Preliminary results of «PASt21» – the Portuguese initiative for performance assessment of water and wastewater treatment plants

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ABSTRACT

Performance assessment of water supply and wastewater services is nowadays a major issue. Over the past six years, LNEC has been developing performance assessment systems (PASs) for water treatment plants (WTPs) and wastewater treatment plants (WWTPs). In 2009, a national field test was launched, 'PASt21', coordinated by LNEC and involving 27 plants (10 WTP and 17 WWTP). This paper presents the second generation of the PI system for the overall performance assessment of WTPs and WWTPs and the PI results obtained with the data available for 2006-2009. It was concluded that all indicators of the systems are relevant, and the results show the ability of the proposed PI systems to assess the overall performance of a given treatment plant. The aggregated results are very important for the continuous improvement of the plant performance through benchmarking and targets' periodic reassessment.

1 INTRODUCTION

Performance assessment of water supply and wastewater services is nowadays a major issue. However, most performance assessment systems (PASs) do not specifically apply to the treatment plants, core elements of these services (Alegre et al., 2000, 2006; Stahre and Adamsson, 2001; Matos et al., 2003; OfWat, 2004; World Bank, 2006; Stahre et al., 2008; DWA, 2008). To overcome this situation, over the past six years, LNEC has been developing PASs for water treatment plants (WTPs) and wastewater treatment plants (WWTPs) (Vieira et al., 2008, 2009, 2010a; Quadros et al., 2010a).

PASs comprise two main components, the Overall Performance Assessment and the Operational Performance Assessment. The former, subject of this communication, is based on performance indicators (PIs), uses historical data and the information produced is aggregated at plant level. The Operational Performance Assessment is based on performance indices to address the daily performance of each unit operation/process of the plant.

In 2009, a national field test was launched, 'PASt21' (http://past21.lnec.pt/), coordinated by LNEC and involving 27 plants operated by 12 water utilities, publically owned (10 companies of the Águas de Portugal holding), private (AGS, SA) or municipal (SMAS Almada). PASt21 project also involves the Portuguese regulator for water and wastewater services (ERSAR) and has the support of two Portuguese water associations (APESB and APRH).

This paper presents: i) the second generation of the PI systems for the overall performance assessment of WTPs and WWTPs, including the relationship between the PI assessment groups and the variable categories, ii) the characterisation of the case-studies and iii) the PI results obtained with the data available for 2006-2009. Data input (%) by variable category and the percentage of PIs calculated for each assessment group are presented. Whenever statistically feasible, aggregated results for each PI (average, median, percentiles 25 and 75, maximum and minimum) are also shown.

2 THE PI SYSTEM FOR OVERALL PERFORMANCE ASSESSMENT OF WTPs AND WWTPs

The developed PASs assumed two general objectives of any undertaking with regard to a WTP or WWTP performance: 1) its effectiveness and reliability, i.e. the compliance over time with the quality requirements of the treated water and 2) its efficiency (in terms of resources utilisation) and sustainability (both economical and environmental).

After establishing the objectives, the structure (the Overall and the Operational Performance Assessment components) and the assessment groups of PASs were defined: *Treated water/wastewater quality*; *Removal efficiency and reliability*; *Use of natural resources and raw materials*; *By-product management*; *Safety*; *Personnel*; *Economic and financial resources*; *Planning and design* (the later only for WWTP) (Vieira et al., 2008, 2009 and 2010a; Quadros et al., 2010a). Analogous portfolios of PIs for WTP and WWTP were then formulated according to the IWA approach (Alegre et al., 2000, 2006; Matos et al., 2003) and to the principles established in ISO 24500:2007.

The work undertaken in the scope of PASt21 allowed identifying opportunities for improving the clarity and formulation of the originally proposed PIs and their variables, and new indicators were developed, giving rise to the second generation of PIs for WTP (94 PI) and urban WWTP (121 PI).

PIs are identified by a code composed of six or eight (the last two are optional) fields identifying the system (t for WTP and wt for WWTP), the assessment group and the PI number, e.g. wtWQ01 is the first indicator (01) of *Treated Wastewater Quality* (WQ). Whenever necessary, an optional numerical field may be included to identify an alternative processing rule (e.g. wtER35.1 for *Pump inspection*, expressed in No./(pump.year), and wtER35.2 for *Inspected pumps*, %/year) and or an alphabetical character for the PI speciation, for instance per reagent used in the plant.

The detailed characterisation of each PI (code and designation, assessment group, objective, processing rule, units, data required, results analysis and observations (for clarification of variables and other relevant aspects to the PI calculation) is presented in Quadros et al. (2010b) and Vieira et al. (2010b).

The proposed PASs deals with a high volume of data, and an automatic tool for the data processing and results visualisation was therefore developed. PAStool was implemented in Microsoft Excel® with VBA programming and also allows for the statistical analysis of results.

The PI systems for WTP and WWTP, including the variables and the relationship between PI assessment groups and the variables' categories, are presented in section 4.1 together with the data input and PIs calculated so far for the case-studies characterised in Section 3. The PI results are illustrated and discussed by assessment group in sections 4.2 to 4.9.

3 THE CASE-STUDIES OF PASt21

The 27 case-studies of PASt21 (10 WTPs and 17 WWTPs) are operated by 12 water utilities, publically owned (10 companies of the Águas de Portugal holding), private (AGS, SA) or municipal (SMAS Almada).

