AN INDICATOR SYSTEM FOR SURFACE WATER QUALITY IN RIVER BASINS

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ABSTRACT

Public utilities, agricultural and industrial economical sectors and ecosystems depend on the water supplied by the natural environment. These water needs, the European Water Framework Directive requirements and the key surface water pollution problems identified at a River Basin scale, lead to the development of a water quality indicator system for surface waters. This is an environmental tool, which allows the assessment of the pressure-state-impact of human activities on surface water quality.

This paper presents a methodology based on the conceptual model Pressure State Response, and on an environmental description of the Portuguese Ave River Basin, based on chemical and hydro-morphological water quality elements, due to the lack of information regarding biological elements.

It is shown that the most relevant questions for the implementation of an indicator system for the surface waters of this river basin are: eutrophication, contamination by bacterias, presence of organic mater, oxidation state and organic metals emission.

Key words Ave River Basin; European Water Framework Directive; Water Quality Indicators; Water Resources Management; Surface Waters.

INTRODUCTION

Water resources planning and management suffered an evolution towards integrated management between water itself and other surrounding resources, as soil use and forest. The main objective of water resources planning is that there is enough quantity of water available, as well as water quality, so that its use can be effective.

The European Water Framework Directive (EWFD) establishes a common framework for sustainable and integrated management of natural waters. This implies a tight connection between technical water management bodies and instruments of analysis for decision making (Vieira, 2003). One of the objectives established for 2006 by the EWFD is the intercalibration of reference conditions and quality criteria, simultaneously with the standardisation of methods for sampling and analysis. Intercalibration allows the interpretation of the class boundary definitions, showing how slight, moderate, major and severe alterations from reference conditions can be quantified (Nõges, 2003).

The definition of instruments for water resources planning and management is based on an environmental information system, collected by data monitoring, after the analysis by previously established methodologies. Data monitoring programs need to be implemented in order to allow the correct comprehension of the phenomena related with environmental values and to establish the criteria for management decision making.

The surface waters, the lakes and their river basins are an indivisible unity, so their management has to be made together. A River Basin is usually submitted to many pressures, including human pressures, and many changes, due to its use and to Human activities. These activities are one of the most important causes of the degradation of water quality, which can become dangerous for the public health. At a river basin scale there is the need to establish a methodology for systematic data monitoring, for the characterization of the superficial water quality and for the correct analysis of collected data, so that the actual and expected future problems and originated pressures may be identified and understood. Assessment of pressure-state-impact interaction can be facilitated using environmental indicator tools.

This paper intends to be a contribution to the development of an answer to this question, in the case of superficial waters. The environmental indicators are parameters or derived values, which describe or give information about a phenomenon (Silva, 2002). The application of the concept of environmental indicator to a river basin is new and limited, due the specificity of these systems.

The methodology that will be developed is based on the conceptual model PSR (of the original designation ***P****ressure,* ***S****tate,* ***R****esponse),* with the main objective of defining final values for the indicators. The proposed methodology will be applied in the Ave River Basin (ARB), in the northwest of Portugal, focused on the selection of an adequate system of indicators. The environmental description of this River Basin will be based only on two quality elements: chemical and hydro-morphological elements, due to the lack of information regarding biological elements.

The organization of the paper is the following. A review of environmental indicator systems is made in the following section. The methodology used to construct a system of indicators is presented in Section 3. Section 4 presents the case study and the results obtained. Section 5 is the final section, with the main conclusions of this work.

INDICATOR SYSTEMS FOR SURFACE WATER QUALITY

The characterization of environmental status, as well as the effects of pollution in rivers, was initiated at the beginning of the 20th Century, with the use of biological indicators (Silva, 2002). But, the methodologies proposed to characterize the quality of superficial waters at a river basin scale remain few and under explored.

Environmental indicators are a subset of the environmental variables usually observed, normalised or integrated over time and space, and contextualized with reference values and objective values, to be accomplished in a specific moment of time (Silva, 2002). Accordingly to OCDE [1], an indicator should be characterized by its relevance, consistency and measurability (DROTRH, 2001).

Environmental indicators are one of the available tools for environmental quality evaluation, and should be analysed inside their own context. An indicator may have different meanings under different conditions, so it should be analysed under a specific regional, social or economical context. An adequate choice of the environmental indicator to be used is one of the main procedures of the selection process.

