Overview of Decentralized System Nutrient Removal Issues and Options

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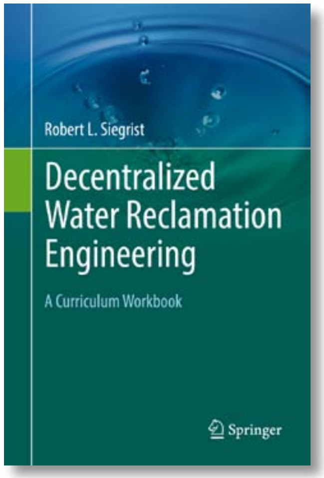
- Outline of today’s presentation
  - Introduction to nutrient issues
  - Nutrient reduction options
  - Principles and processes important to nutrient reduction
  - Design and implementation considerations for different options
- FYI, today’s talk is based on Chapter 13 in my new book
  - The book is 967 pages long with over 300 figures and 150 tables and it has over 200 questions and design problems
  - eBook and hard cover versions are available now

    Springer: www.springer.com/us/book/9783319404714

    Also at Amazon and other sellers



Introduction

- Wastewaters contain nitrogen (N) and phosphorus (P)
  - N and P are critical nutrients that can occur in particulate and soluble forms that can be biodegradable or non-biodegradable
  - Table 13.1 lists the forms of N and P and terms commonly used

Table 13.1. Forms and terms of expression for nitrogen and phosphorus in water and wastewater.

Nutrient	Term	Consists of
Nitrogen	Total N	organic N + inorganic N
	Total inorganic N (TIN)	$NH_4^+ + NO_2^- + NO_3^-$
	Total Kjeldahl N (TKN)	organic N + NH_4^+
	NOx	$NO_2^- + NO_3^-$
Phosphorus	Total P	organic P + inorganic P
	Total inorganic P	orthophosphate + polyphosphate
	Orthophosphate	PO_4^{-3} and H_3PO_4, $H_2PO_4^-$, HPO_4^{-2}
	Polyphosphate	condensed phosphates (e.g., triphosphate ($P_3O_{10}^{-5}$))

- Wastewater N and P can be viewed in two distinct ways
  - Nutrients as constituents of concern
    - Nutrients in wastewater can cause adverse effects, including:
      - Depletion of DO in water causing hypoxia and fish kills
      - NH_3 toxicity to aquatic life in surface waters
      - Methaemoglobinemia caused by NO_3^- in drinking water
      - Water quality effects of N inputs to estuaries, marine waters and other sensitive waters
      - P as a limiting nutrient for eutrophication in inland waters
    - Examples of wastewater nutrient inputs that can be of concern
      - N inputs to groundwater potentially used for drinking water
      - N and P inputs to inland surface waters
      - N inputs to inland springs
      - N inputs to coastal zones and estuaries

- Nutrients as constituents of value
  - Nutrients are needed to support plant growth and for this purpose, chemical fertilizers have been widely used
    - Nitrogen for commercial fertilizers is based on industrial processing
      - Production and use of N compounds in fertilizers is energy intensive and costly and can contribute to greenhouse gas emissions
    - Phosphorus for commercial fertilizers is based on mining of phosphate ores
      - Production is energy intensive and sources of phosphate are diminishing
  - Nutrients recovered from wastewater represent a potentially valuable alternative to commercially manufactured chemical fertilizers

