

Supplementary Materials:

Supplementary Material

1. Survey Content

The following questions were sent to WWTP operators for our survey:

1. Does the WWTP have a primary clarifier?
2. If yes, what is the size of the primary clarifier?
3. How is sludge stabilised in the WWTP?
4. Does the WWTP have a dewatering unit?
5. If yes, which device is used for dewatering?
6. If yes, Which dry solids concentration is achieved with dewatering?
7. Does the WWTP have a sludge drier?
8. If yes, which type of sludge drier?
9. Does the WWTP have a sludge storage?
10. If yes, what is the storage capacity?
11. Does the WWTP perform enhanced biological phosphorus removal?
12. Is phosphorus precipitated chemically at the WWTP?
13. If yes, which precipitant is used?
14. If yes, how much precipitant is used per year?
15. Is there any secondary treatment of sewage sludge?
16. How much sludge was produced by the WWTP in 2016?
17. How was sludge disposed of in the year 2016? How far, where the transport distances and what were the related costs for sludge disposal.
18. What is the phosphorus content and loss on ignition in the sludge?

2. Data

Table S1. Summary data table of use of iron and aluminium in WWTPs with aerobic and anaerobic sludge treatment.

Precipitation agent in % of treated PE	Aerobic (n = 135)	Anaerobic (n = 106)
Iron	66	81
Aluminium	20	8
Iron/Aluminium	14	11

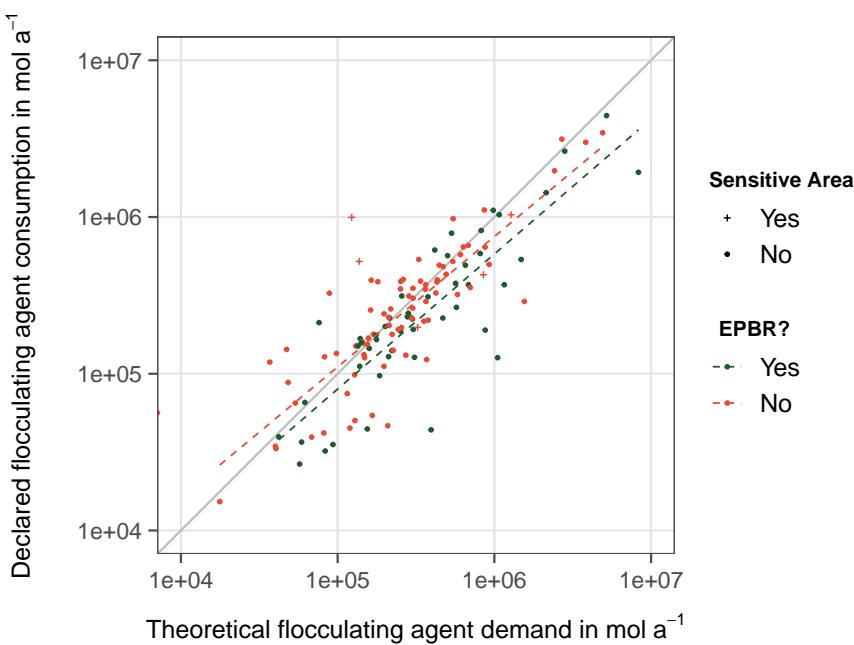


Figure S1. Comparison of theoretical precipitating agent demand derived from precipitable phosphorus amounts and declared demand from WWTP operators in mol per year.

Table S2. Summary data table of observed β values (mol of added precipitating agent divided by mol of phosphorus that need to precipitated) with or without enhanced biological phosphorus removal (EBPR). Groups are significantly different ($p = 0.03$).

β value in mol/mol	with EBPR (n = 49)	w/o EBPR (n = 81)
minimum	0.17	0.28
median (IQR)	1.13 (0.73, 1.49)	1.38 (1.03, 1.75)
mean (sd)	1.18 ± 0.67	1.75 ± 1.72
maximum	4.17	13.77

Table S3. Summary data table of sewage sludge yield in g PE $^{-1}$ d $^{-1}$ according to their sludge treatment process and with or without lime addition for hygienisation.

Sludge production in g PE $^{-1}$ d $^{-1}$	Aerobic (simultaneous) (n = 64)	Aerobic (separated) (n = 21)	Aerobic + lime (n = 13)
minimum	21.10	22.33	39.20
median (IQR)	51.96 (41.04, 67.74)	44.98 (31.49, 56.20)	77.04 (58.27, 92.83)
mean (sd)	57.69 ± 28.15	44.42 ± 14.90	77.26 ± 27.44
maximum	170.12	67.59	138.79

Sludge production in g PE $^{-1}$ d $^{-1}$	Anaerobic (n = 125)	Anaerobic + lime (n = 20)
minimum	11.30	31.63
median (IQR)	36.77 (31.15, 44.20)	57.28 (52.18, 71.32)
mean (sd)	39.86 ± 16.37	61.65 ± 17.98
maximum	114.90	96.85

Table S4. Summary data table of sewage sludge loss on ignition in % according to their sludge treatment process and with or without lime addition for hygienisation.

