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EXPO 2015

Alternative decentralized water sources – Opportunities and challenges

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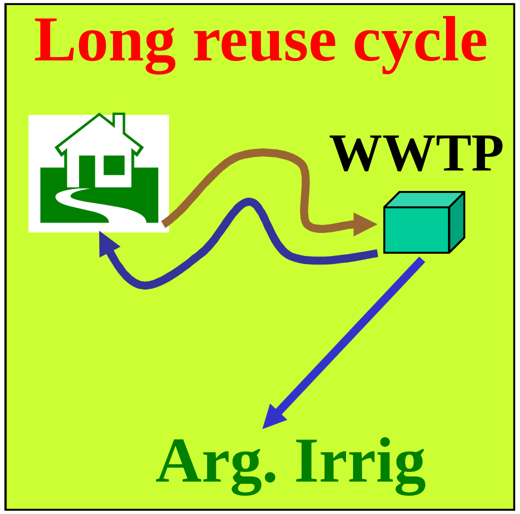
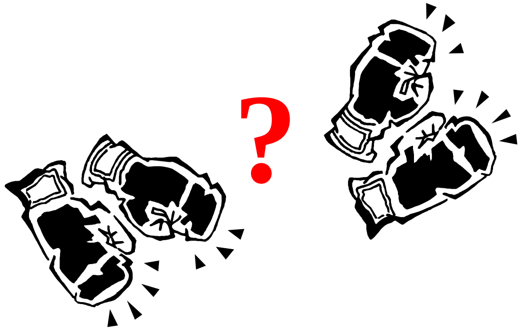
- Opportunities
- Risks / Real world
- System approach

- Rainwater Harvesting
- Stormwater Harvesting

Water Reuse
Decentralised *vs.* Centralised

Centralised





Decentralised

Urban Areas

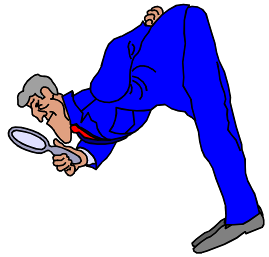
1. Toilet flushing
2. Landscape irrigation
3. Garden farming (urban agriculture)

Rural Areas

1. Landscape irrigation
2. Garden farming (1 - poor areas)
3. Toilet flushing

Laundry; Dishwashing; Car washing; Fire-fighting; Cleaning streets. . .

WW / GW / BW ?



Urban water demand

~70 % → **Domestic consumption**

~30 % → **Other uses**

Domestic consumption

60 - 70 % → **Greywater**

30 – 40 % → **Blackwater**

Greywater

~$^2/_3$ **LGW**

~$^1/_3$ **DGW**

LGW	DGW
Bath	K. Sink
Shower	Dishwasher
Washbasin	W. Machine ?