The case-studies are spread throughout the country (Figure 1) and cover a wide range of treatment capacities and treatment sequences. The 10 WTPs range from 3,000 to 400,000 m^3/d (yielding a total treatment capacity of 1,160,000 m^3/d), have different raw water sources (surface water and groundwater) and unit operations/processes – pre-oxidation using ozone, chlorine dioxide or chlorine, pH adjustment, softening/stabilisation, chemical precipitation, coagulation and flocculation, sedimentation, flotation, filtration and disinfection (Figure 2). The 17 WWTPs cover different capacities (360 to 54,500 m^3/d, corresponding to 2.300 to 250.000 p.e.), include different unit operations and processes for wastewater treatment (e.g. activated sludge processes, trickling filters and biofilters, filtration, microtamisation and UV disinfection) and solids and biosolids (sludge) processing (chemical conditioning, thickening, anaerobic digestion and dewatering), and final disposal of the treated water (discharge and/or reuse) (Figure 3).

Figure 1. PASt21 case-studies location in Portugal.

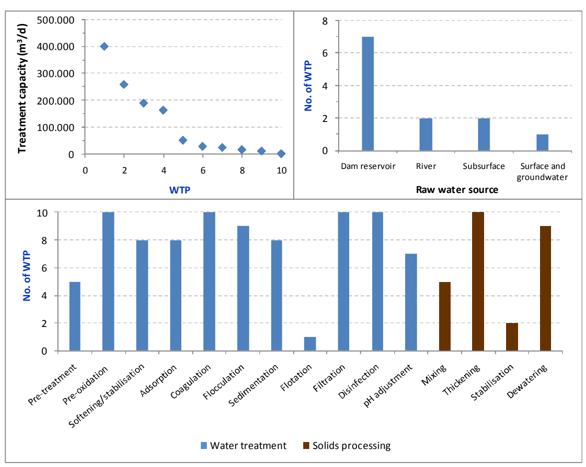


Figure 2. Treatment capacities, raw water sources and unit operations/processes of the 10 WTPs studied.

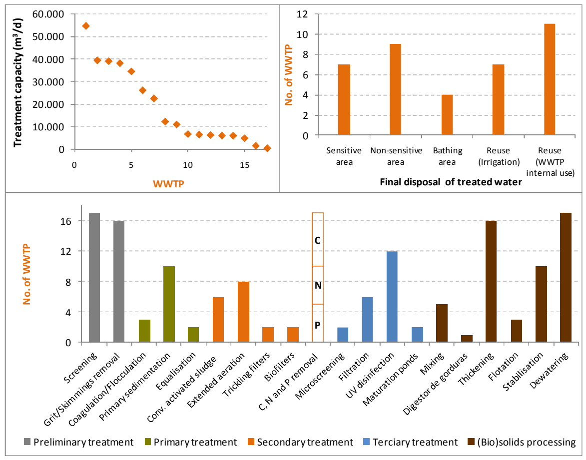


Figure 3. Treatment capacities, final disposal and unit operations/processes of the 17 WWTPs studied.

4 PRELIMINARY RESULTS OF PASt21

4.1 Data input and calculated PIs

Figures 4 and 5 present the number of PIs proposed in each assessment group, the number of variables by category and the relationship between the PI assessment groups and the variable categories. In each category, the most often used variable is also shown (between brackets, in variable category boxes), namely *Treated water* (used in 19 PIs for WTP) or *Treated wastewater* (22 PIs for WWTP), *Chemical dispensers*, *Inflow BOD mass* (WWTP), *Sludge outflow* and *Other by-produts outflow*, *Full-time equivalent employees* and *Running costs* (8 PIs for WTP and 8 PIs for WWTP).

The percentages of data input and calculated PIs – the average values of the consortium and the maximum values obtained in one (W)WTP) – are also presented in Figures 4 and 5. All PIs were considered relevant depending the assessment objectives, although in some treatment plants the lack of reliable data may limit (for the time being) the use of a few PIs, e.g. wtBP19 – *Greenhouse gases emission*. On average, the *Water volumes (and loads)* category obtained the highest percentages of data input (55% to 75% in WTP and 28% to 52% in WWTP), followed by *Infrastructure*, *Operation and Maintenance* and *By-products*.

The percentages of calculated PI evidence the major concern with plant effectiveness and reliability – *Treated (waste)water quality* assessment group presented, on average, the highest percentages (49-68% in WTP and 30-43% in WWTP), followed by *Removal efficiency and reliability*, *Use of natural resources and raw materials* and *By-product management*. The lack of a reliable and accurate method to affect the *Personnel* and the *Economic and financial resources* to a single (W)WTP resulted in low average percentages of PI calculation in these groups, in addition to low data reliability and accuracy. The following results of Pe and Fi indicators should therefore be analysed with reservations.

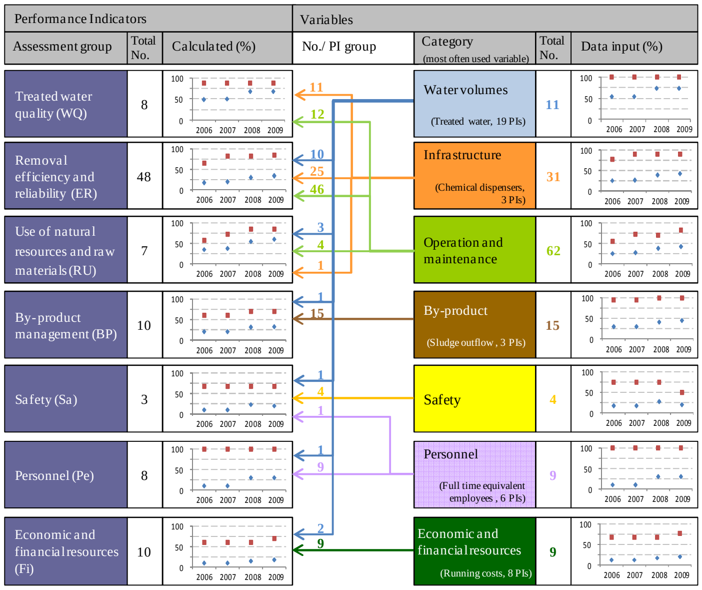


Figure 4. PI assessment groups, variable categories, percentage of PI calculated and data input for WTP (♦ average values, ■ maximum values).

