1. Phosphorus Concentrations in Environmental Samples

1.5 Sewage and Process Water

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Sewage is water that has already been used (e.g. in households, in industry) and can therefore have an increased P load. Phosphorus in the effluent of a wastewater treatment plant is a key quality parameter in wastewater treatment.

Process water is water that is used for specific, usually industrial purposes and which has to meet certain requirements, e.g. in terms of its P content, often also in terms of lime content, conductivity and pH value. The desired water quality is achieved by eliminating or adding certain P-containing substances.

1.5.1 Sewage

In Germany, the population-specific P load in municipal sewage is currently assumed to be 1.8 g TP per inhabitant per day (ATV-DVWKA 198). Industrial sewage is sector-specific. Donnert and Salecker (1999), for example, determined 159 mg TP l^{-1} in the sewage of a starch factory and 5 to 100 mg TP l^{-1} in the sewage of a car factory. Assuming such industrial effluents, this results in phosphorus contents in the influent of the wastewater treatment plants that can deviate significantly in some cases from the typical values listed in Table 1.5-1.

For treated sewage, there are minimum requirements for P concentrations when discharging sewage into bodies of water, which are regulated by the sewage regulation ("Abwasserverordnung", AbwV 31.03.1997) in Germany. For municipal sewage, a TP concentration of 2 mg l^{-1} in the effluent (water after clarification) must be complied with for sewage treatment plant size class 4 (approx. 10,000 population equivalents) and above, and 1 mg TP l^{-1} for sewage treatment plant size class 5 (approx. 100,000 population equivalents) and above. Operational sewage is also subject to official requirements regarding its discharge into the environment. Sector-specific minimum requirements are contained in the annexes to the AbwV.

Further requirements may be formulated by the competent authorities for specific water bodies.

P can be removed from sewage biologically and/or chemically. In principle, microorganisms also absorb P from the sewage for their cell structure and metabolism when decomposing organic carbon compounds and build up biomass. In this way, P is biologically transferred from the sewage water into the sewage sludge, which can then be used as an organic fertilizer, in landscaping or can be used for thermal recycling, depending on its overall composition. Tränckner et al. (2016) state a biological elimination efficiency for P of 47 % in relation to the inflow value. Special process management (anaerobic, aerobic cycles) can double the biological P elimination (Cramer et al. 2018). However, as P retention in biological processes often cannot be operated with a sufficiently high degree of efficiency or sufficient process stability, P is usually additionally precipitated by using metal salts (SEG 2014). Examples of TP concentrations in sewage and its treatment products can be found in Table 1.5-1.

Table 1.5-1 TP concentrations in sewage, sludge and ash

Example	Type	TP (mg l^{-1} for water, mg kg^{-1} for sludge and ash)	Source
All wastewater treatment plants in Germany	Before clarification	0,9 – 12,4	DWA-Leistungsvergleich 2016
	After clarification	0,41 – 0,84	
All wastewater treatment plants in Baden-Württemberg	before clarification	5,9	MUV-BM (2003)
	After clarification	1,7	
	after clarification with phosphate precipitation	0,7	
Sewage sludge (2006)		24,5	UBA (2013)
Ash	From household sewage	40-130	Regeneration station Stuttgart

In particular, the P concentration in sewage sludge depends on the P concentration in the sewage to be treated and thus on its source (urban/ industrial area). It is also influenced by the effectiveness of the biological and chemical processes during the treatment process.

1.5.2 Process Water

Increased requirements are placed on water with regard to water quality if it is used in industrial plants (e.g. power plants) for the industrial manufacture of products (e.g. medicines) or in laboratories (chemical analysis). The elimination of P is achieved through the use of various processes, such as reverse osmosis or the ion exchange process. Quality differences between these different process waters are defined by the conductivity of the respective water (Table 1.5-2) and checked also using blank value target charts for the analyte concentrations (TP or phosphate) (Chapter 6.3).

Table 1.5-2 Conductivity in process water ($\mu S\ cm^{-1}$)

Matrix	Conductivity	Source
Distilled water	0,5-5	Regeneration station Stuttgart
Process water in power plants	< 0,2	
Ultrapure water for analysis	< 0,055	
P addition to drinking water (K_2HPO_4, KH_2PO_4, $K_4(PO_4)_2$, K_3PO_4 $Na_2H_2PO_4$, NaH_2PO_4, Na_2HPO_4, $Na_4(PO_4)_2$, Na_3PO_4, Potassium tripolyphosphate, Sodium polyphosphate, Sodium polyphosphate, H_3PO_4, Phosphonic acid)	2790[1]	Trinkwasserverordnung 2001, UBA 2012

On the other hand, chemicals containing P can also be added to water, for example to minimize the corrosion of pipes. Orthophosphates have an anti-corrosion effect on ferrous materials such as cast iron, steel, and galvanized steel as well as copper materials and lead (quoted in Schmidt 2009). The precipitation of lime (calcite) in pipes is delayed by polyphosphate (Schmidt 2009). If the P-containing chemicals are added to drinking water, they must

[1] Or 2,2 mg l^{-1} as the limit value for addition to drinking water against corrosion according to the "Liste der Aufbereitungsstoffe und Desinfektionsverfahren gemäß § 11 der TrinkwV (19. Änderung)" (UBA 2017)

be listed in Section 11 of the Drinking Water Regulation ("Trinkwasserverordnung") 2001 and must not exceed the maximum addition concentrations specified there (polyphosphates < 2.2 mg P l^{-1} UBA 2017) (Table 1.5-2). Other industrial applications of P-containing reagents include biological nitrate removal, inhibition of membrane blockage and, of course, as buffers for pH adjustment (UBA 2012).

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