# Needs for integrated modelling from the point of view of the European Water Framework Directive implementation

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**ABSTRACT**

*The European Water Framework Directive (EU-WFD) introduces the aspect of integrated water quality management into water policy. In order to comply with standards formulated in the directive, calibrated and verified mathematical models for the assessment of system performances are required. Due to extensive research efforts over the last decade such integrated wastewater system models are available and ready to use. However, the general approach of the EU-WFD as well as the specific formulation of the standards make the unreflected use of existing models a dubious undertaking. The main problem is that standard models aim for other goal functions than specified in the EU-WFD. In this paper the needs and boundary conditions for such models are discussed from the point of view of the EU-WFD.*

## Introduction

The aim of the European Water Framework Directive (EU-WFD) is to achieve a “good status” for all water bodies. The definition of this status is based on ecological and chemical conditions. Thus common models of the urban water system have to be adapted to the new requirements. In order to do that it is necessary to set appropriate boundary conditions and change the goal functions. The Directive proposes a combined use of biological and chemical parameters which are difficult to model. Furthermore the suggested parameters are too many for the modelling. In order to allow a simplification of the problem it is necessary to reduce this number.

## Background

The current regulations to control the status of the environment use either an immission (water quality) or emission based approach. The first approach focuses on the receiving water quality and sets limit values for the allowed status independently of the pollution’s origin. The second one sets limits on the emission values of point sources. The control of CSOs is generally based on design criteria and/or operating conditions, which do not consider the impacts on the receiving waters. Generally in the EU states there are many different criteria for regulating the emission of CSOs, some consider the influence on the receiving water whereas others don’t (Zabel *et al.*, 2001). The EU-WFD implies the necessity to assess the impact of CSOs on the receiving water quality and the possibility to adopt a combined control methodology that takes into account both immission and emission considerations. The common interpretation of this concept is that the most stringent limit (between immission and emission) has to be adopted (Krebs, 2003).

To allow the classification of the water quality of European water bodies, each member state has to set reference and calibration sites. A reference site represents the high ecological status, whereas a calibration site represents the lower boundary of the good status. In Austria both, reference and calibration sites, have been proposed by the federal state authorities on the basis of their insight knowledge in the regions. Criteria for the choice of sites beside the appropriate water quality are the accessibility (i.e. sampling of fish has to be possible) and the availability of existing monitoring devices. The sites are currently still under revision, where final selection and approval is in the responsibility of the federal authorities.

## The needs for integrated modelling

A problem derived by applying the Directive is the definition of the "good status" considering biological together with chemical elements. The relation between pollution input and physical-chemical conditions in the receiving water is clear but the relation between impacts and biological conditions is still unknown. What kind of consequences entails the change of one of the chemical parameters on the biology and what is the relative importance of the single elements. One species can tolerate changes of a condition more than another. Only the knowledge of such relations allows the representation of the functional relationships in the system in an abstract form that is a mathematical model.

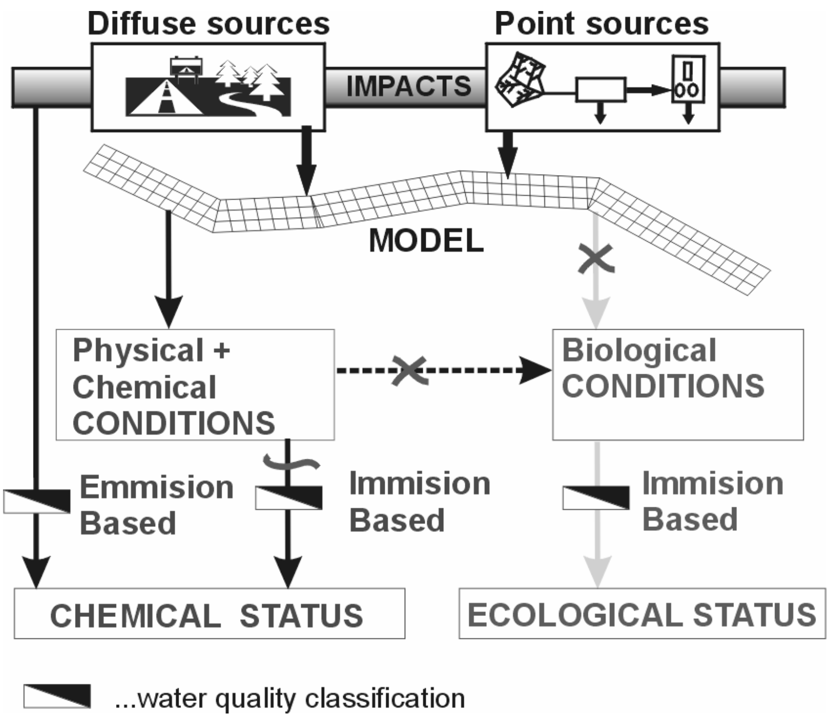


**Figure 1.** Relation between the chemical and biological standards given in the EU-WFD and the possible pathways of cause-effect relations.

