Community-scale and Household-scale Decentralized Reuse Experiences on Two Continents

Nicholas Ashbolt

Decentralized Water/Wastewater Reuse for Clean, Green and Smart Rural & Urban Communities
Nags Head, NC, July 29th, 2009

Office of Research and Development

Contrasting/common water issues in Australia and Sweden


- **The contrasts**
  - Australia's major coastal cities face water scarcity, even without the current drought by 2015
  - Sweden is water rich, yet eutrophication of the Baltic Sea is a major issue (point & non-point sources)
- **The commonalities** (Eutrophication & Energy paradoxes)
  - Energy and fertilizer recovery from excreta/food 'wastes' could be net positive – currently heavy burden
  - P if not K & N reuse essential for future agriculture
  - Ecosystem services need restoration

→ Common sustainability framework

Content

- **How to assess health risks**
  - Within a sustainability framework / ? Institution home
  - Verifying performance – key to new regulations
- **Lessons learned**
  - Community-wide reuse strategies in Australia
  - Wastewater reuse at individual homes throughout Sydney in Australia
  - Swedish reuse methods and approaches
  - Graywater reuse system health outcomes
- **Emerging issues & possible novel directions**
  - Non-fecal opportunistic pathogens (e.g. *Legionella*)

PREAMBLE: NEED TO START WITH THE RIGHT INSTITUTIONAL HOME

The problem

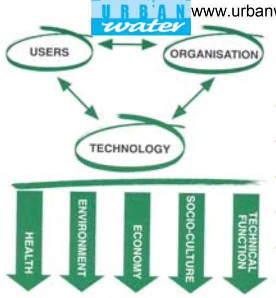
- In current planning and decision-making processes, product-oriented methods are rarely adapted to local circumstances
- Rather, they are guided by norms like linearity, objectivity, certainty and comprehensiveness (i.e. maintains the *status quo*)

The solution

- Use of specific process-oriented tools to aid in assessments, and
- Product-oriented decision support systems to aid in stakeholder involvement in the process

Water Sustainability Framework

www.urbanwater.org



Multi-Criteria Decision Aid (MCDA) using:

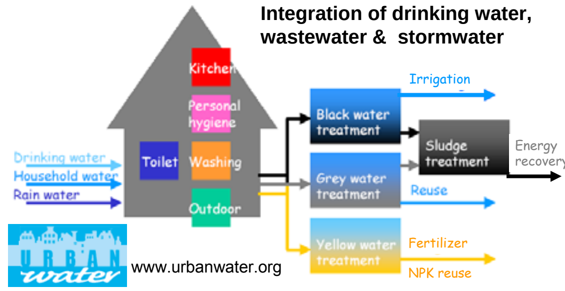
- Human risk assess't
- Life Cycle Assessment
- Life Cycle Costing
- Reliability/ robustness
- Stakeholder participation

http://www.urbanwater.org

6 **Lundie *et al*. (2008) Sustainability Framework. WSAA Occasional Paper No.17. Water Services Association of Australia, Melbourne.**

Options for households

Integration of drinking water, wastewater & stormwater



7 Ashbolt *et al.* (2006) In: 2nd IWA Leading-Edge on Sustainability in Water-Limited Environments. WEMS vol 10, IWA Publishing, London.

Tension over Public-Private systems in Australia & Sweden

- The private sector is dominating in innovation at the household/cluster level as decentralized infrastructure is:
  - usually on private property;
  - services are customized for each buyer; and
  - homeowners & builders used to hiring their own contractors and subcontractors
- Generally, neither the customer nor the municipality is interested in direct utility management of this work
  - municipal utilities are used to managing large treatment plants and pipes & nervous about trying to work with & control thousands of quirky & demanding homeowners and businesses

Need a new institution home?

