LABORATÓRIO NACIONAL
DE ENGENHARIA CIVIL

HYDRAULICS AND ENVIRONMENT DEPARTMENT
Groundwater Division
Water Resources and Hydraulic Structures

Proc. 0607/19/16864
Proc. 0605/533/5674

IDENTIFICATION AND PROTECTION OF WATER BODIES SENSITIVE TO POLLUTION FROM ROADS

Report produced in the framework of a bilateral cooperation between Portugal and Slovenia sponsored by the Portuguese Fundação para a Ciência e Tecnologia (FCT), *Project n.º 4.1.1 Eslovénia* and by the Slovene Research Agency (ARRS)

Lisbon • June 2010

I&D HIDRÁULICA E AMBIENTE

RELATÓRIO 225/**2010 – NAS / NRE**

MINISTÉRIO DAS OBRAS PÚBLICAS, TRANSPORTES E COMUNICAÇÕES

Laboratório Nacional de Engenharia Civil

HYDRAULICS AND ENVIRONMENT DEPARTMENT

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Geological Survey of Slovenia

DEPARTMENT OF HYDROGEOLOGY

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I & D Hidráulica e Ambiente

Identification and Protection of Water Bodies Sensitive to Pollution from Roads

ABSTRACT

This report contains the results of a bilateral cooperation project between Portugal and Slovenia, held in 2008/09.

The purpose of this project is to contribute to promote a more sustainable protection of the water resources from road pollution, as required by the Water Framework Directive.

The aim of the study is to select and develop sounder procedures to protect water resources from road runoff pollutants, considering both economic and environmental sustainability.

In this context, the objectives of the project are twofold: (1) to develop a common (Portuguese and Slovene) procedure to identify and classify water bodies sensitive to pollution coming from the road and, based on that, (2) to identify efficient protection measures to be recommended for each of these classes and for different infrastructure planning stages.

Identificação e Protecção de Massas de Água Sensíveis à Poluição Rodoviária

RESUMO

Este relatório contém os resultados de uma cooperação bilateral entre Portugal e a Eslovénia, decorrida em 2008 e 2009.

O objectivo deste projecto é contribuir para uma protecção mais sustentável dos recursos hídricos da poluição de estradas, tal como requerido pela Directiva Quadro da Água.

Com o projecto propõe-se seleccionar e desenvolver um conjunto de procedimentos para proteger os recursos hídricos de descargas de escorrências de estradas, considerando a sustentabilidade tanto económica como ambiental.

Neste contexto, os objectivos podem ser resumidos em dois aspectos principais: (1) desenvolver uma metodologia comum (para Portugal e para a Eslovénia) para identificar e classificar massas de água sensíveis à poluição rodoviária e, com base nela (2) identificar medidas de protecção eficazes para serem recomendadas para cada uma das classes definidas, e para diferentes fases do processo de planeamento.

Identifikacija in zaščita vodnih teles občutljivih na onesnaženje s strani cest

IZVLEČEK

Poročilo podaja rezultate bilateralnega projekta med Portugalsko in Slovenijo, ki je potekal v letih 2008/09.

Namen projekta je bil prispevati k promociji celostne zaščite podzemne vode pred negativnimi vplivi s cest, kot jo zahteva Evropska okvirna direktiva o vodah.

Namera študije je bila izbrati in razviti tehtne postopke za zaščito vodnih virov pred odtokom onesnaževal s cest, ob hkratnem upoštevanju okoljsko in ekonomsko vzdržnega razvoja.

Na podlagi tega so bili cilji projekta dvojni (1) razviti skupno (Portugalsko in Slovensko) metodologijo za identifikacijo in klasifikacijo vodnih teles občutljivih na onesnaženje s cest in (2) v različnih fazah načrtovanja za vsako od klasifikacij opredeliti učinkovite zaščitne ukrepe, ki ustrezajo vsakemu od razredov.

ACKNOWLEDGMENTS

The authors would like to thank their own institutions for allowing preparing this report: the research programme "Groundwater and geochemistry" of the Geological Survey of Slovenia and National Laboratory for Civil Engineering. The financial support is also acknowledged: the Slovene Research Agency, ARRS and the Portuguese National Foundation for Science and Technology (FCT).

The authors wish to thank João Fernandes, from the Water Resources and Hydraulic Works Division, Hydraulics and Environment Department of LNEC, for his help concerning the establishment of limits for high and medium flow, in the common methodology.

The help of Miriam Rot in preparing an application of different sensitivity concepts in Portugal and Slovenia is acknowledge.

We also wish to thank Maria José Henriques from the Groundwater Division, Hydraulics and Environment Department of LNEC, for her help in the text regarding the Portuguese legislation.

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1 | INTRODUCTION

Highway runoff pollution has a diffuse pattern and may impact water systems. There are two main types of occurrences: (1) the typical rainfall events that washout the pollutant load accumulated at the paved surface; and (2) the washout of chemical and other materials resulting from maintenance activities - of the pavement or surrounding vegetated areas - that are combined with the traffic pollutant emissions causing permanent pollution, however with a seasonal variation. A third type of pollution from road surfaces may occur after accidental spillages of toxic and dangerous substances, usually as a result of accidents involving vehicles which transport such material.

Typically, road runoff quality is characterized by a large quantity of suspended solids, heavy metals – mainly lead, zinc and copper – petroleum derived hydrocarbons, and organic matter, amongst other pollutants. The characteristics of the continuous discharges and the possibility for acute impacts derived from accidental spillages on the road must be correctly assessed, and its effects in the environment evaluated, taking into account requirements given by the European Water Framework Directive (WFD). The conclusions of the studies should indicate the needs for measures for pollution prevention and control.

Concerning the continuous discharges of contaminants in the natural environment, vehicle runaway prevention measures, sealing of road structure and treatment systems for road runoff pollution control are common technologies for impacts reduction. The case of accidental spillages on the road requires specific systems or devices inserted into ordinary treatment systems, able to contain the liquid that has been spilled – commonly, fuels.

Such systems must be monitored and its performance periodically assessed, in order to understand if they are accomplishing the targets for environmental protection. These results are incorporated in the future decision making, for the improvement of existing protection systems as well as for establishing the best management and maintenance practices.

This report includes information concerning the use (project and construction) and practice (maintenance and monitoring) of systems for road runoff pollution control in Portugal and Slovenia, as well as some guidelines designed for the improvement of the future practices. The data used resulted from different studies, some of them conducted by LNEC for the Portuguese Water and Portuguese Road Authorities, and some of them conducted by the Geological Survey of Slovenia and the Department of Geology, University of Ljubljana, for various authorities dealing with roads and water resources in Slovenia. Data from other sources, such as academic research, have also been used for this assessment of the situation in Portugal and Slovenia. Empirical information, resulting from visual inspection of treatment systems and systems to contain accidental spillages on the road has been included. For Portugal a total of 45 different national systems have been characterized by Barbosa and Fernandes (2005). For Slovenia common practices for the treatment systems are described. For both countries different types of layouts for treatment systems have been observed.

This report also identifies the situation in Portugal and Slovenia concerning the project design, construction, operation and monitoring methodologies. Such information is useful to upgrade/correct the existing systems and as guidelines for the future practice. The report is based on the experiences gained during the design and construction of roads, especially of highways, in both countries. Portugal and Slovenia have constructed an extensive highway monitoring network since the 90's and a technical know-how has been accumulated, related to the interactions between road and water bodies. In spite of the fact that the two countries are positioned in different climatic regimes, and therefore different hydrological regimes, many pertinent questions about water protection from negative influences from the roads seem similar and even universal on the global level.

The very different approaches and practices applied in protecting water bodies from pollutants generated from road infrastructures, both at international and European level (for Portugal and Slovenia, see chapter 2 |) show that the absence of transparent procedures in defining and protecting sensitive water bodies can lead to high and unnecessary design and construction costs, which can also later provoke non-transparent and high maintenance costs, or the opposite: the non-identification of a water body that needs protection.

The purpose of this project is to study and develop more sound procedures to protect water resources from traffic pollutants, considering economic and environment sustainability. Therefore, chapter 3, in particular section 3.3, is considered to be the core of the outputs from this cooperation project between Portugal and Slovenia.

2 | REVIEW OF CURRENT PRACTICES FOR ROAD POLLUTION PROTECTION IN PORTUGAL AND SLOVENIA

2.1 Key-pollutants in road runoff

Rainfall events are the mechanism of transportation of pollutants from the road paved surfaces into the water systems. Stormwater and highway runoff quality are characterized by a large quantity of suspended solids, heavy metals – mainly lead, zinc and copper – petroleum derived hydrocarbons, and organic matter, amongst other pollutants. The discharge of such contaminants in the natural environment is a continuous and cumulative process (Barbosa, 2005).

In order to correctly manage road runoff, with respect to preventing impacts in water bodies and related ecosystems, it is of most importance to understand, select and assess the pollutants to be controlled. These key pollutants must be identified based on their constant presence in road runoff, in concentrations that are likely to provoke acute or cumulative impacts, and in their effects in specific environmental conditions (e.g. physical, chemical, hydrodynamic and ecological characteristics of the receiving water body).

This section presents an overview of recent studies concerning the identification of key pollutants in road runoff.

The European DayWater project[1] took place between 2002 and 2005 and produced several information and tools concerning urban storm water management. The objective of the study was to establish an "*Adaptive Decision Support System (ADSS) for the Integration of Storm Water Source Control into Sustainable Urban Water Management Strategies*". Among the tasks of this EU project, there was the establishment of Selected Stormwater Priority Pollutants (SSPP) – "which is a group of pollutants with hazardous or otherwise problematic inherent properties, which is available at critically high concentrations, and has been selected among a database by a group of experts" (Eriksson *et al.*, 2006). The Selected Stormwater Priority Pollutants, accordingly to the DayWater results, consist of 24 parameters divided into the following categories:

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[1] Under the EU RTD 5th Framework Programme, http://www.daywater.org (the participating countries were the Czech Republic, Denmark, France, Germany, Greece, Netherlands, Sweden and United Kingdom)

- Basic parameters (5)
- Metals (7)
- PAH (3)
- Herbicides (4)
- Miscellaneous organic compounds (5)

The pollutants studied in the *DayWater* represent of all kinds of stormwater, i.e. road runoff and all sorts of urban stormwater. In the urban environment, the buildings and human activities are sources of pollution not present for the case of roads, which means that some of the SSPP are not of much interest for the case of road runoff.

Table 1 presents the list of the basic parameters, metals and poly-aromatic hydrocarbons - PAH, selected as stormwater priority pollutants within the *DayWater* project, containing also some justification for the inclusion of the constituent. The categories of herbicides and miscellaneous organic compounds are too specific. Hence this data does not exist for road runoff in Portugal or Slovenia, and therefore is not included in Table 1.

In the literature, many studies dealing with road pollution and road pollutants can be found. One recent overview of the knowledge is presented by Folkeson et al. (2008). They have summarized concentration ranges commonly reported (see Table 2).

A recent study undertaken in the UK by the Highways Agency (HA), aiming at ensuring that the HA will meet the requirements from the EU Water Framework Directive, consistently monitored and analysed highway runoff in 24 different locations in England (Crabtree *et al.*, 2008). From the results, a list of significant pollutants was produced and the development of a risk assessment approach was based on them. The selected pollutants were the following:

- Total and dissolved copper
- Total and dissolved zinc
- Total cadmium
- Total fluoranthene
- Total pyrene
- Total PAHs
- Total Suspended Solids

Table 1 - List of basic parameters, metals and PAH, selected as stormwater priority pollutants within the DayWater project (adapted from Eriksson *et al.*, 2006)

Type	Constituents		Justification
Basic Parameter	BOD/COD	Biological/Chemical oxygen demand	Basic parameters
	SS	Suspended solids	
	N	Nitrogen	
	P	Phosphorus	
	pH	pH	
Metals	Cd	Cadmium	Persistent and bioaccumulating; has carcinogenic/mutagenic/reproduction hazardous and/or endocrine disrupting effects
	Cr	Chromium/Chromate	Persistent and bioaccumulating; anionic in natural waters
	Cu	Copper	Persistent and bioaccumulating; high acute aquatic toxicity
	Ni	Nickel	Persistent and bioaccumulating; has carcinogenic/mutagenic/reproduction hazardous and/or endocrine disrupting effects
	Pb	Lead	
	Pt	Platinium[1)]	
	Zn	Zinc	Persistent and bioaccumulating; accumulated load
PAH		Naphthalene	Indicator of PAH, water and sediment phase, persistent and bioaccumulating
		Pyrene	Indicator of PAH, sediment phase, persistent and bioaccumulating
		Benzo [a] pyrene	Indicator of PAH, sediment phase, persistent and bioaccumulating; has carcinogenic/mutagenic/reproduction hazardous and/or endocrine disrupting effects

[1)] Specific human sources

Table 2 - Illustrative values of highway runoff water quality obtained in various studies (obtained from Folkeson *et al*., 2008)

Country, location, publication	AADT	pH		Cond. (µS/cm)		TSS (mg/l)		Pb (µg/l)		Zn (µg/l)		Cu (µg/l)		Cd (µg/l)		Cr (µg/l)	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
USA, Bellevue WA (Ebbert *et al.* 1983)[a]		3.4	7.9	12	1 480	1	2740	4	1 800	-	-	-	-	-	-	-	-
USA, Ohio (Pitt 1985)[b]		5.2	7.4	16	300	24	620	<100	820	30	370	-	-	-	-	-	-
Norway (Lygren *et al.* 1984)[b]	8 000	6.7	9.1	41	5 870	162	2420	62	690	91	740	10	430	-	-	-	-
Germany (Stotz 1987)[b]	41 000	-	-	-	-		137	-	202	-	360	-	97	-	-	-	-
	47 000	-	-	-	-		181	-	245	-	620	-	117	-	-	-	-
	40 600	-	-	-	-		252	-	163	-	320	-	58	-	-	-	-
UK (Revitt *et al.* 1987)[b]	37 600	-	-	-	-	2	192	-	181	-	-	-	63	-	-	-	-
UK (Hamilton *et al.* 1987)[b]	720	-	-	-	-	-	-	-	28.1	-	16.6	-	6.5	-	-	-	-
Germany (Dannecker *et al.* 1990)[b]	500	-	-	-	-	-	-	-	122	-	166	-	75.9	-	-	-	-
USA (Hvitved-Jacobsen & Yousef 1991)[b]	-	5.9	7.8	45	175	-	-	30	379	13	173	10	101	-	-	-	-
UK (Hewitt & Rashed 1992)[b]	150	-	-	-	-	-	-	1	151	0.7	65	0	14	-	-	-	-
France (Bardin *et al.* 1996)[b]	-	-	-	-	-	37	128	<5	90	177	681	9	49	-	-	-	-
USA (Thomson *et al.* 1997)	-	-	-	-	-	-	116	-	-	-	169	-	-	-	-	-	-
USA, Texas (Barrett *et al.* 1998)	8 780	-	-	-	-	-	91	-	15	-	44	-	07	-	-	-	-
	47 200	-	-	-	-	-	19	-	3	-	24	-	12	-	-	-	-
	58 200	-	-	-	-	-	129	-	53	-	222	-	37	-	-	-	-
Portugal, Vila Real (Barbosa 1999)	6 000	5.9	7.2	8.8	184	<8	147	<1	200	<50	1 460	<1	54	-	-	-	-
UK (Hares & Ward 1999)	140 000	-	-	-	-	-	-	-	81	-	208	-	274	-	14.1	-	105
	120 000	-	-	-	-	-	-	-	70	-	188	-	248	-	11.9	-	86
UK (Moy *et al.* 2002)	71 900	-	-	-	-	-	88.6	-	-	-	8.6	-	-	-	-	-	-
	23 600	-	-	-	-	-	318	-	51.4	-	163	-	33.6	-	0.99	-	11.5
	36 100	-	-	-	-	-	101	-	50.4	-	66.8	-	23.3	-	0.56	-	9.08
	83 600	-	-	-	-	-	82.7	-	16.7	-	29.0	-	11.8	-	0.25	-	7.73
	65 000	-	-	-	-	-	45.8	-	15.4	-	55.7	-	17.6	-	0.43	-	4.82
	37 200	-	-	-	-	-	51.4	-	4.38	-	21.4	-	16.5	-	0.21	-	2.72
USA (Kayhanian *et al.* 2003)	All	-	-	-	-	15.2	1 350	0.00	178	0.00	536	0.00	90.0	0.00	5.40	0.00	49.0
	<30 000	-	7.0	-	-	-	168	-	1.2	-	35.3	-	6.5	-	-	-	1.7
	>30 000	-	7.4	-	-	-	145	-	6.1	-	79.1	-	14.7	-	0.3	-	2.6