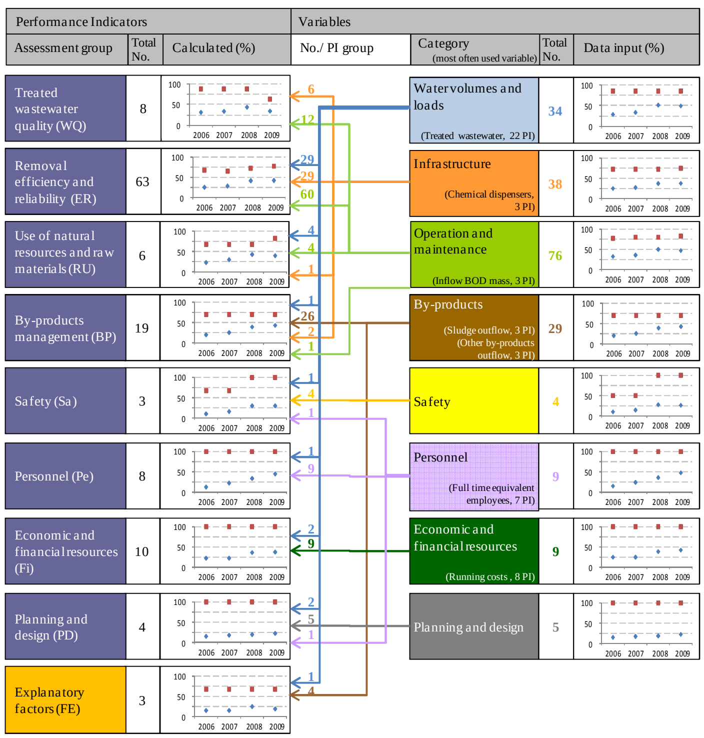


Figure 5. PI assessment groups, variable categories, percentage of PI calculated and data input for WWTP (♦ average values, ■ maximum values).

The values obtained for each PI and for each year are, whenever statistically feasible, aggregated in a box plot (Figure 6), which includes the average, median, percentiles 25 and 75, maximum and minimum, and extreme outliers (values below or above 3 times the P75-P25 difference).

The percentage of calculation, i.e. the percentage of case-studies entering the calculation of a given performance indicators, is also shown. Whenever the later varies from year to year, interpretation of PI variations should be considered with reservations.

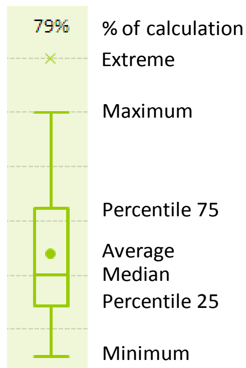


Figure 6. Box plot automatically produced by PAStool.

PI results and discussion is enclosed in Tables 1 to 7 (one for each assessment group). The PIs shown were selected for their interest, variation throughout the 5-years period under study and/or higher percentage of calculation. A box plot for the overall 5-years period is also available although not always significant. Results for 2010 are not shown since the data input is not complete.

4.2 Treated (waste)water quality

The assessment group *Treated water quality* evaluates WTP performance in terms of compliance with water quality criteria established by the utility for the finished water leaving the plant and at consumption points.

Test results compliance is evaluated in terms of all parameters defined by the water supplier and for key parameters (tWQ02, Table 1) and in terms of parameters analysed. The values of PI tWQ02 reveal high levels of compliance for these key parameters.

The ability of the WTP to produce water that has an adequate quality at the delivery/consumption point(s) is assessed by the chlorine residual (minimum and maximum residual, tWQ06 in Table 1), THM concentration and microbiological quality. PI tWQ06 shows that for some WTP the residual chlorine exceeded the maximum value recommended by the Portuguese legislation (1 mg/L). This situation recommends further analysis of the disinfection.

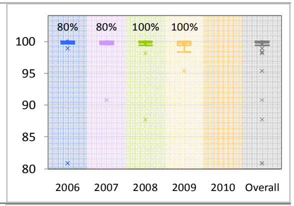
For a WWTP, *Treated wastewater quality* compliance with discharge permit regulation is evaluated on three aspects: quality tests carried out, parameters analysed and compliance with wastewater quality established in discharge consents. Table 1 shows the results for the first and third aspects (PI wtWQ1.2 and wtWQ3.2, Table 1). These results showed a significant improvement in performance. Nevertheless, concerning the quality, in 2009 there are parameters for which the wastewater does not comply with discharge permit regulation. The assessment of water reuse is done by an analogous methodology.