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In Australia

- **The drought**
  - During 2007-2008 inflows into storages serving large urban areas were generally higher than those experienced in 2006, yet
  - Perth only received 43% of its long-term average inflows, Sydney 67%, Brisbane 15%, Melbourne 63% and Adelaide 31%
- **Desalination (political 'knee jerk' solution)**
  - $30B source water investment program
  - $2B in desalination for 2007/8 alone
    - 150 GL/y (Melbourne), 90 GL/y (Sydney), 45 GL/y (Brisbane), 50 GL/y (Adelaide & Perth)

9 WSAA Report Card 2007/8

AUSTRALIAN REGULATORY SCENE: NATIONAL GUIDELINES STATE & LOCAL REGULATIONS

www.ephc.gov.au/ephc/water_recycling.html

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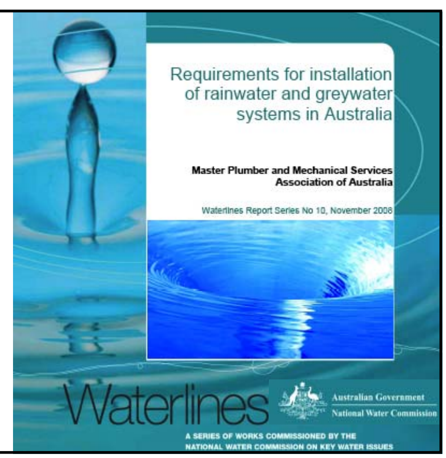
National info for plumbers on codes and standards for each state



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e.g. Defining responsibilities for greywater treatment systems NSW

Actions	Responsibility		
	Owner	Plumber	Other
Undertake a water balance to determine water demand requirements	√		
Ensure GTS meets the requirements of the *NSW Code of Practice: Plumbing and Drainage* (CUPDR 2006)		√	
Apply for and obtain approval to install and approval to operate the GTS and associated irrigation from the local council	√		
Install a subsoil, subsurface or surface irrigation system to distribute greywater		√	
Notify the local water utility that a GTS has been installed at the property	√		
Undertake regular maintenance of the GTS in accordance with the manufacturer's recommendations and these guidelines		√	
Undertake annual testing of backflow protection device	√		√

Source: DEUS (2007, p21.)

greywater treatment system (GTS)

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Australian principles of risk management: Water reuse guidelines

- Aim is to ensure (as much as possible) that recycled water is safe before use
- Reduces reliance on recycled water testing (too little, too late)
- A coordinated approach from source to point of use
- Water fit-for-purpose
- Same approach for drinking, rec & reuse

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Problems with Recycled water monitoring

- Tests results received after water used
- Too many parameters for frequent testing
  - –the only microorganism commonly tested is *E. coli*
  - –But it is a poor indicator for viruses and protozoa
- For many parameters there are no suitable tests

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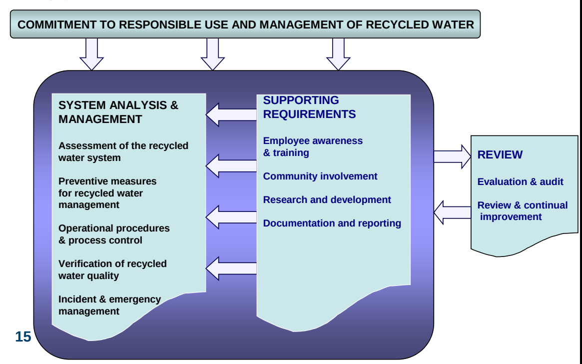
Risk Management Framework



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Contents of Health Risk Chapter

- New guidelines provide greater justification for targets based on levels of risk
- Definition of tolerable risk
- Targets for bacteria, protozoa and viruses (and how to calculate these from first principles)
- Discussion of preventive measures (treatment and on-site controls) and their impact
- Look-up tables of typical schemes and safe uses

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Tolerable Risk

- Defined in terms of DALYs (years of illness + years lost by early death)
- DALYs use health impact scores (death 1, diarrhoea 0.1-0.2)
- DALYs include acute impacts (e.g. diarrhoea) & chronic impacts such as:
  - HUS (*E. coli* 0157) reactive arthritis (*Campylobacter*)
  - cancer from chemical exposure
- Tolerable risk 10^{-6} DALYs (also used in WHO guidelines). Equivalent to a lifetime cancer risk of 10^{-5} or an annual risk of diarrhoea of 10^{-3} from a pathogen like *Cryptosporidium*

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Risk Assessment

- Used to determine DALYs for reference hazards
- Risk assessment involves consideration of 3 inputs:
  - hazard identification (e.g. pathogens)
  - dose-response
  - exposure assessment (frequency and volume)
- DALYs can be calculated using this information:
  - *average personal dose = concentration in water x exposure vol*
  - *probability of illness = personal dose x dose-response*
  - *DALYs = probability of illness x DALY per case*
- Variables determining DALYs are hazard concentration and exposure volume