In the European Union, EUROSTAT [2] proposes a system of indicators for the characterization of the human activities with major negative impact in the environment (Lammers & Gilbert, 1999). There have been chosen indicators for problematic areas, under pollution, climate changes and biodiversity problems.

Under the EWFD, there have been suggested pilot case studies for the construction of a water quality indicator system. In the Netherlands the concept of environmental indicators, has been used for long time. The periodic publication of the "Dutch Water Policy Documents", about water quality and planning aspects, intends to define marks and verification criteria about water quality and management. In the United Kingdom, methodologies about characterization of the aquatic system were developed. In Scotland, there are already in practice procedures which can be applied to fresh waters. In France, the priority themes for the environmental characterization are associated to public health and environmental balance. In this country, for surface fresh waters, was defined a global quality indicator. In Lake Peipsi, in Estonia, the main objective of establishing an indicator system for rivers in Lake Peipsi Watershed was pursued (Nõges, 2003), including the river itself, and 32 potential biological indicators were evaluated, resulting in the reference values for a set of

[1] OCDE – Organisation for Economic Co-operation and Development

[2] EUROSTAT – Statistical Office of the European Communities

20 biological indicators. In Portugal, Mano and Santana (1990) presented an index system for the evaluation of superficial water quality. Their work resulted in a methodology for the characterization of the inner superficial waters quality (rivers and lakes), used for the elaboration of River Basin Plans, where the water quality parameters are aggregated accordingly to the expected water use, resulting in indexes that allow the definition of the quality class of a specific body of water. Water quality assessment using indicators and indexes can be found in transboundary rivers by Silva et al. (1994). The use of biological criteria for water quality assessment can be found in Graça and Coimbra (1998), Ferreira (1994 a, b), Ferreira et al. (1996) and Fontoura and Moura (1994).

EWFD Quality Elements for Rivers

The EWFD has added new elements in the normative definitions of ecological status classifications: high, good or moderate status, based on the quality elements defined in Table 1. The ecological status is classified under five degrees, which are qualitatively defined by the changes caused by human activities in quality elements. It should be pointed out that the quantification of this correspondence must be made, so that this law can be effectively applied. So, there is the need for the assessment of reference conditions and the quantification of the five quality classifications. There is also the need for intercalibration of these reference conditions and quality classification when comparing different member states, their climate and ecological conditions.

Table 1 Quality elements for the classification of ecological status of surface waters in rivers (EWFD, 2000)

BIOLOGICAL ELEMENTS	HYDROMORPHOLOGICAL ELEMENTS SUPPORTING THE BIOLOGICAL ELEMENTS	CHEMICAL AND PHYSICO-CHEMICAL ELEMENTS SUPPORTING THE BIOLOGICAL ELEMENTS
• aquatic flora (composition and abundance); • benthic invertebrate fauna (composition and abundance); • fish fauna (composition, abundance and age).	• Hydrological regime (quantity and dynamics of water flow; connection to groundwater bodies); • River continuity; • Morphological conditions (river depth and width variation; structure and substrate of the river bed; structure of the riparian zone).	• General (Thermal conditions; Oxygenation conditions; Salinity; Acidification status; Nutrient conditions); • Specific pollutants (Pollution by all priority substances identified as being discharged into the body of water; Pollution by other substances identified as being discharged in significant quantities into the body of water).

Criteria for the Selection of an Environmental Indicator

The choice of an indicator should result from the application of the following criteria (adapted from Silva (2002) and Nõges (2003)):

a) The indicator must be quantitative, widely and cost-effectively measured in different measuring programs;

b) The indicator must be of easy construction, based on data accessed in reliable conditions;

c) The indicator must be officially accepted as a good indicator of water quality, and requires valid water quality standards;

d) The indicator must characterize the main water protection problems, being sensitive to management actions, so that its values may reflect the political and management measures undertaken;

e) The indicator must describe common the health and functioning of the ecosystem, as well as types of pollution in the country, being sensitive to the pressures due to the use, and be sensitive to spatial and temporal variability;

f) The indicator should be able to give information about the evolution trends, either past or future.

g) Standard methods for analytical measurements must be available (ensures reliability and comparability of data);

h) Precision and accuracy of analysis must be maintainable to ensure validity of results;

Conceptual Model PSR

There are several conceptual models of system of indicators for environmental quality analysis (Silva, 2002). The most widely accepted framework for environmental indicators is based on PSR model (Nõges, 2002), adopted by OCDE and EUROSTAT for the characterization of the environmental status (Silva, 2002).