Further, to handle biological parameters it has to be considered that the reactions of the organisms depend on different time and spatial scales. It is necessary to include not only acute toxicity but also accumulation processes in the simulation. It has to be considered that different organisms with different life times have different reaction times, relative to habitat changes. Short living biota like bacteria can react in hours, where effects on longer living species like fish can take years. It is also necessary that the regulations give standards not only based on concentration, but also on the return periods of such a concentration. A difficulty is that those standards are varying for different river types, populations and climatic conditions. An attempt to tackle these problems can be found in the "Urban Pollution Manual" (Foundation for Water Research, 1998) of Great Britain. The methodology developed in the UK sets different intermittent standards for the river types salmonid fishery, cyprinid and marginal cyprinid. The UPM procedure is designed for the protection of aquatic life, taking into account the duration of pollution impact as well as the frequency of occurrence. Given Maximum Concentration Limits (MCL) increase with increasing return periods, where they decrease at higher impact durations. Thus the approach considers recovering periods needed by the organisms after exposure to a certain pollutant of a certain level of duration.

a) Ecosystem suitable for sustainable salmonid fishery

| Return period | Un-ionised ammonia concentrations (mg $NH_3$-N/l) | | |
|---|---|---|---|
| | 1 hour | 6 hours | 24 hours |
| 1 month | 0.065 | 0.025 | 0.018 |
| 3 months | 0.095 | 0.035 | 0.025 |
| 1 year | 0.105 | 0.040 | 0.030 |

**Table 1**. Example of intermittent standards for un-ionised ammonia (Foundation for Water Research, 1998)

A further hindrance caused by the EU-WFD is the large number of parameters proposed for quality assessment. As each of the quality parameters constitutes a state variable in the model, the maximum number of those is limited in practice. A parameter reduction strategy istherefore urgently needed for integrated modelling. A possible solution is to identify the key contaminant for a single type-region. For each area the most important stress factors are to be identified and those that can be disregarded. Since various authors already suggested such an approach e.g. (Schilling *et al.*, 1997), (Borchardt and Sperling, 1997), it is only necessary to modify that consideration under the point of view of the EU-WFD.

| Type of receiving water | Location of catchment (slope) | Hydraulic disturbance | Oxygen depletion | Toxic $NH_3$-N | Formation of sediments |
|---|---|---|---|---|---|
| Creeks/small rivers | Hilly regions (High gradient) | +(++) | (+) | (+) | ? |
| | Lowland regions (Low gradient) | +(++) | (++) | (++) | (++) |
| Rivers/streams | Hilly regions (High gradient) | | | | ? |
| | Lowland regions (Low gradient) | | +(+) | +(+) | (++) |
| Impounded Rivers/streams (with phytoplancton blooms) | | | ++(+) | +(++) | +(+) |

(x: important; xx: very important; xxx: dominant; (): dependent on local conditions)

**Table 2.** Types of receiving waters and relative importance of impact parameters affected by urban stormwater runoff (Borchardt and Sperling, 1997)

## The case study Drau

A procedure to obtain the best suited parameters to describe the water quality status was developed within the case study on the alpine river Drau (see Figure 2), located in Austria. A part of this river was investigated for suitability as calibration stretch for alpine river conditions (Engelhard *et al.*, submitted 12/2003). At that site data on the emissions from the three wastewater treatment plants (WWTP) is available as well as data on water quality (M) and water level in the river (T). The dashed line in Fig. 2 is the bypass conduit supplying the hydropower station, so that the WWTP number 2 and 3 discharge in the residual water stretch. Due to these characteristics this site is appropriate to describe the interaction between urban wastewater and hydropower and their influence on the water quality. Such interaction between hydro power and wastewater is a typical configuration for an alpine river.