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Starting points –default values

- **Pathogen densities in raw sewage (95th percentile):**
  - **2000 Crypto, 8000 rotaviruses, 7000 *Campylobacter* per L**

(0.2 -1.6 DALYs per Litre)

- **Exposures**

Activity	Exposure route	Volume (mL)	Frequency per y
Garden irrigation	Aerosol Ingestion	0.1 1.0	90 90
Toilet flushing	Aerosol	0.01	1100
Urban irrigation	Ingestion	1.0	50
Food crop	Ingestion	5.0 (lettuce) 1.0 (other)	70 140

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Performance targets

- Performance target = reduction in hazard concentrations to achieve < 10^{-6} DALYs in a year

Activity	Exposure Litres per year	Log10 reduction required		
		Crypto	Rotavirus	*Campylobacter*
Residential use	0.66	4.9	6.0	5.0
Commercial crops	0.49	4.8	5.9	4.9
Urban irrigation	0.05	3.7	4.8	3.8

Residential use = outdoor use, toilet flushing & laundry
Commercial crops include spray irrigation of salad vegetables

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Achieving compliance

- Performance targets can be met by reducing concentrations of hazards in recycled water or by controlling exposure
- Concentrations of microbial hazards are reduced by treatment barriers
- Exposure can be controlled on-site *e.g.:*
  - by selective use (irrigation of almond trees rather than salad vegetables)
  - via methods of application (drip vs spray irrigation)

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Indicative Treatment Performances

	Log10 reductions		
	Bacteria	Viruses	Protozoa
Primary treatment	0 - 0.5	0 - 0.1	0 - 1.0
Secondary treatment	1.0 - 3.0	0 – 2.0	0.5 – 1.5
Dual media + coagulation	0 – 1.0	0.5 – 3.0	0.5 – 3.0
Lagoon storage	1.0 – 5.0	1.0 – 4.0	1.0 – 4.0
Chlorination	2.0 – 6.0	1.0 – 3.0	0 – 1.5
UV light	2.0 - > 4.0	1.0 – >3.0	> 3.0

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On-site Preventive Measures

Preventive measure	Exposure reduction
Cooking or processing	5-6 log
Drip irrigation	2 log
Subsurface irrigation	4 log
Withholding periods	0.5 log per day
Spray drift control	1 log
No public access when irrigating	2 log
Subsurface landscape	5-6 log
Buffer zones	1 log

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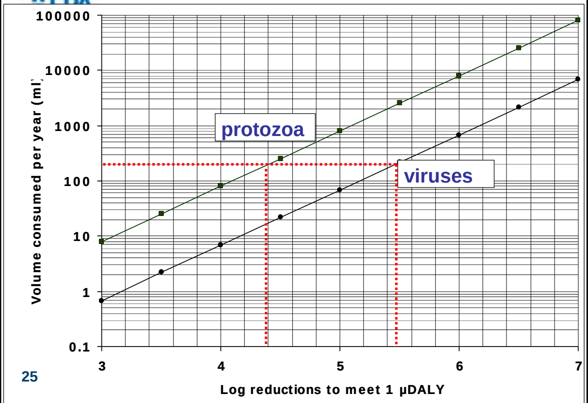
Different exposures

Guidelines include a look-up graph that enable performance targets to be determined for different exposures without going through all the calculations

Look up table to calculate $\log_{10}$ pathogen reductions



Calculations (!!!????)

- Prefer not to calculate from first principles
- Guidelines provide 2 look-up tables
- One table starts from specific uses and allows selection of preventive measures
- Second table starts from existing treatment schemes and shows what uses are appropriate

Preventive measures for specific uses

Use	Log reduct^n (virus)	Treatment	Log	On-site	Log
Dual distribution	6	2^o, coag, filtration disinfection	6		
Salad crops	6	2^o, coag, filtration disinfection	6	1.5-2 days to market	1
Wine grapes	6	2^o,disinfection	1-3	Wine making	5-6
Citrus crops	6	2^o,disinfection	1-3	No ground contact + skin removed 1.5-2 days to market	3 1
Urban irrigation	5	2^o, coag, filtration disinfection	6		
Urban irrigation	5	2^o,disinfection	1-3	No access Buffer zones Spray drift control	2 1 1