The conceptual PSR model seeks to develop indicators which highlight the causal links between human activities, subsequent changes in the state of the environment arising from these pressures, and the responses of the society to these changes (Lammers & Gilbert, 1999). This model is elaborated after the definition of three broad types of indicators of: pressure, state and responses (DROTRH, 2001), which should reflect the relationship between environmental effects, their causes and the measures taken (Nõges, 2002). The pressure indicators aim to describe pressures from human activities exerted in the environment. The state indicators are designed to describe the actual condition of the environment changes over time. The response indicators show the extent to which society is responding to environmental change and its concerns (Lammers & Gilbert, 1999). The indicators that are chosen reflect the relationship between environmental effects, and/or their causes and measurements taken (Nõges, 2003).

The DPSIR model (***d**riving forces, **p**ressure, **s**tate, **i**mpact, **r**esponse*) can be considered a more sophisticated version of the PSR model (Nõges, 2002). This is a model of integrated environmental evaluation, that accounts for the fields of human activity responsible for generating pressures, i.e. ***d**riving forces*, and considers elements of the impact on the environment, that call for answers materialized in different sectors (macro-economical and politics actions). This models searches for the interactions between the environment and social-economical development, and is very useful in structuring the gathering of information. The state of the environment can not be understood unless the pressures that it is submitted to are understood (Silva, 2002).

METHODOLOGY

The construction of an indicator system and its application to a river basin requires the development of an adequate methodology to characterize its surface waters (Silva, 2002), which consists on the following procedures:

a) Identification of the items to be considered

The relevant items are related to the physical characterization of the case study, and their main uses (current and planned), such as point and non-point pollution. There should be taken into account the data available in the environmental monitoring of water quality, hydrometric and meteorological stations.

b) Conceptual Model to be adopted

The methodology that will be developed is based on the conceptual model PSR.

c) Selection of the parameters to be observed

For each item considered on first step, the next step consists on selecting the parameters associated to pressure, to state and to response indicators.

d) Definition of the descriptive references and the determinants

The descriptive reference values are the natural characteristics of surface waters, i.e., water with high quality, which expresses background values of river water not influenced directly by human activity. These values are transformed into indicators, when they are significant and enable to judge the system.

e) Definition of the reference conditions and objective values

The reference values for different parameters are obtained in different ways, depending on the availability of data. In others, collected data environmental monitoring or from specific studies have been used (Nõges, 2003). The objective values are usually between the observed values and the reference values.

f) Characterization of the case study

The environmental description of Ave River Basin will be based on two quality elements: chemical and hydro-morphological elements, due to the lack of information regarding biological elements. These elements will provide the significant values, according with the proposed in the EWFD.

g) Dimension removal and normalization of the significant values determined on the previous step

This step consists on the dimension removal and normalization of the significant values, applying algebraic and graphical operators. After this, it is possible to establish the concordance with the desired environmental quality (Silva, 2002).

h) Definition of the class boundaries based on the selected indicators. Applicability to case study

According with EWFD, the class boundaries in quality classification are set using five ecological quality ratios (ERQ), i.e., a numeric index showing the degree of deviation of any studied parameter from the initial reference value (Nõges, 2003). Extent of deviation is usually classified on a 5-level scale. These class boundaries are related on the Table 2, which provides a general definition of ecological quality.

Table 2 General definition of ecological status for rivers (adapted from EWFD, 2000)

ECOLOGICAL STATUS	LEVEL	HUMAN ACTIVITY EFFECTS	GENERAL DEFINITION
HIGH STATUS	**I**	**MINIMAL**	There are no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions. The values of the biological quality elements for the surface water body reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion.
GOOD STATUS	**II**	**LIGHT**	The values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions.
MODERATE STATUS	**III**	**STRONG**	The values of the biological quality elements for the surface water body type deviate moderately from those normally associated with the surface water body type under undisturbed conditions. The values show moderate signs of distortion resulting from human activity and are significantly more disturbed than under conditions of good status.
POOR STATUS	**IV**	**SEVERE**	Major alterations to the values of the biological quality elements for the surface water body type and

ECOLOGICAL STATUS	LEVEL	HUMAN ACTIVITY EFFECTS	GENERAL DEFINITION
			in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions.
BAD STATUS	**V**	**VERY SEVERE**	Severe alterations to the values of the biological quality elements for the surface water body type and in which large portions of the relevant biological communities normally associated with the surface water body type under undisturbed conditions are absent.