Loss on ignition in %	Aerobic (simultaneous) (n = 19)	Aerobic (separated) (n = 5)	Aerobic + lime (n = 10)
minimum	45.00	50.00	20.67
median (IQR)	70.90 (64.52, 76.25)	64.33 (51.73, 71.33)	35.12 (32.42, 38.40)
mean (sd)	68.96 ± 10.73	62.44 ± 11.23	34.13 ± 6.79
maximum	84.77	74.80	42.43

Loss on ignition in %	Anaerobic (n = 54)	Anaerobic + lime (n = 15)
minimum	47.53	19.50
median (IQR)	58.55 (55.52, 63.57)	33.83 (26.90, 37.05)
mean (sd)	59.22 ± 5.86	32.98 ± 8.00
maximum	72.60	50.00

Table S5. Summary data table of sewage sludge dry solid concentrations in % after dewatering with various devices.

Dry solid concentration in %	Centrifuge (n = 79)	Filter press (n = 42)	Filter press + lime (n = 26)	Belt press (n = 20)
minimum	18.00	22.10	26.00	15.00
median (IQR)	25.50 (23.00, 27.75)	27.50 (26.23, 30.84)	34.00 (30.00, 36.92)	21.20 (20.00, 24.55)
mean (sd)	25.46 ± 3.13	28.21 ± 2.99	33.76 ± 4.36	21.77 ± 3.66
maximum	32.50	33.00	41.00	27.20

Dry solid concentration in %	Screw press (n = 58)	Mobile (n = 9)
minimum	16.50	21.00
median (IQR)	23.70 (22.00, 25.60)	22.60 (21.79, 28.53)
mean (sd)	23.75 ± 3.25	25.37 ± 5.43
maximum	30.00	34.00

Table S6. Type and number of installed sludge dryers in Austria as well as mean dry matter content after drying in percent.

Type	Mean	n
Solar dryers	71	9
Belt dryers	73	2
Convection dryers	84	2

Table S7. Summary data table of sewage sludge disposal costs (wet substance) in € t⁻¹ according to the applied sludge disposal method.

Disposal cost in € t ⁻¹	Agriculture wet (n = 5)	Agriculture dewatered (n = 43)	Composting at WWTP site (n = 3)	Composting external (n = 84)	Thermal treatment (n = 50)
minimum	3.50	12.20	35.71	37.60	49.00
median (IQR)	6.15 (4.04, 6.19)	30.00 (21.95, 43.45)	40.00 (37.86, 43.93)	58.59 (53.00, 70.98)	74.50 (65.84, 80.92)
mean (sd)	5.50 ± 1.70	34.11 ± 15.28	41.19 ± 6.16	61.56 ± 11.96	73.79 ± 12.14
maximum	7.63	78.43	47.86	87.53	100.00

Table S8. Summary data table of sewage sludge disposal costs (dry substance) in € t⁻¹ according to the applied sludge disposal method.

Disposal cost in € t ⁻¹	Agriculture wet (n = 5)	Agriculture dewatered (n = 43)	Composting at WWTP site (n = 3)	Composting external (n = 84)	Thermal treatment (n = 50)
minimum	100.90	21.29	111.62	69.23	72.00
median (IQR)	125.30 (102.46, 173.50)	93.83 (74.31, 142.21)	178.43 (145.02, 181.16)	233.72 (186.67, 301.40)	287.82 (256.98, 346.67)
mean (sd)	142.65 ± 48.21	112.83 ± 59.76	157.98 ± 40.24	237.12 ± 66.31	291.15 ± 90.24
maximum	211.10	314.58	183.89	370.57	555.56

Table S9. Summary data table of sewage sludge transport distances (one-way) in km according to the applied sludge disposal method.

Transport distance in km	Agriculture wet (n = 7)	Agriculture dewatered (n = 44)	Composting at WWTP site (n = 4)	Composting external (n = 139)	Thermal treatment (n = 115)
minimum	1.00	0.50	0.00	0.03	0.06
median (IQR)	3.75 (2.50, 6.00)	15.00 (8.15, 20.10)	0.25 (0.00, 1.88)	49.25 (22.52, 94.24)	117.38 (68.74, 172.76)
mean (sd)	4.68 ± 3.35	17.03 ± 13.24	1.62 ± 2.93	109.14 ± 147.93	127.08 ± 89.39
maximum	11.00	63.17	6.00	520.67	373.93

Table S10. Summary data table of sewage sludge phosphorus content in g kg⁻¹ according to their sludge treatment process and with or without lime addition for hygienisation.