Typical uses for existing treatments

Treatment	Use	On-site control	Water quality
2^o, coagulation filtration disinfection	Dual distribution Urban irrigation Salad crops	General (signage etc)	Turbidity < 2 NTU Chlorine Ct >60 *E. coli* <1/100mL (Dual) *E. coli* <10/100mL (Urban) BOD < 20mg/L
2^o,disinfection	Urban irrigation	No access Buffer zones Spray drift control	Chlorine Ct >15 *E. coli* <100/100mL BOD < 20mg/L
1^o, 60d lagoons 2^o, 30d lagoons	Urban irrigation	No access Buffer zones Spray drift control	*E. coli* <1000/100mL BOD(sol) < 20mg/L
2^o	Landscape irrigation	Microspray, drip irrigation	*E. coli* <1000/100mL BOD < 20mg/L
1^o, lagoons	Tree lots, turf	Drip irrigation, Spray - no access	*E. coli* <10000/100mL BOD < 20mg/L

Greywater

- Large variation in water quality depending on inputs. Some results show *E. coli* concentrations just below those of sewage
- Evidence that thermotolerant coliforms can regrow in greywater but evidence of faecal contamination a common theme (Ottoson & Stenström, 2003)
- Risk analysis showed that direct exposure to low volumes of partially treated greywater is unacceptable. Treatment such as disinfection required
- Household chemicals may also be a problem

Ottoson, J. and Stenström, T.A. (2003) Faecal contamination of greywater and associated microbial risks. *Water Research* ***37:645-655.***

Use of Greywater

- **Protect source water**
  - avoid laundry water with fecal material (diapers)
  - use detergents with low boron, phosphate, sodium
  - avoid discharge of household or garden chemicals
  - exclude kitchen waste
- **Restrict use of untreated greywater**
  - only subsurface or very limited drip irrigation
  - no irrigation of vegetables
  - limit storage (odours)
- **For other uses apply the same approach adopted for reclaimed water**

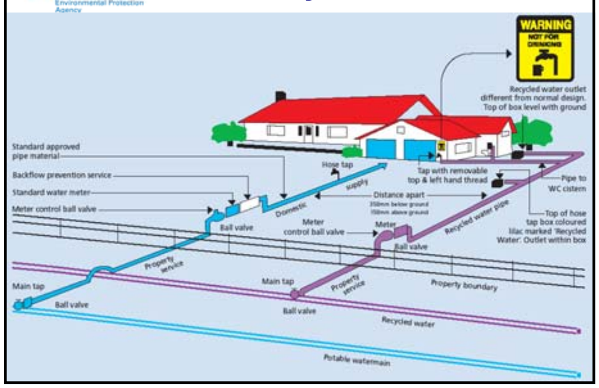
Monitoring (Chapter 5)

- Discussion of the various types of monitoring
- Validation (will it work, accredited systems)
  - intensive monitoring before commissioning
  - assessment of published data (established processes)
- Operational (is it working now)
  - routine monitoring showing processes are under control
  - testing (on-line or grab samples) and observational monitoring (e.g. are irrigation systems working correctly)
- Verification (did it work)
  - old style compliance monitoring at end of treatment (e.g. *E. coli* testing)

Summary of Guidelines

- The guidelines are practical while providing the basis for safe recycling. Focus on risk management
- Guidance on health risk more transparent than previous guidelines:
  - methods provided to enable assessments and management requirements from 1st principles
  - look up graphs and tables also provided
- Existing schemes that are well-designed and managed should comply with public health requirements
- Consistent with new WHO Guidelines

