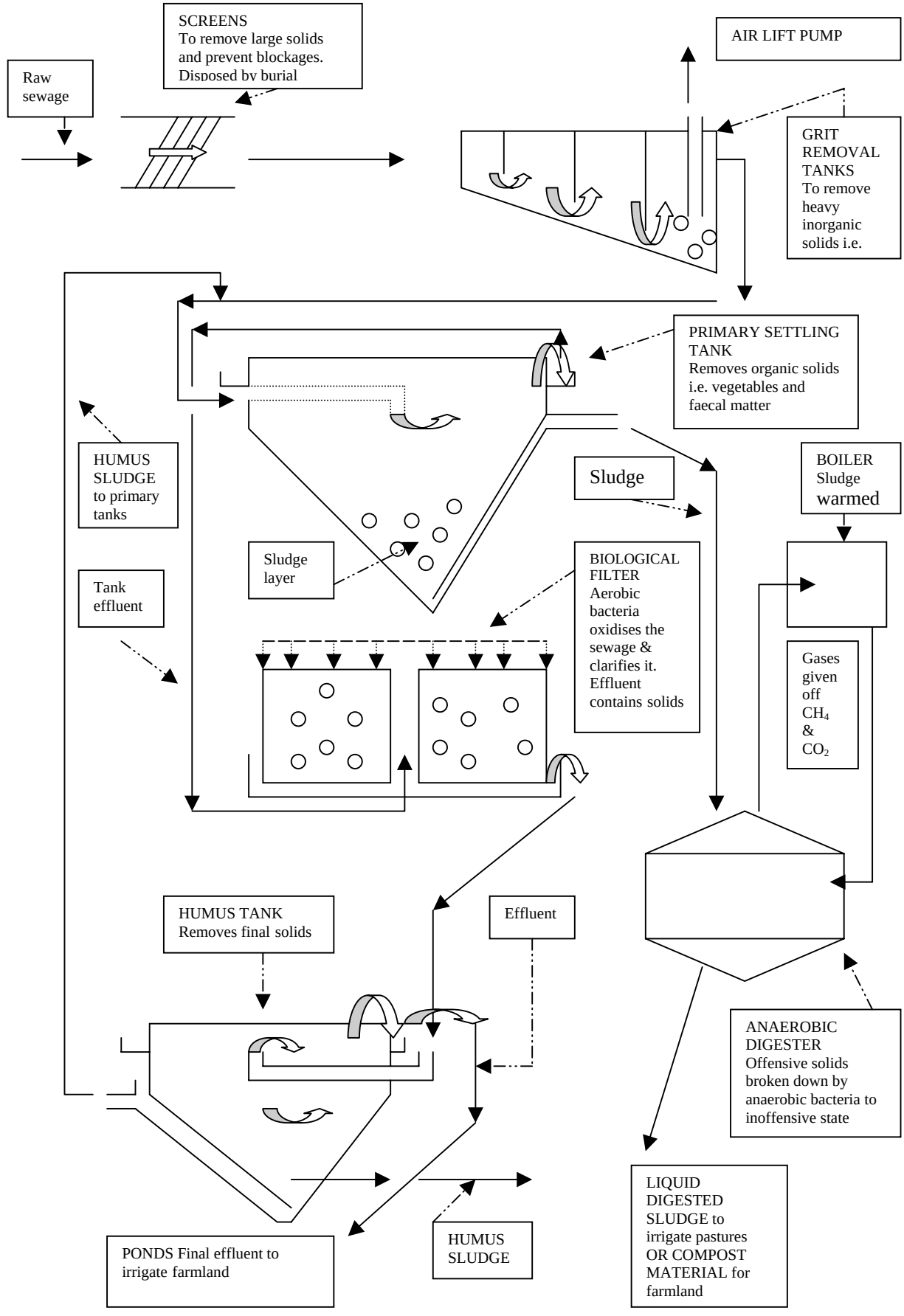
Appendix 1: Sewage treatment processes at Firle Wastewater treatment Plant



Types of treatment technologies used at Firle Wastewater Treatment Plant

Firle Wastewater Treatment Plant utilises two types of sewage treatment technologies, namely biological trickling filtration plants and biological nutrient removal activated sludge plants. Sewage treatment or wastewater processing normally comprises unit operations and processes that provide various levels of treatment. The processes are commonly referred to as preliminary, primary, secondary and tertiary. The term preliminary and/or primary refers to physical processes, where coarse suspended materials are removed. Secondary treatment refers to chemical and biological processes whereas tertiary treatment is a combination of the three. The diagram shown above presents the treatment processes in the two technologies at Firle Treatment Works and these are briefly described below.