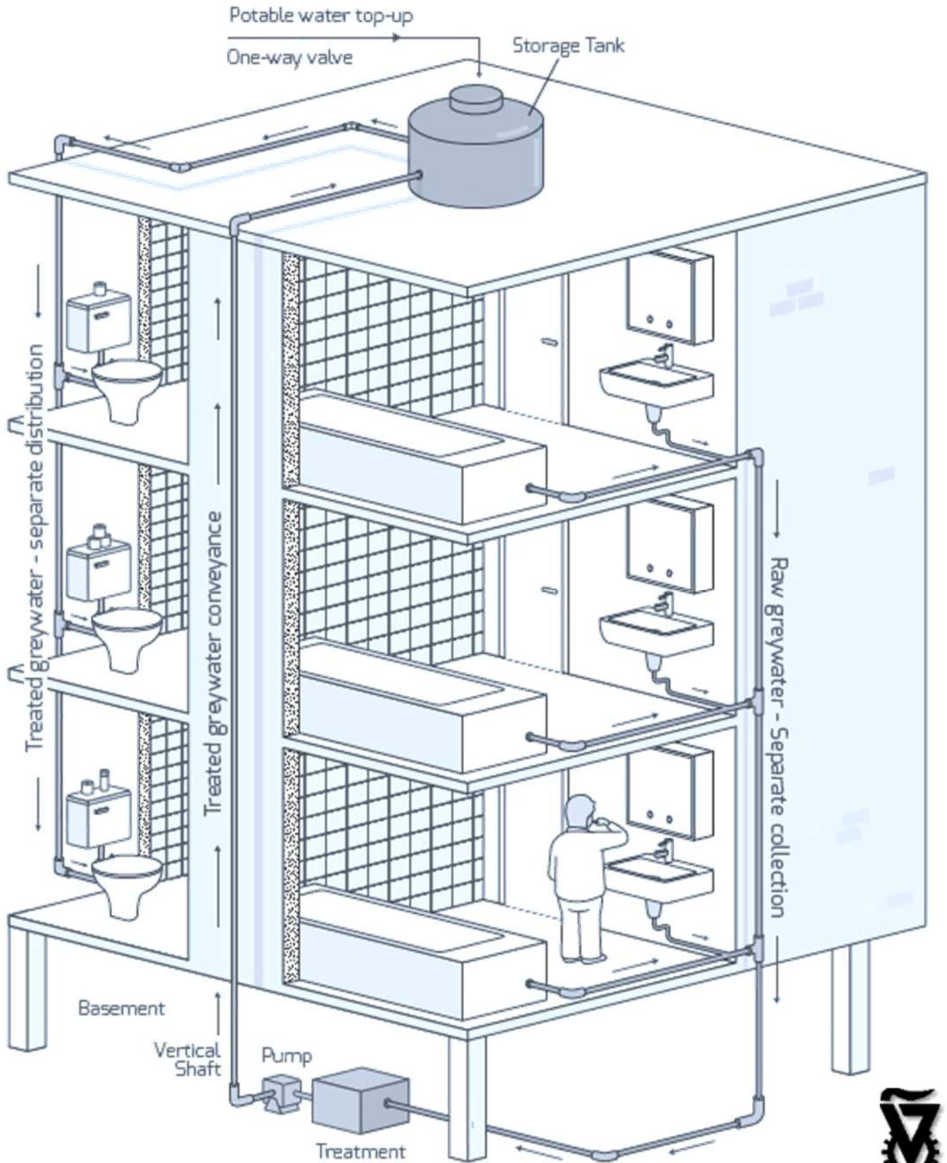
Potential reduction

GWR (Toilet) ~ 30%

GWR (Toilet & Garden) ~ 40%

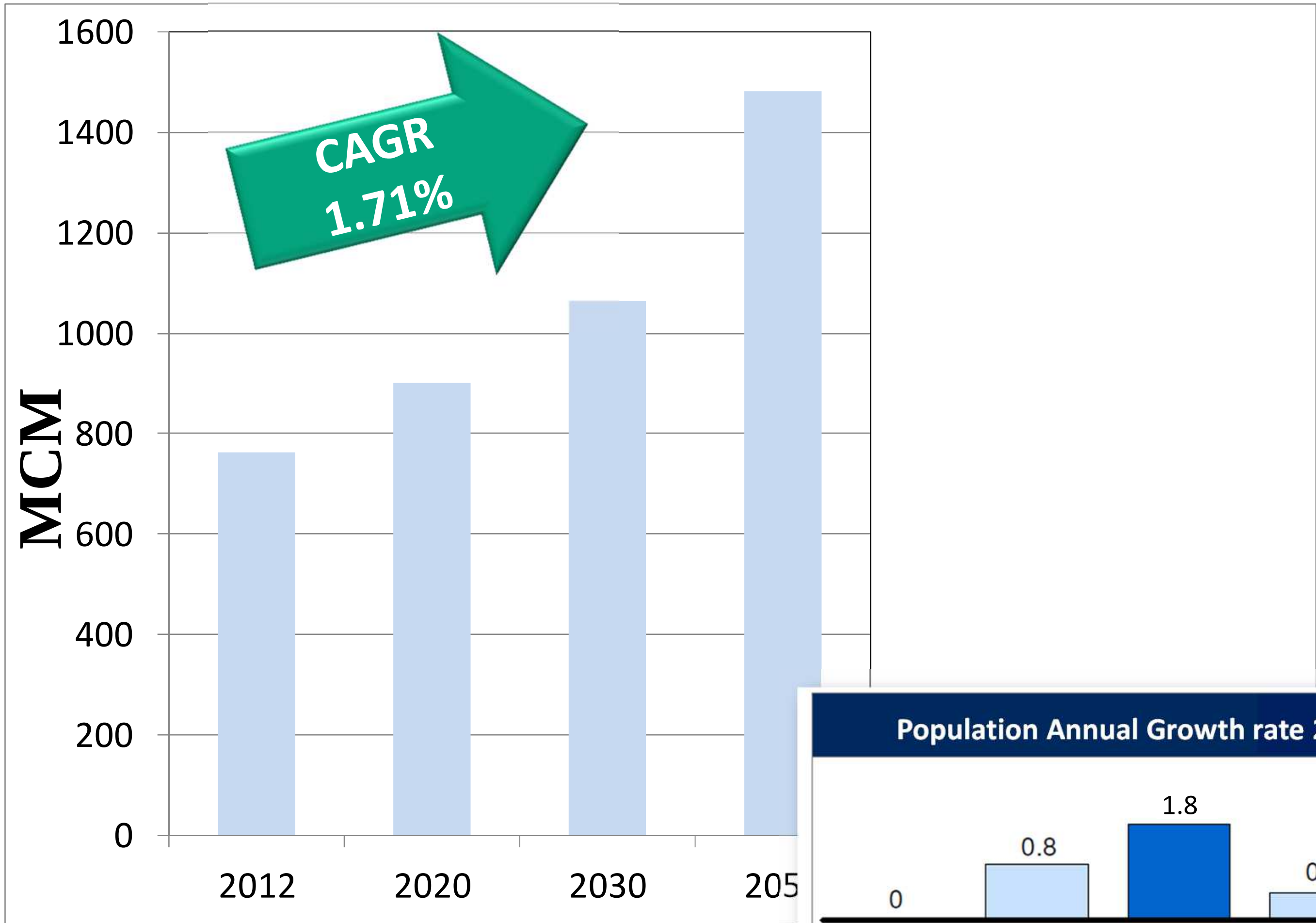
10-20% of Urban water demand