NSW dual system standards

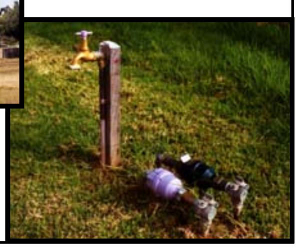


Rouse Hill dual distribution system

↑ **nutrients**

↓ **hydraulic demand**

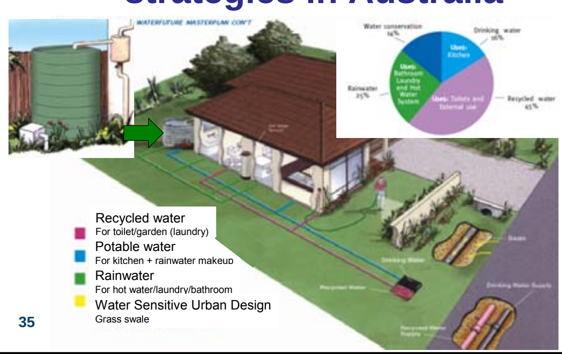
↑ **microbial activity**



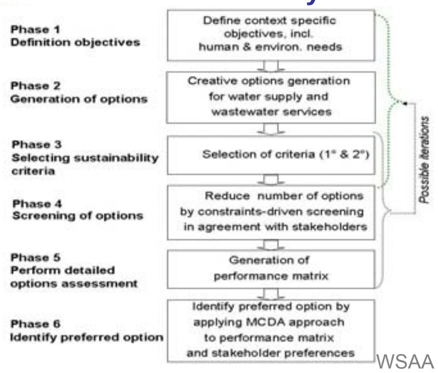
↑**biofilm formation**

is *Legionella* an issue

Community-wide reuse strategies in Australia



Australian Sustainability Framework



WSAA 2008

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*Lundie *et al*. (2006) Water, J. Aust. Wat. Assoc. 33(11), 54-59

Example: Pimpama Coomera Water Futures Project

Gold Coast, 2004

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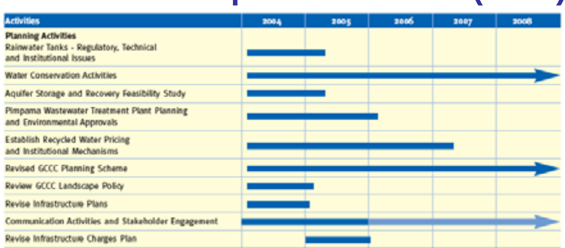
Pimpama Qld. full-scale development timeline (2004)



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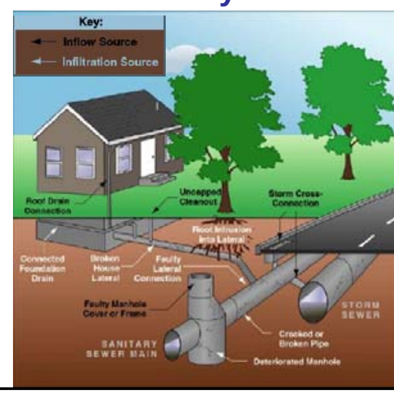
'Smart' sewers: why the need

- Stepping stones to the sewer-less community
  - Pressure or vacuum system
  - Small bore direct drilled pipe system



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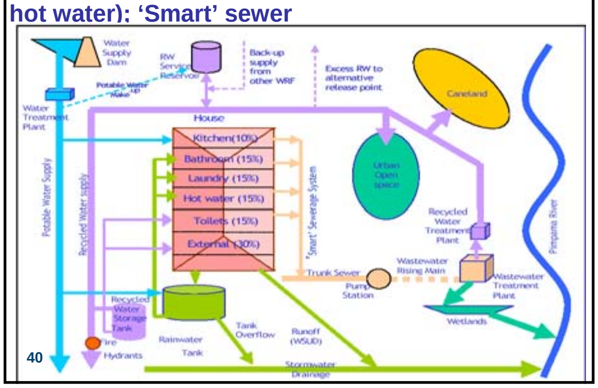
Dual distribution (supplying gardens and toilets); Rainwater tanks (supplying bathroom, laundry and hot water); 'Smart' sewer



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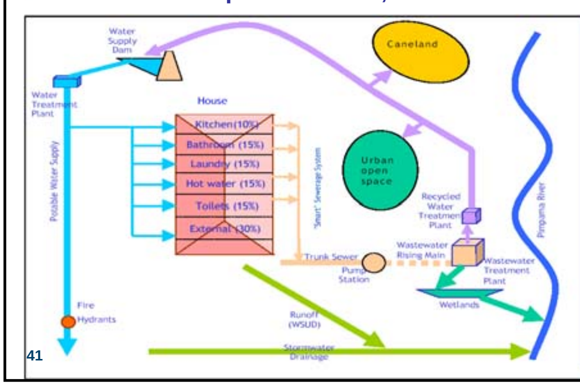
Industry preference: Recycled water pumped to dam for indirect potable reuse; 'Smart' sewer



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Water reuse at individual Sydney homes

