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Assessing factors affecting the reduction of phosphorus and faecal microbes in wastewater by decentralised wastewater treatment systems

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Definition

- Decentralised systems
  - small-scale
  - commonly used in rural and isolated locations
  - domestic and/or commercial and industrial
  - developing and developed world

Types

[Standalone or in various combinations]

- Septic tanks, ST (most common)
- Constructed wetlands, CW (common)
- Reedbeds, wastewater stabilisation ponds, etc.
- Filtration systems
  - Media: soil/minerals, plastics, plants, etc.
- Chemical coagulation/flocculation/settling systems
- Package systems
  - Aerobic/anaerobic completely mixed liquor and fixed film systems, etc.

Challenges

- Usually bought off the shelf
  - system selection and operation less informed by robust wastewater characterisation, lifestyle of owners, and general site and climatic conditions
  - Often marketed by non-sector professionals
- System efficiency subject to operational *'trial and error'* and non-committing maintenance culture
- Performance often suffers from poor consumer awareness leading to increased costs and conflicts with environmental regulators

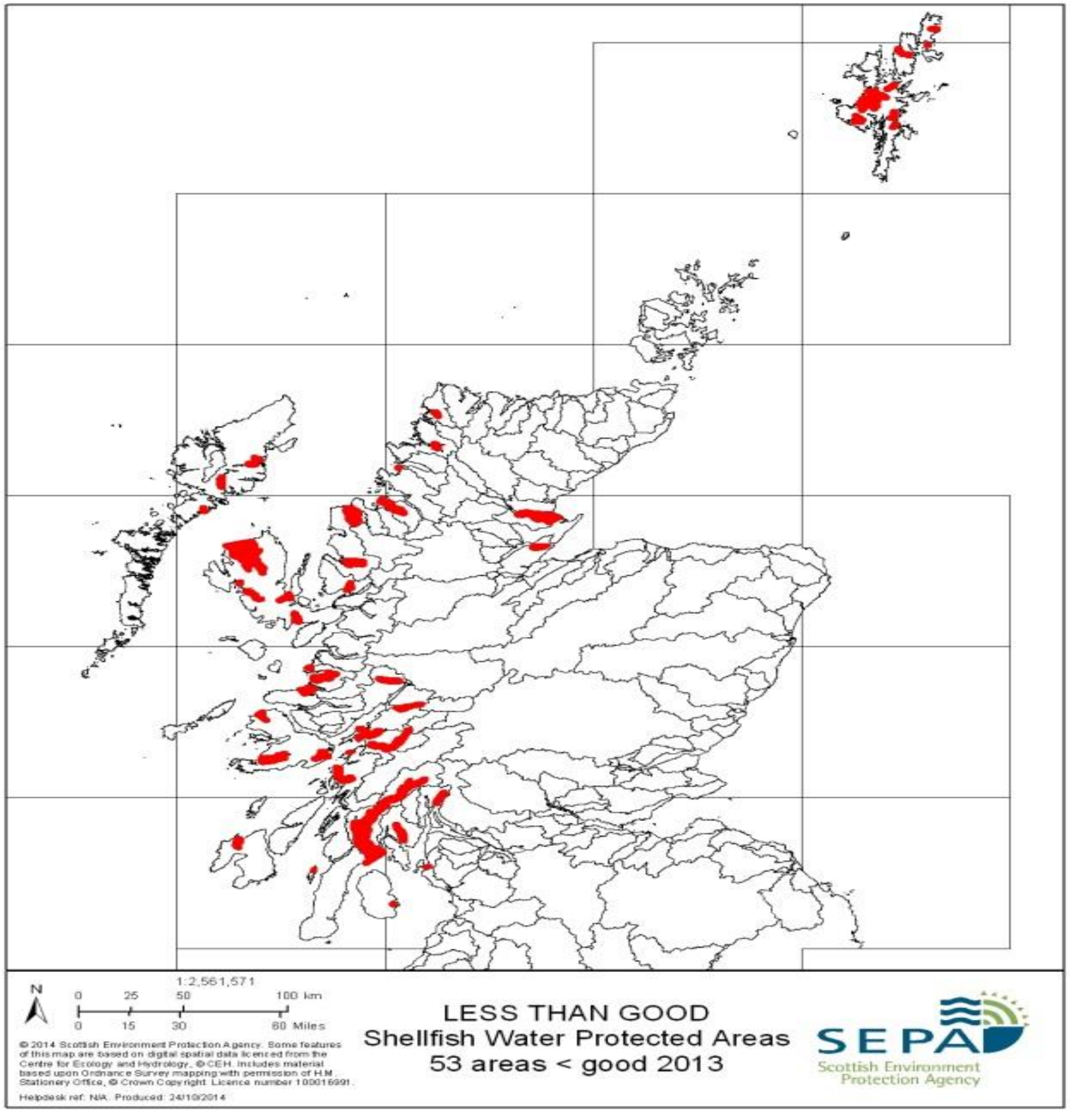
Common DWST target pollutants:
Solids, BOD, Ammonia