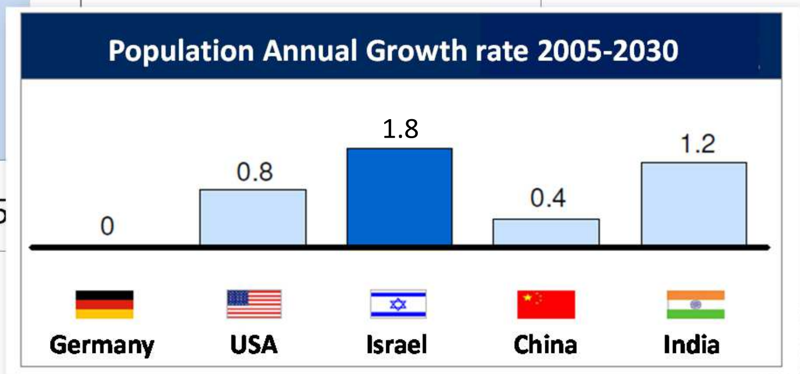
Typical installation in a multi-storey building



Taken from: Gross *et al.* (2015)

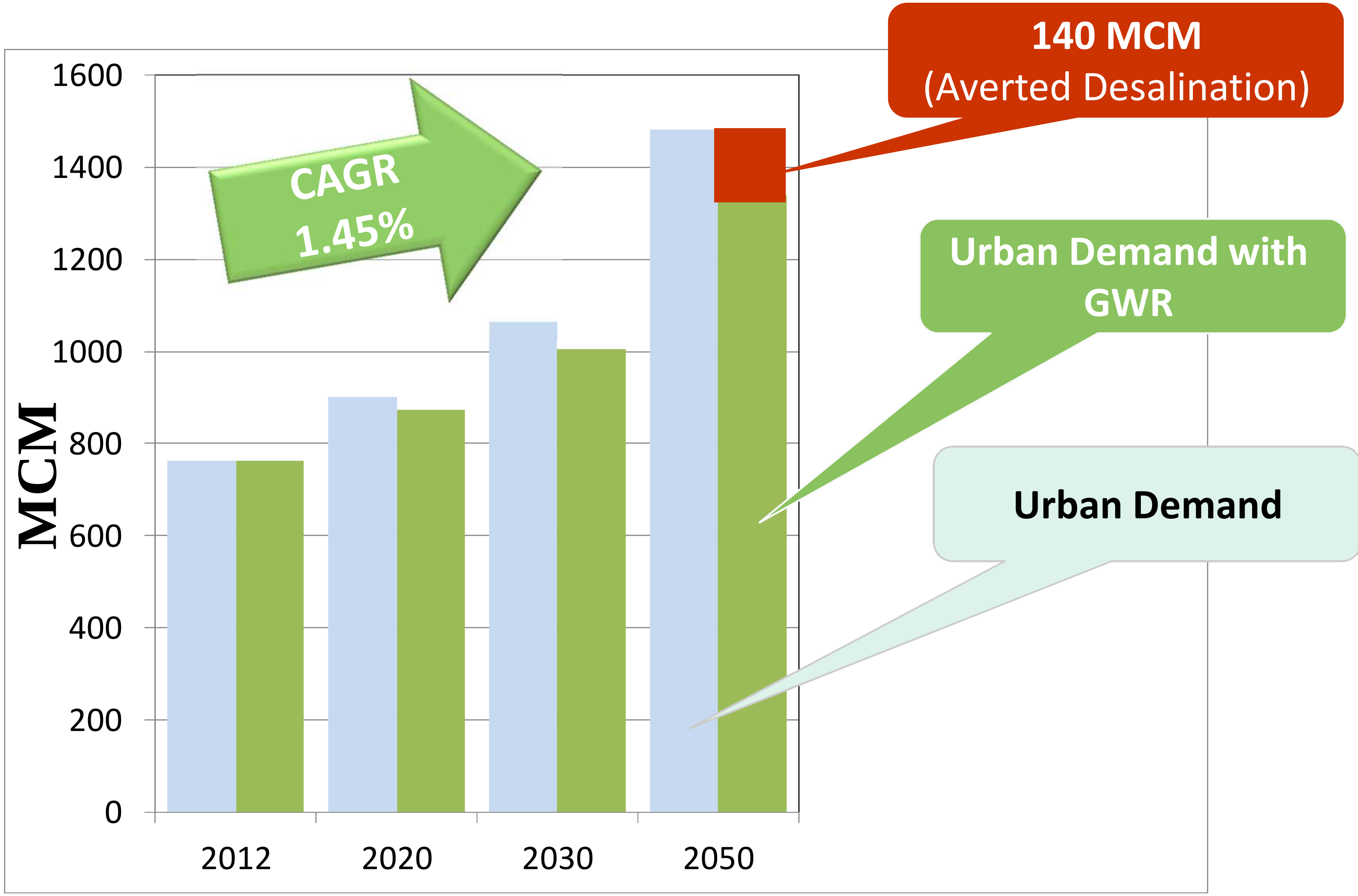
Growth rate of urban water demand in Israel