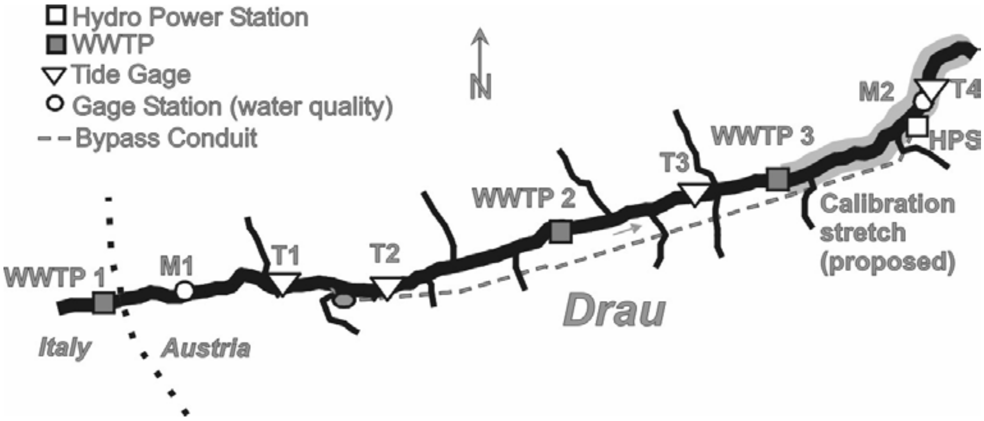


**Figure 2.** Schema of the analysed part of catchment.

The first step of the study was the collection of data about the plants of the analysed river basin part.

*Plants*

The stretch is influenced by emission of three WWTPs. The WWTP 1 (see **Figure 2**) located in Italy is the biggest and obviously had the largest impact on the river. The other two plants (WWTP 2 and 3) are situated in the low water stretch. Here the flow rate is directly influenced from the hydro power plant. Tide measures are available in all parts of the river, whereas water quality information only outside the low flow stretch. Further studies will try to calculate the water quality in this stretch too, in order to verify the effective impact of the plant in each flow situation.

| **WWTP** | **1 - Innichen-Sexten** | **2 - Anras** | **3 - Assling** |
|---|---|---|---|
| **State** | Italy | Austria | Austria |
| **Capacity** (PE) | 26.110 | 4.500 extension: 14.000 | 4.200 |
| **Completion** | 1999 | 1990 extension: 1999 | 1997 |
| **Connection rate** | | 85% | 90% |
| **Sewer system** | Separate system | Separate, combined system | Separate system |
| **Waste water** | predominantly communal | predominantly communal | 2/3 communal 1/3 industrially |

**Table 3**. Characteristics of the WWTPs in the studied site.

As mentioned before another factor disturbing natural conditions is the hydro power plant, situated on the right side of the **Figure 2**. Its intake is located between the gage stations T1 and T2, diverting the water to the bypass channel through a little storage lake.

*Morphology*

Due to the near rail- and roadway the river banks are mostly constructed. Along the river course anti-erosion devices are installed. Further the river continuity is not everywhere warranted. Strong impact is present due to high sediment loads introduced by lateral creeks. A study (Schöberl and

Reindl, 2002) demonstrated that the slow downstream sediment transport in the low water stretch is not influenced from the hydropower plant. The river presents naturally the tendency to deposit in the stretch until the second WWTP, namely the slope to this point is clearly lower.

*Hydraulic*
15 minutes data on the flow rate were collected for the years 2000 to 2002. They allow the recognition of the nival regime (influenced by snowmelt water) in which the largest flow occurs in the months May and June. Further the swell-sunk relation can be analysed to understand the dimension of the acceptable flow rate variations. The fact that the biological water quality status always was assessed as moderately polluted (see later) and that the stretch was proposed as calibration stretch allows the assumption of this swell-sunk value as acceptable. The calculated value in a representative day was 5:1. On the basis of data from 1999 to 2001, the swell-sunk ratio (SSR) was analysed using daily min/max values. In mean the SSR was 1:4.2, where the 95% percentile was 7.2. The SSR of 1:5 was exceeded in 31% of the days during the evaluation period. (calculation from TIWAG).