Country, location, publication	AADT	pH		Cond. (µS/cm)		TSS (mg/l)		Pb (µg/l)		Zn (µg/l)		Cu (µg/l)		Cd (µg/l)		Cr (µg/l)	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
	All	5.1	10.1	-	-	1	5 100	0.2	414	3	1 020	1	121	0.02	6.1	0.6	22
UK, Reading[c]	98 200	6.0	7.7	150	12 000	160	704	43	1 800	140	4 200	50	1 000	<1	13		<20
UK, Oxford[c]	77 700	6.5	6.7	72	2 000	70	134	<20	54	84	200	22	55		<1		<20
Netherlands, Nieuwegein[c]	150 000	6.5	7.6	120	9 600	-	-	3	95	52	1 700	17	160	0	2	0	5
Netherlands, Spaarnwoude[c]	90 000	5.7	7.8	90	3 500	-	-	0	88	28	290	13	61	0	3	0	20
Sweden, Svaneberg[c]	7 350	6.3	7.1	30	10 000	-	-	3	18	51	220	6	70	0	0	0	2
Sweden, Norsholm[c]	18 000	6.2	7.7	50	33 000	-	-	4	43	92	490	12	100	0	1	2	11
Finland, Lohja[c]	13 700	6.8	7.6	59	5 100	<10	50	6	15	54	88	0	17	0.08	0.2	0	3
Finland, Utti[c]	8 000	6.9	7.1	57	2 400	<10	10	5	10	57	92	0	16	0.05	<0.3		<10
Denmark, Vejenbrod[c]	29 000	6.8	7.9	42	14 000	<10	40	8	46	47	330	3	95	<0,1	1	4	66
Denmark, Rud[c]	22 000	6.6	7.3	31	20 000	13	607	5	47	100	700	18	140	0.07	1	1	9
France, Erdre[c]	24 000	6.7	7.8	41	5 300	6	507	5	41	130	460	<2	32	<0.10	2	<0.5	2
France, Houdan[c]	21 000	7.0	7.9	91	1 300	0	114	10	76	<10	300	8	48	0.10	1	1	6
Portugal, Recta do Cabo[c]	21 800	7.5	8.3	120	1 400	18	1560		<100	<100	170	2	130		<10		<100
Portugal, Vila Real[c]	8 500	6.6	7.5	<50	<110	<3	316		<100	1 100	2 000	1	<100		<10		<100

AADT: annual average daily traffic (vehicles/day). Cond.: electric conductivity. TSS: total suspended solids. # porous asphalt. [a] Matos *et al.* (1999); [b] Barbosa (1999); [c] Folkeson (2000, EU POLMIT project) and TRL (2002)

2.2 Legislation related to road pollution and water bodies

2.2.1 Introduction

Water is one of the most comprehensively regulated areas of the EU environmental legislation with Directives regulating quality and standards for dangerous substances in water, fishing water, drinking water and groundwater.

The Water Framework Directive (WFD)[2], published in December 2000, aims to establish a framework for the protection of inland surface waters, transitional waters, coastal waters as well as groundwater. It intends at preventing further deterioration, and protecting and enhancing the status of aquatic ecosystems, by promoting sustainable water use based on a long-term perspective. This implies the implementation of the necessary measures to prevent or limit the input of pollutants into water.

Furthermore, Member States shall protect all water bodies with the aim of achieving a good status, at latest 15 years after the date of entry into force of the WFD, i.e. 2015. Good water quality is such that the concentrations of pollutants do not exceed the quality standards applicable under other relevant Community legislations. Pollutants exceeding the standards will induce failure to achieve the environmental objectives. Common environmental quality standards and emission limit values for certain groups or families of pollutants should be laid down as minimum requirements in Community legislation.

The WFD presents an indicative list of what, in general, is considered the main groups of pollutants in water. Some of these are toxic while others are nutrient salts or substances causing oxygen depletion. In particular, a number of priority substances have been given special attention (the List of Priority Substances in the field of water policy). Some of these are typical traffic and road pollutants.

The Groundwater Directive 80/68/EEC on the protection of groundwater against pollution caused by certain dangerous substances is also an issue of the WFD. Environmental quality standards must be established, by member states, for individual pollutants or groups of pollutants, for those water bodies identified as being at risk of failing the environmental quality objectives to or via the aquatic environment. The pollutants will depend on the specific risks identified.

[2] WFD, 2000/60/EC; http://ec.europa.eu/environment/water/water-framework/index_en.html

The Environment Impact Assessment Directive 1997[3] requires an assessment of the environmental effects of any project involving the construction of motorways and express roads[4], and the construction of new roads of four or more lanes, or realignment and/or widening of an existing road to provide four or more lanes with more than 10 km in length[5].

The main aim of this chapter is to summarize the main legislation in Portugal and Slovenia, connected (directly or not) to the protection of water from road pollution. As expected, some of this legislation is common, because it is based on the application of EU Directives.

2.2.2 Legislation in Slovenia

Road runoff and pollution in Slovenia is regulated by general rules included in the Law for Environment Protection, and in the Water Law. Some aspects of relevance, mainly indirect requirements, can also be found in the legislation related to the spatial planning and, in the case of public works, in the investment legislation. These laws implement guidelines and regulations from European directives such as the WFD. General demands defined in these laws are transferred to subsidized technical legislation which defines rules and ordinances. The main legal document dealing with road runoff is the "*Decree on the emission of substances in the discharge of meteoric water from public roads*" (Official gazette RS 47/2005) – further in this report referred as Decree. Some requirements for road runoff are defined also in the "*Decree on the emission of substances and heat in the discharge of waste water from pollution sources*" (Official gazette RS 35/1996 and later improvement RS 21/2003 with later supplements). This document is dealing with technical regulations for waste waters in general.

The Decree is the first technical regulation dealing with questions related to the emission of runoff from roads. Before its implementation, the old "*Decree on the emission of substances and heat in the discharge of waste water from pollution sources"* caused much controversy in the design and implementation of road runoff treatment systems. This was the reason why the highway authority – DARS d.d. (Company for Highways in Republic of Slovenia) issued some technical guidelines (Rismal *et al.*, 1994, Rismal, 1999; Ajdič *et al.*, 1999) helping to implement proper technical measures for water bodies protection. After the implementation of the Decree, these technical documents were annulled. Because the methodology for the definition of water bodies sensitivity is strongly incorporated into the

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[3] 97/11/CE, cf. http://www.citet.nat.tn/english/citet/metap/eie-doc-legislation.html

[4] 7. b) Annex 1

[5] 7. c in Annex 1

decree, its details are described in the subchapter “Definition of water bodies sensitive to road pollution, Slovene methodology”.

The Decree supposes that all other legal documents must be considered during the implementation of road drainage design and construction of roads. In the Decree this is defined as category “other legal regimes in the space”. These legal regimes are usually defined by:

- Rules on criteria for the designation of a water protection zone (Official gazette RS 64/2004).
- Decree on special protection areas - Natura 2000 areas (Official gazette RS 49/2004 with later supplements).
- Legislation related to nature protected reserves; Nature Conservation Act and subordinate Decrees and Governmental Ordinances.
- Decree on bathing water areas and the monitoring of bathing water quality (Official gazette RS 70/2003 with later supplements).
- Landsliding and flooding legislation; Removal of consequences of natural disasters act (Official gazette RS 75/2003 and later supplements); Rules on methodology to define flood risk areas and erosion areas connected to floods and classification of plots into risk classes (Official gazette RS 60/2007); Decree on conditions and limitations for constructions and activities on flood risk areas (Official gazette RS 89/2008) and many other Governmental Ordinances.

The only legal document directly related to the water protection from road pollution is called “Rules on criteria for the designation of a water protection zone”. Since 2002, when the new Water Law was implemented, responsibility for water protection and safeguarding is a state responsibility from the Ministry for Planning and Environment, and its services. Before its implementation, in 2002, local communities were responsible for their own drinking water resources, and therefore decided their own local protection ordinances. Such situation lead to the fact that some communities were not able to implement protection zones, and in others, protection zones were extended only to their borders and not across the territory of another community.

The new Water Law defines that these local ordinances are valid until the implementation of the new state issued ordinances. At the moment, nearly one fifth of the Slovene territory is covered with safeguard drinking protection zones, and mainly all of them are local community ordinances. In older community ordinances, measures for negative influences from roads protection are very different. In some ordinances there are no regulations to roads, but in others the conditions are so strictly regulated that even the road design with precise protection measures is defined. More detailed analysis of these ordinances in the relation of road influences can be found elsewhere (Brenčič, 2001).

Presently, drinking water is protected based on a document prepared by a qualified person, defined as expert ground. In this document the delineation of protection zones is given together with the list of all restrictions, limitations and protection measures. The delineation is prepared to the level of cadastral map, and delineation follows borders between different allotments. This document together with the maps delineating the borders is used for public discussion and negotiation with local community and interested parts. After these processes are concluded, the government publishes the decree with the water protection zone in the particular water body (*e.g*. Decree on the water protection zone for the aquifer of Ljubljansko polje). At the end of 2009, only 7 of these ordinances were implemented at the state level. In the year 2004, it was envisaged that this process needed to be faster. However, it was recognized that negotiations with local communities are very time consuming.

Based on the new Water Law, safeguard zones are divided into three zones (inner, middle and outer zone) and the capture zone. They are mainly divided into protection zones of intergranular aquifers and zones of karstified aquifers; however, also other type of aquifers exists. In the former, zones are defined according to the travel times of groundwater and in this case zones are defined in the regular way, following flow direction into the well or capture zone. In the karstic aquifers, zones are of more irregular shape following areas with more profound development of karstic features (*e.g*. caves and potholes). A schematic sketch of safeguard zones in Slovenia is given in Figure 1. More details about Slovene drinking water safeguard zones can be find elsewhere (Brenčič *et al.*, 2009).

The situation that Slovene state has several types of drinking water safeguard protection ordinances has also lead to a confusion concerning the protection of drinking water bodies form the negative influences from roads. In the new state ordinances, based on the new Water Law, rules for the protection from negative influences from roads are clearly defined. They are listed in the Annex I to the ordinance and reproduced in Table 3.

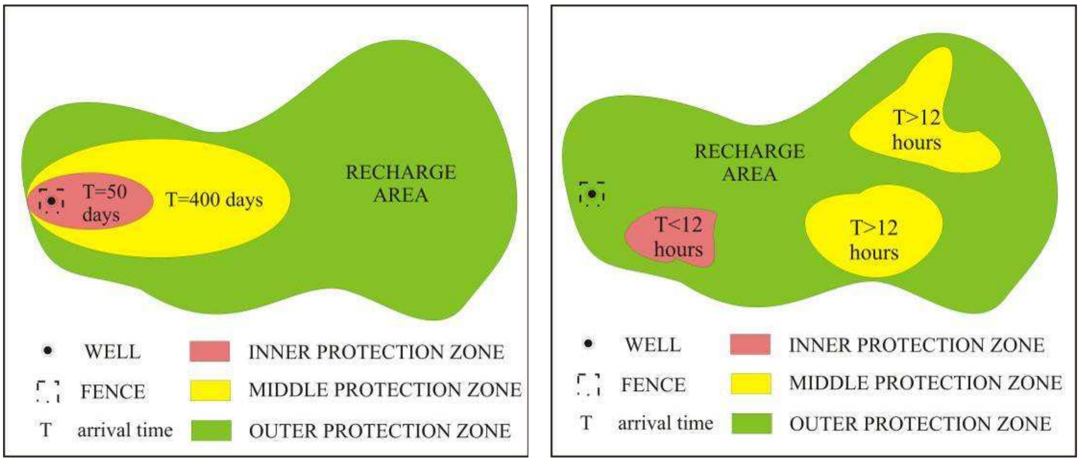

Figure 1 - Shape of drinking water protection zones; intergranular aquifers (left) and karstic aquifers (right) – after Brenčič *et al.*, 2009

Table 3 - Example of the list of measures, prohibitions and regulations from drinking water safeguard zones in Slovenia

TRANSPORT INFRASTRUCTURE	**SFGZ I**	**SFGZ II**	**SFGZ III**
Highways, expressways, main ways, regional roads	ra	ra	ra
Local roads, forest roads	ra	+	+
Parking lot	-	ra	ra
Bridges and crossings	ra	ra	ra
Tunnels and cuts	-	ra	ra

Legend:
\+ *allowed*
\- *prohibited*
ra requires risk analysis

In the recent "Rules on criteria for the designation of a water protection zones", a special mechanism for the assessment of impacts on water resources was implemented, called risk assessment to the pollution of water. This assessment is related to procedures of safety analysis and performance as it is usually performed in the case of the planning and designing procedures for hazardous material deposition (e.g. radioactive waste disposals). It consists of the exact modelling procedures for illustrating the fate of pollutants in water resources, where models must be calibrated and validated based on the prescribed procedures. Risk analysis was implemented in the technical legislation to improve the assessment of spatial planning and design procedures. It is impossible to precisely define all the conditions that can appear in a particular field with the legislation. Therefore, it is possible to check if certain plans or designs are suitable for the particular natural conditions.

The necessity for such risk analysis – *ra* is defined in the tables of ordinances for particular safeguard zones, as it is represented in Table 3. If the risk analysis is not performed, then the construction or plan is not allowed. The result of risk analysis can be positive or negative. However, an important benefit from the risk analysis can be a new design procedure that improves the water protection, for later implementation.

Under the new Water Law, other water rights besides water for drinking purposes must be considered (*e.g*. water for irrigation). Identification of existing water rights is very much related to the planning stage of the road project where all spatial planning and permitting stakeholders are identified. These stakeholders are performing their requirements and demands on the proposed plan and planner is responsible for identification and verification of their rights according to the law. At the same time, the plan is assessed through the environmental study. Very often it happens that planning and designing stages are covering each other or they follow in very tight schedule. The assessment of other water rights than for drinking water is not prescribed by legislation; it is very much related to best practices established during the course of the years.

Natura 2000 regions can be from road drainage point of view considered only in some cases when the region is protected due to the presence of habitats that rely on water. These regions can be understood in the manner defined by Water Framework Directive as ecological sensitive zones. Great part of Slovenia is covered by Natura 2000 but only some small portion are related to water habitats. When roads are crossing or passing such ecosystems, the water drainage design is part of the permitting system where the authority responsible for nature protection estimates if the designed measures are acceptable or not.

Natura 2000 regions are very often related to natural and national parks. Considering the fact that in Slovenia many of them are positioned in the karstic regions, with very vulnerable karstic and fissured aquifers, the drainage problems inside of these regions are considered with great detail.

Rules of bathing waters are defined, from a legal point of view, in the similar way as drinking water safeguard zones. Criteria for their determination are defined by technical legislation and their implementation is related to the ministerial decree. Usually, these acts prohibit direct discharge of water from roads in the area of bathing water.

As a country, Slovenia is very vulnerable to landsliding and flooding and therefore an important part of environmental, planning, and construction legislation dealing with water is related to these issues. Questions related to these are not directly linked to the water quality problems originating from roads; however flooding and landsliding are representing very important constraint in the design of treatment facilities and retention ponds. Sometimes on flat lying plains it is difficult to find places suitable for the construction of retention ponds that can function by gravity and simultaneously not begin threaten by floods. Similar situation can happen in mountainous regions prone to landsliding. Retention ponds not properly designed and constructed can be a source of seepage water influencing slope stability bellow the road.