Nutrient reduction (NR) strategies and unit operations

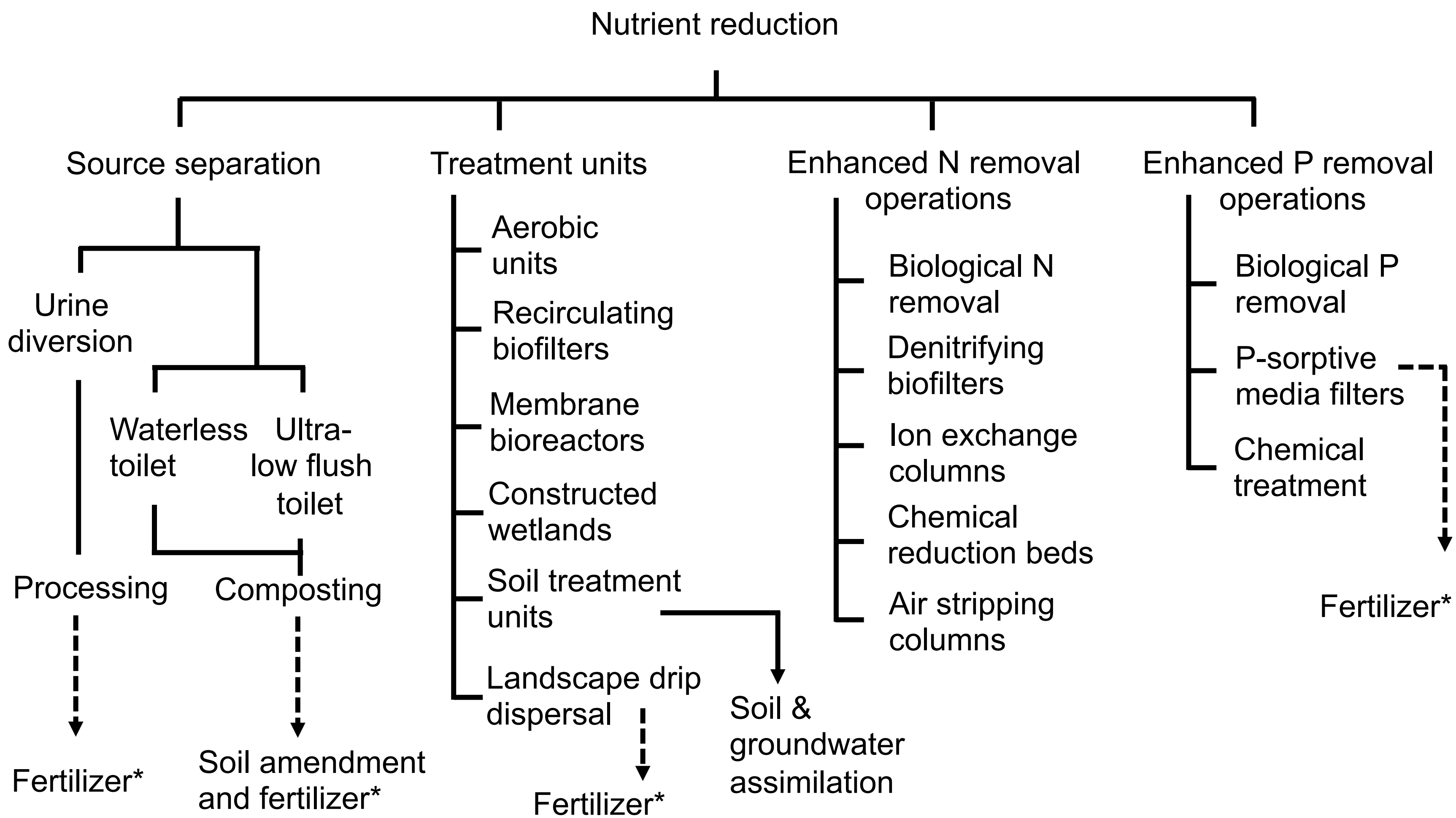
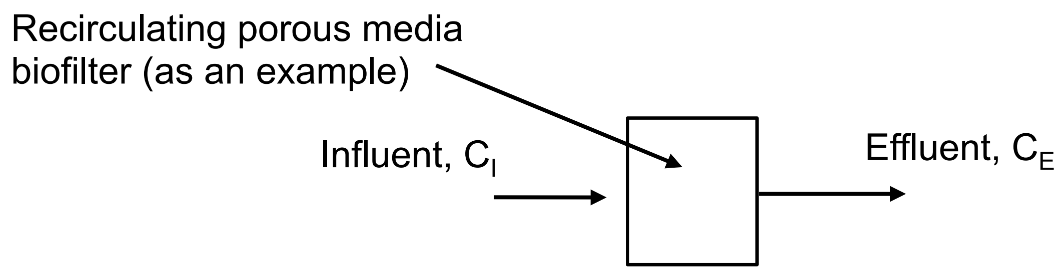


Fig. 13.1. Classification of nutrient reduction strategies and technologies.
Note: An "*" denotes a potential fate and recovery path for the nutrients removed.