Table 1. PI results of *Treated (waste)water quality*.

tWQ02 – Compliance with key water quality parameters [%] (Fe, Mn, Al, NTU, THM, BrO3, coliforms) =

(Tests of key parameters complying with criteria defined by water supplier (no.)/Tests carried out to key parameters (no.)) x100

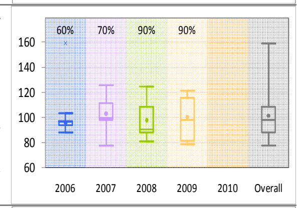
All values are above 80% ranging on average from 99.6% to 99.9%. P25-P75 is 99.8-100%. Some values were considered extreme.



tWQ06 – Maximum chlorine residual at delivery/ consumption point(s) [%] =

(Average of the 10% highest values of free chlorine recorded in the distribution network (mg/L) / Maximum allowable value of free chlorine (mg/L)) x 100

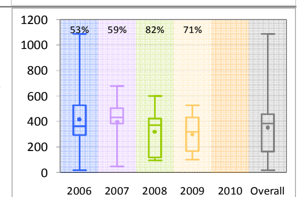
The lowest median was obtained in 2008 (90.8%). Although there are some values below 100%, in 2006-2009 the average is ca. 101% and P25-P75 is 88-109%.



wtWQ01.2 – Quality tests carried out [%] =

(Tests carried out (discharge permit regulation) (no.) / Tests required (discharge permit regulation) (no.) x 100

On average, the tests performed were 3 to 4 times the tests required. The minimum increased over the analysed period to 100% in 2009, which corresponds to compliance with the number of tests required.



wtWQ03.2a – Compliance with wastewater quality established in discharge consents [%] =

$$\frac{\sum_{i=1}^{m} J_i}{m} \times 100$$

m = total of required parameters analysed
J_i = compliance with parameter 'i' (0 = no compliance; 1 = compliance)

Improved performance over the time period: the average increased from 53% to 84%; P25 also increased, resulting in tighter P25-P75 in 2008/2009.

4.3 Removal efficiency and reliability

The assessment group of *Removal efficiency and reliability* evaluates the plant performance in terms of plant robustness, flexibility, removal efficiency and reliability.

The *Water source utilisation* was assessed by tER01 (Table 2) and allowed to identify, in some WTPs, situations of full use of these resources. In terms of adequacy of treatment capacity, tER04 (Table 2) showed that most of the WTPs are over sized.

As the reliability of a treatment plant is higher if the possibility of dosing alternative chemicals is planed, this performance aspect was evaluated through tER19 (Table 2), which showed that, on average, the studied WTPs may use a number of alternative chemicals that is about one quarter the chemicals used in regular operation.

The equipment calibration must be verified periodically to validate the results of the measurements. PI tER34 to tER38 evaluate the periodic calibration (or verification of calibration) procedures for chemical dispensers, flow meters, water/sludge level meters, pressure meters and online water/sludge quality meters. The obtained results show that some equipment was not calibrated in 2006-2009, as illustrated by tER34, whose average is less than one calibration for dispenser (Table 2).

For WWTP, the plant mass efficiency is evaluated by a set of five indicators concerning BOD stabilisation and BOD, COD, TSS and nutrients removal, respectively. The results of wtER03 (Table 2) show that every year, P25-P75 lies within the typical range of literature for conventional secondary treatment, 86-91% (Qasim, 1999) and 85-97% (Metcalf & Eddy, 2003) and over the range of the Portuguese discharge permit regulation (70-90%). This indicator shows a relationship with the wtWQ3.2a, removal efficiencies below 90% being associated with lower values of compliance, due to highly concentrated raw wastewater (Table 2).

Equipment inspection can be assessed by the total number of inspections and/or the percentage of inspected equipment. These two options are tested only for pumps (wtER35.1 and wtER35.2, Table 2) and aerators. For the other equipments (valves, signal transmission equipment, flow meters, water/sludge level meters, pressure meters, online water/sludge quality, bed filter, dewatering equipments and other key equipments) only the second option is proposed.

In 2006-2009, these PI showed an increase in the practice of inspection, a procedure that reduces the risk of equipment failure. These failures are evaluated by PIs of interruption of the operation (> 30 min) of equipment, such as pumps (wtER54, Table 2), valves, aerators, dewatering equipments and other key equipments. As expected, there is an inverse correlation between wtER35 and wtER54 (Table 2).

4.4 Use of natural resources and raw materials

This assessment group evaluates the plant performance in terms of efficiency of use of most important treatment inputs: water, energy, chemicals and filter media.

As for water consumption in all WTP uses, tRU01 (Table 3) shows a high performance of the studied plants.

The Energy consumption in the studied WWTPs (wtRU04) increased slightly over 2006-2009 and was, on average, 4 times higher than the energy consumption in the WTPs (tRU04).

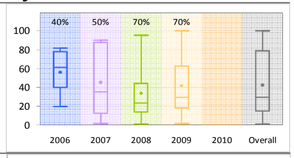
The consumption of acids and bases in the studied WTPs (tRU05, Table 3) was 10 times higher than in the WWTPs (wtRU04).

Table 2. PI results of *Removal efficiency and reliability*.

tER01 – Water source utilisation [%/year] =

(Raw water (m^3) x 365(day/year) / Assessment period (day)/ Annual abstraction capacity of the source (m^3)) x 100

Wide range of results. Some case-studies have values close to 100%. In 2006-2009 the average is 43% and P25-P75 is 15-80%.



tER04 – Adequacy of plant capacity [%] =

$$\left(1-\frac{\sum_{d=1}^{n} Qt_d \times J_d + \sum_{d=1}^{n} Qt_d \times K_d}{\sum_{d=1}^{n} Qt_d}\right)\times 100$$

n = assessment period (day)

J_d = 1, if $Qr_d > 0.95\ Qt_d$ in day 'd'

= 0, if $Qr_d \leq 0.95\ Qt_d$ in day 'd'

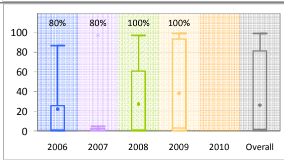
K_d = 1, if $Qr_d > 0.7/fs\ Qt_d$ in day 'd'