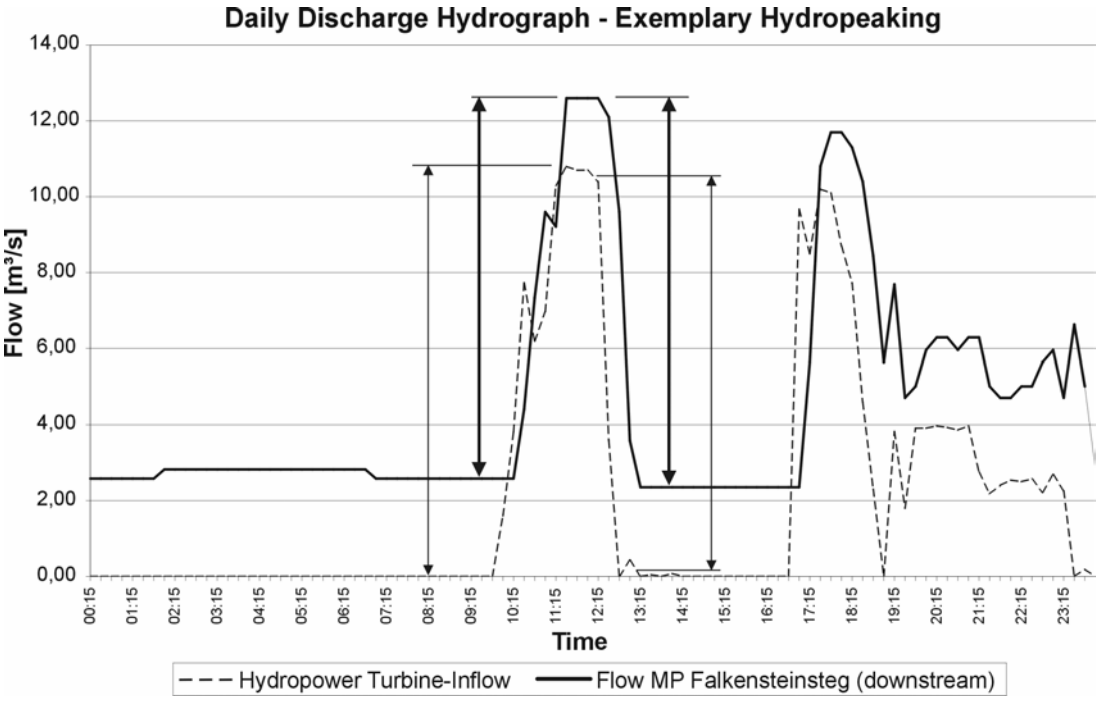


**Figure 3.** Example of swell-sunk relation in the Drau.

Moreover historical data were collected on water quality and chemical parameters. The procedure of comparing these with the successive building phases of the WWTPs and the hydro power plant, allowed the underlining of plants' influences being present or not.

*Chemical parameters*
All chemical parameters being monitored were evaluated, where most of them were under the detection limits of the instruments. Remaining chemicals were analysed regarding their historical development.

Oxygen
Oxygen concentration present was never of concern for the studied stretch of the Drau. The oxygen rate was found always being above 85%. The building of the different plants presented no alteration to this characteristic.

Biological Oxygen Demand ($BOD_5$)

The $BOD_5$ was high, especially near to the Italian national boarder (see **Figure 2** M1). Due to the self-purification capacity of the river, readings of $BOD_5$ at the second gage station (see **Figure 2** M2) were lower. The construction of the largest WWTP (WWTP 1), caused an explicit attenuation of the $BOD_5$ values. The construction of the WWTP 3 and the extension of the number 2 had no significant effect of the $BOD_5$ in the river.