- Rainwater
  - Up to 40% homes in Adelaide SA
- Greywater
  - WSP
  - Accreditation

Filtration; Adsorption; Biological treatment; and
- UV disinfection for storage prior to recycling

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NSW Basix (Home) targets

- Since 1 October 2006, BASIX applies to all new residential dwellings and any alterations or additions throughout the Australian state of NSW
- BASIX, the Building Sustainability Index, ensures homes are designed to use less potable water and are responsible for fewer greenhouse gas emissions by setting energy and water reduction targets for houses and units
  - 90% of new homes are covered by the 40% water target (30% energy), and the intent is that no new home built in NSW will use more water than the current state average
  - All new developments have dual water supplies

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Atypical engineering options

Urine-diversion toilet

Urine-diversion dehydrating toilet

Vacuum toilet

Greywater recycling

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Biolytix™ Waste Treatment System

- Costs 90% less to run than the average aerated treat't syst
- Low ongoing costs – only needs one annual service
- It is so reliable offer the option of a 20 year guarantee
- It doesn't need expensive or potentially hazardous chemicals, such as chlorine
- Is resilient to household chemicals
- As it is so compact, it is easier to transport and install
- Unlike a number of systems, it doesn't smell after high loadings
- It can be used to upgrade septics
- It loves food scraps, so also goes well with an In-Sink-Erator

46 http://www.abc.net.au/newinventors/broadband/20040630_2000/biolytix.ram

Biowater - Town Scale Sewerage Networks and Package Sewage Treatment Plants

- Biowater Networks for resorts, commercial developments, subdivisions and towns
- Biolytix Modular Sewage Treatment Plants for treating up to 300 kL/day
- Design Build Operate - "turn key" sewage solutions for small treatment plants or whole village sanitation and water networks
- Biological macerator pump stations for sewage screening, pre-treatment and transfer off-site that will outlast and outperform mechanical macerator pump stations every time

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Lessons learnt

- Water conservation
  - Essential first step, highest savings for least cost, heavily promoted by media/utilities
- Needed local/national guidelines (WSP auditors)
  - So health departments allow novel systems
    - **Need challenge microbes as background conc. too low/variable to show required performance**
  - So companies would move into this market place
- Rebates/tax concessions
  - provide moderate incentive, but initial frustrations as no full economic, system lifetime justification against established water agencies position

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Swedish urine 'fetish'

- **As early as 1850's urban Sweden began diverting urine from new multi-storey houses**
  - to reduce the volume of excreta in the bucket toilet, which had to be carried downstairs regularly for emptying
  - Following urine diversion in a down pipe, the remaining excreta in the buckets smelt less, and could be emptied monthly, rather than daily

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The common need for change

- Traditional on-site systems in Sweden (typically septic tanks and leachfields) are failing environmental performance requirements because
  - they are not removing enough phosphorus
  - Therefore alternative sanitation solutions, like urine diversion are increasingly being explored to reuse nutrients

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Sweden: Environ, political & socio-demographic factors diverting urine

- The principle of 'closing the loop' on nutrient cycles, such as phosphorus, as finite resource
- Eutrophication of lakes and coastal waters is seen as a key reason to divert urine from municipal outfalls
- The dominant environmental political movement of the 1990s where the symbolism of urine diverting toilet
- Many 'summer houses' in Sweden, dry toilets are common, diverting urine reduces odor & improves composting of feces
- The boycott on using sludge on arable land (due to chemical contaminants) was a driving force for considering new ways of returning urban nutrients

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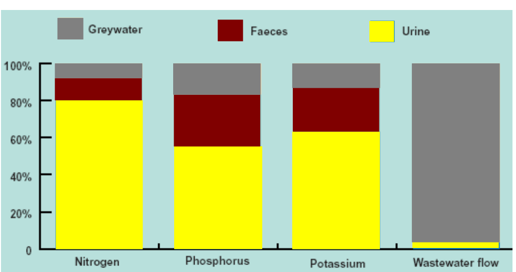
Why Divert the Urine?



