Wastewater Treatment Nutrient Regulations: An International Perspective with Focus on Innovation

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ABSTRACT

A wide diversity of regulatory practices for nutrient removal exists throughout the world. This contribution aims to provide an overview of the different schools of thought in nutrient regulations as well as discuss the implications of choosing certain nutrient permitting structures, objectives, standards and compliance testing methods for protecting environmental and human health. The work is based on the nutrient regulations workshop that was held from 19 to 20 October 2015, in Alexandria, VA, USA, focusing on regulations from Europe and North-America. It was concluded that innovation in the wastewater industry is significantly driven by local regulations, some stimulating innovation whereas others inhibiting innovation and leading to excessive conservatism and cost.

KEYWORDS: Barriers, comparison, drivers, eutrophication, innovation, legislation, nutrient, policy, pollution, regulation.

INTRODUCTION

In a limited literature review on current policies for municipal wastewater treatment, Vanrolleghem (2011) illustrated the wide diversity of regulations that have been put in place throughout the world to pursue the protection of environmental and human health. This diversity not only reflects the variety of receiving water bodies and their beneficial uses (bathing, fishing, drinking water source, transport, hydropower production, etc.), but also the many ways in which jurisdictions make regulations operational through standards, permits and compliance testing methods.

A workshop was held from 19 to 20 October 2015, in Alexandria, VA, USA, discussing the goals underlying the different regulations in wastewater treatment found worldwide, and in particular Europe and North America. It was hypothesized that innovation in the wastewater industry is significantly driven by local regulations, some stimulating innovation whereas others inhibiting innovation and leading to excessive conservatism and cost. As part of an attempt to create the space for extensive innovation, it was therefore considered imperative that a closer look is taken at the role that regulations and permitting structures play in innovation.

The workshop was attended by 21 water professionals, representing 7 countries and encompassing utilities, academia, regulators, consultancy and advocacy. Discussion topics included the:

- Large spectrum of technology and water quality driven regulatory approaches and compliance schemes for nutrients;
- Innovation stimulating and limiting aspects of regulations;
- Way to demonstrate differences in regulatory approaches and showcase how regulation can improve environmental performance.

LEGISLATIVE BACKGROUND

Europe

National regulations on nutrient discharges from wastewater treatment plants in Europe are based on the European Urban Waste Water Treatment Directive of 1991 (UWWTD 91/271/EEC) and the European Water Framework Directive of 2000 (WFD 2000/60/EC). Essentially, the UWWTD imposed a timetable for meeting certain minimum standards of discharge depending upon the population served and the type of receiving water. Nutrient removal is required for wastewater treatment plants (WWTP) above 10,000 people equivalents (p.e.) in sensitive areas (i.e. risk of eutrophication, drinking water abstraction) with annual average limits for total nitrogen and phosphorus depending on plant size (Table 1). Compliance is assessed through daily composite sampling and evaluated either on the basis of concentrations or load reductions. The minimum number of samples is determined by the size of the treatment plant, from 4 daily composite samples per year for treatment plants under 10,000 p.e. up to 24 samples for plants above 50,000 p.e. The Directive allows the use of a so-called bubble arrangement in which facilities with low standards are enabled to buy emission rights from facilities in the same area that overcomply, as long as the load reduction in the whole area is at least 75 % for both TN and TP. Apart from the identification of sensitive water bodies, the end-of-pipe limits do not take receiving environmental conditions or dilution ratios into account.

Table 1. Annual average nutrient limits for WWTP > 10,000 p.e. in sensitive areas according to the 91/271/EEC UWWTD Directive.

Parameter	Concentration (mg l^{-1})	% reduction
TP		
> 100,000 p.e.	1	80
< 100,000 p.e.	2	80
TN		
> 100,000 p.e.	10 [(1)]	70 – 80
< 100,000 p.e.	15 [(1)]	70 – 80
TP + TN: bubble option		75

[1] *Alternatively, the daily average must not exceed 20 mg/l N for water temperatures equal or above 12°C*