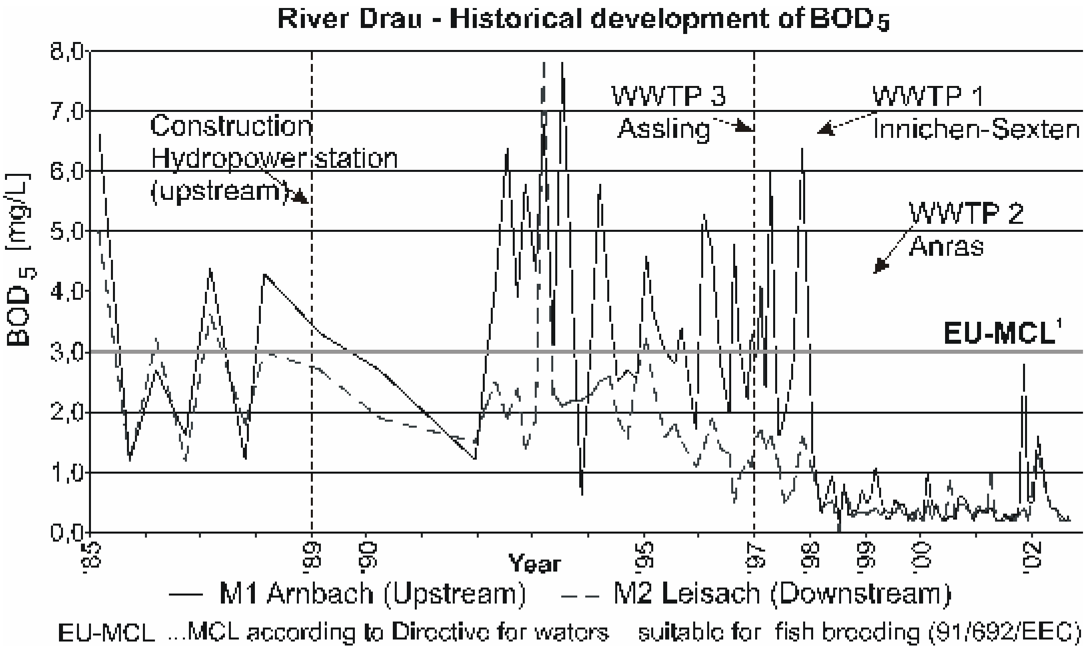


**Figure 4.** Historical development of BOD5 in the Drau.

Nitrogen

This parameter is strongly influenced by WWTP 1, a comparison of the effluent level with the stream concentration demonstrates that the peaks occur mostly in the same periods. The construction of the first WWTP and the extension of the second caused an attenuation of the ammonium concentration. The influence of the third plant was found to be less relevant.

Phosphor

Similar analysis for phosphor demonstrated that the main influence results from the first WWTP.

Chloride

This parameter is strongly influenced from the street sweeping water in winter. In this region sodium-chloride is used as de-icer, where salt is entering the river via the separate sewer system. The historical development confirms this assumption. It is clearly seen that peaks of chloride concentration occur always at the end of the winter months. For the analysed case the concentration is always lower than 8 mg/l, where the proposed Austrian immission regulation sets 100 mg/l as limit value. (AImVF, 1987)

*Water quality*

The biological water quality classification, according to the Austrian Saprobic Index, showed that the construction of the WWTPs and the hydropower caused no noticeable effects (see Figure 5), the status of the river is influenced mostly from the morphology. Water quality classes are drawn on the y-axis, in which "I" marks the good and "IV" the bad status. The class II represents the moderately burdened class. The construction of the WWTP 1 caused an improvement of the water quality at the first gage station. The improvement was seen retarded due to the reaction time of the biotic fauna used as indicator for the water quality.