Traditional DWST are not commonly designed for Phosphorus and Pathogen removal

Our research

- Review effectiveness of small DWTS for *phosphorus* and *pathogen* removal
- Assess factors affecting the efficiency of various DWTS in the removal of these pollutants; and
- Propose measures to improve effectiveness of DWTS for new and existing systems

DWTS in Scotland



In rural Scotland approximately 160,000 properties rely on DWTS to treat their wastewater.

DWTS have been estimated to contribute approximately 23.5% of diffuse load of E. Coli , and 7.6% of the total load (diffuse and point source) to Scottish groundwaters and surface waters (*SNIFFER 2006)*


BLAIR ATHOL

Type of discharge location	Private Untreated	Private Preliminary	Private primary	Private Secondary	Private Tertiary	Number of discharge locations	% discharge location
Sea	64	1	861	88	8	1,022	1.7
Inland water	118	3	10,439	2,439	196	13,195	21.3
Soakaway/ land	351	8	44,481	1,990	102	46,932	75.9
Insufficient data	11	2	466	179	12	670	1.1
Total	544	14	56,247	4,696	318	61,819	100
% of all discharges	0.9	0.0	91.0	7.6	0.5	100	

Sources of Phosphorus

Source apportionment of phosphorus in raw domestic waste water (Defra 2008)

Source	Contribution to phosphorus load
Faeces	23%
Urine	41%
Food waste	5%
Mains supply (phosphate added to reduce Pb in drinking water)	5%
Toothpaste	1%
Dishwasher detergent	7%
Laundry detergent	18%

Mean phosphorus concentrations in septic tank effluent

(Influent TP ~ 6.6 - 26.8 mg l^{-1} ***Lowe et al. 2007, Jenssen et al. 2010*****)**

STE concentration (mg l^{-1}) SRP	TP	System details	Reference
1.9	3.3	Old ST; no soil adsorption bed (field drain discharge)	Ockenden *et al*. 2014
1.4	1.9	Old ST supplemented with modern tank (field drain discharge)	Ockenden et al. 2014
4.8 (0.3-10.6)	9.1 (4.5-18.0)	STs (4) median concentrations	Brownlie *et al*. 2014
8.8 (2.3-11.9)	11.9 (5.8-14.4)	ST (1) with mechanical mixing (4 mo median)	Brownlie *et al*. 2014
5.5 (1.4-10.6)	9.3 (1.9-14.4)	ST with chemical dosing, aeration and filter system (median from two STs over 4 mo)	Brownlie *et al*. 2014
11.6	15.0	ST (concrete)	May *et al*. 2014
14.5	18.4	ST (brick)	
9.4	17.4	ST (concrete)	
13.4	15.0	ST (brick)	
10.7	12.9	Klargester® PTP	

Mean pathogen concentrations in raw wastewater and septic tank effluent (UK and Ireland)

Parameter	Mean concentration in raw wastewater (cfu 100 ml^{-1})	Mean concentration in septic tank effluent (cfu 100 ml^{-1})	Reference
Total coliforms	3.9×10^7	2.5×10^7	Kay et al. 2008
	-	7×10^8	Gill et al. 2007
	$2.0\text{-}3.5 \times 10^8$	-	Kadam et el. 2008
Faecal coliforms	1.2×10^7	-	Harrison et al. 2000
	$2.0\text{-}8.0 \times 10^7$	-	Kadam et el. 2008
	1.7×10^7	7.2×10^6	Kay et al. 2008
	-	2.9×10^5	Pundsack et al. 2001
Enterococci	1.9×10^6	9.3×10^5	Kay et al. 2008
	1.0×10^6	-	Blanch et al. 2003
E. coli	$1.2\text{-}3.3 \times 10^6$	-	Kadam et el. 2008
	-	5.0×10^5	Gill et al. 2007