The European Water Framework Directive (2000/60/EC) aims to protect all waters, i.e. ground, surface and coastal waters, except marine waters. A major aspect of the WFD, other than the requirement of international river basin management planning, is its environmental objective of ‘good status’ which for surface waters translates into certain biological, physical-chemical and hydromorphological elements, i.e. acquire good ecological and chemical status. ‘Good status’ allows for only a limited deviation from ‘high status’ (i.e. largely pristine), at the same time taking into account regional diversity (e.g. Scandinavian vs. Mediterranean lakes in terms of temperature, turbidity, etc.). The nutrient limits set for WWTPs under the UWWTD and nitrate limits for agricultural sources under the Nitrates Directive remain valid but are seen as minimum measures as more stringent limits may be required to achieve ‘good status’. The WFD is binding on environmental objectives but implementation and effectively taken measures can be different in each of the member states. River basin plans in the WFD have to be updated every 5 years and are structured according to the DPSIR framework, requiring a detailed description of Driving forces (e.g. agriculture), Pressures (e.g. run-off), State (e.g. nutrient concentrations in ecosystems), Impact (e.g. eutrophication) and Responses (e.g. cost-effective emission abatement). The division of costs between upstream and downstream areas and the various sectors is based on the principles of polluter pays and proportionality.

USA

Point source discharges to surface waters in the USA are regulated under the National Pollutant Discharge Elimination System (NPDES) permit program, authorized by the Federal Water Pollution Control Act, also known as the Clean Water Act (CWA). In most cases, the United States Environmental Protection Agency (USEPA) has delegated the responsibility for NPDES permits (and therefore, regulation of municipal wastewater treatment effluents) to each state while retaining oversight of the program. Minimum Water Quality Standards (WQS) are set by the EPA, but states with delegated authority can set more stringent requirements. NPDES permits are typically issued at five-year intervals on a site-specific basis, considering both the technology available to treat the effluent (i.e., technology-based effluent limits - TBEL) and protection of designated uses of the receiving water relative to the state’s WQS (i.e., water quality-based effluent limits - WQBEL). Technology-based regulations apply to all municipal treatment plants and represent the minimum level of effluent quality attainable by secondary treatment.

The CWA requires for every state to develop WQS applicable to all water bodies within the state and review/revise them on a three-year basis. These WQS are composed of three key parts. The first part involves use designations for water bodies based on an assessment of beneficial uses. The second part includes numerical and/or narrative water quality criteria sufficient to protect each of the designated uses assigned to the specific receiving water body. For nutrients, EPA’s recommended eco-regional criteria do not include specific duration or frequency components. States may adopt seasonal or annual averaging periods for nutrient criteria instead of the 1-hour, 24-hour, or 4-day average durations typical of aquatic life criteria for toxic pollutants. The third part of the WQS includes adoption of an antidegradation policy with 3 tiers of protection for maintaining and preserving existing water uses (i.e. tier 1: all waters) and quality (i.e. tier 2 and 3: high and outstanding quality waters).

The general process for determining whether technology-based regulations are sufficient or whether WQBEL are required is described in the Technical Support Document for Water Quality-based Toxics Control and the NPDES Permit Writers’ Manual. It takes into account effluent dilution at the edge of the mixing zone under various flow regimes (e.g., annual average, low flow 7Q10 – the average minimum flow for 7 consecutive days with a recurrence interval of once in 10 years) to estimate if there's reasonable potential to exceed the relevant criteria. For those parameters requiring WQBEL, waste load allocations (WLA) or total maximum daily loads (TMDL) are determined and from there permit limits are developed for the facility. The TMDL calculation methodology, addressing both point and non-point sources, is an important tool for implementing water quality standards. It is based on the relationship between pollution sources and in-stream water quality conditions. As this is related to a lot of uncertainty, TMDL are often calculated on worst-case assumptions for streamflow (low), WWTP loading (high) and water-quality parameters (stringent). Some particular options regarding water quality based permits are watershed-based permits, where the broader context of the watershed in which the discharge is located is considered when setting the limit values; and effluent trading, when emission rights can be exchanged between point and non-point sources within a bubble or watershed.

NPDES compliance is verified through self-monitoring programs, discharge monitoring reports and site inspections. The NPDES permit generally specifies the effluent limitations, schedules of compliance and reporting requirements. In addition, self-monitoring procedures including frequency of analysis, sampling location and procedures, acceptable or required analytical techniques and frequency of reporting are normally stipulated in the permit.