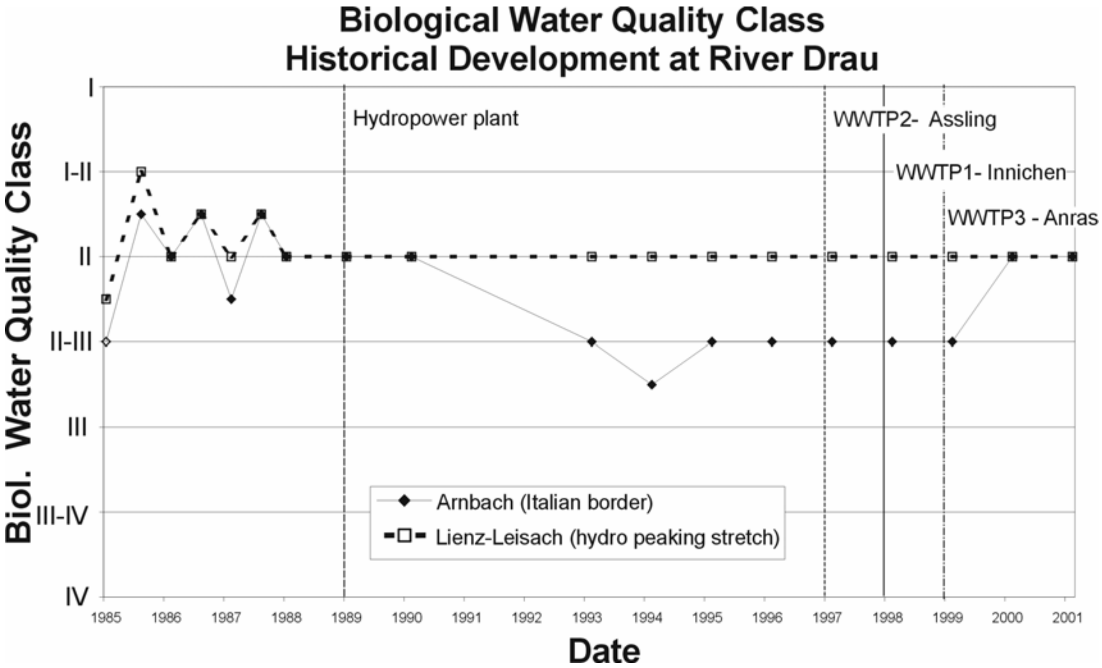


**Figure 5.** Historical biological water quality development.

### Impact parameters for modelling

Derived from the above case study Drau the relevant quality assessment parameters for modelling, as required by the EU-WFD implementation, can be summarised as in the following table.

| | Hydraulic disturbance | Morphology | DO | Toxic | Nutrients | Cl |
|---|---|---|---|---|---|---|
| **Alpine rivers** | xx | xxx | / | (x) | / | (x) |

**Table 4.** Impact parameters importance for an alpine river (x: important; xx: very important; xxx: dominant; (): dependent on local conditions)

However, the integration of the morphology in the water quality modelling constitutes at the moment a problem.

### Conclusions

In this paper we describe a methodology for defining the boundary conditions and goal functions of integrated models for EU-WFD implementation. The key aspect is seen in the identification of relevant quality assurance parameters, that constitute the model state variables and also temporal and spatial scales of the model.

In this paper we derive the relevant parameters by analysis of a proposed calibration stretch for water quality classification. Due to a comparison of the historical development of the biological water classification and concentration of the measured constituents it was possible to derive key parameters that can be seen as typical for alpine rivers. These parameters can thus be further applied for analysis and classification of other water bodies in the same type region.

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## References

AImVF -Verordnung des Bundesministers für Land- und Farstwirtschaft betreffend die allgemeine Beschränkung von Immissionen in Fliessgewässern. (Allgemeine Immissionsverordnung Fließgewässer - AImVF). Ausbesserung 1995 (Entwurf) (1987). *Verordnung des Bundesministers für Land- und Farstwirtschaft betreffend die allgemeine Beschränkung von Immissionen in Fliessgewässern. (Allgemeine Immissionsverordnung Fließgewässer - AImVF). Ausbesserung 1995 (Entwurf)*

Borchardt D. and Sperling F. (1997). Urban stormwater discharges: ecological effects on receiving waters and consequences for technical measures. *Water Science and Technology*, **36** (8-9),173–178.

Engelhard C., Achleitner S., De Toffol S., Schulz K. and Rauch W. (submitted 12/2003). Chemical and hydraulic characterisation of the „calibration stretch“ on a hydro-power and urban drainage influenced river stretch - A case study on the Drau, East-tyrol (in German). *Riverhabitat - Flood prevention, Hydropower, ecology*, Wallgau, Germany.

Foundation for Water Research (1998). *URBAN POLLUTION MANAGEMENT MANUAL - A planning guide for the management of urban wastewater discharges during wet weather*. Foundation for Water Research (FWR), Buckinghamshire, Great Britain.

Krebs P. (2003). *Dynamic in integrated wastewater systems (in German)*. Wiener Mitteilungen, **183**, Institut für Wasservorsorge, Gewässerökologie und Abfallwirtschaft / BOKU-Wien, Austria.

Schilling W., Bauwens W., Borchardt D., Krebs P., Rauch W. and Vanrolleghem P. (1997). On the Relation Between Urban Wastewater Management Needs and Receiving Water Objectives. *XXVII IAHR Congress "Water for a Changing Community"*, San Francisco, USA.

Schöberl F. and Reindl R. (2002). *Geschiebebewirtschaftungskonzept Obere Drau*. Sediment-Hydraulik und Tiroler Wasserkraft AG im Auftrag der Wasserwirtschaft Tirol und dem Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW), Innsbruck, Österreich.

WRG -Austrian Water Act 1959 (2003). *Austrian Water Act 1959-amendment 2003 (in German)* (**WRG 1959 - BGBl. I Nr. 82/2003**).

Zabel T., Milne I. and Mckay G. (2001). Approaches adopted by the European Union and selected Member States for the control of urban pollution. *Urban Water*, **3** (1-2),23-32.