Achievable NR Performance

- Approaches to assessing nutrient reduction performance
  - For source separation or a confined treatment unit (Fig. 13.2)

Fig. 13.2. Cross-section view of a unit operation to illustrate the typical approach to determine treatment efficiency.



  - For a land-based treatment system (Fig. 13.3)

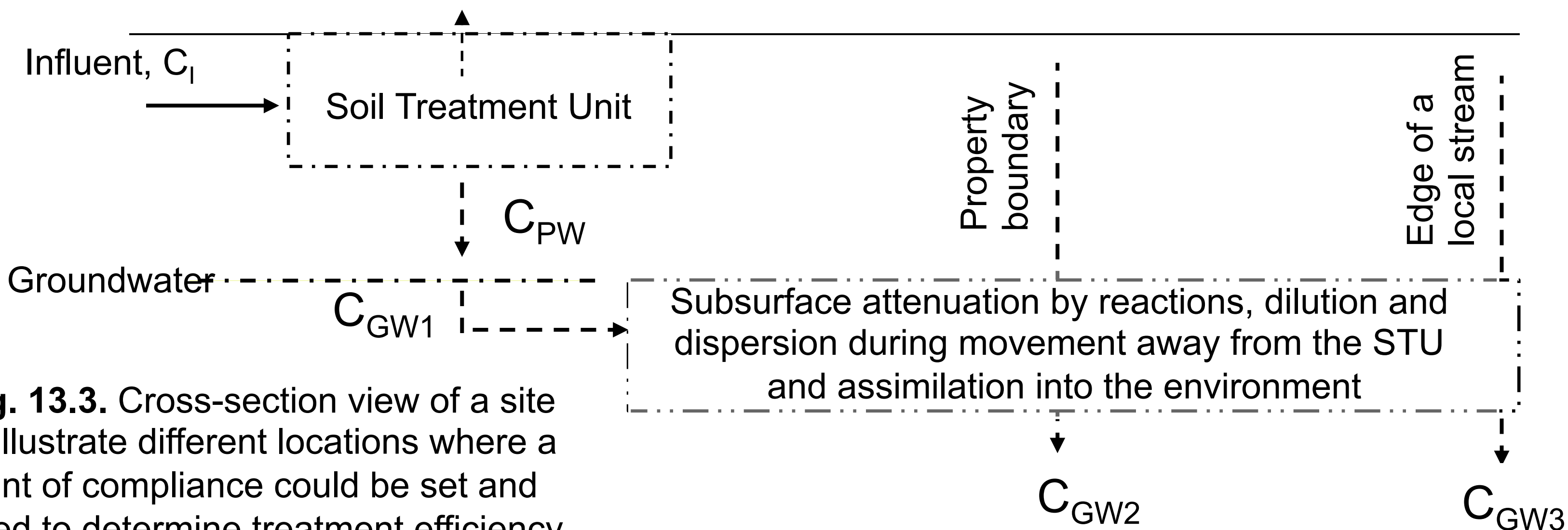


Fig. 13.3. Cross-section view of a site to illustrate different locations where a point of compliance could be set and used to determine treatment efficiency.

Examples of N and P reductions appear in Table 13.3

Table 13.3. Representative nutrient reduction efficiencies achievable with several technologies.

Nutrient reduction	Nitrogen [1]		Phosphorus [1]		Comments
	Removal (%)	C_E (mg/L)	Removal (%)	C_E (mg/L)	
Urine diversion	85%	9	50%	5	Assumes 100% urine diversion and processing
Aerobic units	20 – 50%	30 – 48	10 – 30%	7 – 9	Typ. suspended growth or fixed film ATU
Recirculating biofilters	45 – 70%	18 – 33	-[2]	10	Sand and synthetic media for BOD and TSS removal
Membrane bioreactors	50 – 85%	9 - 30	30 – 90%	≤1 – 7	Removals depend on MBR operating parameters
Constructed wetlands	20%	48	-	10	Wetlands designed for BOD and TSS removal
Soil infiltration/dispersal	20 – 70%	18 – 48	≥ 99%	≤ 0.1	Removals depend on conditions and do not include removal in groundwater
N removal biofilters	95%	3	-	10	Designs with bionitrification and biodenitrification
P sorptive filter units	-	60	≥ 90%	≤ 1	Filter designs using P-sorptive media
Chemical treatment	-	-	>90%	<0.1	Depends on design and operation

[1]Influent N = 60 mg-N/L, P = 10 mg-P/L. [2] "-" = negligible removal for common system designs.