2.2.3 Legislation in Portugal

The basis of the environmental policy in Portugal dates from the 1976 Constitution, which established the right to a healthy environment as one of the human rights that must be assured by the State. Another important source of environmental principles and general regulations is the Environmental Framework Law established by the Law 11/87. Both the Constitution and the Framework Law provide the general rules and principles of environmental policy, being the latter that stipulates them in detail. The main principles of these laws are: prevention by eliminating or reducing the causes of environmental damage; participation of the different social groups in the execution of public environmental measures; combined management and action guaranteed by a national entity; international cooperation; establishing the most adequate level of intervention; rehabilitation by adopting urgent measures to restore the damaged areas; and establishing the liability of the parties responsible for the damage who should bear the costs.

In 1990 there was the publication of the Portuguese legislation concerning the Environmental Assessment Process, the Decree Law 186/90. It transposed into national law the Directive 85/337/CEE concerning the "legal framework for environmental impact assessment of public and private projects likely to have significant effects on the environment". The legislation was further complemented with other legal documents (such as, Decreto Regulamentar 38/90 and Portaria 590/97) and, following the publication of the new Directive 97/11/CE, the Decree Law 69/2000 replaced the former legislation. It was recently updated by the Decree Law 197/2005, which transposed the Directive 2003/35/CE.

In paragraph 7 of the Annex I of the Decree Law in force (Decree Law 197/2005), it is referred the obligation to submit to the environmental impact assessment (EIA) all projects of highways and roads construction, with two side lanes and with a central separator, and with at least two traffic lanes for each side; and the construction of other main roads in sections more than 10 km length. According to Annex II, construction of road with small cross sections may also be subject of EIA when they are located on sensitive areas

This legal regulatory instrument establishes the need to conduct an environmental impact study (EIS) prior to the legal consent for the project construction. Among other contents, the EIS must:

- Indentify and analyze all possible direct and indirect effects of the project (construction and operation) on the environment, including socio-economic factors;
- Evaluate the significance of each impact and propose the implementation of measures to avoid, minimize or compensate significant impacts.

On the other hand, DL 58/2005, which transposes into national law the Directive 2000/60/EC, sets the measures for protecting water abstractions for human consumption defining also protection zones for groundwater and surface water bodies. The Ordinance 702/2009 establishes criteria for defining surface water protection zones and relates its restrictions concerning pollution risks that occur by land use and anthropogenic activities.

The projects require another kind of environmental assessment - if they are situated in sensitive areas such as Ecological Reserves, Protected Areas or "Natura 2000" areas. A licence or authorisation of a project must be preceded by an environmental decision; otherwise it will be null.

Presently, the main legal and regulatory instruments considered for assessing road pollution sensitivity are:

- Decree-Law No. 2/88 – Classify the reservoirs as public water utility.
- Decree-Law No. 84/90 of 16 March - Spring waters exploitation.
- Decree-Law No. 86/90 of March 16 - Mineral waters exploitation.
- Decree-Law No. 90/90 of 16 March - Geological resources (including hydro mineral resources).
- Decree-Law No. 93/90 of 19 March – Nature protected reserves, National Ecological Reserve.
- Decree-Law No. 152/97 of 19 June - Sensitive areas to the discharge of urban wastewater and its withdrawal, DL No. 172/2001 of 26 May and DL No. 149/2004 of June 22.
- Decree-Law No. 235/97 of 3 September – Vulnerable areas to pollution caused by nitrates from agricultural sources (Decree No. 1100/2004 of 3 September -vulnerable areas list).
- Notice No. 12677/2000 23 August – Classify as fishing waters some water courses.

- Decree-Law No. 140/99 of 24 April – Special protected areas, Natura, 2000.
- Resolution of the Council of Ministers No. 142/97 of 28 August and 76/2000 of 5 July – 1st and 2nd phases , first stages of national Site list.
- Decree-Law No. 382/99 of 22 September – Delimitation criteria of Wellhead protection areas around wells intended to public supply.
- Directive 2000/60/EC of 23 October 2000 - Water Framework Directive (and future Water Framework Law).
- Decree-Law No. 3/2002 of 4 February - Classification of Public waters reservoirs.

Drinking water is protected based on Decree-Law No. 236/98 of 1 August 1998 that establishes quality standards, criteria, and objectives in order to protect the aquatic environment and improve the quality of waters in keeping with their principal uses. Chapter VI covers the Protection of water against pollution caused by wastewater discharges. This chapter covers, discharge standards (Sec. 64), conditions governing the issuance of discharge licences (Sec. 65), the protection of surface waters from pollution by hazardous substances (Sec. 66), the protection of groundwater from pollution by hazardous substances (Sec. 67). Appended to this Decree-Law are 22 Annexes, including the following: VI. Quality of water for human consumption; XV. Quality of bathing waters; XX. Specific provisions relating to pesticides and organochlorine compounds; and XXI. Minimum environmental quality objectives for surface waters.

The Ordinance No. 702/2009 of 6 July under the Decree-Law 58/2005 of 29 December that transposes into national law the Directive No. 2000/60/EC, establishes definition criteria for surface water protection areas and its related restrictions concerning the pollution risks that occurring by land use and anthropogenic activities. The Article No. 6 establishes the following related to the road runoff:

- 6. “The protection areas delimitation … are subject to hydrological and economic criteria established according to the characteristics of the water body where the abstraction point is located, including:

    a) Drainage basin delimitation were the abstraction point is located and identification of critical areas inside the immediate and extended zones with significant impact on water quality.

    b) Identification and characterization of water pollution sources and diffuse pollution.

    c) Accidents risks identification, including pollutants identification and its associated risks”.

Wellhead protection area (WHPA) is the surface and subsurface area around a well which limits are defined to assure that potential bacteriological contaminants, after reaching groundwater inside or outside protection zones, become harmless before reaching the well. Groundwater resources polluting activities are prohibited or restricted inside the WHPA.

According to the Portuguese law, all groundwater extraction wells designed for public water supply shall have a zone of immediate protection. Wells extracting water for public supply with a discharge above 100 m^3/day or serving more than 500 inhabitants shall have three protection zones (immediate, intermediate and extended).

The Decree-Law 382/99 (see also Annex I) refers also the following restrictions concerning the land use and anthropogenic activities:

- Zone of immediate protection - area around the well in which, by default, all activities are prohibited, except those for conservation, maintenance or better exploration of the aquifer.
- Zone of intermediate protection - area around the zone of immediate protection with variable extension, in which the objective is to reduce or eliminate pollution of the groundwater resources. Installations or activities susceptible of polluting groundwater resources are prohibited or restricted; this includes infiltrating pollutants or favouring the infiltration in the zone close to the well (e.g. agricultural use or cattle rising, main roads and railways, industrial units, sanitary landfills, garages and gas stations).
- Extended zone of protection - area around the zone of intermediate protection, in which activities are prohibited or restricted regarding installations capable of polluting groundwater resources with persistent pollutants, taking into account the nature of the terrain, the nature and quantity of pollutants as well as the type of emission of these pollutants (e.g. application of persistent pesticides, cemeteries, transport of hydrocarbons, radioactive materials or other hazardous substances, deposits of radioactive materials, chemical industries and refineries).

In the case of karstic or fractured aquifers where preferential flowpaths exist, special protection zones can be set up. These zones limit areas located outside the WHPA, characterized by hydraulic connection with the well due to the existence of fractures or fissures. Restrictions are similar to those applied inside the zone of immediate protection.

In coastal regions, saltwater intrusion protection zones can be defined, inside which extraction rates that might lead to an eventual degradation of groundwater quality, by favouring saltwater intrusion, are limited. The construction or exploitation of new wells can be limited and the exploitation regime can also be conditioned.

The main national entities responsible for the administration and enforcement of the environmental law are the Ministry for the Environment, Planning and Regional Development and its subordinated entities referred to as the Regional Development Coordination Commissions and several Agencies, such as the Water Authority (INAG, I.P.), Nature Conservation and Biodiversity Agency (ICNB, I.P.), Water and Waste Regulation Agency (ERSAR, I.P.), Administrations of Hydrographic Regions (ARH), and also the Portuguese Environmental Agency (APA). The Municipalities have also responsibility for ensuring compliance with environmental law particularly in the context of licensing civil constructions. All these entities have a different kind of approach related to the level and scope of their responsibilities and the specific procedures which they are required to intervene in. In general, they provide legal opinions, technical advices and recommendations but they also prepare proposals for Ministerial decisions in Environmental Impact Assessments and they issue several authorisations and licenses. They have also an important role in the control and inspection of certain activities.

The Portuguese authority responsible for the strategic road network is the Portuguese Road Agency (EP). As part of its responsibilities the EP Environmental Office is involved in all processes related to environmental planning, road design and its implementation. Its core competencies in this matter are:

- Collaboration with sponsorship of research projects on issues related to the roads environmental impacts.
- Confirm and verify if the previous studies and project executions are designed under the EIA law.
- Control the environmental monitoring during the road construction and operation.
- Follow-up of environmental monitoring studies.
- Guarantee the landscape integration.

Because there is no national law in Portugal concerning the case of road runoff discharges, the INAG and the EP commissioned National Laboratory for Civil Engineering (LNEC) and other research institutions to establish procedures for a sounder prediction of pollutants concentrations in road runoff, including the main steps of the EIA process and methodology (e.g., Barbosa *et al.*, 2009 and Leitão *et al.*, 2005).

2.3 Systems and methods to control pollution

2.3.1 General overview

Stormwater and highway runoff impact surface and groundwater in two aspects: quality and quantity. There are the typical rainfall events that washout the pollutant load accumulated at the paved surface, mainly due to the traffic, abrasion of road structures, the behaviour of users (e.g.: rubbish), animal and vegetation detritus. There are also less frequent occurrences that washout chemical and other materials resulting from maintenance activities - of the pavement or surrounding vegetated areas. In countries with snow precipitation during winter and ice appearing on the pavement surface de-icing activities with salt (NaCl) and some other agents and additives can influence the surrounding soil characteristics and the runoff quality during thawing. There may be also accidental spillages of toxic or dangerous substances, usually as a result of accidents involving vehicles of transport of liquid substances (Brenčič & Vidmar, 2002; Barbosa, 2005).

The U.S.A. did a huge amount of studies since the 80’s. There is considerable bibliography published and easily available, reports, guidelines, scientific papers, and so on. Reports such as FHWA (1996) present a complete picture of highway runoff characteristics and management procedures. Consulting the U.S.A. literature, it is seen that different layouts for treatment and control systems are implemented in different states and sites. An important emphasis is placed on the suitability of the system to the site characteristics and the environmental requirements.

Mitigation measures, or Best Management Practices (BMP) are structural or non-structural practices, or a combination of practices, designed to act as effective practicable means of minimizing the impacts of development on water quality (FHWA, 1996).

Structural BMP are used to treat stormwater at the place where it is generated or near the discharge into the receiving waters, or into the urban rain sewer system. They operate by trapping and detaining runoff until unwanted pollutants settle out or are filtered. Examples: extended detention ponds, wet ponds, infiltration trenches, infiltration basins, sand filters, grassed swales, constructed wetlands, etc.

Nonstructural BMP are systems or practices designed to minimize the accumulation of pollutants, and reduce their initial concentrations in stormwater runoff. Such practices may include street sweeping, fertilizer application controls, vegetated buffer areas, and land use planning and are often used in conjunction with structural controls, to create more efficient treatment systems (FHWA, 1996).

One of the most important decisions when it comes to stormwater and highway runoff is to choose when it is necessary to implement a specific control measure. In synthesis, three types of measures can be chosen, separately or in a combined manner, according to the situation:

- Alteration of the road drainage project, eliminating runoff discharges to sensitive areas, such as: areas of aquifer recharge; drinking water safeguard zones; areas with irrigation channels; protected ecosystems – Natura 2000 areas.
- Construction of treatment systems when it is not possible to eliminate the discharge. Whenever possible the flow from the natural surroundings (impermeable land and road soil side slopes) is separated from the highway runoff in order to reduce the size of the treatment facility (and maintain the natural hydrological cycle).
- Construction of systems to control accidental spillages of dangerous substances (in wet weather) is a structural measure, meant to control accidental pollution.

Treatment solutions in several countries are and should be mostly based on natural processes. Figure 2 shows some aspects of treatment systems in Southern France. Although the physical, chemical and biological processes are the same the layout of the systems are different. It is important to adapt the solutions to the specific local conditions such as: space availability, slope, climate, soil, geology, other constructions, and so on. Otherwise the objective of the system may be threatened.

Correct construction, maintenance and monitoring – especially of new solutions or the first years of operation of new systems - are crucial factors.

Figure 2 - Example of a detention pond with a system for oil retention, based on a manual process: the closing of a pipe. Highway in Southern France, near Toulouse (Barbosa, 2005); left: Inlet to the system, right: Pond with high L:W ratio

2.3.2 Situation in Slovenia

2.3.2.1 Design procedures

In Slovenia the first treatment facilities (retention ponds with oil separators) were constructed in the mid 70's when the highway Vrhnika Postojna in central east Slovenia, crossing extensive karstic aquifer was built. Retention ponds with infiltration facilities in coarse gravel aquifer were constructed in the mid 80's for the highway Ljubljana Kranj. The design for these facilities was performed based on the in-situ oil spill experiment, when it was determined that through coarse grained sediments oil seeps vertically very slowly. Based on these results it was decided that intervention measures should be integral part of the maintenance procedure during the operation of highways.

Extensive construction of highways started in 1994. This was also the time of the start of the development of new environmental and construction legislation. At the start of the highway construction company responsible for highway construction and operation DARS issued Guidelines for the design of drainage systems (Rismal, 1994) with later revision (Rismal, 1999). Later Guidelines for groundwater protection (Ajdič *et al.*, 1999) were published as an additional document for groundwater protection. In 1993, the Environment Protection Law was enacted and after its implementation technical legislation related to the Environmental Impact Assesment – EIA was published. First Environmental Impact Studies (EIS) for road construction started in the mid 90's. According to the current practice established at the beginning of the highway construction program, in 1994, definition of sensitive areas vulnerable to the road pollution is part of the design procedures.

In the first preliminary design phase, exhaustive analysis of hydrological and hydrogeological conditions based on field investigations are performed. The results of these investigations are part of the preliminary design collected in the chapter defined as "Geological and Geotechnical Report". Findings resulted in the report are usually included into the EIS that defines demands for water bodies protection. Both "Geological and Geotechnical Report" and EIS represent baseline for the design of protection measures performed by the qualified designer. They are usually implemented in the document "Hydrotechnical and Drainage Report" that describes the road drainage system and the road runoff treatment measures. At the executive design stage, only optimization of protection measures proposed at the preliminary stage are performed. This optimization is intended for precise cost estimation and for the preparation of tendering documents.

2.3.2.2 Protection procedures

Runoff treatment systems are among the most well known protection measures; however other technical solutions can also be implemented. In Slovenia roads very often cross different drinking water safeguard zones. They are positioned in the alluvial aquifers as well in the karstic regions that represent nearly half of the country. Besides passive measures that are implemented during the planning and design stage (e.g. avoidance of sensitive areas, and traffic limitations) other construction measures are implemented. Technical and construction measures are conceptually shown in Figure 3.

