Nutrient Removal

Nutrients of Concern in Wastewater

- **Phosphorus** (P) and **Nitrogen** (N) are the principal nutrients of concern in on-site wastewater
- Nutrients are essential for biological growth
- In excess, they encourage nuisance growth of algae and aquatic plants and nitrate may pose a threat to human health
- Both N and P are found in a variety of forms in domestic wastewater

Phosphorus

- **Phosphorus** is typically found in one of three forms in domestic wastewater: orthophosphate complexes (e.g. PO_4^{3-}, HPO_4^{2-}, H_2PO^{4-}); polyphosphate (e.g. P_2O^{4-}) and organic phosphate
- Orthophosphates are readily available for biological metabolism, while poly and organic phosphates must first undergo some form of conversion
- Analytical results typically express the combined values for all forms of P as total phosphorus (TP) in milligrams per litre (mg/L)

Nitrogen

- **Nitrogen** in wastewater is typically found in one of four forms: ammonia (NH_3) / ammonium (NH_4) (dependent on pH); nitrite (NO_2); nitrate (NO_3) and organic nitrogen
- In domestic wastewater the ammonia/ammonium and organic nitrogen forms dominate
- Nitrate nitrogen is highly mobile in the soil/water environment and is a potential public health risk

Nitrogen

- Analytical results are typically expressed as either:
  - Total Kjeldahl Nitrogen (TKN) - consisting of ammoniacal nitrogen and organic nitrogen,
  - Total Oxidised Nitrogen (TON) - consisting of the oxidised nitrogen forms (NO_2 and NO_3), or
  - Total Nitrogen (TN) - the combined values for all forms of N
- Results are expressed as milligrams per litre (mg/L)

Typical Effluent Quality

- Constituent mass loadings and concentrations in typical residential wastewater

Constituent	Mass Loading g/person/day	Concentration mg/L
Total Nitrogen	6-17	26-75
Ammonia	1-3	4-13
Nitrite/Nitrate	<1	<1
Total Phosphorus	1-2	6-12

Source: USEPA

Nitrogen Transformations

- After discharge to the infiltrative surface aerobic bacteria convert the ammonia to nitrite then nitrate
- When nitrate reaches groundwater it moves freely with little retardation
- Some denitrification occurs in the saturated zone in the presence of carbon or sulphur
- Groundwater nitrate concentrations are reduced primarily through dispersion and dilution by rainwater

Nitrogen Transformations

- Biological denitrification converts nitrate to gaseous nitrogen
- This occurs under anaerobic conditions in the presence of electron donors such as carbon or sulphur
- Limited ability of conventional subsurface wastewater infiltration systems to reduce nitrogen means that systems in drinking water or otherwise sensitive catchments should have additional nitrogen removal capacity

Nutrient Removal Processes

- Soil infiltration and treatment typically reduces:
  - Total nitrogen by 10-40% through denitrification, volatilization, microbial attack and other processes
  - Total phosphorus by up to 100% through chemical adsorption (little sorption in sands)
- Vegetation uptake of nutrients occurs at the approximate rate of 10:1 (N:P) and can be the major mechanism for nitrogen removal, but is normally not the dominant P-removal process

Nutrient Removal by Different Forms of Treatment

- Representative nutrient concentrations after various forms of treatment:

Treatment form	Total N mg/L	Total P mg/L
Domestic STE	40-100	5-15
Mound / Sand filter	10-50	<1-10
Foam or Textile filter	30-60	5-15

Source: USEPA

Phosphorus Retardation

Depends on:

- Soil characteristics
  - Soil texture and structure
  - Fe, Ca and Al content of soil
  - Redox potential
- Depth of the unsaturated zone through which wastewater percolates
- Applied loading rate
- P-sorption estimates based on the Langmuir isotherm may underestimate P-sorption as it does not take into account slower precipitation reactions