Usually, the class boundaries are defined by the indicator that reveals the “worst” environmental situation.

CASE STUDY – THE AVE RIVER BASIN (ARB)

Characterization

The ARB is located on the northwest of Portugal (Fig. 1) and has an area of about 458 km^2, 247 km^2 belonging to the River Este Basin and 340 km^2 belonging to River Vizela Basin, the two most important rivers of this river basin.

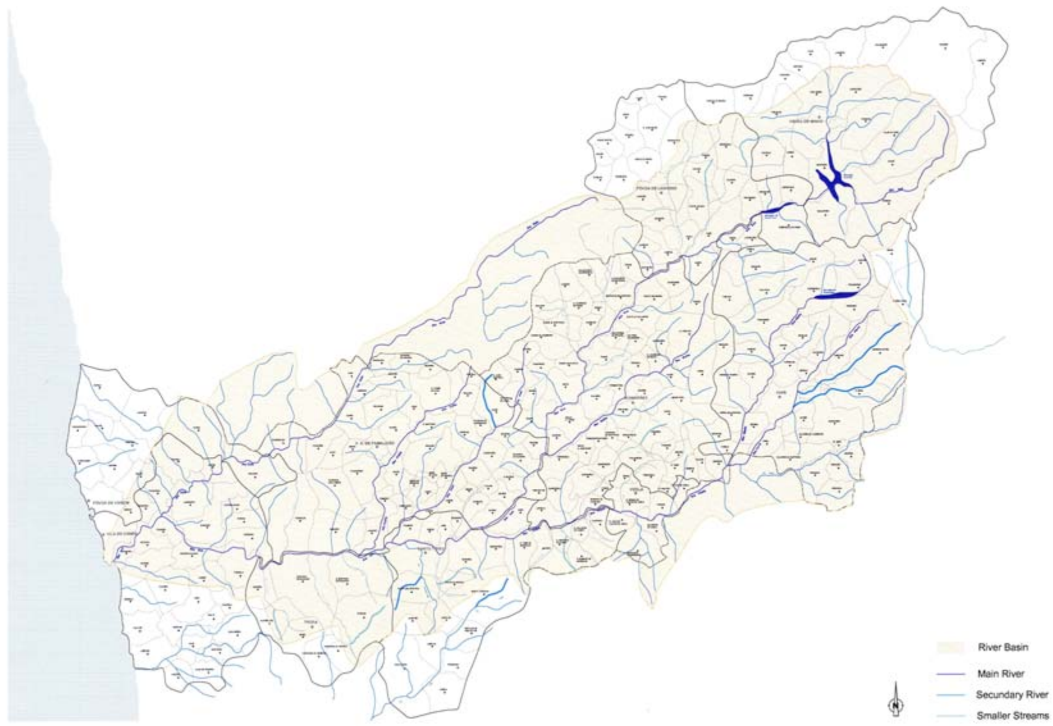

Fig. 1 Ave River Basin.

For the past thirty years, the River Ave main watercourse has been subjected to multiple discharges of wastewater, without previous treatment, due to strong industrial textile activity. This situation causes the deterioration of the water quality, resulting in water that is not only inappropriate for several uses, such as water supply for domestic and industrial use, recreation uses, fishery and irrigation, but also dangerous for the public health.

Due to these extreme pollution problems the Integrated Management Commission of the ARB was created in 1985, with the purpose of studying, planning and executing the necessary measures to the correct management of water resources in ARB. As a result, the "SIDVA – Sistema Integrado de Despoluição do Vale do Ave" was created, involving municipals, economic agents and the state himself. Later, in 1997, this system initiated his activity, with the purpose of rehabilitating the ARB. The SIDVA infra-structures were developed based on a River Basin Scale, on an integrated and mutual solution of collecting and wastewater treatment, composed by three main collecting systems and three Water Treatment Plants located on the most polluted area of ARB.