Canada

Wastewater treatment policies in Canada range from strictly technology-based generic effluent limits to environmental risk-based derivation of site-specific discharge limits for specific water uses (Minnow Environmental Inc., 2005). The majority of Canadian jurisdictions have adopted a hybrid approach, however, with generic limits for conventional parameters as minimal measures and more stringent site-specific limits when needed. The latter are typically developed by back calculation from water quality standards for protecting uses of the receiving water, much like described before for the USA. In some cases, environmental risk is taken into account using generic limits within broad categories reflecting receiving environment type and dilution characteristics. None of the Canadian jurisdictions consistently requires assessment of indigenous receiving environment biota. It should also be noted that health aspects (e.g. fecal coliforms and toxicants) are a federal matter, while environmental protection is situated on provincial level.

In 2009, in response to the variety in regulatory approaches, the Canadian Council of Ministers of the Environment (CCME) developed a Canada-wide strategy for the management of municipal wastewater effluent (CCME, 2009). The strategy articulates the collective agreement reached by the 14 provincial ministers of the environment in Canada to harmonize regulations for municipal wastewater treatment effluent. It requires that all facilities achieve minimum national performance standards (NPS) for carbonaceous BOD_5, TSS and total residual chlorine (TRC) and develop and manage site-specific effluent discharge objectives (EDO) established through environmental risk assessments for specific substances like pathogens, nutrients and metals. For the NPS minimum compliance monitoring requirements (i.e., sampling type and frequency, averaging period) are specified while for the EDO it is left at the discretion of individual jurisdictions. The strategy was implemented into the respective federal and provincial regulatory frameworks by 2012 and upgrades in wastewater treatment are foreseen over a period of 30 years.

Nutrient guidelines are used in some Canadian jurisdictions, but they often do not take into account the large natural variations in nutrients across different natural regions or the modifying factors that affect the translation of nutrient concentrations into biological responses. As such, the CCME very recently prepared a guidance manual for developing nutrient guidelines for rivers and streams to support a harmonized and science-based development of state water quality standards (CCME, 2016). However, the translation from water quality standards to end-of-pipe limits for wastewater treatment plants is not discussed in the manual.

INNOVATION BARRIERS AND DRIVERS

In their review on innovation in water policy, Moore et al. (2014) state that a growing need for innovation in water policy is increasingly recognized to cope with the immediate and potential future challenges and uncertainties both from within the sector and around the sector. However, the types of innovation and changes being considered or undertaken, and the conditions that enable or hinder those changes, remain unclear. Especially when moving beyond issues related to technology, the notion of innovation becomes a "black box". A typology of water policy innovations was proposed to elucidate this black box and includes changes in:

- Organizational structures (e.g. development of a river basin organization);
- Water management regulations or instruments (e.g. water utility billing);
- Social conditions for technological change (e.g. water reuse and recycling);
- Engagement processes (e.g. participation of stakeholders);
- Management paradigms (e.g. technology vs. water quality based policy);
- Capacities to implement new practices (e.g. administration).

The core supporting conditions for innovation include:

- Legal and political reforms (e.g. decentralization of water governance);
- Policy entrepreneurship and agency (e.g. individuals advocating policy changes);
- Networks and collaboration (e.g. social and professional networks);
- Social learning (e.g. stimulation of ideas due to cross-pollination of knowledge);
- A philosophical approach to water policy that is adaptive or integrated;
- The establishment of ''safe'' spaces for policy experiments.

The latter two indicate a recognition of the importance of testing policy innovations at small scales and using an adaptive approach to allow for flexibility to respond to unexpected outcomes arising from policy changes. Potential pitfalls and barriers to innovation are described to be:

- Accepted and supported policy changes tend to be mainstream;

- Management pathologies resisting and controlling attempts for innovation.

During the workshop, however, the emphasis lay more on technical and regulatory challenges, as these are more tangible, although it is important to note that protecting water quality and quantity requires not just technological innovation, but also social, political, economic, and behavioral changes.

Nutrients vs. Toxicants

An issue with some existing water quality guidelines is their focus on toxicants. However, a distinction should be made between nutrients and toxicants. Except for ammonia, with limits for acute and chronic toxicity, the most stringent legislation for nitrogen (N) and phosphorus (P) comes from protective measures against eutrophication, i.e. the unwanted increase of aquatic productivity resulting from nutrient enrichment. It can lead to increased turbidity, low oxygen levels, pH imbalances, production of algal toxins, etc., in turn causing various secondary effects on aquatic biota. While nutrient concentrations are important factors related to eutrophication, other environmental conditions such as temperature, light availability and hydraulics should not be ignored. Only when all conditions are favorable, excessive growth can occur. Also, nutrient-based responses are slower to occur than those of toxic substances. Temporary exceedances of nutrient criteria are unlikely to invoke an acute-type response. As such it makes sense to regulate nutrients differently than toxicants. For example (Brown and Caldwell, 2014; European Commission, 2009):