Italy ~ 0.3

GWR can <u>slow-down</u> the <u>growth</u> rate of urban water demand - Opportunity



2050 – 30% penetration (only buildings built after 2012)

- Opportunities
- Risks / Real world
- System approach

- Rainwater Harvesting
- Stormwater Harvesting

Potential impacts of GW reuse

Close proximity between the reused GW & the public

⬇

Sanitary quality of GW is very important !

Treatment Technologies – Requirements

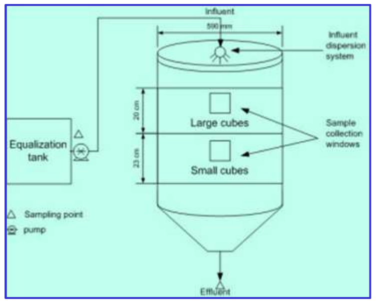
GW is polluted - Barrier

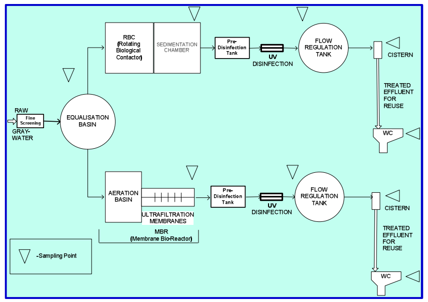
- Sanitary quality (**public health**)
- Aesthetic quality (**public acceptance**)
- Eliminate negative **Environmental effects**

Treatment of "Light" GW !

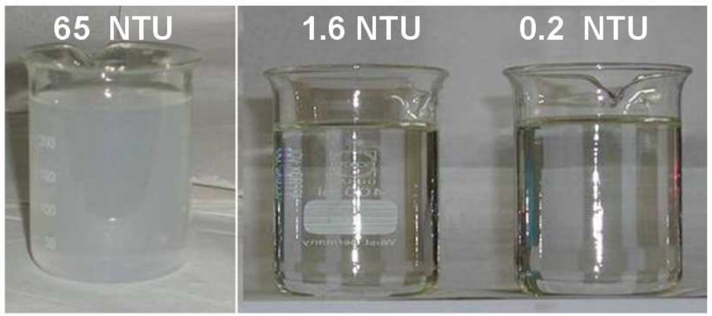
Requirements from treatment technologies (Solution):

- **Efficiency**
- **Reliability**
- **Safety**
- **Reasonable O&M (technical & economical)**





Raw GW | RBC eff. | MBR eff.