The main surface water quality problems in ARB are the organic pollution, turbidity and colour problems, due to domestic and industrial discharges in the water courses which have subjected to insufficient treatment; the eutrophication; the pollution caused by harmful substances – specific pollutants, heavy metals and organic metals emissions and other problems with natural phenomena, such as the high content of organic substances.

Available Data

The present work is based on collected data from environmental monitoring (water quality and quantity), i.e. data collected from 24 water quality stations (actually, data is being received from only nine stations, because, fifteen of these stations are recent, only started collecting data on January 2005), 8 hydrometric stations and 18 meteorological stations. These stations are classified according to the Table 3.

Table 3 Characterization of Water Quality Stations located on ARB, in December 2004

CODE	WATERCOURSE	STATION NAME	GOAL	TYPE
AV1	Ave	Cabeçeira do Ave	Reference, Fishing Waters	Conventional
AV2	Pequeno	Foz do Pequeno	Fishing Waters	Conventional
B5	Vizela	Golães	Catchment	Conventional
B6	Vizela	Vizela (Santo Adrião)	Catchment, Fishing Waters	Automatic + *On-line* + Conventional
B8	Ave	Taipas	Catchment, Fishing Waters	Conventional
B15	Ferro	Ferro	Catchment, Fishing Waters	Conventional
G3	Ave	Riba d'Ave	Impact	Conventional
G4	Ave	Santo Tirso	Impact	Conventional
F1	Ave	Ponte da Trofa	Impact, Flux	Conventional

Special distinguish deserves the "catchment stations" and the "impact stations", located after the current and future Water Treatment Plants.

Items to be considered

The identification of the items to be considered obeys to a number of criteria, related with legal obligation and its relation with ecological status, aquatic life and public health. This selection is also related with the main pollution problems existing in ARB. Based on the work by Silva (2002), the list of relevant items was completed for this case study, resulting on Table 4. The selection of the items has in consideration the existence or not of data, there so, the default of data limits the possibility of the implementation of a system indicator.

To fulfil the objectives proposed, i.e, implementation of an indicator system of surface water quality of ARB, long term hydrological, physical and hydro-chemical data of ARB were collected. The data base contains data on flow rates, precipitaton, behind others, and on about 47 chemical parameters for ARB since 1996.

Table 4 Relevant Items and selection criteria

ITEM	CRITERIA				
	LEGISLATION	RELEVANCE		AVAILABLE DATA	FINAL RESULT
		ECOLOGICAL	PUBLIC HEALTHY		
Eutrophication	+ (d), (f), (g)	+	-	+	+
Contamination by Bacterias	+ (b), (a), (f), (g)	-	+	+	+
Oxidation State	+ (f), (g)	+	-	+	+
Emissions of Organic Matter	+ (f), (g)	+	-	+	+
Heavy Metals and Organic Metals Emissions	+ (c), (a), (f), (g)	+	+	+	+
Esthetic Quality (Colour)	+ (f), (g)	+	-	- /+	-
Habitats Integrity	+ (e), (g)	+	-	-	-
Hydrological Regime	(g)	+	-	+	+
Morphological Conditions	(g)	+	-	+	+

(a) Directive 75/440/EEC (EU Quality of Surface Water used for Drinking Water Directive)
(b) Directive 76/160/EEC (EU Bathing Waters Directive)
(c) Directive 76/464/CEE (EU Discharges of Toxic Substances), plus sub-directives
(d) Directive 91/271/CEE (EU Urban Wastewater Treatment Directive) and Decreto-Lei 152/97, 15th September (Portuguese Law)
(e) Directive 92/43/CEE (EU Conservation of Natural Habitats and of Wild Fauna and Flora Directive)
(f) Decreto-Lei 236/98, 1st August (Portuguese Law)
(g) Directive 2000/60/CEE, 23rd October (EU Water Framework Directive)

According with the criteria showed on Table 4 and with data available, the most relevant questions, to the case study, are: eutrophication, the contamination by bacterias, the presence of organic mater, the oxidation state and heavy and organic metals emissions.