- Due to long hydraulic retention times and internal nutrient recycling, eutrophication in lakes and reservoirs often relates better to total nutrient loading on an annual or seasonal basis rather than actual concentrations. As a consequence, setting daily maximum limits for effluent nutrient concentrations will likely not be the best approach of regulation in this case.
- Effluent limits are often based on the amount of river flow available (i.e. as a worst case scenario) to dilute the effluent stream, leading to more stringent criteria for low flows. However, the latter approach can be questioned when, in the case of phosphorus, a significant amount of pollution comes from diffuse sources (i.e. fertilizer application in agriculture) with peak emissions only arising at high flows due to runoff in wet weather conditions.
- Responses to nutrient loading can be very different depending on the relative levels of control of nitrogen and phosphorus. For receiving waters that are co-limited by nitrogen and phosphorus, it is possible to achieve the same levels of response variables with different combinations of nitrogen and phosphorus reduction, and some combination might be much more cost-effective than others. A potential reason to preferentially control phosphorus over nitrogen in lakes is to maintain sufficient nitrate in the water column to avoid iron-reducing or anaerobic conditions in shallow lake sediments, which tend to release phosphorus and ammonia to the water column and can exacerbate algal blooms.
- Phosphorus is regarded as the main limiting nutrient in freshwaters, while marine open waters are primarily nitrogen-limited. However, as nutrient concentrations increase due to anthropogenic loading, on average higher N/P ratios, but also lower Si/N ratios - Silicon is an important nutrient for algal growth as well - are observed in

coastal areas which are likely to have either or both P and Si limitation. It is to be recognized that the eutrophication phenomena in coastal areas are not only determined by the single nutrient concentrations but also and even more relevant by the nutrient ratios.

- Not all nutrient species are equally bioavailable. A portion of the dissolved organic nitrogen (DON) component in many wastewater discharges is highly resistant to degradation and does not sustain algal biomass over short timeframes.

Appropriate discharge permit structures for nutrients should therefore include long averaging periods and consideration should be given to the variability in quality of receiving waters and reliability of the removal performance of wastewater treatment systems, especially at very low concentrations. Special consideration should be given to the limit of technology for nutrients, the cost-effectiveness of certain options in a watershed perspective (effluent trading), nutrient speciation and bioavailability, the use of mixing zones, non-point sources, preferential nutrient control and level of conservatism in deriving limits and acceptable probabilities of limit exceedance.

Uncertainty and Compliance

In many steps towards the development of effluent limits one has to deal with uncertainty. There is uncertainty regarding the potential effect of pollutants, expected environmental conditions, monitored data, envisioned technological capabilities, etc. When confronted with uncertainty, generally, safety factors or procedures are applied, in line with the precautionary principle. However, the use of safety factors in each subsequent step can lead to an undesired culmination. An example are the worst case assumptions made for both WWTP loading and available river dilution when deriving TMDL. While the latter approach is valid for toxicants, it seems overly protective for nutrients and will lead to cost-ineffective solutions for the environmental objectives that were set out. The following two main factors are of importance and should be looked at:

- A sound scientific basis on load-response relationships for nutrients in various ecosystems, incorporating temporal, spatial and mechanistic aspects;
- Assessment of meaningful effluent limits in relation to the variability in environmental conditions and attainable treatment plant performance, particularly at the limit of technology.

Despite the uncertainty and the stochastic nature of the processes involved, many regulations tend to be deterministic with strict, not-to-exceed effluent limits. While such limits are easily understood and enforceable, they can lead to unsustainable and expensive investments in wastewater treatment infrastructure in order to comply even under extreme and rare events. Moreover, they do no encourage to increase monitoring effort as specified in the permit (e.g. introducing online water quality sensors) since this increases the chances of not compliance. More meaningful compliance schemes incorporating stochastics do exist though.

The main elements in the compliance assessment, i.e., the evaluation of whether a given effluent meets the criteria in the effluent standard, include not only the limit values for the relevant parameters, but also a specification of the corresponding methods for sampling, analysis and assessment of the data. Each of these elements has an influence on the evaluation of whether an effluent is judged to comply. Jacobsen and Warn (1999) have clearly illustrated that direct comparisons between effluent standards from different countries can be very misleading due to different methods in sampling (e.g. grab vs. composite, frequency), chemical analyses, data treatment (e.g. exclusion of extreme events, averaging) and compliance assessment (e.g. all data points must comply vs. percentiles). All these elements should be considered as an integrated part of the standard.