Science of the Total Environment 533 (2015) 557–565

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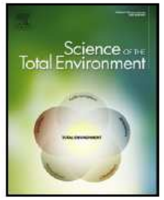
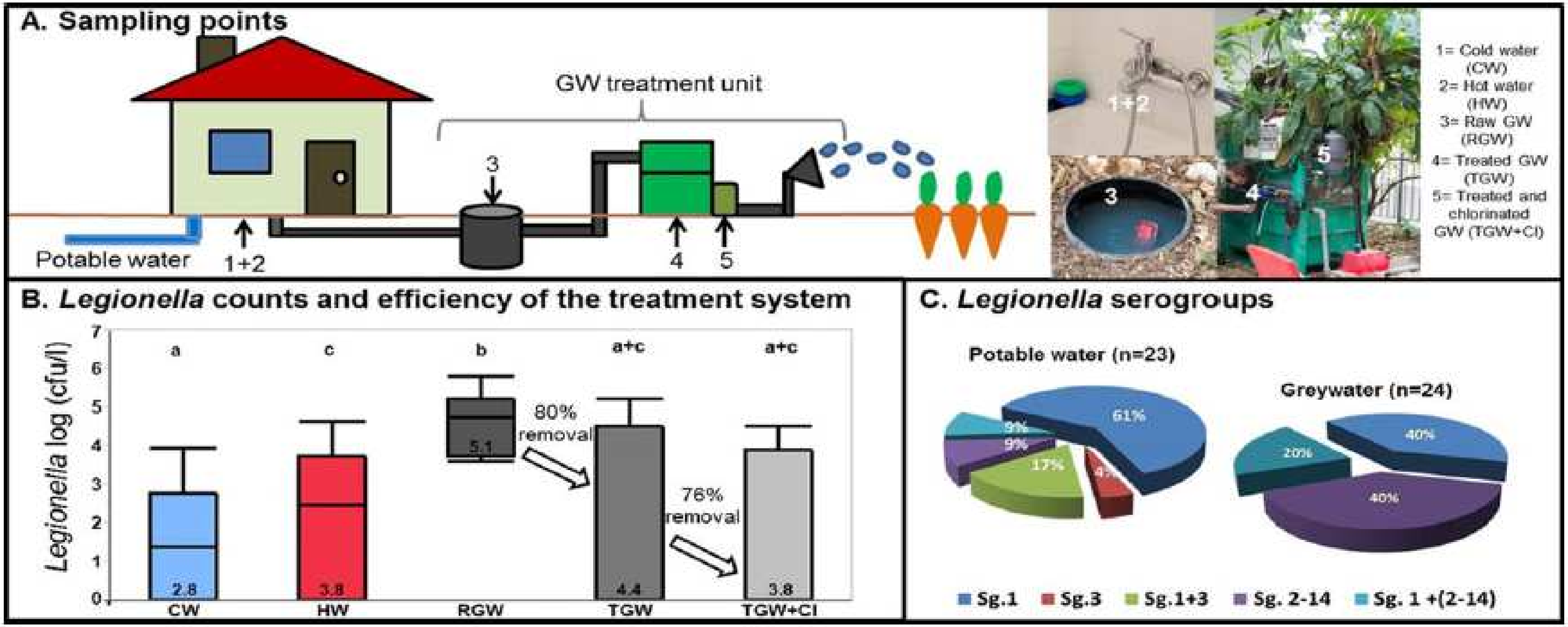
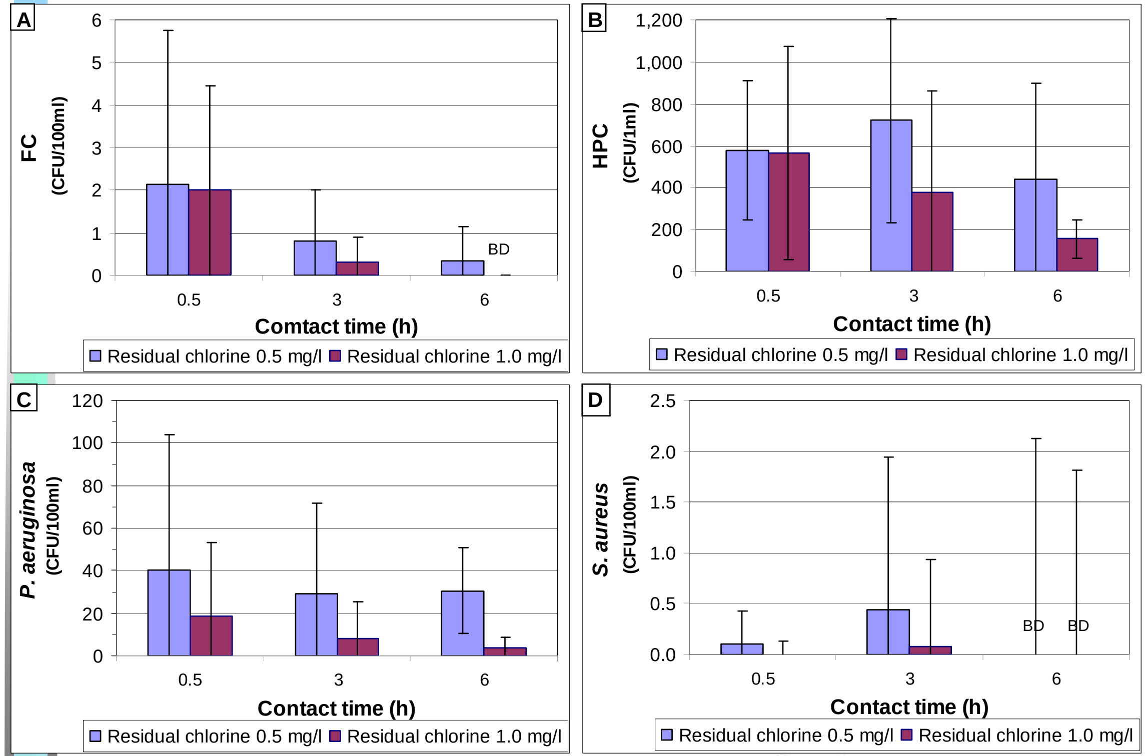


