75E-03	0,00 €	0,00 €		64	5,00E-07	0,00 €	0,00 €
	14	1,75E-03	0,00 €	0,00 €		40	1,00E-04	798.080,00 €	79,80 €		65	5,00E-07	802.313,33 €	0,40 €
	15	0,00E+00	0,00 €	0,00 €		41	1,00E-04	798.080,00 €	79,80 €		66	2,20E-07	11.200,00 €	0,00 €
	16	1,75E-03	0,00 €	0,00 €		42	1,00E-04	798.080,00 €	79,80 €		67	5,00E-02	100.000,00 €	4.877,06 €
	17	1,75E-03	0,00 €	0,00 €		43	1,75E-03	0,00 €	0,00 €					
Primary Treatment	18	1,00E-04	586.400,00 €	58,64 €		44	1,75E-03	0,00 €	0,00 €					
	19	1,00E-04	586.400,00 €	58,64 €		45	1,75E-03	8.222,22 €	14,39 €					
	20	1,75E-03	8.566,67 €	15,00 €		46	1,75E-03	8.222,22 €	14,39 €					
	21	5,00E-02	29.000,00 €	1.414,35 €		47	1,75E-03	8.222,22 €	14,39 €					
	22	1,75E-03	371.900,00 €	651,00 €		48	3,00E-02	29.000,00 €	857,08 €					
	23	6,91E-02	29.000,00 €	1.935,25 €		49	3,00E-02	29.000,00 €	857,08 €					
	24	0,00E+00	29.000,00 €	0,00 €		50	3,00E-02	29.000,00 €	857,08 €					
	25	1,75E-03	8.566,67 €	15,00 €		51	6,72E-04	29.000,00 €	19,49 €					
	26	3,00E-02	29.000,00 €	857,08 €		52	1,75E-03	0,00 €	0,00 €					