In primary treatment a portion of suspended solids and organic matter is removed using physical operations such as screening and sedimentation. As such effluent from primary treatment normally has a considerable amount of organic matter and a relatively high BOD. Conventional secondary treatment is targeted at the removal of biodegradable organic materials and suspended solids. It includes biological treatment by activated sludge, fixed-film reactors and sedimentation. Tertiary treatment is a level of treatment that goes beyond conventional treatment to remove constituents of concern including increased amounts of organic matter and solids, toxic compounds and nutrients.

Biological trickling filtration system

In trickling filter treatment (shown as biological filter in diagram), raw sewage is directed to screens where large objects and grit are removed using grit removal tanks, before the sewage flows to primary settling tanks. In the tanks the sewage is separated into settled sewage and primary sewage. The settled sewage then flows to bio-filters where the trickling effluent goes to secondary sedimentation tanks in which secondary sludge (humus) is removed. The effluent from the secondary sedimentation tanks then goes to maturation tanks/ponds. This effluent does not meet Zimbabwe's effluent discharge standards, therefore it cannot be discharged into rivers. Instead, in the case of Firle Treatment Works it is mixed with sludge and directed to irrigated pastures.

Biological nutrient removal sludge activated system

In the biological nutrient removal activated sludge treatment system, the preliminary stage comprises screening and grit removal. The primary stage physically separates primary sludge and effluent. After that the sludge is sent to digesters (shown as anaerobic digesters in diagram) and the settled sewage is directed to the activated sludge aeration tank.

Bacteria in the aerated tank use up most phosphates and nitrates in the sewage. Once the sludge has settled in final settling tanks (clarifiers) some of it is sent out as waste activated sludge while the other is returned to the head of the aeration basin to enrich the incoming sewage with degrading bacteria. The effluent from the biological nutrient removal treatment plants generally meets the Zimbabwe effluent standards and is therefore discharged into Manyame river

Appendix 2: Randomised block design layout of pots in greenhouse

Block 3		Block 2		Block 1	
Water		Cd_{80}		Cd_{10}	
Cd_{20}	Cd_{10}	Cd_{20}	Cd_{20} + Pb_{600}	Pb_{1200}	Cd_{80}
Pb_{1200}	Cd_{80}	Effluent & sludge	Cd_{10}	Cd_{40}	Effluent & sludge
Cd_{10} + Pb_{300}	Cd_{60}	Water	Pb_{1200}	Water	Pb_{300}
Pb_{300}	Cd_{20} + Pb_{600}	Cd_{40} + Pb_{1200}	Pb_{300}	Cd_{10} + Pb_{300}	Cd_{20} + Pb_{600}
Pb_{600}	Cd_{40} + Pb_{1200}	Cd_{60}	Cd_{10} + Pb_{300}	Cd_{20}	Cd_{60}
Cd_{40}	Effluent & sludge	Cd_{40}	Pb_{600}	Pb_{600}	Cd_{40} + Pb_{1200}