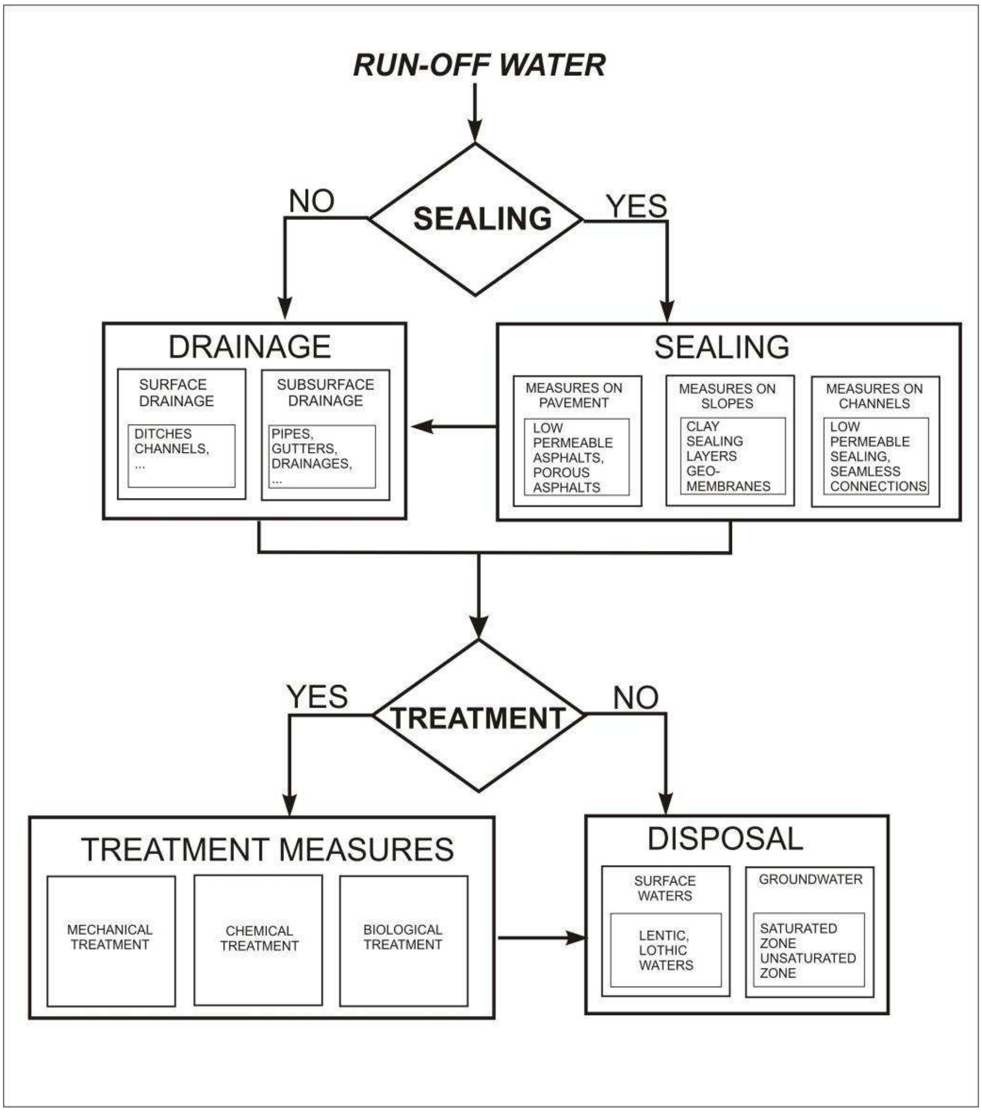

Figure 3 - Procedure for the water bodies' protection from road runoff pollution in Slovenia

In general, technical protection measures can be divided into two groups:

a) Sealing measures

b) Treatment measures

Sealing measures are necessary only in the very vulnerable areas where risk for drinking water resource is very high (e.g. in near vicinity of pumping wells – Ljubljana waterworks Kleče). These measures can be divided into three subgroups:

1) Measures concerning the pavement – they are implemented in the areas that are represented as direct recharge areas to the particular wells (e.g. inside a depression cone). They consist of special low permeable asphalts as well as from stress absorption membranes. In some places also porous asphalts can be implemented intended to control and divert rainfall runoff in a more controlled manner.

2) Measures concerning the slopes – they are mainly implemented in the cuts bellow the surface where road structure approaching groundwater level. Very often they are represented by clay buffers of different thickness (depending on the quality of clay and slope characteristics) on the slopes and in the sub-base of the road. On several places also different types of geo-membranes and geo-textiles were implemented.

3) Measures concerning the road drainage system – in the sensitive areas it is important that pipes and channels for the diverting polluted surface runoff as well as seepage water are tight and impermeable. Different measures can be implemented to seal pipe and channel junctions (e.g. seamless junctions, high quality pipes etc.).

	
Figure 4 - Ground retention pond along the highway Trojane Vransko – Central Northeast Slovenia	Figure 5 - Ground retention pond with sedimentation pond and spillway along the highway Ivančna gorica – Novo mesto Southeast Slovenia

Predominantly used and implemented are runoff water treatment systems. Until now over 700 retention ponds and treatment facilities were constructed at the Slovene highway system. This large number is causing several problems related to monitoring and maintenance. Treatment facilities can be divided into three main groups.

1) Physical treatment can be performed with various combination of sedimentation pond, oil separation and retention basin or pond.

2) Chemical treatment – in Slovenia it exist only as possibility, however on road network until now according to the authors' knowledge it was not implemented.

3) Biological treatment is usually implemented as artificial wetland at the outflow from the mechanical treatment system

In general retention and treatment systems in Slovenia are separated into two large groups, depending mainly on the available space to construct retention/treatment facility. They consist of:

a) Ground retention ponds/facilities – constructed where space for the construction is available as well as in the places where relatively big inflows from the recharge area are expected. Usually they are constructed as dry retention ponds with two parts: a sedimentation ponds and an oil separator. In the recent period after long technical discussion and some demands from regulatory agencies; oil separators lamella filters were introduced on some sections of highways. They are relatively expensive measure requiring intensive maintenance, and their widespread use remains controversial.

b) Concrete retention ponds/facilities – constructed on the places where less space is available and where the recharge area of the structure is relatively small. They are predominantly constructed on the karstic region of Southwest Slovenia (e.g. along highway Postojna – Koper). Typical build retention pond construction is schematically shown in Figure 6.

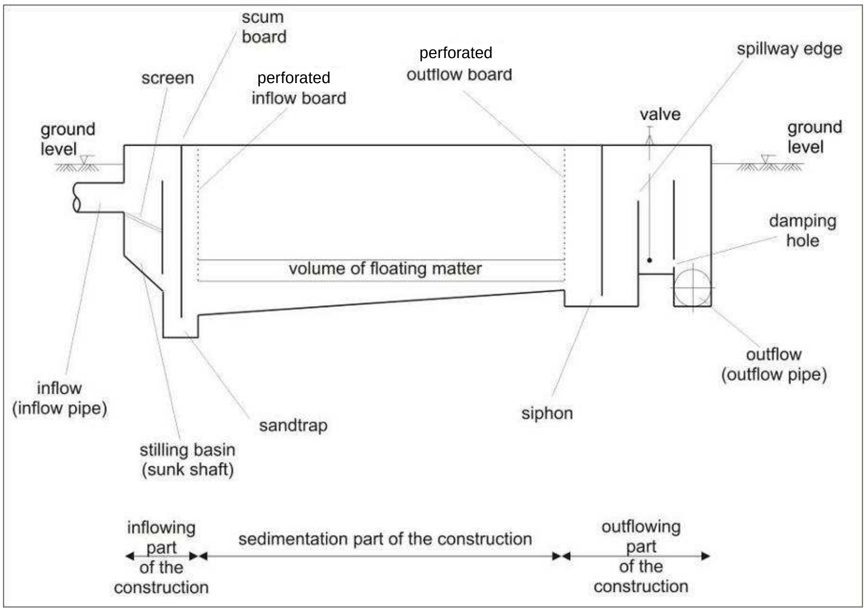

Figure 6 - Typical design of concrete retention pond constructed at the Slovenian highway network

These measures can be also combined. Very often in the practice physical and biological treatment are combined (e.g. highway Ljubljana Celje or highway Ljubljana Ivančna gorica - Figure 7).

Figure 7 - Combination of mechanical and biological treatment with rush in artificial wetland – highway Ljubljana Ivančna gorica – central east Slovenia

After runoff water is treated or directly released into the environment it is disposed into surface water or into the groundwater. The latter can be done directly into the groundwater body or indirectly through dispersal and infiltration through the soil. It is prohibited by the legislation to directly infiltrate untreated road runoff on groundwater. As a consequence of intensive rain showers that can appear in some parts of Slovenia the outflow from the particular road sections can be even hundred litres per second or more. In such cases is important to protect receiving stream from the inrush of water flowing from the road. In BMP it was accepted that the ratio of inflowing water (Q_{inf}) from the road and receiving flowing water body (Q_{rec}) should not be larger than 0.2. As a design (Q_{rec}) average minimum water discharge defined on monthly basis is accepted. In spite of being a simple measure, in the practice it is difficult to estimate Q_{rec} due to the lack of reliable field data.

It is very often that it is not possible to dispose runoff in the surface water body. In such cases infiltration ponds and wells are constructed. It remains an open question what should be the chemical status of the infiltrated water. In recent design practices, infiltration facilities are combined with various treatment facilities and water is infiltrated through the soil or constructed sand and gravel filters (Figure 8).

At present there is a strong discussion about maintenance activities and operational monitoring. Large number of treatment and retention facilities require high financial and working load for proper maintenance that is, from a practical point of view, difficult to obtain. There are some experiences with monitoring, however because sampling was not performed by automatic devices, the results are not reliable. It is planned that some of representative retention ponds and treatment facilities will be equipped with all necessary devices to obtain a consistent characterization of quantity and quantity processes. This data will be the basis for future decisions and management procedures.

Figure 8 - Retention pond with infiltration pond and infiltration wells – highway Jesenice Kranj; Northwest Slovenia

2.3.3 Situation in Portugal

In Portugal, the assessment of highway runoff and the approach to mitigation measures started in the scope of the Environmental Impact Assessment (EIA) process, in 1990 - as already stated in section 2.2.3. In that year the law (Decreto-Lei) n. º 186/90 was published in Portugal. Being this the transposition of an European Directive, before the publication the content and purpose of the law was known. For this reason, BRISA, responsible for the project, construction and operation of A1 highway (the first major highway in Portugal) decided to carry on an Environmental Impact Study of the highway project. This study gave place to the very first system for highway runoff treatment in Portugal. A detention pond was build approximately 136 km northern to Lisbon, intended to protect the groundwater – in this area there is an important karstic formation that is also part of a Natural Reserve Park (Parque Natural da Serra de Aires e Candeeiros) (Barbosa, 2005).

Since 1990, many other Environmental Impact Studies recommended the construction of treatment systems for highway runoff control – or other type of measures to control road runoff pollution.

Treatment systems are not the only method used to control highway runoff pollution in Portugal; the other options referred to in chapter 2.3.1 are also common. For instance alteration of the road drainage project, eliminating runoff discharges to irrigation channels was done at A2 on a bridge, over a large valley (Figure 9).


Figure 9 - A2, over Sado river valley. Runoff from this bridge is collected through plastic pipe to the structure at the base of the bridge and conducted to a major pipe. The discharge is made to river Sado, considering that the dilution factor is sufficient to eliminate significant impacts

A study by LNEC (Barbosa *et al.*, 2003) for the Road Administration concluded that most of the accidents involve the transportation of fuel, and diesel is the most frequently transported fuel. Barbosa *et al.* (2003) proposed a project layout for a passive system able to contain the fuel even during rainfall events. This system has been tested at a pilot scale (reduction to a scale 1:10) and showed a good performance. Figure 10 shows the project design layout and a picture of the pilot system, during the tests. This solution may be implemented when the road serves industrial areas and/or harbours, and consequently the rate of fuel transportation is very high. Sometimes such roads also cross sensitive ecosystems or water bodies making the need for protection even stronger.

Different types of layouts for treatment systems have been observed in Portuguese projects. For several reasons, some of them have not been built, and many of the constructed ones have not been monitored which makes difficult to assess the soundness of the project and the construction.

There has been a comprehensive monitoring study of the infiltration pond at IP4 highway included in a Ph.D. dissertation (Barbosa, 1999), and evaluations included in research studies and students projects /Master Thesis. A study by LNEC assessed a pond for preliminary treatment of highway runoff at A6, near Borba and A1 pond (Leitão *et al.*, 2005). A Master Thesis dissertation (Albuquerque, 2006) included the study of the performance of the treatment pond at the highway A23. Figure 11 to Figure 13 illustrate some of these sites.

A problem that was observed in these studies is that sub superficial water flow is feeding some ponds. This fact makes not only difficult the evaluation of the pond performance but modifies all the sizing calculations that were made for the project. The conclusions to be drawn are that it is very important to know the physical and environmental characteristics of the site where the treatment system is to be built, and it is fundamental to monitor the systems otherwise this issues cannot be identified and the same errors can be again made.

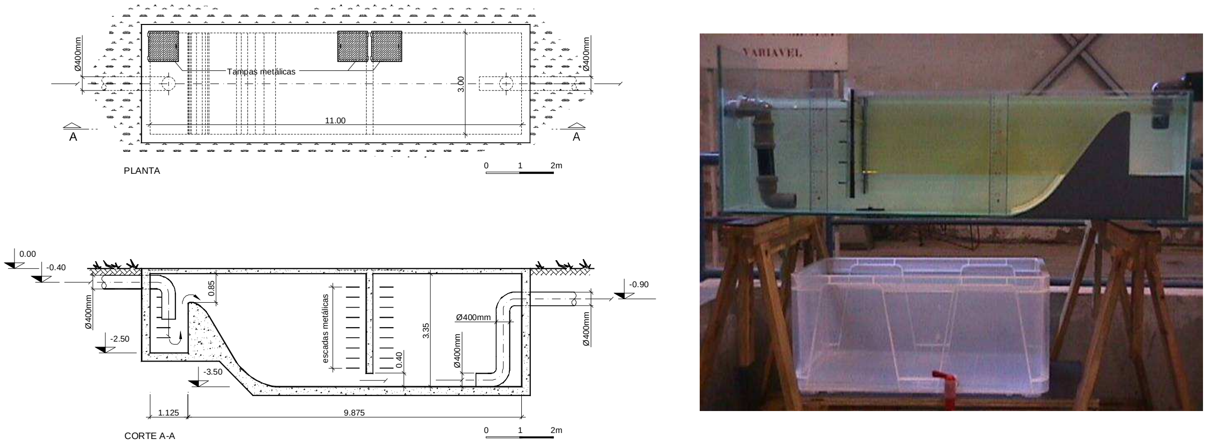

Figure 10 - Project layout for a passive system able to contain the fuel even during rainfall events and picture of the pilot system, during the tests. It is clear that the diesel used in the experiments accumulates in the first section of the system (Barbosa *et al.*, 2003)

To thoroughly analyse the data concerning the constructed treatment systems, their operation, maintenance and efficiency and provide conclusions able to enhance national best management practices were understood as a priority by the Portuguese Roads' Institute that, in 2005 commissioned to LNEC a study. A synthesis of the results of this 2.5 years study has been presented by Barbosa and Fernandes (2009).

A total of 27 different treatment systems, corresponding to a total of 13 different project typologies, have been evaluated in this assessment, either by collecting data already existing or by direct observation of the system at the field and meetings with the road operation staff. Many of the evaluated systems have the same layout and operations, belonging to the same road (Barbosa and Fernandes, 2009). During this study, different types of technologies and combination of operations have been observed, namely:

1. Detention basin/pond.
2. Wastewater treatment plant, with different physical and chemical operations, including the addition of $FeCl_3$.
3. Retention pond.
4. Sedimentation pond + infiltration basin.
5. Sedimentation pond + infiltration bed.
6. Oil separator + decantation pond.
7. Oil separator + detention basin.
8. Multifunction basin (detention basin + oil separator located inside an inspection chamber before the outlet).
9. Grassed swale.
10. System for control of accidental spillages (oil separator chamber).

Figure 11 - A1 pond, near Fátima. Aerial view of the highway and the pond, and picture of the entrance to the pond (Area=100mx40m; Volume=9148 m^3)

Figure 12 - IP 4 pond, near Vila Real, left: pond shortly after its construction; right: pond 7 years after construction

Figure 13 - One of the A6 preliminary treatment ponds, near Borba. The pond is feed with sub superficial and/or underground flow: it was observed a water pool even during months of dry weather. (Leitão *et al.*, 2005)

The evaluation of these systems was done based on the study of the project, the visual inspection at the site, meetings with the operating companies to gather empirical information like the construction and operation/maintenance costs and results of the monitoring reports.

Half of the systems analysed by Barbosa and Fernandes (2009) have been constructed after the year 2002 so there was not much maintenance experience yet. There were different levels of information for the various treatment systems and sites; at the study the objective was to gather and make the most out of the existing data.

It was observed during the field work, the high level of sediment accumulation below the inlet pipe at the majority of the most recent systems. The need for rehabilitation and adaptation works due to some errors in the design project was noticeable for some cases (Barbosa and Fernandes, 2009).