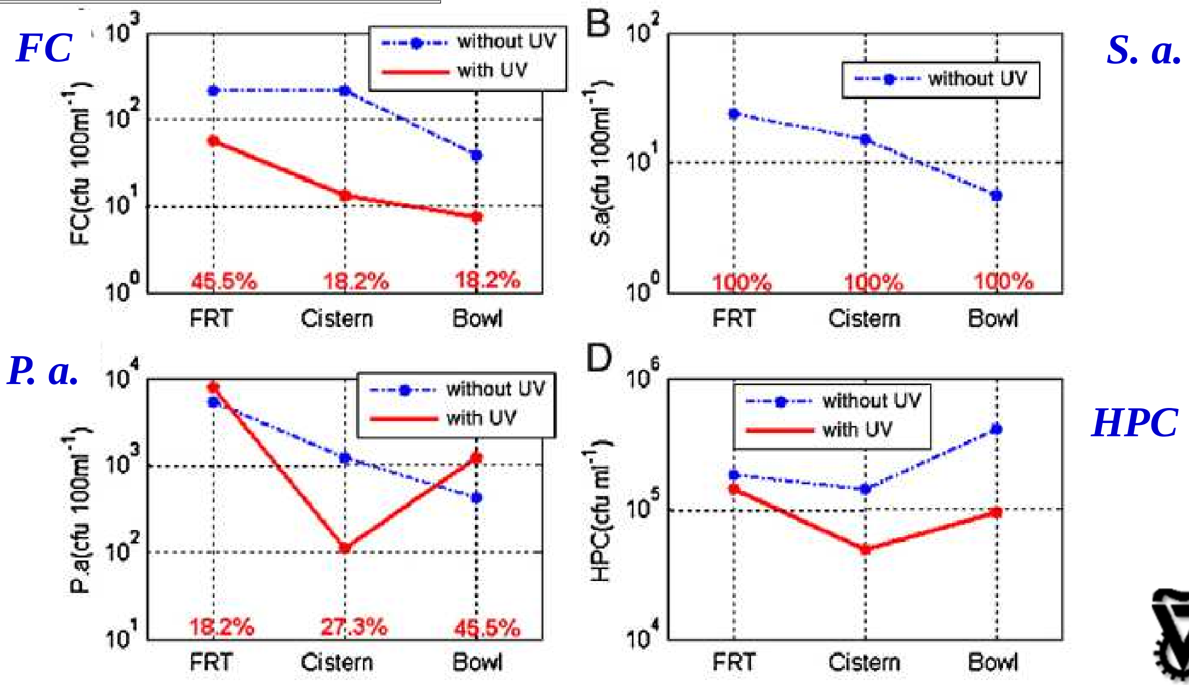
Legionella pneumophila: From potable water to treated greywater; quantification and removal during treatment

CrossMark

Marina Blanky [a], Sara Rodríguez-Martínez [b,*], Malka Halpern [b,c], Eran Friedler [a]