Appendix 3: Quantities of treated sewage and metals applied to field plots

Irrigation event	Plot number	Volume of irrigation (m^3/plot)	Pb applied to plots		Cd applied to plots	
			(mg/l)	(mg)	(mg/l)	(mg)
1	T 1.1	3.32	0.3	995.40	0.1	331.80
2	T 1.1	2.53	0	0.00	0.3	760.09
3	T 1.1	3.30	0.1	329.82	0.10	329.82
4	T 1.1	3.32	0.40	1326.06	0.30	994.54
5	T 1.1	3.33	0.9	2993.14	0.2	665.14
6	T 1.1	3.30	0.6	1982.50	0.1	330.42
7	T 1.1	3.30	0.55	1812.26	0.15	494.25
8	T 1.1	3.31	0.4	1323.25	0.2	661.62
Mean		**25.70**	**0.42**	**10762.43**	**0.18**	**4567.69**
1	T 1.2	3.32	0.3	996.35	0.1	332.12
2	T 1.2	3.36	0	0.00	0.3	1008.01
3	T 1.2	1.79	0.25	448.63	0.05	89.73
4	T 1.2	3.36	0.40	1344.67	0.30	1008.50
5	T 1.2	3.31	0.9	2982.35	0.2	662.74
6	T 1.2	3.29	0.6	1976.93	0.1	329.49
7	T 1.2	3.29	0.55	1807.04	0.15	492.83
8	T 1.2	3.32	0.4	1326.87	0.2	663.43
Mean		**25.05**	**0.43**	**10882.84**	**0.18**	**4586.85**
1	T 1.3	1.61	0.3	0.00	0.1	0.00
2	T 1.3	3.29	0.25	986.46	0.05	328.82
3	T 1.3	3.29	0.40	822.20	0.30	164.44
4	T 1.3	3.30	0.9	1319.05	0.2	989.29
5	T 1.3	3.31	0.55	2977.83	0.15	661.74
6	T 1.3	3.29	0.55	1807.71	0.15	493.01
7	T 1.3	3.30	0.25	1814.96	0.05	494.99
8	T 1.3	3.32	0.4	830.98	0.2	166.20
9	T 1.3	1.72		687.66		343.83
Mean		**26.42**	**0.43**	**11246.84**	**0.14**	**3642.31**
1	T 2.1	3.33	0.3	998.15	0.1	332.72
2	T 2.1	5.78	0.1	578.14	0.10	578.14
3	T 2.1	6.57	0.40	2629.66	0.30	1972.24
4	T 2.1	6.63	0.9	5970.30	0.2	1326.73
5	T 2.1	6.60	0.55	3630.35	0.15	990.10
6	T 2.1	6.57	0.55	3614.36	0.15	985.73
7	T 2.1	6.58	0.25	1645.28	0.05	329.06
8	T 2.1	6.61	0.4	2643.62	0.2	1321.81
Mean		**48.68**	**0.45**	**21709.86**	**0.16**	**7836.53**

Appendix 3: cont'd

Irrigation number	Plot number	Volume of irrigation (m^3/plot)	Pb applied to plots		Cd applied to plots	
			(mg/l)	(mg)	(mg/l)	(mg)
1	T 2.2	6.60	0.3	1980.56	0.1	660.19
2	T 2.2	6.57	0.25	1643.35	0.05	328.67
3	T 2.2	0.90	0.2	179.71	0.05	44.93
4	T 2.2	6.60	0.40	2639.77	0.30	1979.83
5	T 2.2	6.62	0.9	5957.68	0.2	1323.93
6	T 2.2	6.59	0.55	3623.49	0.15	988.23
7	T 2.2	6.60	0.55	3630.43	0.15	990.12
8	T 2.2	6.56	0.25	1638.88	0.05	327.78
Mean		**49.88**	**0.43**	**21293.87**	**0.13**	**6643.66**
1	T 2.3	6.61	0	0.00	0.3	1982.94
2	T 2.3	6.58	0.25	1645.02	0.05	329.00
3	T 2.3	6.62	0.40	2646.93	0.30	1985.20
4	T 2.3	6.61	0.9	5952.30	0.2	1322.73
5	T 2.3	3.35	0.6	2011.04	0.1	335.17
6	T 2.3	6.57	0.45	2958.68	0.1	657.49
7	T 2.3	6.66	0.25	1664.10	0.05	332.82
8	T 2.3	6.59	0.5	3295.39	0.2	1318.16
Mean		**49.59**	**0.41**	**20173.46**	**0.17**	**8263.51**
1	T 3.1	13.27	0.3	3979.97	0.1	1326.66
2	T 3.1	13.17	0	0.00	0.3	3950.85
3	T 3.1	13.15	0.40	5259.65	0.30	3944.74
4	T 3.1	13.15	0.9	11838.99	0.2	2630.89
5	T 3.1	8.83	0.6	5297.54	0.1	882.92
6	T 3.1	12.47	0.45	5612.36	0.1	1247.19
7	T 3.1	13.21	0.45	5943.74	0.25	3302.08
8	T 3.1	13.21	0.5	6605.56	0.2	2642.23
Mean		**100.46**	**0.44**	**44537.81**	**0.20**	**19927.55**
1	T 3.2	13.23	0.3	3969.85	0.1	1323.28
2	T 3.2	6.26	0	0.00	0.3	1878.03
3	T 3.2	13.19	0.9	11871.46	0.2	2638.10
4	T 3.2	13.15	0.40	5259.05	0.30	3944.29
5	T 3.2	13.20	0.3	3959.38	0.1	1319.79
6	T 3.2	13.22	0.45	5947.58	0.1	1321.68
7	T 3.2	13.18	0.45	5931.27	0.25	3295.15
8	T 3.2	13.17	0.5	6586.33	0.2	2634.53
Mean		**98.60**	**0.44**	**43524.93**	**0.19**	**18354.87**
1	T 3.3	13.17	0	0.00	0.3	3949.55
2	T 3.3	8.82	0.40	3526.35	0.30	2644.77
3	T 3.3	5.43	0.9	4888.54	0.2	1086.34
4	T 3.3	13.16	0.9	11845.62	0.2	2632.36
5	T 3.3	14.17	0.3	4249.63	0.1	1416.54
6	T 3.3	13.17	0.45	5924.35	0.1	1316.52
7	T 3.3	13.18	0.45	5932.16	0.25	3295.65
8	T 3.3	13.17	0.5	6583.36	0.2	2633.34
Mean		**94.25**	**0.46**	**42950.01**	**0.20**	**18975.08**