= 0, if $Qr_d \leq 0.7/fs\ Qt_d$ in day 'd'

f_s= correction factor for seasonal variation of the flow rate through the assessment period

Qt_d= Plant capacity (daily average flow rate) at day 'd' (m^3/day)

Qr_d= Daily average flow rate recorded at day 'd' (m^3/day)

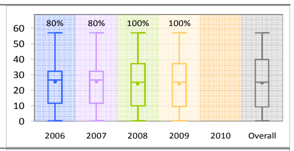


Increase over the period, with a very wide range of results. On average, the values are below 70%, indicating a poor performance. Case-studies with poor performance are underutilised.

tER19 – Possibility of dosing alternative chemicals [%] =

(Chemicals not used in regular basis (no.) / Chemicals used regularly during WTP operation (no.)) x 100

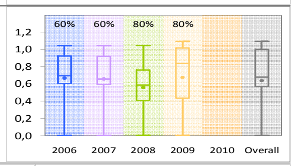
Similar values throughout the analysed period. In 2008 and 2009 the median is 25%. In 2008-2009, P25-P75 is 10-37%.



tER34 – Chemical dispenser calibration [no./(dispenser.year)] =

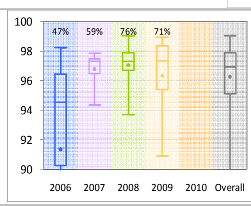
(Chemical dispenser calibrations (no.) x 365 (day/year) / Assessment period (day)) / Chemical dispensers (no.)

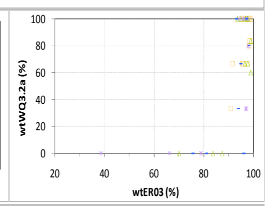
Wide range of results, ranging from 0 to 1.1 calibrations per dispenser. In 2006-2009, the average is 0.64 no./(dispenser.year) and P25-P75 is 0.57-1 no./(dispenser.year).



wtER03 – BOD_5 mass removal efficiency [%] = [(Inflow BOD_5 mass – Outflow BOD_5 mass (effluent + by-pass)) /Inflow BOD_5 mass (kg)] x 100

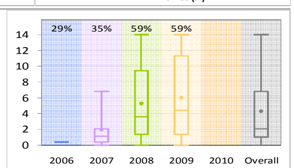
P25 is above 90%. Values below 90% (not shown): minimum of 2006 (76%), 3 extreme outliers in 2007 (39%, 66% and 79%) and 3 in 2008 (70%, 84% and 88%).





wtER35.1 – Pump inspection [no./(pump.year)] = Pump inspections (no.) x 365 (day/year) / Assessment period (day) / Pumps (no.)

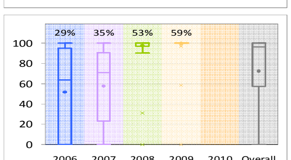
Significant increase in PI during the period analysed, ranging on average from two pump inspections in 2007 to 6 inspections in 2009. These results (higher than one) do not mean that all pumps were inspected during the period, aspect assessed by PI wtER35.2.



wtER35.2 – Inspected pumps [%/year] =

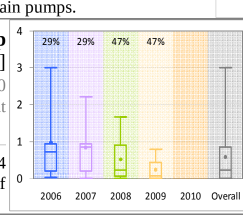
(Inspected pumps (no./year) / Pumps (no.)) x 100

This processing rule option also shows an increase in the practice of inspection, although there are values lower than 100% per year. Comparing the two PI options (wtER35.1 and wtER35.2), it is concluded that the inspection effort was directed to certain pumps.



wtER54 – Interruptions of pump operation (> 30 min) [no./(pump/year] = Interruptions of pumps operation (> 30 min) (no.) x 365 (day/year) / Assessment period (d) / Pumps (no.)

PI decreased on average from 0.98 to 0.24 no./(pump /year) in 2006-2009. In 2009, half of the case-studies has no interruptions.



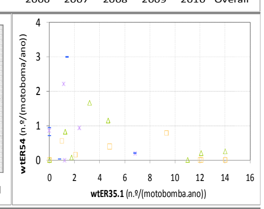
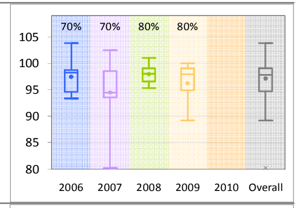
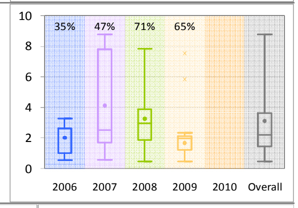
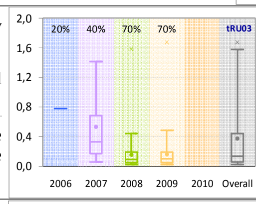
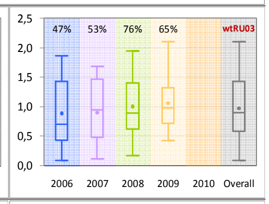
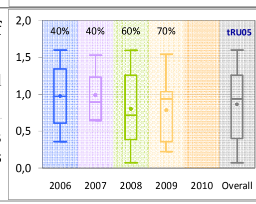
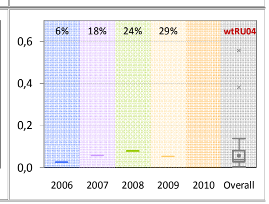


Table 3. PI results of *Use of natural resources and raw materials*.