Common removal processes

- Phosphorus
  - Adsorption
  - Uptake
- Pathogens
  - Inactivation
  - Immobilisation
  - Predation
  - Natural die-off

Phosphorus Removal

Phosphorus removal by various systems

DWTS type	% TP reduction in effluent	Reference
Soil filter beds (aged 14 – 22 years)	12	Eveborn *et al*. 2012
One-chambered ST	29.3	Nasr and Mikhaeil 2013
Three-chambered ST	33.1	Nasr and Mikhaeil 2013
Klargester RBC (PTP)	47.6	Kingspan Environmental 2010
Sequencing batch reactor (SBR) package treatment plant (PTP)	87.5	Akunna and Jefferies 2000
CW (during the first year)	60	Ockenden et al. 2014
ST plus two-step vertical flow CW	71.4	Nguyen *et al*. 2007
ST plus subsurface flow CW (un-planted)	85.7	Chang *et al*. 2011
ST plus subsurface flow CW (planted)	95.7-98.3	Chang *et al*. 2011
ST plus sand filter bed	almost 100	Robertson 2012
ST plus peat filter	Year 1: 50 Year 12: 26.6	Patterson 2001
ST plus filter bed systems (biofilter (LWA) and media filter bed (Filtralite P®)	> 94	Jenssen *et al*. 2010

Performance of various filter materials used in Constructed Wetland (Vohla *et al*. 2011)

Material	Study type	P treatment efficiency
Shellsand	Meso-scale CW in field, HSSF filter in greenhouse for household	Saturated before 2 yrs,
Gravel	Three gravel based CWs, 2° effluent, 2 years	P removal -40% to 40%;
	Full-scale CW, VSSF planted gravel filter	PO_4^{3-}-P removal 4.33%
Wollastonite tailings	Full-scale CW SSF wetland cell (wastewater from dairy farm)	Soluble P removal 12.8%
Limestone	Full-scale CW (SSF wetland cell treating wastewater from dairy farm, 1.5 years)	P removal 14.5%,
	Meso-scale experimental CW received effluent from a treatment wetland for 19 months	TP removal 46%
Norlite	Full-scale SSF CW cell, dairy wastewater	P removal 34%
Marl gravel	Full-scale CW, Filter treating swine wastewater after anaerobic lagoon treatment	TP removal 37-52%
Peat	Small-scale CW in field (landfill leachate from activated sludge plant and bio-pond)	TP removal: 77% from sludge water, 93% from bio-pond water (at 6 mo.)
Sand	Full-scale CW, HSSF sand filter	P removal 72% (8 yrs)
	Full-scale CW, HSSF sand filter	P removal 78.4% (5 yrs)
Blast furnace slag (BFS)	Full-scale CW VSSF reed bed, granulated BFS	TP removal 45%
	Small-scale CW (dairy farm wastewater, seven months.)	P removal 72%
	Full-scale CW (seven months)	TP removal up to 99%
Fly ash	Full-scale CW, three stage system, one filled with fly ash	TP removal about 83%
Filtralite-P®	Full-scale CW, upflow filter 3 years	P removal 99.4%
Leca (Estonian)	Full-scale CW, VSSF + HSSF filter bed, 2 years	TP removal 89%
LWA(Norsk Leca)	Full-scale CW (wastewater from households, 4 years)	P >95% removal

Pathogen Removal

Pathogen removal efficiency: Basic systems

Treatment type	Total coliforms		Faecal coliforms		E. coli		Enterococci		Ref
	Conc (cfu/100 ml)	Removal %	Conc. (cfu/100 ml)	Removal %	Conc. (cfu/100 ml)	Removal %	Conc. (cfu/100 ml)	Removal %	
ST only	5.98×10^7	37.40	2.53×10^7	40.17	-	-	-	-	Mbuligwe 2005
	2.5×10^7	35.9	7.2×10^6	57.6	-	-	-	-	Kay *et al.* 2008
ST + soil drainage field	-	-	-	90	-	85	-	-	Tomaras *et al.* 2009
	-	-	$1.60 \times 10^6 – 1.6 \times 10^7$	82.0-98.6	-	-	-	-	Harrison *et al.* 2000