Appendix 4: Mean soil bio-available concentrations (standard deviations), mg/kg and soil depth

Depth	Control			Treatment 1			Treatment 2			Treatment 3			Treatment 4		
	Har 1	Re-g3	Re-g 4	Har 1	Re-g3	Re-g 4	Har 1	Re-g3	Re-g 4	Har 1	Re-g3	Re-g 4	Har 1	Re-g3	Re-g 4
							Lead								
0-10	0.37	0.23	0.50	1.28	0.80	0.80	1.31	0.90	0.16	1.82	1.00	0.47	17.92	16.91	19.30
	(0.12)	(0.12)	(0.20)	(0.26)	(0.46)	(0.35)	(0.09)	(0.60)	(0.06)	(0.34)	(0.26)	(0.12)	(2.86)	(2.12)	(1.19)
10-20	0.40	0.28	0.60	1.34	0.83	0.60	1.30	0.87	0.75	1.85	1.10	0.93	7.18	8.65	12.71
	(0.17)	(0.13)	(0.15)	(0.43)	(0..51)	(0.46)	(0.24)	(0.49)	(0.07)	(0.16)	(0.44)	(0.75)	(2.59)	(3.41)	(2.66)
20-30	0.40	0.50	0.90	1.21	0.43	0.73	1.39	1.00	1.30	1.82	1.33	0.90	-	4.79	8.45
	(0.10	(0.10)	(0.31)	(0.37)	(0.23)	(0.23)	(0.29)	(0.46)	(0.96)	(0.33)	(0.23)	(1.14)	-	(0.97)	(2.21)
30-40	-	-	-	0.94	0.87	0.77	1.35	1.35	1.27	1.56	1.27	0.05		5.6	9.30
				(0.21)	(0.46)	(0.15)	(0.15)	(0.21)	(1.25)	(0.61)	(0.31)	(0.07)		(2.33)	(1.78)
							Cadmium								
0-10	0.01	0.04	0.04	0.02	0.01	0.12	0.04	0.04	0.06	0.07	0.02	0.03	1.2	1.2	0.15
	(0.00)	(0.03)	(0.03)	(0.00)	(0.01)	(0.06)	(0.00)	(0.04)	(0.05)	(0.02)	(0.01)	(0.02)	(0.01)	(0.04)	(0.03)
10-20	0.01	0.01	0.03	0.02	0.01	0.13	0.04	0.04	0.00	0.07	0.05	0.03	1.0	0.93	0.07
	(0.00)	(0.01)	(0.02)	(0.00)	(0.01)	(0.07)	(0.00)	(0.03)	(0.00)	(0.01)	(0.05)	(0.02)	(0.05)	(0.45)	(0.01)
20-30	0.02	0.01	0.03	0.02	0.02	0.13	0.04	0.69	0.01	0.07	0.02	0.02	0.80	0.77	0.1
	(0.02)	(0.01)	(0.01)	(0.00)	(0.01)	(0.06)	(0.01	(0.14)	(0.01)	(0.02)	(0.02)	(0.01)	(0.04)	(0.13)	(0.03)
30-40	0.01	0.02	0.01	0.03	0.03	0.11	0.04	0.03	0.01	0.07	0.04	0.02	0.70	0.72	0.07
	(0.00)	(0.01)	(0.00)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)	(0.03)	(0.01)	(0.01)	(0.03)	(0.32)	(0.02)

Har - Harvest 1 (i.e. first crop); Reg - re-growth; - missing values