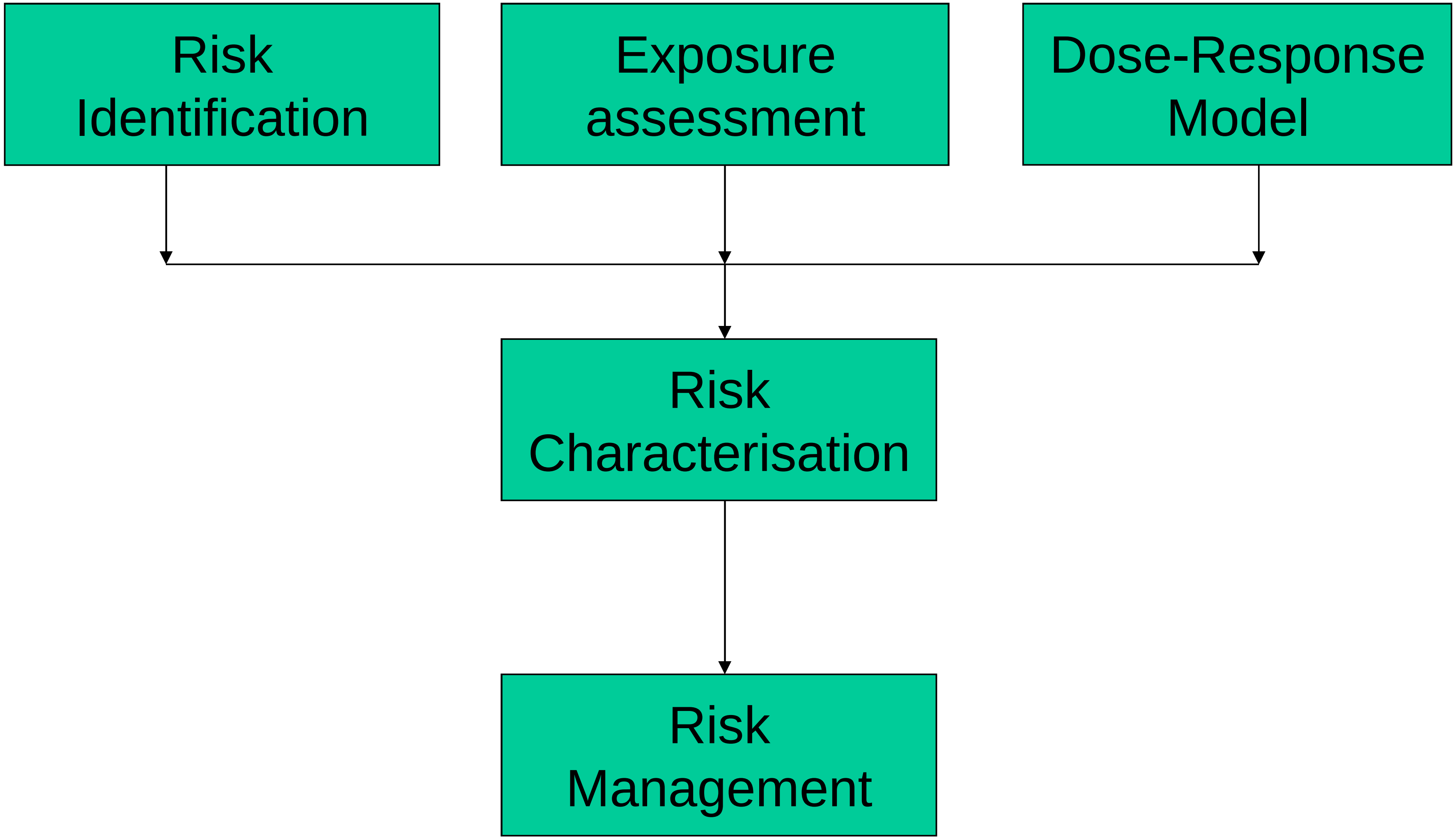


RBC effluent along the reuse system

% Zero

FRT - Flow regulation tank

Risk Assessment – QMRA
(Quantitative Microbial Risk Assessment)



Risk Identification
Single family ←→ Multi family home

	Single family home	Multi family home
Exposure Routes	Various	Especially via greywater
Vector of disease	Low	High
“import-export”	-	+

Risk Identification

Toilet Flushing

1. Splashing
2. Aerosols

} Inhalation / ingestion of small droplets

3. (Cross connections)

Garden Irrigation

1. Splashing (large volumes)
2. Punctures (irrigation equipment)
3. Miss-use

} Body contact / ingestion

4. (Cross connections)

Exposure Assessment

Exposure scenarios	Volume (ml/event)	Frequency (event/y)
Accidental ingestion	100	1
Routine ingestion from touching plants & lawns	1	37 Days (300 h/y)
Ingestion of sprays from irrigation system	0.1	
Ingestion of soil contaminated by GW	10-100 mg	5 Days (60 h/y)
Eating home-grown plants that was exposed to GW	0.36 - 10.8	

- Literature (volumes)
- Questionnaires (frequencies)

Dose Response Model

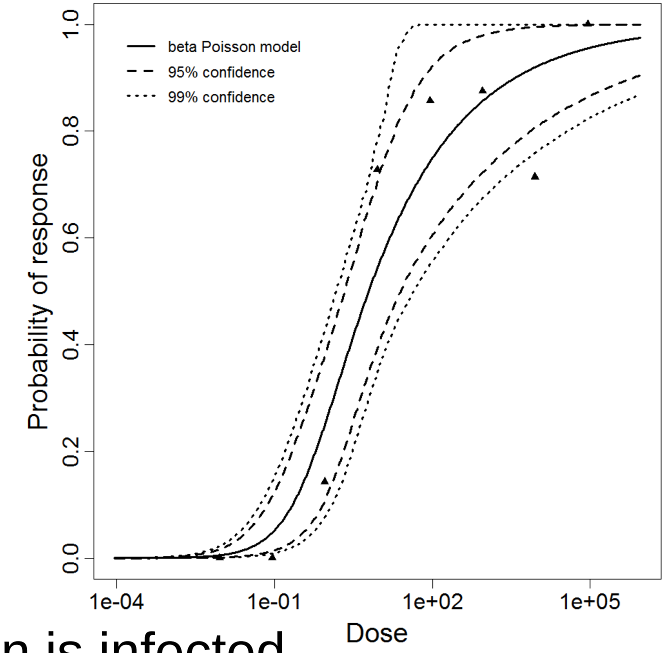
Probability of infection vs. Pathogen concentration

$$Pi(d) = 1 - [1 + (d/N_{50})(2^{1/\alpha} - 1)]^{-\alpha}$$

Haas's *beta-poisson* dose-response

For *Rotavirus:*

$\alpha = 0.253,\ N_{50} = 6.17$



$$Pi_{(A)}(d) = 1 - [1 - Pi(d)]^{n}$$

d - Pathogen dose

Pi(d) - Probability of infection

N_{50} - Dose at which 50% of the population is infected

α - Infectivity constant (pathogen specific)

$Pi_{(A)}(d)$ - Annual risk of infection

n - Number of exposure events *per* year.