tRU01 – Efficiency of raw water use at the WTP [%] = (Treated water (m^3) / Raw water (m^3)) x 100 Most of the results are above 90%. In 2006-2009, the average is high (97%) and P25- P75 is 95-99%. Values above 100% were due to flow measuring errors.	
wtRU01 – Fresh water consumption [m^3/10 m^3] = (Fresh water (m^3) / Treated wastewater (m^3)) x 10^3 P25-P75 decreased from 1.7-7.8 m^3/10 m^3 in 2007 to 1.2-2.1 m^3/10 m^3 in 2009. However, there are some values above the maximum, considered extreme outliers (some not shown), particularly in 2006 (17.8 m^3/10 m^3), 2008 (31 m^3/10 m^3) and 2009 (5.8 m^3/10 m^3, 7.5 m^3/10 m^3 and 68.9 m^3/10 m^3).	
tRU03, wtRU03 – Energy consumption [kWh/m^3] = Energy consumption (kWh) / Treated (waste)water (m^3) P25-P75 is 0.05-0.44 kWh/m^3 for the WTPs and 0.72-1.32 kWh/m^3 for the WWTPs.	 
tRU05, wtRU04 – Consumption of acids and bases [eq./m^3] = Acids and bases consumed (eq) / Treated (waste)water (m^3) For the studied WTPs, the average is 0.9 eq./m^3. For the WWTPs, P25-P75 is 0.03-0.09 eq/m^3.	 

4.5 By-product management

By-product management assessment group evaluates the plant performance in terms of production and disposal/beneficial use of by-products, including: sludge, filter media, screenings, grit, skimmings and biogas, greenhouse gases emission.

Sludge production in the WWTPs (wtBP01.1, Table 4) increased from 2006 to 2009. The increase of sludge production is mainly due to the production of less concentrated sludge (wtBP08) and/or to lower BOD stabilisation efficiency (wtER02).

However, wtBP08 shows high and constant values of sludge dry weight over 2006-2009 and wtER02 was not possible to calculate.

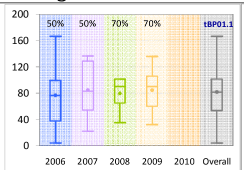
Sludge dry weight produced in the WTPs (tBP02, Table 4) was also high but decreased over the analysed period. In the WTPs, less concentrated sludge corresponded to higher sludge production (tBP01.1, Table 4).

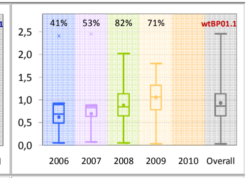
In most WTPs and WWTPs the sludge produced were outflowed (wtBP02 and tBP03) in 2006-2009. The wtBP04 indicator (Table 4) shows that there was an increase in the beneficial use of sludge.

Table 4. PI results of *By-product management.*

tBP01.1, wtBP01.1 – Sludge production [g/m^3; kg/m^3] = Sludge produced (g or kg) / Treated (waste)water (m^3)

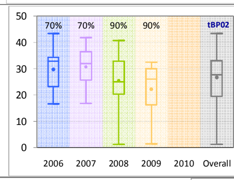
Production increase during 2006-2009. P25-P75 is 0.65-1.14 kg/m^3 for the WWTPs and 54-101 g/m^3 for the WTPs.

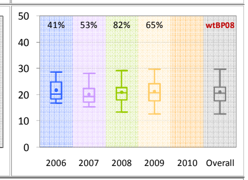




tBP02, wtBP08 – Sludge dry weight [%] = Dry weight of sludge produced (%)

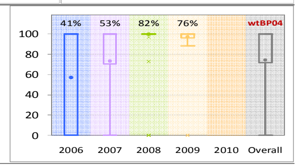
For WTPs, sludge dry weight decreased, on average from 30% in 2006 to 22% in 2009. The sludge produced in the WWTPs during 2006-2009 was on average 21%.





tBP05, wtBP04 – Beneficial use of sludge [%] = (Sludge with beneficial use (kg) / Sludge outflow (kg)) x 100

The beneficial use of WWTP sludge increased over the analysed period, with an average value of 100% (2008) or near (2009).



4.6 Safety

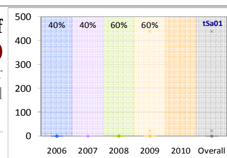
The *Safety* PIs evaluate the plant performance in terms of: environmental, plant and personnel safety.

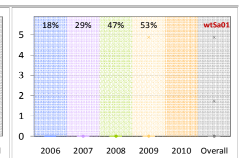
Indicators of environmental safety ((w)tSa01) and personnel ((w)tSa02) are zero for many case-studies. There is, however, the occurrence of incidents at work (injuries and professional illnesses) in the studied WTPs in 2008 and in the WWTPs in 2009 (Table 5).

Table 5. PI results of *Safety.*

tSa01, wtSa01 – Spills and/or leakages of chemicals, by-products (or wastewater) [kg/10^6 m^3] = (Chemicals, by-products (or wastewater) accidentally released (kg) / Treated (waste)water (m^3)) x 10^6

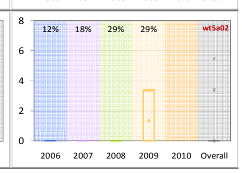
This PI has mostly null values.





tSa02, wtSa02 – Incidents at work (injuries and professional illnesses) [no./(10 employee.year)] = (Incidents at work (no.) x 365 (day/year) / Assessment period (day) / Full time equivalent employees (no.)) x 10

In all the years the median is zero.