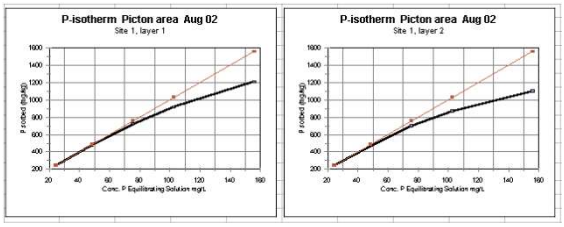
Phosphorus Retardation

- Phosphorus sorption is, however, finite
- The ultimate retention capacity depends on several factors
- Several methods of phosphorus sorption estimation are used and their results vary widely
- Some methods are inappropriate for determining the soil capacity to bind and reduce the potential for effluent applied inorganic P entering surface or groundwater

Phosphorus Retardation

- A five point test plotting P-sorbed (mg/kg) against the concentration of P equilibrating solution (mg/L) allows the potential leakage of P from added inorganic-P to be determined by determining the deviation of the P-sorption isotherm from the concentration gradient. Up to that point P-sorption is strong, then it slowly diminishes

Phosphorus Retardation

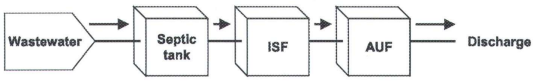


- Natural soils with good P-sorption

Nutrient Removal Potential of Intermittent Sand Filters

- Most biochemical treatment occurs in the first 150mm of a sand filter or mound
- Intermittent Sand Filters typically remove 18-33% of total nitrogen
- Effluent is highly nitrified, but denitrification is generally limited
- Whilst nitrification is provided by the mound / ISF, denitrification can be provided by recirculation or by additional polishing in a separate anaerobic filter or subsurface flow wetland

Nutrient Removal Potential of Intermittent Sand Filters



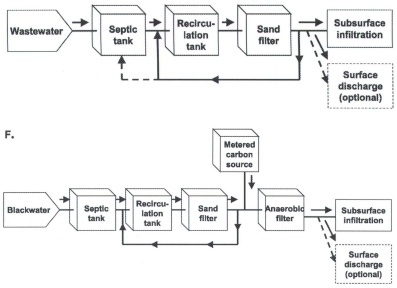
Source: USEPA

- Intermittent Sand Filter with anaerobic upflow filter (AUF)

Nutrient Removal Potential of Recirculating Sand Filters

- Recirculating Sand Filters with a dedicated recirculation tank typically remove 40-50% of total nitrogen. Mounds generally do not recirculate
- With recirculation to the preceding septic tank or a separate anaerobic filter or subsurface flow wetland such a system would typically remove 70-80% of total nitrogen
- Denitrification potential can be further enhanced by supplementing the carbon supply. Typically the system is dosed with methanol or ethanol

Nutrient Removal Potential of Recirculating Sand Filters



Source: USEPA

Nutrient Removal Potential of Alternative Media

- Various media have potential to remove nutrients if incorporated into sand filter and mound systems:
  - Zeolite (clinoptilolite) has excellent selectivity for ammonium by cation exchange when anion (-ve) concentrations in solution are low (also sorbs some P)
  - Red Mud and Blast Furnace Slag, respectively by-products of aluminium and steel production have a high affinity for phosphorus

Nitrogen Removal using Zeolite

- Zeolite (clinoptilolite) is a naturally occurring mineral removes contaminants from wastewater by ion exchange and adsorption
- Studies have demonstrated over 98% ammonium removal (at concentrations of 100mg NH^{4+}-N/L) and ammonium retention of between 1.63-13.05kg NH^{4+}-N/tonne of zeolite
- Zeolite can be rejuvenated once it becomes saturated by flushing with brine
- Mined in the Upper Hunter, NSW, Huntingdale, VIC and Emerald, QLD and has been trialed in an experimental sand filter

Phosphorus Sorption

- Few phosphorus removal processes are well developed for on-site wastewater systems
- Most successful have been sorption processes using materials rich in aluminium, iron and calcium compounds
- Service lives of these media are finite but in some cases are quite substantial and may well exceed other elements of the system
- Once saturated with sorbed phosphorus these media must be disposed of and replaced