For most of the treatment systems, the choice of the type of operation was according to the targets proposed in the environmental impact study. It was noted that several studies did not present a clear objective for pollutants removal at the designed system, which is thought to be a relevant lack of information, for the measured efficiency must be compared to the proposed efficiency (Barbosa and Fernandes, 2009).

Concerning the monitoring, several observations lead to specific recommendations, in order to improve it and avoid problems that are now common faults. It was observed, for several cases, that the quantification limits used by the analytical laboratory, for quality parameters measured in road runoff samples, were quite high. Sometimes, the concentrations measured at both the inlet and outlet samples were below these limits leading to no conclusions at all, in spite of the investment made to obtain such results. It is of main importance to discuss detection and quantification limits with the laboratory in charged of analysis, previous to the start of the monitoring programme, giving them possible ranges for the expected concentrations (Barbosa and Fernandes, 2009).

3 | DEFINITION OF WATER BODIES SENSITIVE TO ROAD POLLUTION

3.1 Slovene methodology

The legally defined methodology for the definition of water bodies sensitive to road pollution is not directly related to the sensitivity concepts as they are understood in hydrological sciences. The definitions given by the Decree are practically oriented, and the definition of the type of drainage systems is based on the traffic characteristics, in combination with the natural characteristics of the water bodies. Roads and their sections are divided into two groups; one with the required treatment of drainage water and the other without treatment.

The decision process for the selection of the proper protection measure is incorporated in the existing legislation responsible for the protection of water bodies from impacts caused by roads. The decision process is strongly related to the project stage and the life cycle of the road. The life cycle of the road can be divided into two main parts: development and operation period. During the development period, the following phases can be recognised: planning, designing and construction period. The planning period is usually performed as desk studies based on the available data. Only occasionally, when some unsolved questions exist, field overview mapping is performed. The design period is further divided into two stages: preliminary design and detailed (executive) design.

During the operation of the road there are three sub phases: operation, refurbishment, and post operational period. Operation is understood as a common behaviour of road structure, traffic and accompanied activities. Under the refurbishment are included all activities to repair the damages that may happen to the road structure and special structures such as bridges, side lanes, etc. Post operational period starts when the road structure, or part of it, is abandoned.

The interaction between roads and waters may occur in two ways: there is an influence of roads on waters and an influence of waters on roads. This relation is a dynamic process and cost-benefit ratios must be established. Roads influence the quantitative, qualitative and ecological status of waters. Water can influence the construction of roads (e.g. water inrush in pit and tunnels etc.) and their operation (e.g. occasionally flooding, aqua planning, freezing etc.).

The interaction with water and roads is understood as interaction with water bodies. We are recognising two types of inland water bodies: surface water bodies and groundwater bodies. Only a small part of the country is lying in the coastal area, however until now the coastal area and seawater and road interaction was not regarded as important.

To understand the relation between roads and water bodies, it is important also to conceptualize the relation between water flowing direction and the discharge of water precipitated on the road body and road environment in the vicinity of the road body. Interaction between roads and water phenomena can be conceptualized on the basis of the recharge area of the water that intercepts the road. These phenomena of water road interaction can be divided into three groups:

1. Road runoff.
2. Hinterland water.
3. Remote water.

The road runoff is a consequence of precipitation falling onto the carriageway and onto the associated embankment. Inland waters come from the near-road environment (e.g. slopes from a cutting) and which are flowing towards the road embankment. Remote waters have recharge areas far away from the road but are crossing the road line (e.g. rivers, lakes, groundwater flow, etc.).

The general structure of the decision process is implemented in the Decree on the emissions from drainage of precipitation water from public roads. This decree is a result of the highway construction process. In the last two decades there were a lot of controversies and open questions put onto agenda. These questions are mainly related with the fact that a large part of the country is covered with drinking water protection zones and that residents are mainly supplied with drinking water from groundwater. There is also much crossing of streams with relatively low flows (small creeks of some 10 l/s).

At any stage during the life cycle of the road, the process of sensitivity definition starts with a legislation overview. When the impact of roads on water systems is of concern at the first stage, general requirements are listed (e.g. principles of good water status, etc.); then spatial characteristics are defined. The overview of all legally spatially defined zones is reviewed. This is performed as listing (mapping) of their spatial distribution and with the overview of all legal documents (texts). In these documents demands can be divided into two groups; general requirements that usually repeat rules of conducts from law, and precise requirements related to the particular space and phenomena in the space that will be crossed or are already crossed with the road.

Requirements from the legislation must be fulfilled. However, legislation is complex and not always straightforward. This has lead to weak and even contradictory past decisions, taken based on the different levels of knowledge available. In these cases, the principle of maximum protection was applied, i.e. the stricter rule. The decision scheme used is shown in Figure 14.

After a legislation review, the water bodies natural conditions along the road location are reviewed and defined. These processes are very much related to the roads life cycle definitions and are included in the preparation of the documents.

When a road is crossing an area that it is not under a particular legislative demand, natural conditions should be defined. The first division is between surface and groundwater bodies. For groundwater bodies, further division is based on the aquifer types; intergranular (sedimentary) aquifers, karstified and fissured aquifers, and areas without significant groundwater appearance. The latter is defined as an area where vertical permeability is less than 10^{-6} m/s or where groundwater is not present.

In the next step of the decision process the structure of the traffic is considered. Structure of the traffic is understood as passenger car equivalent (PCE). If the prescribed limit of PCE is exceeded, then road runoff treatment should be performed. On the karstic aquifers the limit is of 6,000 PCE, on porous aquifers is of 12,000, and on low permeable areas is of 40,000 PCE. In the case that road's own waters are disposed into the flowing stream or into the sea the limit is set to 12,000 PCE.

The Decree defines two modes of water drainage from the road surface called the point of dispersion and dispersal. The point of dispersion is represented by the concentration of run-off in different drainage facilities. The dispersal is regarded as unsuitable if the prescribed PCE limit is exceeded. In special cases, when very sensitive areas are crossed, the environmental impact assessment report can define more strict sensitivity and more demanding treatment can be required.

For the case of surface water bodies, the relation between discharges of road runoff and receiving water is important. This question is not regulated with strict values; however, in practice and in some guidelines, the principle that 10% of the average low discharge of the receiving stream should not be exceeded by the discharge from the road runoff is applied. When exceeding this criterion, retention ponds need to be constructed to treat road runoff before its disposal. This can also be required when the road runoff is disposed into the public sewage system.

Treatment is required only for the critical rainfall event of up to 15 minutes defined with the intensity of 15 l/s/ha. This is an average value obtained form the current experiences and average meteorological conditions in Slovenia.

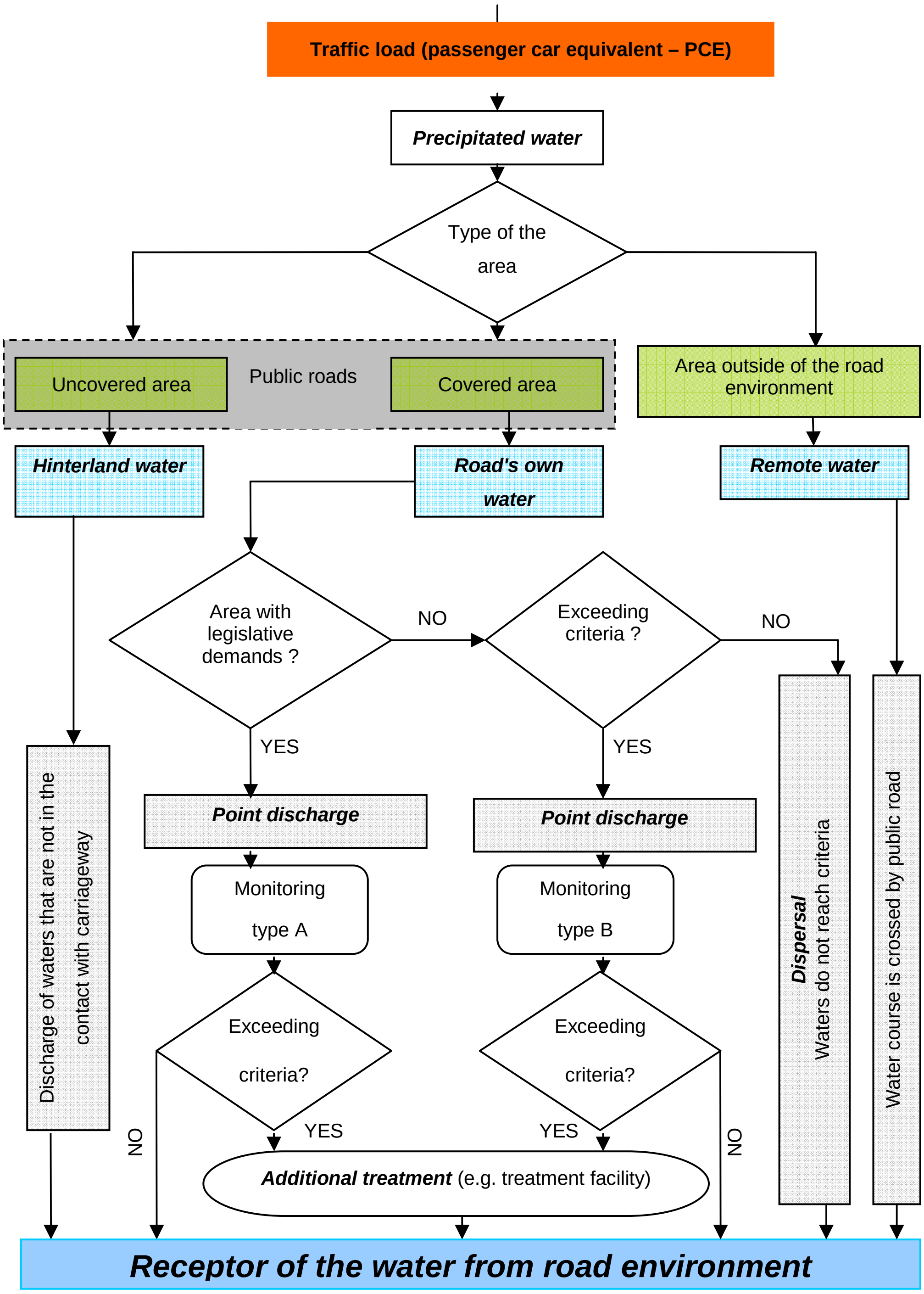

Figure 14 - Decision process for the drainage system selection in Slovenia

3.2 Portuguese methodology

3.2.1 Concept

This chapter will focus on the Portuguese approach to understand and defining what is a water body sensitive to road pollution. The general methodologies used for environmental impact assessment of road infrastructure projects in waters resources are among the common approaches followed internationally for the different phases of the road project. Publications such as the one by Ministerio de Medio Ambiente (2000) describe very consistently methodologies for use in Environmental Impact Studies of roads.

In Portugal there is no official methodology to define sensitive areas to road pollution. Nevertheless, in 2005, during a study accomplished by LNEC to the Portuguese Water Institute (INAG), the participating researchers and experts from both institutions have proposed such a methodology (Leitão *et al.*, 2005 and Leitão, Barbosa and Telhado, 2005). In this report, a synthesis of this methodology is briefly presented. It should be understood that it is not a regulation and therefore its use is not mandatory.

The "water bodies sensitive to road pollution" are understood to be the inland surface waters, transitional waters, coastal waters or groundwater which form, either by their uses and/or supported aquatic ecosystems, alone or cumulatively, areas that are more sensitive to road pollution. In the next sections a flowchart for identification of such water bodies is presented.

Sensitive water bodies are hereby understood as areas to be protected, where direct road runoff discharges should not be allowed. However, often the discharge elsewhere is not possible and, in those cases, an adequate treatment system is required. These systems should promote the reduction to acceptable levels of the pollution level loads discharges, namely considering the priority hazardous substances as the ones defined in the WFD, and ensuring that the receiving water quality is not reduced or impacted by the road runoff discharge.

The quality of the runoff discharge should be such that prevents further deterioration and protects water bodies with regard to their water needs (human consumption, irrigation, etc.), terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems.

3.2.2 Water bodies sensitiveness

Classification

The methodology adopted to categorize "water bodies sensitive to road pollution" aims to classify the receiving water bodies into three classes: "sensitive", "non-sensitive" and "requiring site specific analysis".

The application of this methodology is especially important in the variance study phase, so it can help deciding the best alternative for the road track, from the view point of water protection.

In the following sections, an explanation of the Figure 15 information is presented. It considers: inland surface waters, groundwater, transitional waters, and coastal waters.

Inland water (surface water)

The methodology is based on the physical and hydrodynamic characteristics of the receiving surface water body, where two types of media are considered:

1. Still water (Lentic water bodies, such as reservoirs).
2. Dynamic water (Lotic water bodies).

1. Lentic water bodies

The situations for which they should be defined as sensitive are the following:

- Water abstraction protection areas within public reservoirs (particularly the ones classified as protected by the Portuguese law).
- Small scale systems for water retention[6] (it is also easy to avoid direct discharge to them, given their space scale).
- Irrigation channels, namely within agricultural areas.

Road runoff discharges must be prevented in all the following cases:

- Water bodies that support sensitive uses and/or ecosystems (e.g. protected areas, irrigation perimeters infrastructures).
- Lagoons, reservoirs, wetlands, polluted areas or areas with rehabilitation plans.

[6] These systems are typical in the Portuguese countryside, being a way of retaining water for cattle and/or agriculture.

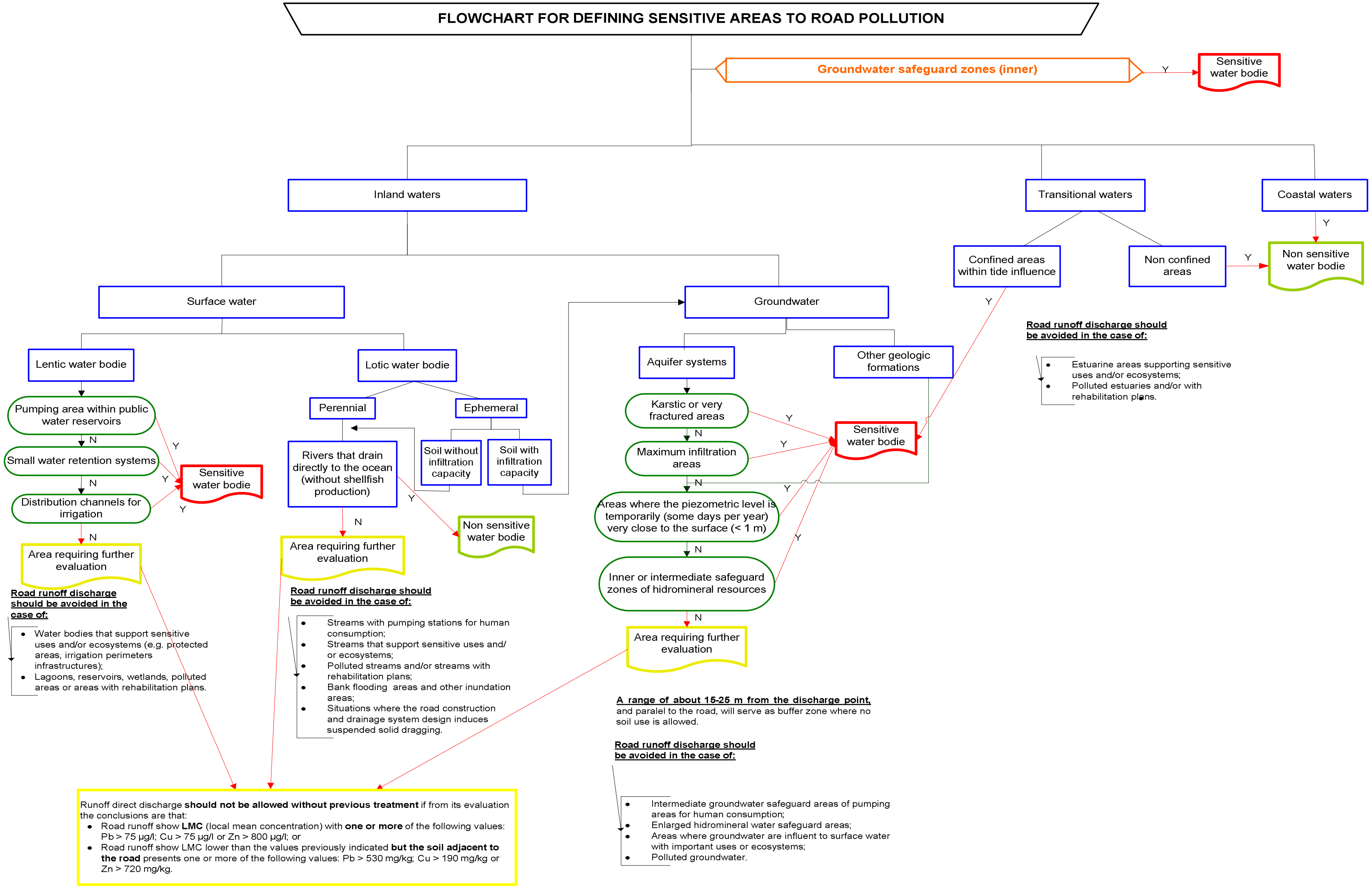

Figure 15 - Flowchart for defining sensitive areas to road pollution (Leitão *et al.*, 2005)

2. Lotic water bodies

There are two different situations for lotic water bodies: the seasonal water courses (ephemeral) and the permanent water courses (perennial).