Pathogen removal efficiency: ST + natural media filters

Treatment type	Total coliforms		Faecal coliforms		E. coli		Enterococci		Ref
	Conc (cfu/100 ml)	Removal %	Conc (cfu/100 ml)	Removal %	Conc (cfu/100 ml)	Removal %	Conc (cfu/100 ml)	Removal %	
ST + Constructed soil filter	1.5×10^5 - 3.6×10^5	99.80-99.93	3.1×10^4 –8.3 $\times 10^4$	99.56-99.92	1.5×10^4 - 2.4 $\times 10^4$	98.91-99.95	-	-	Kadam *et al*. 2008
ST + sand filter	-	-	4.2×10^4 – 1.8×10^5	99.4-99.96	-	-	-	-	Harrison *et al*. 2000
	-	-	(35-60)	99.986-99.992	-	-	-	-	Pundsack *et al*. 2001
			(110-220)	99.93-99.96					
ST + peat filter	-	-	6	99.997	-	-	-	-	Pundsack *et al*. 2001
			4-5	99.9984-99.9987					
	-	-	<200(initial)	>99.96	-		-	-	Patterson 1999[c]
			650 (12 mo)	99.90					
			1650 (6 yr)	99.70					
			3200 (13 yr)	99.50					
	-	-	-	-	2.7×10^3 -1.2 $\times 10^4$	97.60-99.95	-	-	Gill *et al*. 2007

Pathogen removal efficiency: ST plus CW (alternative filter media)

Treatment type	Total coliforms		Faecal coliforms		E. coli		Enterococci		Ref
	Conc (cfu/100 ml)	Removal %	Conc (cfu/100 ml)	Removal %	Conc (cfu/100 ml)	Removal %	Conc (cfu/100 ml)	Removal %	
ST plus CW	-	99.50	-	-	-	99	-	-	O'Luanaigh *et al*. 2009 (reed bed)
	-	-	400-500	99.87	-	-	-	-	Pundsack *et al*. 2001 (cattails and bulrush)
			5900-7100	99.83					
	4.5×10^3	>99.99	3×10^3	>99.99	-	-	-	-	Mbuligwe 2005 (engineered CW)
Subsurface upflow CW plus filter media (treating STE)	-	-	71-1738	97.06-99.98	<1-63	99.80 - 100	-	-	Chang *et al*. 2011
ST plus biofilter (LWA) plus media filter (LWA-Filtralite-P®)	-	-	0-<3	~100%	0	~100%	<10 to <300	~100%	Jenssen *et al*. 2010

Summary

- The most effective measures:
  - Maximise physical removal, through adsorption and filtering, (maximise solids reduction)
  - Immobilise pathogens within the soil - encourage favourable conditions for retention (biomat) and microbial predation of pathogens
  - Maintain good conditions for biological uptake of phosphorus
  - Are designed to production characteristics, as well as to site specific conditions; Maintain efficacy of filter media by renewing over time

Summary

- ST most common – but alone provide limited treatment
- Package plants are more generally amenable for phosphorus removal – limited data for pathogens
- Filtration-based treatment systems are <u>most</u> effective for removal of <u>both</u> pollutants; efficiency depends upon
  - Type of filter media and configuration
  - Time of operation, and performance over time
  - Climatic conditions
- Constructed wetland systems are also effective for the removal of <u>both</u> pollutants; efficiency also depends on:
  - Climatic condition (e.g. temperature, rainfall), wastewater characteristics and types of pre-treatment.

Perspectives

- Data
  - influent and effluent concentrations!
  - efficiency of package treatment plants on P and pathogen removal
  - Pathogen reductions – limited range of organisms have been studied (bacteria); effect on viruses not well covered
- Study of the impact of operation and maintenance on releases of P and pathogens (evidence of P increases from desludging)

Thank you for listening!