TBEL vs. WQBEL

Overall, two main approaches can be discerned, namely, regulations that are technology based and lead to technology-based effluent limits (TBEL) and those that start from an environmental risk management perspective and result in water quality-based effluent limits (WQBEL). There is an increasing tendency for developed countries to employ a mix of TBEL and WQBEL, e.g. the UWWTD and WFD in Europe. The former are used to set a minimum baseline of treatment and are rather easily understood and implemented. The latter ensure that adequate treatment is provided to protect the environment. However, they are more complex to set up.

TBEL do not ensure an optimal allocation of the limited resources but are a valid first solution for building up an environmental protection scheme. When the UWWTD was implemented in the EU member states' national policies it, generally, led to large reductions in pollution load and significant improvements in water quality. However, it did not provide a solution to the eutrophication of European regional seas. Several suboptimalities of the UWWTD were brought forward, such as the narrow focus on conventional, centralized wastewater treatment instead of integrated water management (Kemp, 2001). Alternative options were often not considered due to the strict deadlines. The UWWTD did also not have an impact on innovation because of its clear technological content, i.e. specifying what was needed technologically, and unchallenging effluent limits. Finally, the scope of the UWWTD was not sufficiently broad to prevent partial solutions and there was a lack of flexibility to redesign regulations so as to incorporate policy lessons about good practice. The WFD was developed in response of some of the aforementioned issues. The WFD is binding on the challenging, water quality-based, environmental objectives, but is to a large extent flexible on the tools to achieve these objectives, as well as on organization, property ownership and financing, and is thus much more open to innovation and technological progress.

Another important aspect of the WFD is the integrated approach for controlling point and diffuse pollution sources per river basin, allowing for more cost-effective solutions for the problem of eutrophication. However, a fair and efficient distribution of nutrient abatement efforts and costs is not straightforward (Iho et al., 2015). Not only one has to deal with the various jurisdictions within a watershed, but there's also a historical difference in approach to point and non-point discharges. Point sources are often very strictly regulated according to the 'polluter pays' principle, while nutrient reductions from non-point sources mainly rely on voluntary-based programs according to the 'pay the polluter to do better' principle, with for instance subsidies for good agricultural practices. This has led to a significant imbalance in marginal costs for nutrient abatement between the different dischargers, which inherently means that the limited resources for environmental protection are not optimally used. One way to overcome such asymmetries is to use effluent trading as market-based instrument to allow dischargers to find the most cost-effective way to achieve the required nutrient reductions. Effluent trading is currently possible under the CWA, but mainly practiced within small-scale watersheds.

Incentivizing, performance-based permitting

The implementation of environmental charges on emissions (i.e. effluent taxes, levies or fines, Vanrolleghem et al., 1996) is a stronger driver and incentive for innovation than prescriptive and punitive effluent standards. The direct link between charges and actual emissions leaves room to optimize treatment plant performance at all times during the life-time of a treatment plant, adjusting capital and operational expenditures in accordance to the governing local economic conditions. A prerequisite is that the charges are environmentally sound from a life-cycle-impact assessment point of view and the revenues are channeled back to environmental protection and measures on resource efficiency. The charges can be adapted if required in accordance to changes in environmental objectives. Prescriptive legislation, e.g. specifying the use of certain technology, would hamper design and operational flexibility and therefore diminish the environmental effectiveness of investments as well as preclude innovative solutions. It would also be required that temporary improvements in treatment performance are not taken as an opportunity for more stringent legislation (cf. anti-backsliding principle, Novak et al., 2015) and innovators are given sufficient time to implement their solutions (i.e. safe harbor principle).

CONCLUSIONS

There is a large spectrum of regulatory approaches for nutrient discharges in the world. It appears that the principles and tools of several legislative frameworks could be combined to an ‘ideal’ policy to attain a better overall protection of the environment. The aspect of innovation is seldom discussed with regards to effluent regulations. Nevertheless, certain conditions can help spawning innovative solutions:

- ambitious environmental objectives which challenge the current technological and organizational boundaries
- a flexible legal framework that allows for some freedom in achieving the environmental goals
- an appropriate financial framework that incentivizes

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