- Use as a plant fertilizer
  - Normal nitrogen application (80-100 kg/ha)
  - ≡ 10-40 tonnes of urine/ha is needed

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Urine-diverting toilets

- WM-Ekologen model DS
- Other models have combine vacuum system or dry fecal collection with urine diversion.
- BB Innovation & Co. model Dubbletten
- gives 3.3 - 3.6 g N / L

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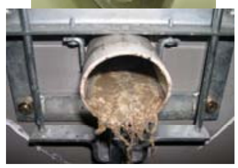
Urine-Diversion: Sending P back to plants & pharmaceuticals to soil

Urine-diversion toilet (Gustavsberg)

Waterless urinal



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Urine storage tank (1000-L)

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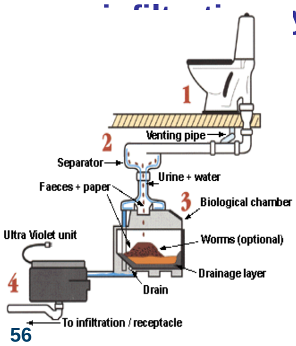
Solids composting/wastewater infiltration system



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http://www.aquatron.se/start.uk.html

Urine diversion system

6 months Storage

Same or better yields of wheat, rye, barley as with inorganic fertiliser

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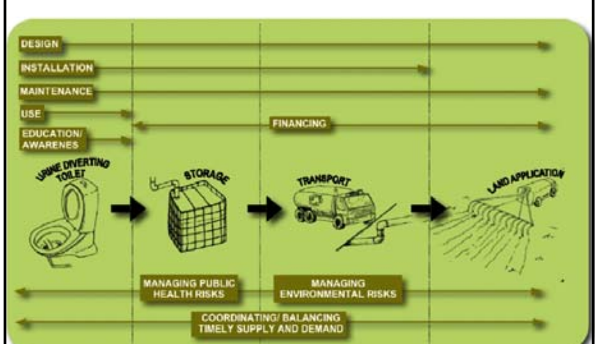
Urine diverting systems



Lessons from Sweden

(Dana Cordell, UTS)

- Need one coordinating agency
  - –e.g. municipality to ensure its residents install a urine diverting system when they apply to build a new house or undertake major renovations
  - –They provide a checklist to the householder of what toilets & contact list of farmers to collect the urine
  - –Municipality has the actual contract with the farmer and
    - *"if someone doesn't want to use one of these farmers, the municipality has the responsibility to empty the urine tank, because the municipality has the responsibility for sewage".*
- LCA shows transport of yellow water up to 120 km OK

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Hammarby Sjöstad Project

Docklands redevelopment in Stockholm

Microbial aerosols from toilet flushing

- Microbial Risk Assessment:
  - –microorganisms added to household water
  - –selection of 8 toilets
  - –measure microorganisms in 1000 L air near toilet
  - –"male simulation"
  - –1 L of contaminated household water run through pipette from 0.5 m above toilet into pedestal
  - –measure microorganisms in 1000 L air near toilet

Kiwa Research & Consultancy
Medema *et al*. (2000) WQTC Salt Lake City

Toilet flushing

	Concentration in household water (n/ml)	Concentration in air before flushing (n/1000 l)	Concentration in air after 3-4 flushings (n/1000 l)	Concentration in air during "simulation" (n/1000 l)
E. coli	200,000	0 - 1	0 - 5	0 - 3
MS2	220,000	0 - 4	0 - 37	0 - 8
Spores	100,000	0 - 60	31 - 492	51 - 414

Garden tap

- Spiked water as before
- Assayed 1000 L down wind
- Simulation of
  - –Spraying
  - –High pressure cleaning
  - –Water activities in garden

Garden sprayer

	Concentration in household water (n/ml)	Concentration in air before spraying (n/1000 l)	Concentration in air during spraying (n/1000 l)
E.coli	1,840,000	0	44 - 94
MS2	10,000,000	0	200 - 414
Spores	35,000	2	128 - 172

High pressure cleaner

	Concentration in household water (n/ml)	Concentration in air before spraying (n/1000 l)	Concentration in air during spraying (n/1000 l)
E.coli	1.180.000	0	2200
MS2	10.000.000	0	>1700
Spores	21.000	2	330 - 650

Household water quality for 10^{-4} risk

	Crypto (n/l)	*Giardia* (n/l)	Viruses (n/l)	*Campylo bacter* (n/l)
Spraying	2.6	6.5	1.9	65
High pressure	2.0	5.0	0.6	1.5
Laundry skin	2.6	6.4	0.7	12
Laundry driers	0.4	1.1	2.4	300
Toilet	0.1	0.3	0.05	25