For ephemeral water courses there is the need to assess the soil infiltration capacity. In case it is high, the area sensitivity will by defined by the underlying groundwater sensitivity. For the cases of low soil infiltration rate, it is considered that water will flow down gradient, and therefore the impact of the runoff discharge is based on the effects on the receiving surface water body.

For perennial water courses there is the need to distinguish high flow rivers, where the dilution effect is considerable, and discharge is not a problem. In this situation are the rivers that flow directly into the ocean, which are considered non sensitive. Exception is made for the ones that support aquaculture as well as the ones that discharge into beach zones.

Road runoff discharges must be prevented in all the following cases:

- Rivers with water abstraction for use for human consumption.
- Rivers that support water uses and/or sensitive ecosystems and that have been classified or protected for this(these) reason(s).
- Polluted rivers and/or under rehabilitation plans, unless the road runoff is treated prior to the discharge (because the water quality is already too poor).
- Areas with a high rate occurrence of floods (where there is the potential for flushing of the soil accumulated pollutants which could induce acute impacts downstream).

Other situations that deserve attention are steep areas, and any similar circumstances that may provoke the washout of solids to surface water bodies. For these cases, it should be considered the construction of sediment traps and flow control.

All the non listed situations require further specific site analysis.

Inland water (groundwater)

Before defining which are the sensitive areas to road pollution (i.e. where specific protection measures should be taken), there are some situations in Portugal for which the construction of roads is forbidden. This is the case for: (1) the inner protection zone of groundwater wells for water supply; and (2) the inner and intermediate zones for hydromineral waters. These are cases *a priori* considered as sensitive to road pollution.

The methodology to define sensitive groundwater bodies to road pollution was based on the hydrodynamic and chemical characteristics of the aquifer. The situations defined are based on the pollutants infiltration capacity and further migration into the groundwater body, as well as in the capacity for pollution retention.

Two types of formations were distinguished:

1. **Other geologic formations**

These are local and limited groundwater or essentially areas with no groundwater. In the latter the areas are considered non sensitive, and in first case there is the need to further analyse some conditions to access their sensitivity related to the distance to the piezometric level and to the existence of safeguard zones.

2. **Aquifer systems**

These are aquifers (porous, fissured and karstic) defined at national level as being important aquifers for potential exploitation, i.e. having good storage capacity and transmissivity characteristics.

The situations for which they should be defined as sensitive are the following:

- Karstic aquifers, since they are sensitive areas due to its very high porosity and transmissivity, as well as the very low capacity of retaining pollutants, making them very vulnerable to pollution.
- Very fractured aquifers, since it controls the infiltration capacity, as well as the deep flow interconnections between these fractures.
- Maximum infiltration areas, i.e. areas where the aquifer recharge preferentially takes place.
- Areas with high piezometric level, < 1m, (even if temporarily), i.e. very close to the surface, since there is a strong potential for soil pollutants leaching[7] towards groundwater.
- Inner or intermediate safeguard zones of hydromineral resources.

Road runoff discharges should be prevented in all the following cases:

[7] The process of separating a soluble substance from one that is insoluble, by washing with water.

- Intermediate groundwater safeguard areas where water abstraction is for human consumption.
- Enlarged hydromineral water safeguard areas.
- Areas where groundwater are influent to surface water that supports water uses and/or sensitive ecosystems and that have been classified or protected.
- Polluted groundwater and/or under rehabilitation plans.

All the non listed situations require further specific site analysis.

<u>Transitional waters</u>

Accordingly to the WFD, transitional waters are bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows.

The sensitivity of these bodies is very much depending in their containment degree, i.e., if they are confined areas within the tide influence or not confined. This will define their physical and chemical characteristics and hence the biological population structure and composition and overall sensitiveness.

Non confined areas are considered non sensitive since the great volumes of water that enter the system each tide can dissemble the effects caused by the comparably smaller road discharges.

Confined areas have a small water height and usually support sensitive ecosystems, shellfish, and salt production, among other. They are therefore considered sensitive areas.

Besides, road runoff discharges should be prevented in all the following cases:

- Estuarine areas supporting sensitive uses and/or ecosystems.
- Polluted estuaries and/or with rehabilitation plans.

<u>Coastal waters</u>

Accordingly to the WFD, coastal water means surface water on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters.

Considering the characteristics of these waters, they are considered non sensitive.

3.2.3 Range of key-pollutants concentrations above which water bodies protection should be considered

In the previous section there was a set of situations that required further specific site analysis, i.e. their main characteristics did not allow to classify them either as sensitive or non sensitive. The procedure presented in this section is meant to be used just for those cases (water bodies) requiring a specific evaluation.

The aim of this section is to answer the following question, within the areas that require further specific evaluation: "which should be the ranges of pollutants concentration above which water protection measures should be considered"?

To answer these question two issues need to be defined: what are key-pollutants, and what should be the maximum concentrations ranges?

Key-pollutants and maximum concentrations for road SMC[8]

The elements chosen are among the pollutants typically presented in road runoff in most road discharges.

For the cases requiring a specific site analysis, it is proposed the implementation of proper environmental mitigation measures every time road runoff average concentrations are above one or more of the following key pollutants:

- Pb: 75 µg/l
- Cu: 75 µg/l
- Zn: 800 µg/l

The mitigation measures may be of two kinds: either the drainage of road runoff to discharge points outside the area that may receive it, or the construction of treatment systems prior to discharge. Even for the cases of roads with SMC below the limits above established, an evaluation of the local soil is still needed, before accepting discharges in those areas. The soil conditions are explained in the following section.

Integration of key-pollutants concentrations and soil conditions

Soils are the interface media between surface and groundwater, therefore they act as a buffer zone for groundwater protection. If a soil has high heavy metals background levels it means that its capacity to retain more metals (from road runoff) is lower.

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[8] **SMC** (**Site Mean Concentration**) is a characteristic runoff annual pollution loads for a specific site, typically defined by the arithmetic mean value of the EMC's measured at one site [Hvitved-Jacobsen & Vollertsen, 2003]. **EMC** (**Event Mean Concentration**) is calculated for an individual storm event as the total mass load of a pollutant parameter (cv) divided by the total runoff water volume (v) discharged during the storm [Hvitved-Jacobsen & Vollertsen, 2003]: EMC = ∑cv/∑v.

With the objective of establishing concentrations of Pb, Cu and Zn in soils that can act as a guideline, there was a search for international procedures/guidelines concerning the issue.

There is no Portuguese legislation on the subject. Internationally, criteria from Holland (concerning soil pollution), and from Canada are often considered (Table 4). It was concluded that limit values from the Dutch legislation were the most suitable for the case of assessment of soils conditions for receiving road runoff.

Table 4 - Limit values for heavy metals concentrations in soils, according to the Canadian and Dutch legislation

Country	Type of value	Cu	Pb	Zn
		(mg/kg)		
Holland	Guide value[1)]	36	85	140
	Value demanding intervention[2)]	190	530	720
Canada	For agriculture use	150	200	600
	For residential areas and parks	225	200	600

[1)] Indicates a basic condition for soils sustainability giving its use for human, animal or plants life.

[2)] Indicates the concentrations above which the soil functions for human, animal or plants life is at risk.

Hence, the proposed methodology indicates that receiving soils with one or more concentrations above the limits settled (Pb = 530 mg/kg; Cu = 190 mg/kg and Zn = 720 mg/kg), cannot receive road runoff discharges without treatment, even if the road runoff has SMC lower than the values proposed for surface runoff (Pb: 75 µg/l, Cu: 75 µg/l or Zn: 800 µg/l).

3.3 Proposal of a common methodology to define water bodies sensitive to road pollution

3.3.1 Introduction

The need for broader common methodologies that can define the sensitivity of water bodies to road pollution was the leitmotif of this bilateral cooperation. Presently, the different countries approaches have lead to measures that very much depend on subjective decisions during planning and designing, and to solutions that depend only on technical considerations. Furthermore, project quality control is not a well developed practice and the requirements of EU legislation concerning good water status and water protection are difficult to fulfil. As a result, not optimal solutions are implemented, sometimes even completely wrong technical measures are emplaced. Consequently, excessive costs (short and long term) can easily occur and the sustainability and precaution, both in an environmental and economic perspective, are difficult to guarantee.

The main scientific interest of the project was to contribute to overcome the constraints identified, by establishing a set of methodologies and minimization procedures that are useful for both countries.

This chapter proposes a new common methodology to define "water bodies sensitive to road pollution", based on the Portuguese and Slovenian experiences that were previously explained. Envisaging the water bodies' protection, this methodology aims at giving a first approach for identifying the most sensitive areas to road pollution, where control of water discharges from road surface and constructions as well as emissions that may have potential negative effects on water bodies should be made.

The spirit of this methodology is within the Water Framework Directive which implies that member states take the necessary measures to prevent or limit the input of pollutants into different water bodies.

This methodology was developed using a flow chart procedure (Figure 16). It is represented as a decision tree, and several steps must be considered during its application. In the first step, the user should define what general type of water body is crossed by the road; whether they are inland waters, transitional waters or coastal waters. In the following step it is given a sub-classification. Due to the complicated natural conditions and many possible influences of roads on their status comparing to other general types of waters the classification of inland waters is complex.

Following the guidelines, from box to box, in the decision tree the user will arrive to three final categories:

a) Sensitive – water body classified as such is, *per se,* sensitive to road runoff pollution. All necessary precaution and protection measures must be used. The best solution, if possible, is to avoid any road construction in these areas. Sometimes this is not possible; such is the case of Slovenia, where nearly half of the country is formed by karstic aquifers. These are also areas where direct discharge of road runoff to water bodies is not possible.

b) Non-sensitive – these areas are not sensitive to road pollution. The main reason for such classification is the presence of a large volume of water or high water flow. Consequently there is a considerable dilution of road pollutants. In such areas there is no restriction for road runoff disposal.

c) Study – this category means that it is impossible to decide in advance if the water body is sensitive or not. The decision must be taken based on further data collection, field and desk studies, for each particular case.

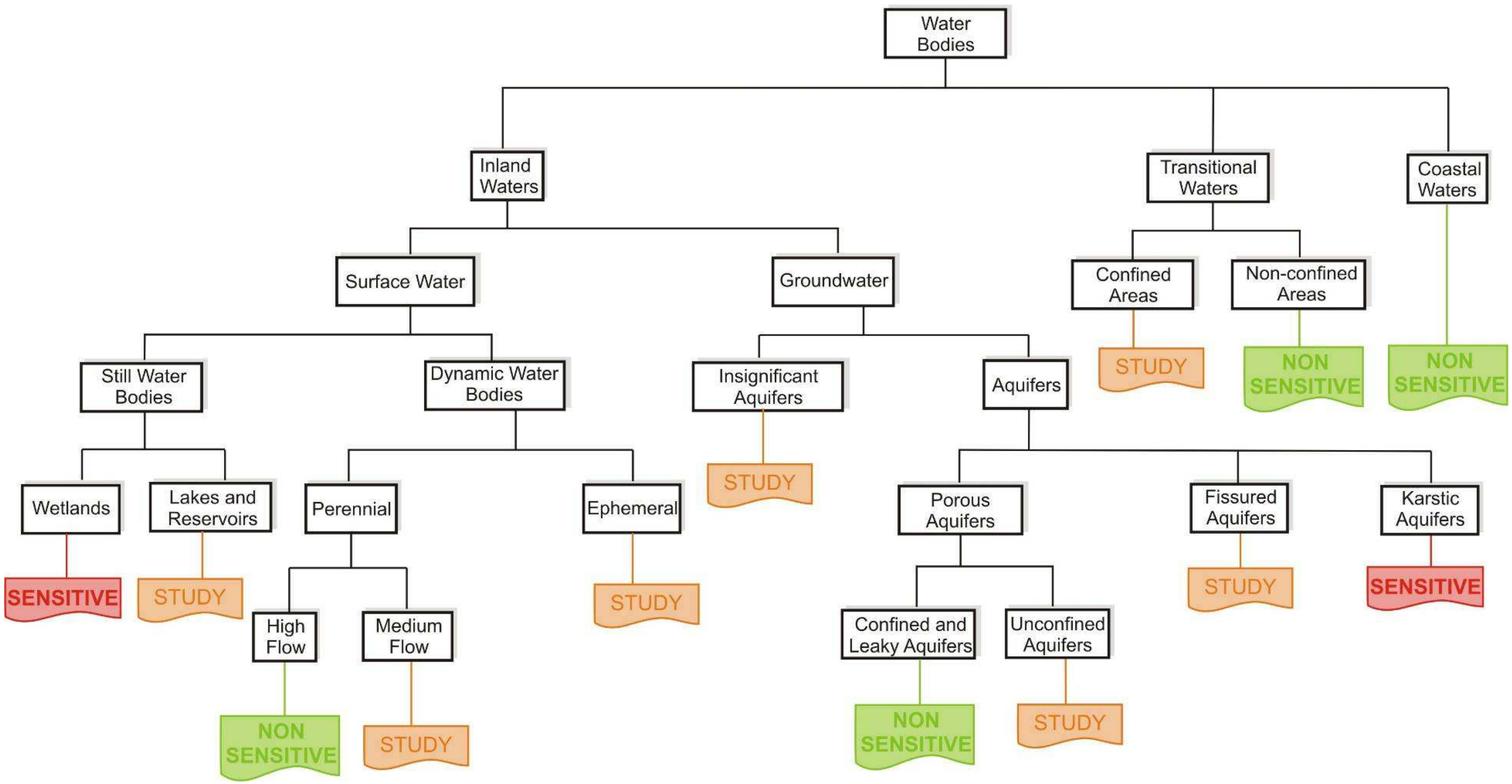

Figure 16 - Flowchart proposal of a common Portuguese-Slovenian methodology to define water bodies sensitive to road pollution.

This flow chart is simple to use and straightforward. It is the conviction of the authors that it will contribute to enhance the transparency and consistency of the decision, planning and designing of road project, from an initial stage, taking into account the protection of water resources. It can also be an important tool to the environmental impact study of road runoff discharges in water bodies.

The identification of sensitivity factors, as proposed, is based on the intrinsic physical and hydromorphological properties of the water bodies, and are identified in function of their role in controlling the sensitivity of the water to pollution from roads (e.g. type of receiving water bodies, flow rate, aquifer material permeability, soil properties, pollution assimilative capacity, etc.).

3.3.2 Water bodies sensitivity

3.3.2.1 Inland water: surface water

The classification is based on the physical and hydrodynamic characteristics of the receiving surface water bodies, where two types of water systems were considered: still and dynamic waters.

Still waters

Still waters can be further classified in wetlands, lakes or reservoirs. The first ones are considered sensitive due to the lower rate of water renovation, and to the ecosystems that they usually support. The latter are considered water masses that need specific site analysis based on their characteristics and uses.

Dynamic waters

In what concerns the dynamic waters there are two different situations: perennial and ephemeral water bodies.