Phosphorus Sorption

- Red mud is available in large quantities as a by-product of bauxite refining in parts of W.A., North Queensland and the Northern Territories
- Typically amended with 5% of waste gypsum to reduce pH (typically pH 10-12)
- Used in amended soil systems (Ecomax) in Western Australia at about 18% by volume and has demonstrated >90% phosphorus removal over a ten year period

Phosphorus Sorption

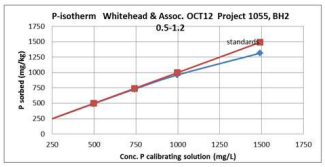
- Blast Furnace Slag is produced as a by-product of steelmaking
- Various products are available, some rapidly quenched and others air cooled
- Studies have demonstrated that Granulated Blast Furnace Slag can have a P-sorption of >> 10,000 mg/kg and can remove >90% phosphorus from wastewater
- Used in amended soil systems (Ecomax) in NSW, VIC and TAS and has ample phosphorus removal potential for an extended period (>25 years)

Phosphorus Sorption

- Crushed brick and tile have been trialled in both the U.S. and Australia for phosphorus sorption
- P-sorption is low by comparison with red mud and blast furnace slag and is critically dependent on grain size
- Contact time and surface area for contact are significant parameters
- Crushed brick >2 mm has an appreciably lower P-sorption than material <2 mm in size

Phosphorus Sorption

- There are some naturally high P-sorbing soils, e.g. Krasnozems
- Some have higher P-sorption than alternative media, and have potential for use in amended soil systems and for significant P-sorption in drainfields



Amended Soil Systems

Alternative Media Filters

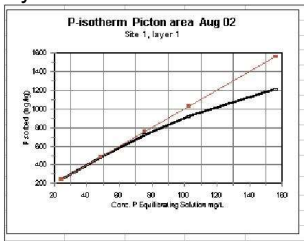
- Variety of natural, waste and synthetic alternative media used
- Some to modify and/or enhance performance of traditional sands and gravels
- Others as economically viable alternatives:
  - Glass
  - Amended soil systems
  - Peat beds
  - Foam filters
  - Fabric filters

Alternative media for nutrient removal

- Amended soil systems use soil or other media for nutrient reduction
  - P-sorption
    - Gypsum amended red mud
    - Granulated steel slag
    - Weathered basalt soils/ Krasnozems
  - N reduction
    - Zeolite

Alternative media for nutrient removal

- Weathered basalt soils/ Krasnozems
  - Widely available



Alternative media for nutrient removal

- Gypsum amended red mud by-product of bauxite refining for aluminium
  - Available in Western Australia, Northern Territories and North Queensland
  - Is basis of original Ecomax design
  - Highly alkaline – amend with gypsum
  - Salt rich
  - 1,680 mg/kg P-sorption (Kayaalp et al. 1988)

Ecomax System

Ecomax installation, Western Australia

Ecomax System

Ecomax installation, Western Australia

Alternative media for nutrient removal

Variety of slag and industrial waste products

- Granulated blast furnace slag
  - Available from both blast furnaces e.g. Port Kembla, Whyalla, and electric arc furnaces e.g. Laverton, Rooty Hill
  - Max. P-sorption >44,000 mg/kg (Sakadevan & Bavor 1998)
- Flyash (FA) and bottom ash (BA)
  - Available from power stations
  - FA 550+ mg/kg P-sorption
  - BA 3,082+ mg/kg P-sorption

Ecomax System

Ecomax installation, NSW

Ecomax System

Ecomax installation, NSW

Ecomax Mound at School, NSW

Ecomax System

Recent Ecomax installation, NSW

Alternative media for nutrient removal

- N reduction
  - Zeolite
  - Wide variety of zeolites
  - Naturally occurring clinoptilolite
  - Effective in removing ammonium ion
  - Best used before N oxidises
  - Also P-sorptive (Geary et al. 2001)

Zeolite amended sand filter