After identified the items to consider and bearing in mind the Conceptual *PSR Model*, its possible to build the Table 5, where is showed the selected variables and associated indicators: pression, state and response indicators.

CONCLUSIONS

The construction of an indicator system and its application to a river basin requires the development of an adequate methodology to characterize its surface waters, which consists on a number of procedures, namely, the identification of the items to be considered related with physical characterization of the case study, the ARB, and their main uses and problems, specifically, source/point and non-point pollution; the adoption of the *PSR* conceptual model; the selection of correct parameters and consequently the definition of the adequate values, enable to be comparable with the data bases available – the reference values and objective values (the environmental objectives) – and finally define the quality class boundaries.

ARB was chosen due to the pollution problems, which have been affecting it for the past four decades. To fulfil the proposed objectives, long-term hydrological, physical and hydro-chemical data of ARB river basin were collected. The database contains data on flow rates, precipitation, behind others, and on about 47 chemical parameters for the case study since 1996.

Related with the parameters selection, the most relevant questions to the case study are: eutrophication (total nitrogen and phosphorus indicates the eutrophication and trophic level of waters), the contamination by bacterias (as indicator of faecal pollution and also organic pollution, the concentration of coliforme and faecal bacteria and *salmonella* were the chosen parameters), the presence of organic mater (showed by the content of dissolved oxygen, chemical and biochemical oxygen demand), the oxidation state, heavy and organic metals emission and esthetic quality (indicated by colour presence).

Table 5 Variables and indicators proposed

THEMATIC	PRESSURE	INDICATOR DEFINITION	STATE	RESPONSE
Eutrophication and trophic level	Total nutrient: Total Nitrogen (N) Total Phosphorus (P)	Load of nitrogen (N) and phosphorus (P) from land sources (domestic sources and economic sectors)	Dissolved Oxygen (mg O_2/l) Nitrate Nitrite Nitrogen Phosphates Chlorophyll a Pigments	• Increase the rate of wastewater treatment; • Provide an increase of the relation Water collected / water treated; • Raise connected industries with the total pollution content of treated wastewater; • Provide good practices on the application of pesticides and fertilisers in agriculture.
Contamination by Bacterias	Total and Fecal Coliforme Bacteria Fecal Streptococcus Bacteria	Quality requirements of drinking water due legal obligation and public healthy protection	Total Coliforme Bacteria Fecal Coliforme Bacteria *Salmonella* Fecal Streptococcus Bacteria	• Increase the rate of wastewater treatment; • Increase the efficiency of treatment.
Oxygen Balance	Biochemical Oxygen Demand (BOD)	Over-saturation and oxygen deficit may significantly influence ecosystem. Biochemical oxygen demand measures de oxygen demanding capacity of discharged wastewater	BOD Dissolved Oxygen (% Sat) Dissolved Oxygen (mg O_2/l)	• Increase the rate of wastewater treatment; • Increase the efficiency of treatment.
Heavy Metals and Organic Metals Emissions	Charge of Heavy Metails Charge of Organic Metails	The total discharge to aquatic ecosystems of heavy metals per metal (e.g. lead – Pb, chromium –Cr, copper – Cu, mercury – Hg, cadmium – Cd, zinc – Zn, arsenic – As) from all sources (industrial, agricultural, domestic).	Lead – Pb Chromium –Cr Mercury – Hg Cadmium – Cd Zinc – Zn Arsenic – As	• Raise connected industries with the total pollution content of treated wastewater; • Adopt "clean technologies" on industrial process
Organic Matter	Biochemical Oxygen Demand (BOD) Chemical Oxygen Demand (CQO)	Quantity of organic material discharged by human activities (domestic, industrial and agricultural).	Oxidable Organic Matter	• Increase the rate of wastewater treatment; • Increase the efficiency of treatment.
Esthetic Quality (Colour)	Colour	Colour Presence	Colour Presence (not visible on 1:20 dilution)	• Raise connected industries with the total pollution content of treated wastewater; • Adopt "clean technologies" on industrial process
Hydrological Regime	---	Quantity and dynamics of water flow	Minimal runoff: sanitary flow, natural flow and modified flow	---
Morphological Conditions	---	Dynamics of water	river depth and width variation Structure and substrate of the river bed; structure of the riparian zone	---

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