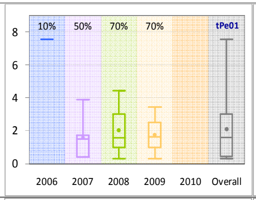
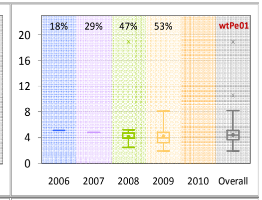
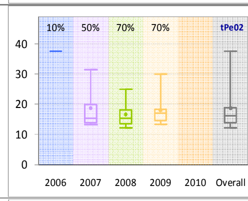
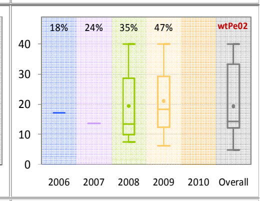
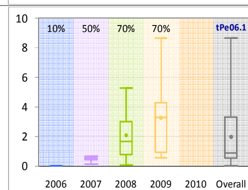
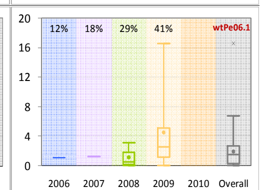
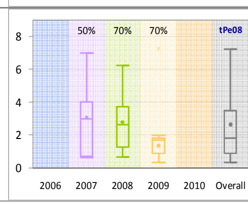


4.7 Personnel

This assessment group evaluates plant performance in terms of availability of personnel, their qualifications and training, absenteeism and overtime work.

In terms of personnel availability ((w)tPe01, Table 6) for the studied WTPs present a median of 1.6 employees/10^6 m^3 of treated water while the WWTPs have a median of 4 employees/10^6 m^3 of treated wastewater, half of which with basic education and one sixth with a university degree ((w)tPe02, Table 6). Total absenteeism ((w)tPe06.1, Table 6) increased in 2009, while much of this increase was due to incidents at work (injuries and professional illnesses) ((w)tPe07). For the WWTPs, the highest absenteeism by incidents at work in 2009 is consistent with the PI relative to *Incidents at work* (wtSa02), which was also higher in 2009. Overtime work ((w)tPe08, Table 6) decreased, showing a better adequacy of (W)WTP personnel utilisation. Data reliability and accuracy are however low as explained earlier.

Table 6. PI results of *Personnel*.

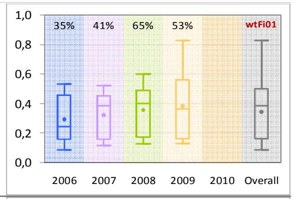
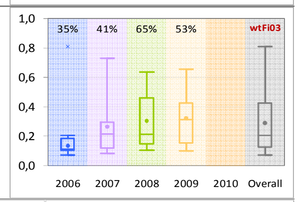
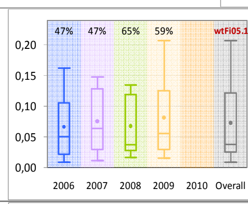
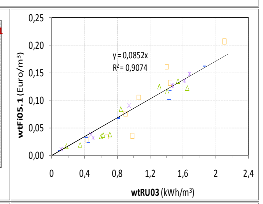
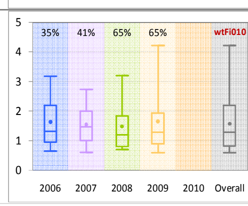
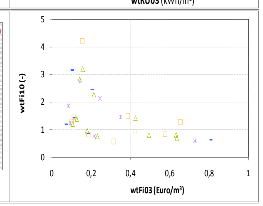
(w)tPe01 – (W)WTP personnel [n.º/10^6 m^3] = (Full time equivalent employees (no.) / Treated (waste)water (m^3)) x 10^6 In 2006-2009, the median is 1.6 no./10^6 m^3 for the WTPs and 4 no./10^6 m^3 for the WWTPs.		
(w)tPe02 – Personnel with higher education [%] = ((W)WTP employees with higher education (no.) / Full time equivalent employees (no.)) x 100 This PI shows that in 2006-2009 20% of the employees have higher education.		
(w)tPe06.1 – Absenteeism [%] = (Absenteeism (hour) x 365 (day/year)/ Assessment period (day) / Maximum potential workload (hour/year)) x 100 The absenteeism increased from 2006 to 2009, with a particularly high value for one WWTP in 2009.		
(w)tPe08 – Overtime work [%] = (Overtime work (h) x 365 (day/year)/ Assessment period (day) / Maximum potential workload (hour/year)) x 100 The WTPs and the WWTPs presented a decrease of overtime work from 2007 to 2009.		

4.8 Economic and financial resources

The *Economic and financial resources* indicators evaluate the plant performance in terms of revenues, costs and economic sustainability. Unit capital costs and unit running costs, taken as a whole and specifying the major contributions (i.e. personnel, electrical energy, chemicals and bed media, by-product disposal, external services for analytical control and maintenance), are considered in this assessment group.

For the studied WWTPs, the *Unit revenues* (wtFi01, Table 7) and the *Unit running costs* were both higher in 2009, particularly the revenues, so the *Running cost coverage ratio* (wtFi10, Table 7) was also higher this year. In some WWTPs the unit revenues did not cover the unit running costs. In addition, the higher the costs were, the lower the coverage ratio was. *Personnel costs* and *Electrical energy costs* account for a major contribution (one fourth each) of the *Unit running costs*. As the *Energy consumption*, the *Electrical energy cost* has also slightly increased over the studied period, and these are as expected directly related (Table 7). The results shown must be however analysed with reservations due to the low data reliability and accuracy.