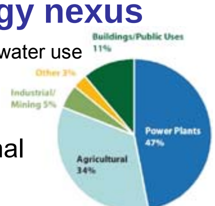
Conclusions from Dutch studies

Application of artificially contaminated household water:

- **Laundry**
  - Tumble driers: no significant increase of concentration of microorganisms in the air
  - Skin contact: small fraction of microorganisms retained on skin
- **Garden spraying and high pressure cleaner**
  - significant increase in concentration of microbes in air (maximum 100-1000x)
- **Toilet flushing**
  - increase of the concentration of viruses & spores in the air (maximum ca. 10x)

Water-Energy nexus

US total water use



- Water and wastewater energy use for US cities consumes 5-10% national electricity production
  - 25-30% water utilities operating cost

Carlson, S.W. and Walburger, A. (2007) *Energy Index Development for Benchmarking Water and Wastewater Utilities*. Denver: American Water Works Association Research Foundation.

Subcommittee on Buildings Technology Research and Development (2008) *Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings. Washington D.C.: Executive Office of the President of the United States.*

Waste to energy-fertilizer and recycle greywater – more decentralized

- Energy from biosolids consumes about 20 kWh/kg after transport, concentration, drying & combustion, so…
  - Vacuum/pressure sewer to MFC energy
  - A city of 100,000 people could power 800 homes (assuming energy usage of 1.5 kW/home)
- NPK nutrients to agriculture (urban & regional)
- All started at the domestic level, readily updated/changed, centrally managed decentralization
  - e.g. household washing machine recycling greywater (saving 50-70 of household water)
  - Living machine/walls built into homes along with solar

What's in the 'pipeline'

Dena Fam
Affiliation: PhD candidate in Sanitation Futures, ISF, Sydney, Australia

- **The 'Propellair' toilet (1.5L flush, www.Propelair)**
  - The 'Propel air' flushing system reduces water consumption to 1.5 Litres per flush, using 84% less water & 80% less energy than avg 9 litre WC
- **The 'Quench' recirculating shower system**
  - The commercially available Quench conservation shower uses up to 67% (25 vs 43 L) less water than a low flow shower head & use up to 87% less energy
- **The Airwash (Electrolux waterless washing machine)**
  - 'Air Wash' is a waterless washing machine which uses negative ions, anti-bacterial deodorants and highly pressurized air to clean clothes
- **The Rock Pool (waterless dishwasher) CO_2 (UNSW)**

In 30y using 48 vs 172 L/person.day

Bathing (shower only)		
QUENCH recirulating shower (25L/7min)	3.50	litres / minute
QUENCH recirulating shower - duration	7.00	minutes / shower
QUENCH recirulating shower - frequency	0.85	showers / person.day
Hyper efficient technology uses 21.25L/p/day		
Existing low flow shower uses approx. 52.96/p/day		
Clothes washing		
Air Wash waterless washing machine	0.00	litres / person.day
Air Wash waterless washing machine - frequency	0.32	washes / person.day
Hyper efficient technology uses 0.00L/p/day		
Existing front loader uses approx.72L/p/day		
Dishwashing		
Rock Pool waterless dishwasher	0.00	litres / person.day
Rock Pool waterless dishwasher - frequency	0.21	
Hyper efficient technology uses 0.00L/p/day		
Existing dishwashers use approx. 1.1L/p/day		
Flushing		
Propelair toilet	5.7	litres / person.day
Propelair toilet L/flush	1.50	litres / flush
Propelair toilet/flushes/p/d	3.80	flushes / person.day
Hyper efficient technology uses 5.7L/p/day		
Existing standard dual 3/6 flush toilets use 45.94L/p/day)		

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  - http://www.gtz.de/ecosan/download/ecosan-symposium-Luebeck-Proceedings-draft.pdf
  - EcoEngineering:
  - http://www.iees.ch/EcoEng011/EcoEng011_F5.html
- **Projects & institutions:**
  - Novaquatis, Switzerland: http://www.nomix.ch
  - Urban Water, Sweden: http://www.urbanwater.org/default_eng.htm
  - Swedish University of Agricultural Sciences: http://www.mikrob.slu.se/avfall/english/urin.htm
  - Lund University, Sweden: http://www.vateknik.lth.se/
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