Phosphorus content in g kg ⁻¹	Aerobic (n = 24)	Aerobic + lime (n = 11)	Anaerobic (n = 53)	Anaerobic + lime (n = 18)
minimum	8.90	10.00	13.00	12.67
median (IQR)	26.57 (18.80, 34.17)	22.17 (13.47, 29.83)	34.00 (29.00, 38.57)	22.30 (18.08, 30.79)
mean (sd)	26.97 ± 10.37	21.58 ± 9.45	34.60 ± 9.24	24.19 ± 7.74
maximum	47.05	35.40	63.00	41.27

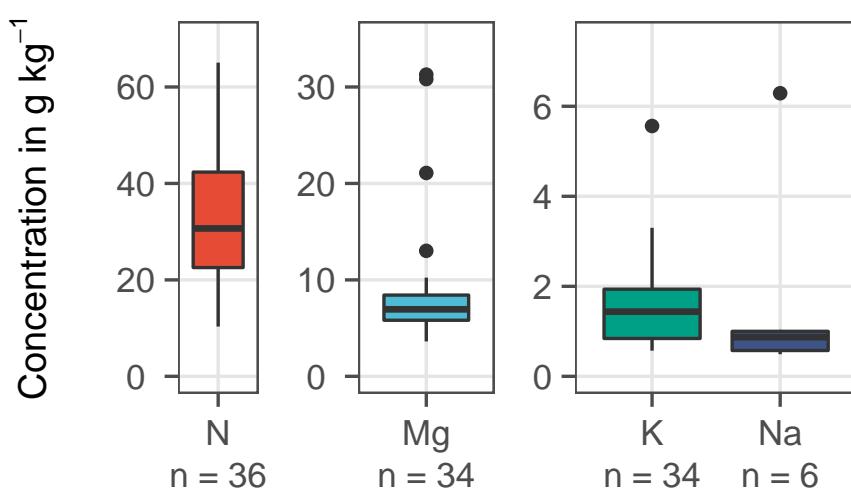


Figure S2. Nutrient (nitrogen, magnesium, potassium and sodium) sewage sludge concentrations in grams per kilogram. Statistical values are provided in Table S11.

Table S11. Summary data table of sewage sludge nutrient content in g kg⁻¹.

Nutrient content in g kg ⁻¹	Potassium (n = 34)	Magnesium (n = 34)	Nitrogen (n = 36)	Sodium (n = 6)
minimum	0.57	3.62	10.32	0.49
median (IQR)	1.44 (0.84, 1.94)	6.95 (5.82, 8.42)	30.67 (22.55, 42.35)	0.87 (0.57, 1.00)
mean (sd)	1.61 ± 1.01	8.77 ± 6.44	32.78 ± 12.06	1.67 ± 2.27
maximum	5.56	31.28	65.05	6.29

Table S12. Summary data table of heavy metal concentrations in sewage sludge in mg kg⁻¹ according to the size group of the respective wastewater treatment plants.

Concentration in mg kg ⁻¹	< 20,000 PE	20,000 to 50,000 PE	> 50,000 PE
Cadmium	(n = 130)	(n = 72)	(n = 42)
minimum	0.13	0.25	0.21
median (IQR)	0.78 (0.59, 1.12)	0.75 (0.59, 0.99)	0.76 (0.58, 0.91)
mean (sd)	0.90 ± 0.47	0.82 ± 0.39	0.75 ± 0.25
maximum	3.60	2.76	1.33
Chromium	(n = 130)	(n = 72)	(n = 42)
minimum	4.93	11.51	5.06
median (IQR)	28.47 (19.25, 37.74)	28.75 (23.75, 46.50)	39.75 (30.15, 59.75)
mean (sd)	32.42 ± 28.21	42.96 ± 46.00	49.61 ± 30.26
maximum	293.40	310.00	140.00
Copper	(n = 130)	(n = 71)	(n = 42)
minimum	48.00	46.30	64.00
median (IQR)	195.43 (145.25, 269.92)	186.65 (139.00, 255.21)	223.59 (142.14, 257.50)
mean (sd)	211.78 ± 101.10	201.26 ± 84.03	214.65 ± 80.31
maximum	646.67	440.00	477.50
Lead	(n = 130)	(n = 72)	(n = 42)
minimum	5.97	7.56	8.83
median (IQR)	28.61 (21.16, 38.91)	26.85 (21.12, 39.11)	27.00 (22.13, 33.79)
mean (sd)	32.01 ± 17.26	33.17 ± 23.62	29.81 ± 16.34
maximum	111.70	169.00	105.50
Mercury	(n = 130)	(n = 72)	(n = 42)
minimum	0.02	0.10	0.10
median (IQR)	0.46 (0.30, 0.75)	0.50 (0.36, 0.73)	0.57 (0.38, 0.70)
mean (sd)	0.66 ± 0.74	0.59 ± 0.38	0.65 ± 0.64
maximum	5.96	2.15	4.30
Nickel	(n = 130)	(n = 72)	(n = 42)
minimum	3.60	8.10	5.79
median (IQR)	23.10 (16.42, 29.65)	21.75 (16.00, 30.98)	22.98 (17.65, 33.03)
mean (sd)	27.24 ± 29.61	28.51 ± 22.10	30.13 ± 32.46
maximum	301.62	140.00	222.67
Zinc	(n = 130)	(n = 70)	(n = 42)
minimum	132.00	170.00	125.49
median (IQR)	662.23 (439.08, 844.92)	700.05 (524.47, 819.89)	678.50 (485.41, 868.57)
mean (sd)	690.54 ± 339.02	676.28 ± 238.46	672.01 ± 245.28
maximum	2,863.80	1,470.78	1,195.00