Table 7. PI results of *Economic and financial resources.*

(w)tFi01 – Unit revenue [Eur/m^3] = (Operating revenues (Eur) - Capitalised costs of self constructed assets (Eur)) / Raw (waste)water (m^3) On average, there is an increase over the analysed period. In 2009, the range P25-P75 is wider (0.16-0.56 Eur/m^3).		
(w)tFi03 – Unit running costs [Eur/m^3] = Operating costs (Eur) - Capitalised costs of self constructed assets (Eur))/ Treated (waste)water (m^3) As in the previous PI, there was an increase over the analysed period. In 2009, P25-P75 is 0.15-0.42 Eur/m^3.		
(w)tFi05.1 – Electrical energy costs [Euro/m^3] = Electrical energy costs (Eur) / Treated waste(water) (m^3) The electrical energy costs increased slightly over the analysed period. In 2006-2009, P25-P75 is 0.02-0.12 Eur/m^3.		
(w)tFi10 – Running cost coverage ratio [-] = Total revenues (Eur) / Running costs (Eur) In 2006-2009, P25-P75 is 0.82-2.2. Some WWTPs present values below 1.		

4.9 Planning and design

Planning and design indicators evaluate other aspects not directly related to short and medium-term technical management decisions but influencing the WWTP environmental and economic performance, such as *Planning and design personnel* (wtPD01), *Land occupation by treatment system* (wtPD02), *Land occupation by landscape and other valuable elements* (wtPD03) and *Current land valuation* (wtPD04).

In 41% of the studied WWTPs, wtPD02 shows constant values during 2006-2009, P25-P75 is 0.33-0.70 m^2/(m^3/d) and the median is 0.47 m^2/(m^3/d).

5 FINAL REMARKS

The work undertaken in the scope of PASt21 allowed selecting, from the developed portfolio of PIs, those associated with the specific objectives of each case-study. Opportunities for improving the clarity and formulation of the proposed indicators and their variables were also identified, and new indicators were developed, giving rise to the second generation of PIs for WTP and urban WWTP.

It was concluded that all indicators of the WTP and WWTP systems are relevant depending on the assessment objectives, although in some treatment plants the lack of reliable data may limit the use of a few PIs. The results show the ability of the proposed PI systems to assess the overall performance of a given treatment plant. The aggregated results of an indicator may be used as reference values whenever these are not included in the PI definition, provided the aggregation is made for a group of similar undertakings in terms of the performance criterion assessed by that particular PI. The aggregated results are ultimately very important for the continuous improvement of the plant performance through benchmarking and targets' periodic reassessment.

The results presented in this communication are considered preliminary since data reliability and accuracy are still aspects to improve by the water utilities for the period of 2006-2009. Results from a second calculation, including the year 2010, will soon be produced.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

Alegre H., Hirner W., Melo Baptista J., Parena R. (2000). *Performance indicators for water supply services*. 1st edition. Manual of Best Practices Series. IWA Publishing, London. ISBN 1-900222-272.

Alegre H., Melo Baptista J., Cabrera Jr E., Cubillo F., Duarte P., Hirner W., Merkel W., Parena R. (2006). *Performance indicators for water supply services*. 2nd edition. Manual of Best Practices Series. IWA Publishing, London. ISBN 1843390515.

DWA (2008). *Corporate Benchmarking - Metric Benchmarking as Component of the Modernisation Strategy - Performance Indicators and Evaluation Principles*. DWA German Association for Water, Wastewater and Waste, Germany. ISBN 978-3-941089-33-4

Matos R., Cardoso A., Ashley R., Duarte P., Molinari A. Schulz A. (2003). *Performance indicators for wastewater services. Manual of Best Practices Series*. IWA Publishing, London. ISBN 19002229006.

OfWat (2004). *Updating the overall performance assessment (OPA) – conclusions and methodology for 2004-05 onwards*. UK Office of Water Services.

Quadros S., Rosa M.J., Alegre H., Silva C. (2010a). A performance indicators system for urban wastewater treatment plants. *Water Science and Technology – Water supply*, 62(10) 2398-2407.

Quadros S., Rosa M.J., Silva C., Alegre H., Vieira P., Ramalho P. (2010b). *Fichas de Indicadores de Desempenho Global de ETAR*. The Portuguese initiative for performance assessment of water and wastewater treatment plants. LNEC. Lisbon, June, 122 pp (in Portuguese).

Stahre P., Adamsson J. (2001). Performance benchmarking: A powerful management instrument for water and wastewater utilities. *Water Technology*, 12, 47-77.

Stahre P., Adamsson J., Mellstrom G. (2008). A new approach for assessment of the performance of water distribution and sewerage networks. *In International Conference on Performance Assessment of Urban Infrastructure Services. Drinking water, wastewater and solid waste*. Eds. E. Cabrera Jr, M.A. Pardo. IWA Publishing, London, ISBN 1843391910, 5-24.

Vieira P., Alegre H., Rosa M. J., Lucas H. (2008). Drinking water treatment plants assessment through performance indicators. *Water Science and Technology - Water Supply*, 8(3) 245-253.

Vieira P., Rosa M. J., Alegre H., Ramalho P., Silva C., Lucas H. (2009). Avaliação de desempenho de estações de tratamento de água. *Águas & Resíduos*, série III. No. 9, January/April, pp 4-17 (in Portuguese).

Vieira P., Rosa M. J., Alegre H., Lucas H. (2010a). Assessing the operational performance of water treatment plants – focus on water quality and treatment efficiency. In *Proceedings of IWA World Water Congress*. Montréal.

Vieira P., Rosa M. J., Silva C., Alegre H., Ramalho P. (2010b). *Fichas de Indicadores de Desempenho Global de ETA*. The Portuguese initiative for performance assessment of water and wastewater treatment plants. LNEC. Lisbon, June, 72 pp (in Portuguese).

World Bank (2006). *IBNET indicator definitions*. World Bank, Washington.