Perennial water bodies were classified in high and medium flow rivers. In the first group, the combined effect of dilution and hydrodynamics should be sufficient to ensure that the discharge of non treated road runoff is not a problem. The definition of a “high flow river” for this methodology, is based on the analysis of the monthly averaged flow measurements that represents the flow of the river. Since seldom this data concern to the study site, it should be done the correction of the flow data to the river section where the road runoff is discharged – in what concerns, for instance, the watershed area, the precipitation and elevation. The flow data should represent a period of, at least, 10 years (the most recent ones). Considering that there may exist seasonal flow variability, which is, for instance typical in Mediterranean countries, the assumption is that when the lowest of the monthly averaged flows calculated is above 20 m^3/s, it is considered for the purposes of applying the present methodology that one is in presence of a “high flow” river – in which it is possible to discharge non treated road runoff.

For the case of medium flow rivers, i.e., rivers for which the lowest of the monthly averaged flows calculated is below 20 m^3/s there is the need for a specific site analysis to access their sensitivity - which has to do with not just the flow but several other processes.

The limit of 20 m^3/s was established based on a conservative principle, and taking into consideration the objectives of the Water Framework Directive. Road runoff may cause both acute and cumulate impacts in river systems, meaning that it is not just a matter of dilution in the river water mass of the dissolved road pollutants; there is also the effect of particulate pollutants that accumulate at the river bed. A high flow enables not only a greater dilution but also increases the sediments transport rate.

In the case of ephemeral water bodies there is the need to assess the soil infiltration capacity in the riverbed. In case it is high, the area sensitivity will by defined by the underlying groundwater sensitivity. For the cases of low soil infiltration rate, it is considered that water will flow downgradient, and therefore the runoff discharge impact should be assessed based on the effects on the receiving surface water body, downstream. Therefore, for these cases, further site specific studies are needed.

3.3.2.2 Inland water: groundwater

The methodology to define sensitive groundwater bodies to road pollution was based on the hydrodynamic characteristics of the aquifer. The situations defined are based on the pollutants infiltration capacity and further migration into the groundwater body, as well as in the capacity for pollution retention. Two types of formations were considered: insignificant aquifers and aquifers.

Insignificant aquifers

These were defined as local and limited groundwater or essentially areas with no groundwater. Although not significant at national scale, these aquifers frequently play an important role in the water supply of local populations, with a small number of inhabitants.

They are considered as areas that need further specific site analysis in the sense that it is important to access the presence of permeable faults and fissured zones, or any other feature that might be responsible for fast pollutant leaching towards groundwater.

Aquifers

These are aquifers defined as being important aquifers for potential exploitation (having good storage capacity and transmissivity characteristics).

There are three different hydrogeologic situations that can be considered: porous aquifers, fissured aquifers and karstic aquifers.

Porous aquifers can be further divided in confined[9] and leaky[10] aquifers and unconfined[11] aquifers. In the first two cases, these areas are considered non sensitive for road pollution. The permeability of soil covering these aquifers is low, the vertical leakage of potential pollutant is very small, and the absorption capacity is high. In the case of unconfined aquifers there is the need of further specific site analysis in which several important properties concerning the potential for leaching of the soil accumulated pollutants should be accessed (e.g. depth to the water table, recharge, soil type and characteristics, topography, hydraulic conductivity, etc.).

Fissured aquifers sensitivity to road pollution depends on the degree of fracturation at the surface, since it controls the infiltration capacity, as well as on the depth interconnections between these fractures. As a result, there is the need of further specific site analysis for areas located in fractured aquifers.

Karstic aquifers are sensitive areas due to its very high porosity and transmissivity characteristics, as well as the very low capacity to retain pollutants, which makes them very vulnerable to pollution.

3.3.2.3 Transitional waters

The sensitivity of these bodies is very much depending on the tidal water renovation within the estuary.

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[9] An aquifer overlain and underlain by an impervious or almost impervious formation (http://www.cig.ensmp.fr/~hubert/glu/EN/GF0233EN.HTM).

[10] An aquifer overlain and/or underlain by a relatively thin semi-pervious layer, through which flow into or out of the aquifer can take place (http://www.cig.ensmp.fr/~hubert/glu/EN/GF0743EN.HTM).

[11] An aquifer containing unconfined groundwater, that is having a water table and an unsaturated zone (http://www.cig.ensmp.fr/~hubert/glu/EN/GF1317EN.HTM).

As a result, non confined areas are considered non sensitive since a great volume of water enters daily the system, being therefore able to dissemble the effects caused by the comparably smaller road discharges.

Confined areas are usually represented by shallow water bodies and at the same time they support sensitive ecosystems, shellfish, and salt production, among other. They are therefore considered as areas that require further study in order to make an environmental impact assessment to study the most sensitive uses and/or ecosystems.

3.3.2.4 Coastal waters

Considering the characteristics of these waters, namely in what concerns its volume when compared to road runoff discharges, they are considered as non sensitive areas.

4 | RECOMMENDATIONS FOR GOOD PRACTICES FOR CONTROLLING ROAD RUNOFF POLLUTION

A good practice for the control of road runoff pollution involves several actions and knowledge/tools that may be stated as follows:

i. Good understanding of road runoff characteristics and effects of pollutants;
ii. A method to predict concentrations of key pollutants in road runoff;
iii. A tool for the assessment of water bodies sensitive to road runoff pollution;
iv. An understanding of when it is needed to implement a treatment system or a system to control accidental spillages on the road;
v. Good project design, construction and operation practices;
vi. Ability to perform monitoring of the systems accordingly to consistent methodologies, and correctly interpret the results;
vii. Being prepared to do rehabilitation of treatment systems or build new treatment systems, when needed.

Table 5 presents the recommendations produced by Barbosa and Fernandes (2005) in order to improve the national Portuguese practice. Although meant for Portugal, it is understood that they may be useful for different countries because the problems identified are commonly observed.

Table 5 - Preliminary recommendations designed to improve the Portuguese national practice in construction, operation and monitoring of systems for road runoff treatment

Activity	Recommendations
Project	Must have a Document with specific content requirements: reason for the implementation of the structural BMP[12] (e.g., protection of groundwater); site constraints; justification of the typology; sizing principles; objectives of each of the treatment operations; targeted efficiencies; estimation of construction and operation costs; access to the site; fencing and gate; methodology for monitoring; structures to support the monitoring activities. Must have Technical drawings following specific requirements concerning descriptions, measurements, views, scales, etc.
Construction	During this phase a Report must be produced, containing: any alteration made to the original project and the cause for it; total construction costs; drainage conditions observed at the site; additional recommendations for the system operation.
Operation	During this phase a Report should be produced on an annual basis, containing: maintenance activities, their periodicity and staff requirements; costs for maintenance activities; report any empirical data concerning the structural BMP behaviour (e.g., variation in the amount of solids transported to the system and consequences for the foreseen maintenance routines); report on unusual events (e.g., accidental spillages of substances on the road pavement draining to the system).
Monitoring	Report should contain: methodologies used; description of equipment; pictures of the site and equipment, procedures used to handle and conserve the samples; results; critical discussion of results, comparison with the target treatment efficiencies; recommendations for future monitoring; recommendations to rehabilitate part of the system (if needed).

(Barbosa and Fernandes, 2009)

[12] BMP – Best Management Practices

5 | CONCLUSIONS

This report presents a review of the state-of-the-art on the current practices for road runoff pollution control in Portugal and Slovenia, including a description of key road runoff pollutants based on the international literature, the legislation related to water bodies protection and road runoff discharges, the most common treatment systems and other methods to minimize the impacts in water resources.

This revision confirmed the need for more specific methodologies in order to improve the practice. Moreover, it was acknowledged that the approach for defining water bodies sensitiveness to road pollution, *i.e.* the areas that need to be protected, is different in the two countries, although some approaches may be considered similar. The difference is also a result of differences in the nature of the surface water bodies and groundwater in Portugal and Slovenia.

A new common methodology for identifying water bodies sensitive to road runoff pollution is proposed, based on the evaluation of both methodologies. It aims at defining the water body sensitiveness to road pollution based on the intrinsic characteristics of inland (surface and groundwater), transitional, and coastal waters. This methodology was applied to two case-studies in both countries (see Annex II): one near Albufeira (Southern Portugal), and the other close to the border between Slovenia and Italy, near Trieste city. The methodology allowed the classification of the case-study areas as: sensitive, non sensitive or requiring further studies. The common methodology proved to be expeditious and easy to apply with information generally available. It is also more easily understood by anyone, because it is not tied up to specific characteristics for Portugal or Slovenia.

Finally, in the last chapter, a set of recommendations for good practices for controlling road runoff pollution is proposed, aiming at more efficient protection measures to be implemented at different stages of the road life.

Lisbon and Ljubljana, June 2010

LNEC Groundwater Division

AUTHOR

Teresa E. Leitão

Ph.D. in Hydrogeology
LNEC Senior Research Officer with Habilitation

VISA

J.P. Cárcomo Lobo Ferreira

Head of the Groundwater Division

LNEC Water Resources and Hydraulic Works Division

AUTHOR

Ana Estela Barbosa

Ana Estela Barbosa

Ph.D. in Biotechnology and Environmental Engineering
LNEC Research Officer

VISA

João S. Rocha

Head of the Water Resources and Hydraulic Works Division

Rafaela de Saldanha Matos
Head of the Hydraulics and Environment Department

Ljubljana University and Geological Survey of Slovenia

AUTHOR

Mihael BRENČIČ

Ph.D. in Geology
Professor at Department of Geology, Ljubljana University, Slovenia
and Department of Hydrogeology, Geological Survey of Slovenia

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Annex I

Criteria for delimitation of protection zones around groundwater points intended to public supply

Decree-Law No. 382/99 of 22 September 1999 establishes criteria for delimitation of protection zones around groundwater points intended to public supply, and proposes a Calculated Fixed Radius (CFR) method that considers six types of aquifer systems: confined porous (Type 1); unconfined porous (Type 2); semi-confined porous (Type 3); limestone (Type 4); aquifer consisting of igneous or metamorphic fissured formations (Type 5); aquifer consisting of igneous or metamorphic poorly fissured formations (Type 6). For these six aquifer types, minimum values of the required protection zones (when there are no hydrogeological studies and it becomes necessary to use the suggested method) are presented in Table A.1.

Table A.1 - Minimum value of protection zone radii when using the CFR method

Type of aquifer system	Immediate zone	Intermediate Zone	Extended zone
Type 1	r = 20 m	r = largest value between 40m and r_1 (t =50 days)	r = largest value between 350m and r_1 (t =3500 days)
Type 2	r = 40 m	r = largest value between 60m and r_2 (t =50 days)	r = largest value between 500m and r_2 (t =3500 days)
Type 3	r = 30 m	r = largest value between 50m and r_3 (t =50 days)	r = largest value between 400m and r_3 (t =3500 days)
Type 4	r = 60 m	r = largest value between 280m and r_4 (t =50 days)	r = largest value between2400m and r_4 (t =3500 days)
Type 5	r = 60 m	r = largest value between 140m and r_5 (t =50 days)	r = largest value between 1200m and r_5 (t =3500 days)
Type 6	r = 40 m	r = largest value between 60m and r_6 (t =50 days)	r = largest value between 500m and r_6 (t =3500 days)

The value of r_i is a variable distance that can be calculated (Figure A.1) using the following equation:

$$r_i = (Q\ t) / (\pi\ n\ b) \qquad (1)$$

where:

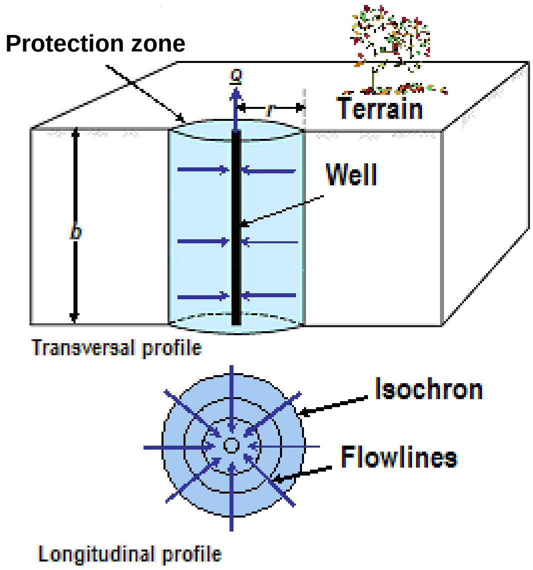
r_i - is the radius of protection perimeter (*m*),

Q - is the extraction rate (m^3/day),

t - is the necessary time for a pollutant to enter the well (days),

n - is the effective porosity and

b - is the saturated thickness in the well (m)



(from EPA, in Moinante, 2003)

Figure A.1 - Protection perimeter using the CFR method suggested by Portuguese Law

The limitation of this method is that it does not take into account regional groundwater flow, causing a hydraulic gradient. It thus can only be applied in situations where a (near-) horizontal initial (before pumping) water table is present. The cone of depression resulting from pumping will then be a circle around the well and with equation (1) the radius of the circle can be calculated, corresponding to a travel time distance of 50 days.

The consequence of this is that by using this method and in situations with a non negligible hydraulic gradient, the calculated perimeter of a protection zone may be inadequate on the upgradient side, while on the downgradient side the extension of the zone is over dimensioned. This may involve an overprotected downgradient area with unnecessary economic consequences, while the other side is under protected resulting in an increased danger of pollutants entering the well.

Krijgsman and Lobo-Ferreira developed a method for the assessment of the intermediate protection zone (t = 50 d) as an alternative to hydrogeological studies referred to in the Portuguese legislation. Using this method one can quickly and without much effort give ranges of perimeters for the required protection zones. This methodology is for use in unconfined aquifers, since these are the most directly vulnerable to pollution.

According to Krijgsman and Lobo-Ferreira (2001), the 50 days protection zone has an ellipse-shaped form which will be more like a circle when the hydraulic gradient is smaller. These authors suggest the use of three equations to calculate the dimensions of the three protection distances of the intermediate zone (r_{max}, r_{min} and r_p) (Figure A.2).

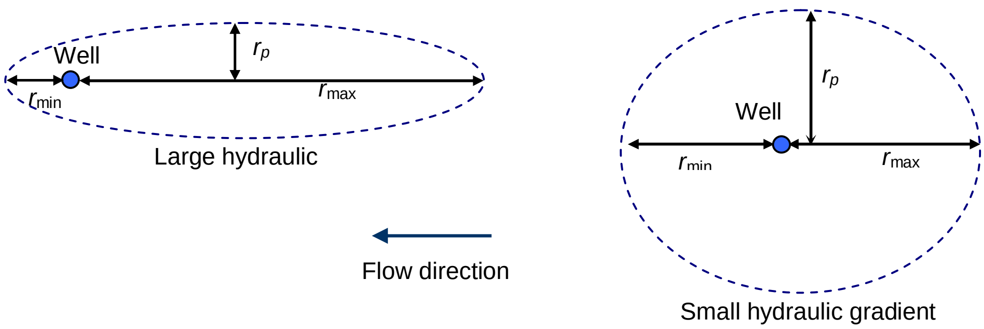


Figure A.2 - Intermediate protection zone in extreme situations of hydraulic gradient (from Krijgsman and Lobo-Ferreira, 2001)

Upgradient protection distance :

$$r_{max} = (0.00002\, x^5 - 0.00009\, x^4 + 0.015\, x^3 + 0.37\, x^2 + x) / F \qquad (2)$$

Downgradient protection distance:

$$r_{min} = (-\,0.042\, x^3 + 0.37\, x^2 - 1.04\, x) / \mathrm{F} \qquad (3)$$

Protection distance perpendicular to flow direction:

$$r_p = 4\, (Q / n\, b)^{1/2} \qquad (4)$$

with $x = 2\, K\, i\, [(\pi\, b\, t) / (Q\, n)]^{1/2}$ and $F = (2\, \pi\, K\, b\, i) / Q$ (5) and (6)

Limitations on the use of these equations:

r_{max}: do not use combinations of parameters resulting in a value of $x > 18$;

r_{min}: if $x < -3.5$ apply a minimum protection distance of 25 m; do not apply equation (3) with values of effective porosity < 0.1 (10%).