Principles and Processes

- Nutrients handled in decentralized systems
  - Different nutrient species can be present
    - Raw waste and wastewaters
      - Nitrogen is typically present as organic N and NH_4^+
      - Phosphorus is typically present as organic P and ortho PO_4^{-3}
    - Septic tank effluent (STE)
      - Most influent organic N is converted to NH_4^+
        - Most organic N is converted to NH_4^+ but there still can be 5 to 20% organic N in STE
      - Influent polyphosphates are converted to PO_4^{-3}
    - Aerobic treatment unit or porous media biofilter effluents
      - Most of the influent NH_4^+ is converted to NO_2^- / NO_3^-
        - Conversion % depends on design and operation
      - Influent PO_4^{-3} remains largely unchanged

- Representative nutrient concentrations
  - Diverted urine (diluted 1:2 with flush water)
    - Total N = 2,000 mg-N/L
    - Total P = 200 mg-P/L
  - Septic tank effluent from residential sources
    - Typical total N = 60 mg-N/L
    - Typical total P = 10 mg-P/L
  - Septic tank effluent from nonresidential sources
    - High N sources - Rest areas, campgrounds, schools, etc.
      - Total N can be 150 mg-N/L or higher
    - High P sources - Laundries, rest areas, etc.
      - Total P can be 40 mg-P/L or higher

Primary reactions involved in N removal

- Nitrogen in wastewater can participate in a variety of reactions
  - Biological uptake of N
  - Biological nitrification of NH_4^+ to NO_2^- and NO_3^-
  - Biological denitrification of NO_2^- or NO_3^- to N_2O and N_2
  - Sorption of NH_4^+ to surfaces
  - Volatilization of NH_3 at elevated pH
  - NO_3^- anion exchange
  - NO_3^- chemical reduction
- These reactions can occur in natural environments or in treatment units that have different levels of design complexity, power and chemical use, O&M needs, and costs
- For decentralized systems, biological nitrification and denitrification occur most frequently with the greatest effects

Primary reactions involved in P removal

- Phosphorus in wastewater can participate in a variety of reactions
  - Biological uptake of P
  - Sorption of PO_4^{-3} to surfaces
  - Mineral formation from PO_4^{-3} sorbed to surfaces
  - Precipitation/complexation of PO_4^{-3} out of solution
  - Struvite precipitation of PO_4^{-3} out of solution
- These reactions can occur in natural environments and in treatment units that have different levels of design complexity, power and chemical use, O&M needs, and costs
- For decentralized systems, sorption, mineral formation, and precipitation occur most frequently with the greatest effects

Design and Implementation

- Considerations for design and implementation (D&I)
  - Nutrient reduction and recovery goals and requirements
  - D&I considerations of specific strategies and technologies that are most widely applicable in decentralized systems including:
    - Source separation – N & P
    - Activated sludge biological systems – N & P
    - Porous media biofilters and constructed wetlands – N & P
    - Specialty denitrifying biofilters – N
    - Specialty P-sorptive media filters – P
    - Chemical treatment systems – P
    - Soil-based treatment operations – N & P
  - D&I considerations related to development-scale situations
    - Soil-based treatment operations and cumulative effects

Summary

- Reduction of N and/or P in decentralized systems
  - Can be required to meet discharge limitations in some settings
  - Can be used to recover nutrients for their fertilizer value
- Treatment options can be selected for a given goal, e.g.:
  - N removal of 40 to 70% can be achieved by biological nutrient removal, porous media biofilters, or landscape drip dispersal
  - N $\leq$ 3 mg-N/L can be achieved by porous media biofilters followed by denitrifying biofilters
  - P < 0.7 mg-P/L can be achieved by soil treatment units, landscape drip dispersal, P-sorptive filters, or chemical methods
- Recovery options yield fertilizer and soil amendment, e.g.:
  - Irrigation benefits of N and P in land applied wastewater effluents
  - Recovering N and P by urine diversion, recovering P by struvite precipitation or via P-sorptive media