In fact, the 50 days protection zone is never a perfect ellipse, especially in cases with large hydraulic gradients. The more the area resembles a circle, the better the estimation will be. Krijgsman and Lobo-Ferreira (2001) suggest a modification of the ellipse on its upgradient side, by drawing a circle on the edge of the ellipse with a radius equal to r_p (Figure A.3)

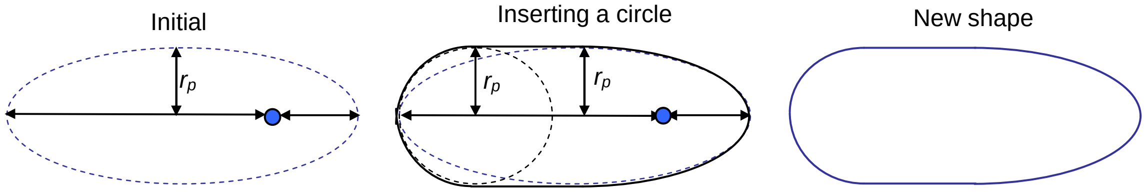


Figure A.3 - Modification of the upgradient limit of the ellipse (from Krijgsman and Lobo Ferreira, 2001)

The Portuguese agency IRAR commissioned National Laboratory for Civil Engineering (LNEC) to publish a Technical Guide (Lobo-Ferreira *et al.*, 2009) establishing uniform criteria and methodologies for definition of protection zones around surface and groundwater bodies, to be used by all entities who have responsibilities on groundwater water supply systems. The Technical Guide incorporates some advises and methodologies to represent surface water and groundwater vulnerability and risk and methods to delineate wellhead protection zones:

- Calculated Fixed Radius (analytical method suggested by Portuguese Law)
- Krijgsman and Lobo Ferreira (analytical method developed to calculate intermediate protection zone dimensions)
- Wellflow (mathematical method) (Feseker and Lobo-Ferreira, 2001)
- USGS Method (Eimers *et al.*, 2000) (http://water.usgs.gov/pubs/wri/wri994283/)
- WRASTIC Index (http://www.nmenv.state.nm.us/dwb/Documents/SWAPP_2000.PDF)

The referred methodologies were developed under several studies carried out by LNEC. As an example, the extended zones (considering t = 3500 days), around groundwater wells are shown in Figure A.4, obtained by the ASMWIN mathematical model (Moinante, M.J. and Lobo-Ferreira, 2005).

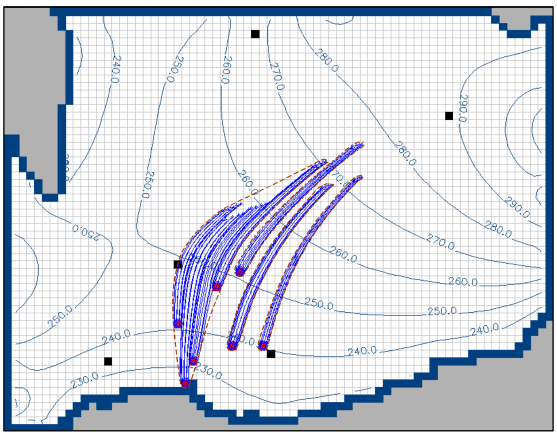


Figure A.4 - Pathlines for *t* = 3500 days (extended protection zones)

Annex II

Definition of areas sensitive to road pollution

Case study of comparison between Portuguese and proposed common methodology

In the frame of the project "Identification and Protection of Water Bodies Sensitive to Pollution from Transport Infrastructure" some of the methodologies applied and proposed in this report were tested by Miriam Rot, guest student at LNEC in the period between September and December 2009. The results of that work are being applied in the student's bachelor thesis at Department of Geology, Natural Science and Engineering Faculty, University of Ljubljana.

During the work, the existing Portuguese methodology (Leitão *et al.*, 2005) and the proposed new Common Methodology, as defined in this report, were applied to testing areas of Portugal and Slovenia. They were selected according to the traffic characteristics of roads, and for similar geological and hydrological conditions. In both cases the methodologies were applied in karstic areas where carbonate aquifers are present. This had the intention of illustrating interesting hydrogeological features and to test methodology on areas very sensitive and vulnerable to pollution coming from road infrastructure and road traffic. Both regions have only few surface flowing streams and therefore precipitation directly infiltrates into the soil.

The information applied for this study was obtained through Portuguese and Slovene governmental agencies, surveys, as well as other data sources dealing with environmental information that can be easily available. The methodologies were applied with the help of ArcGIS 9.3 software.

The testing site for Portugal is located in the Algarve region, between the cities of Silves, Lagoa and Albufeira. The area is consisting of a large karstified carbonate aquifer system Querença – Silves, which is composed of Jurassic formations. The aquifer system has an opened to confined hydrodynamic character (Oliveira *et al.*, 2008), and it is of great importance for the water supply at the coastal region of Southern Portugal.

The testing site in Slovenia is located in its southwestern part, along the highway from the Razdrto (central east Slovenia) to the direction of the Adriatic Sea coast. Geology of the area is represented by Cretaceous and Palaeocene carbonates with the stratigraphical thickness of more than several thousand meters intervened with low permeable Paleogene flysch deposits. The carbonates are forming a large karstic aquifer with an unconfined hydrodynamic character. The aquifer system is very vulnerable and sensitive.

The Portuguese methodology for the definition of sensitive areas to pollution originating from roads is based on physical information about the geology, hydrogeology, soil and land cover characteristics and topographical information. Furthermore, it takes into account the national legislation constraints and water bodies' protection measures concerning road pollution.

The results of both applications are shown in the maps presented in Figure A.5 to Figure A.8. On the maps, sensitive areas are represented in red, areas needing further evaluation are represented in yellow and non sensitive areas are represented in green colour.

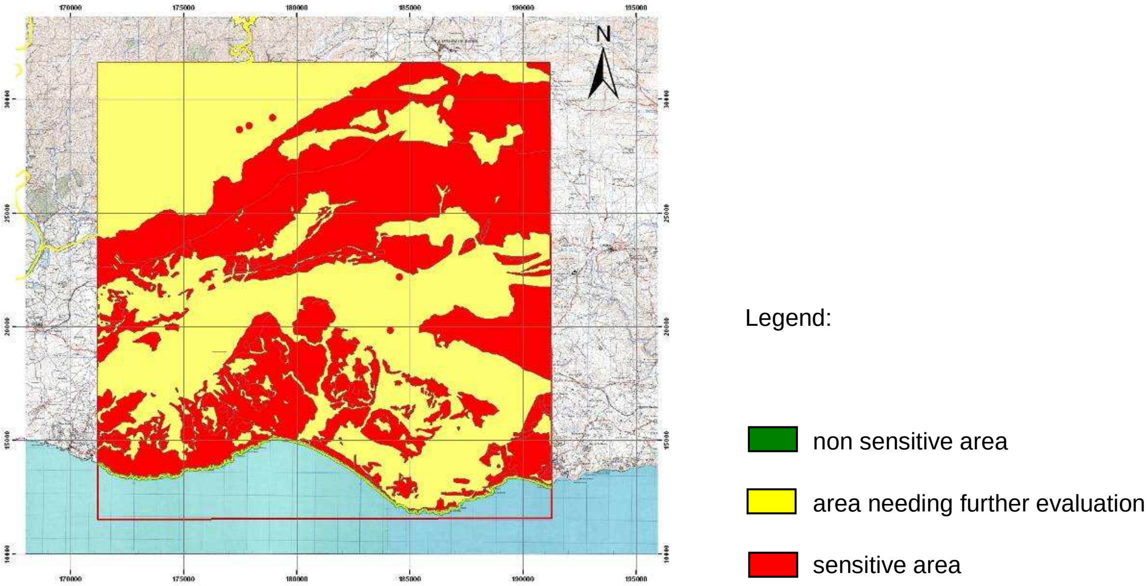


Figure A.5 - Portuguese methodology applied to Querença – Silves aquifer

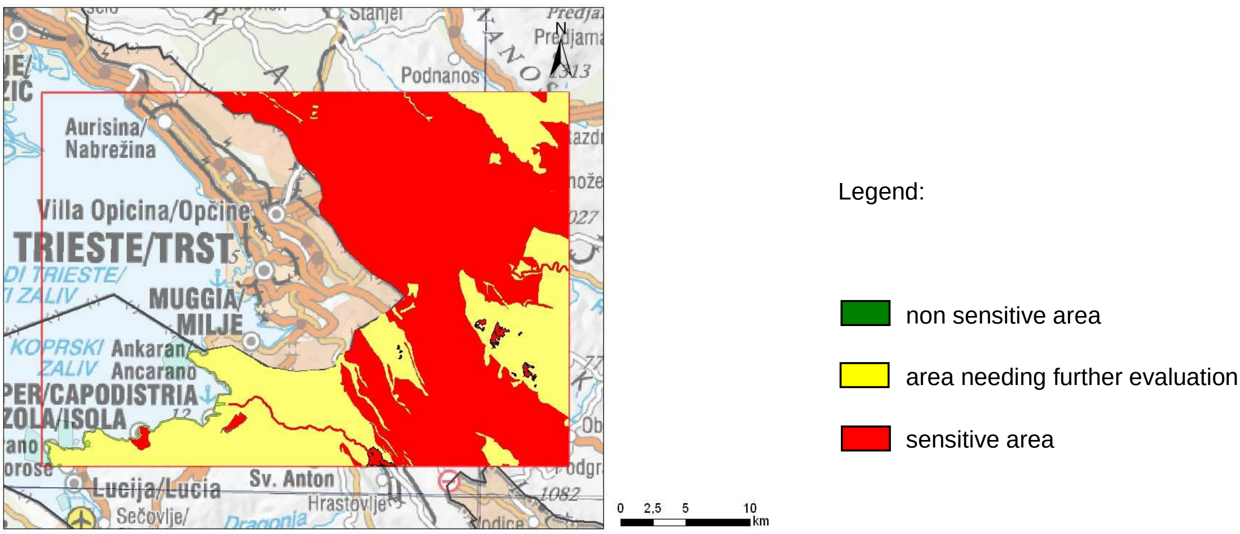


Figure A.6 - Portuguese methodology applied to SW Slovenia

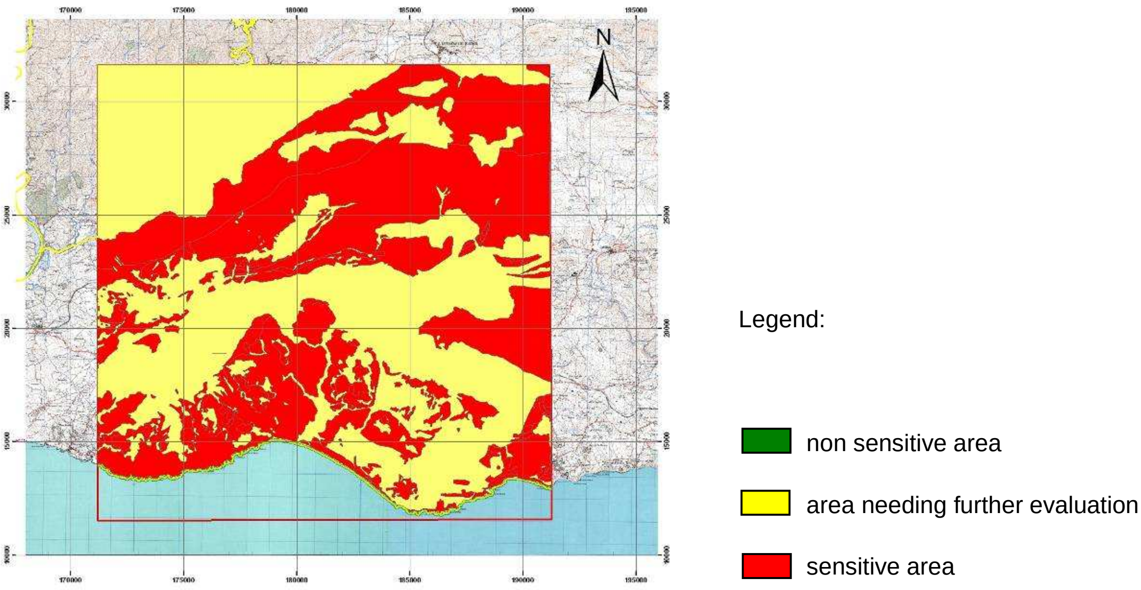


Figure A.7 - New Common Methodology applied to Querença – Silves aquifer

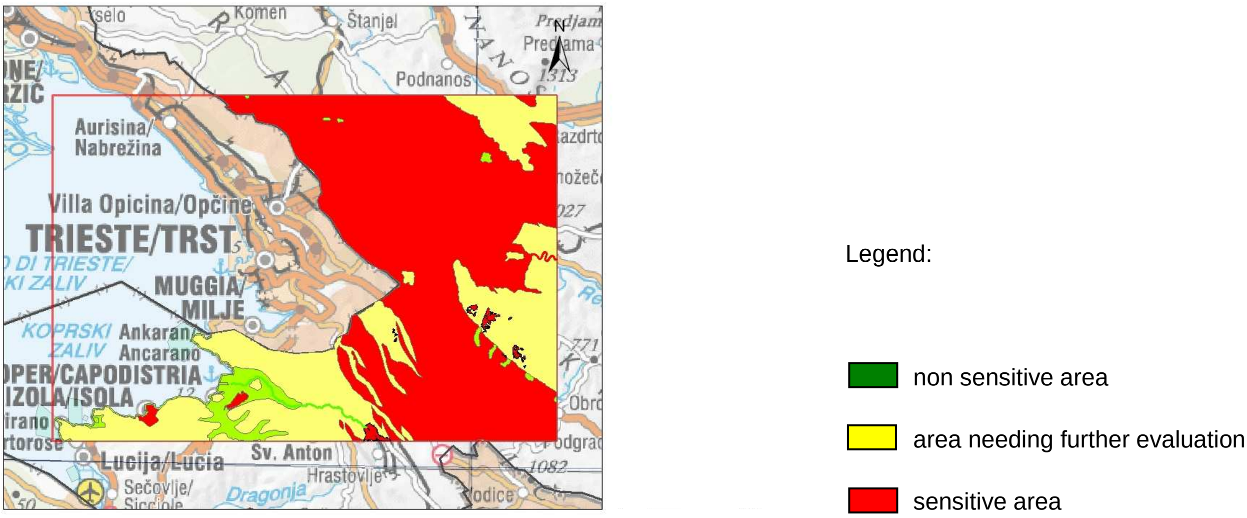


Figure A.8 - New Common Methodology applied to SW Slovenia

For the Portuguese case study, the results presented in Figure A.5 and Figure A.7 are very similar. The only difference is in the application of both methodologies to springs. In the new Common Methodology springs are not classified as sensitive. Spring areas are coloured as yellow and require further consideration. In the Portuguese case study, the new methodology is directly applicable and similar to the already applied methodology defined by Leitão *et al.* (2005).

The comparison of the final maps produced using both methodologies for SW Slovenia area, presented on Figure A.6 and Figure A.8, show some differences. According to the Portuguese methodology, non-sensitive areas are not present. They are present only according to the new Common Methodology. Due to the available knowledge green areas are mainly correctly defined in the coastal region. In the eastern part of the map where small patches of green colour are present interpretation must be reconsidered. These areas are representing ponor valleys – sinkholes in karst geomorphology where water enters the underground. These small areas are showing weakness with the applied new methodology. The comparison of the final maps produced for the SW Slovenia area, using both methodologies, are presented on Figure A.2 and Figure A.4. Their comparison shows some differences.

The comparison of the two methodologies shows differences on the data required for the production of the sensitivity maps. The Portuguese methodology is very specific and requires information that is sometimes not applied to Slovene case because they are not relevant from the legislative or nature characteristics point of view.

For the proposed graduation work of Miriam Rot, the interpretation and data analysis will be further developed. Existing Slovene methodologies will be applied to both case study sites. Based on the additional interpretation all methodologies will be compared and discussed.

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prepared by:

Miriam Rot, Mihael Brenčič and Maria José Henriques