Risk characterisation

Rotavirus - Probability of infection (*Based on E. Coli conc. Found in real systems*) & **37** exposure days (questionnaires)

Daily volume exposure	Average probability of infection (annual) E. coli ~ 10^5 [cfu/100ml]	 E. coli ~ 10^2 [cfu/100ml]
0.01 ml	$2.5 \cdot 10^{-3}$	$5.8 \cdot 10^{-6}$
0.1 ml	$2.1 \cdot 10^{-2}$	$5.8 \cdot 10^{-5}$
1 ml	$1.0 \cdot 10^{-1}$	$5.8 \cdot 10^{-4}$
50 ml (single event)	$1.1 \cdot 10^{-1}$	$8.0 \cdot 10^{-4}$
100 ml (single event)	$1.4 \cdot 10^{-1}$	$1.6 \cdot 10^{-3}$

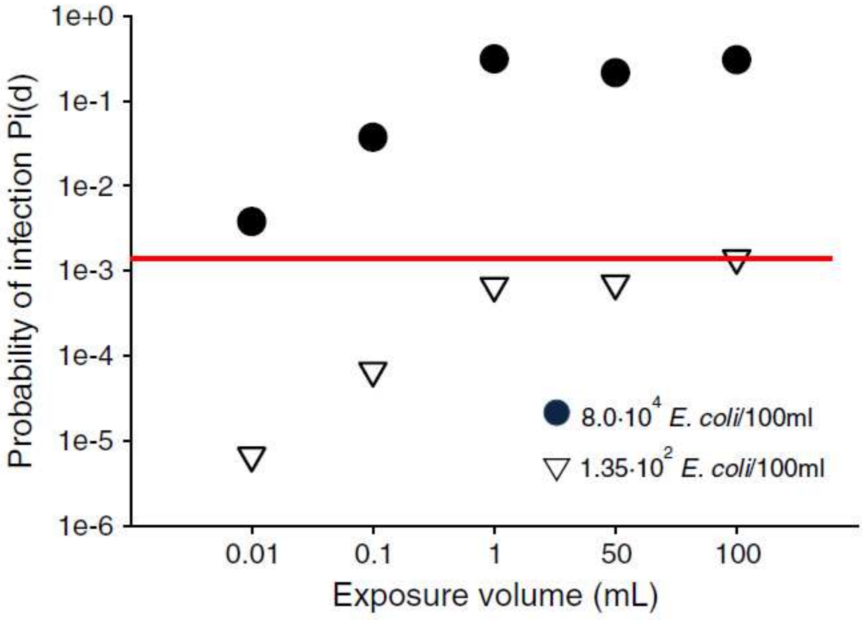
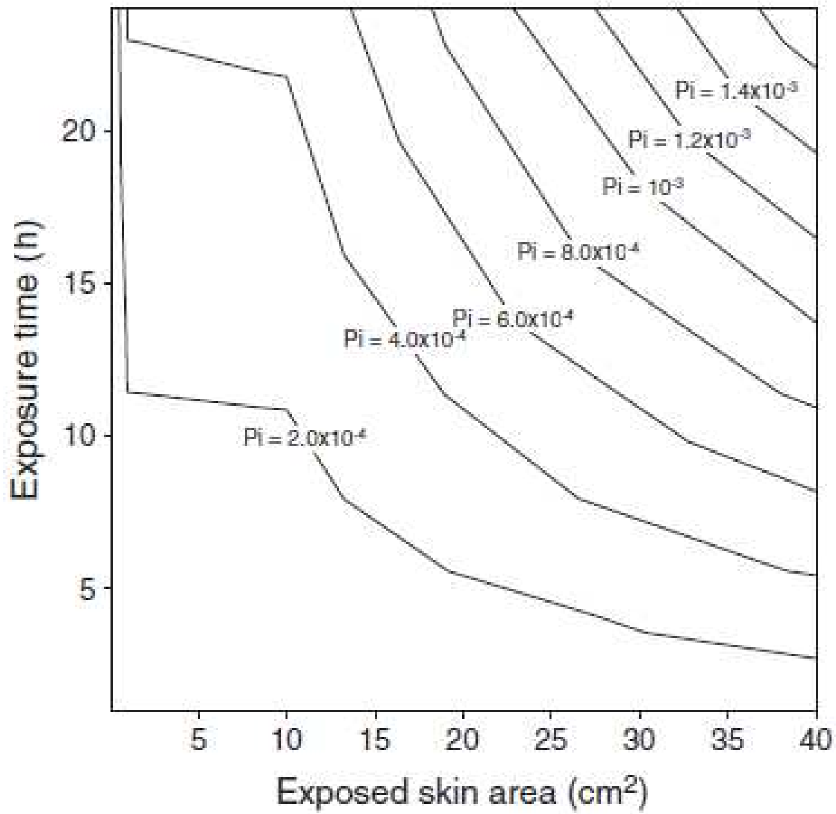


Fig. 2. Cumulative probability for rotavirus infection as a function of exposure volumes for two *E. coli* concentrations in the greywater. Open triangles represent the average concentration found in the survey and circles represent the average concentration of the best treatment (professionally designed treatment of greywater excluding kitchen effluent). Exposure volumes between 0.01 and 1 mL relate to repeated exposures (47 days year^{-1}); 50 and 100 mL represent a single exposure event. The horizontal line represents the WHO's maximum tolerable risk for rotavirus infection.

Figure 3: Cumulative probability for *S. aureus* skin infection based on increasing exposure time and exposed body area to water containing the average concentration found in the survey (1.2 x 10^3 CFU 100 mL^{-1})



What happens in reality?

Are there evidences of "ill GW users"?

Science of the Total Environment 538 (2015) 230–239

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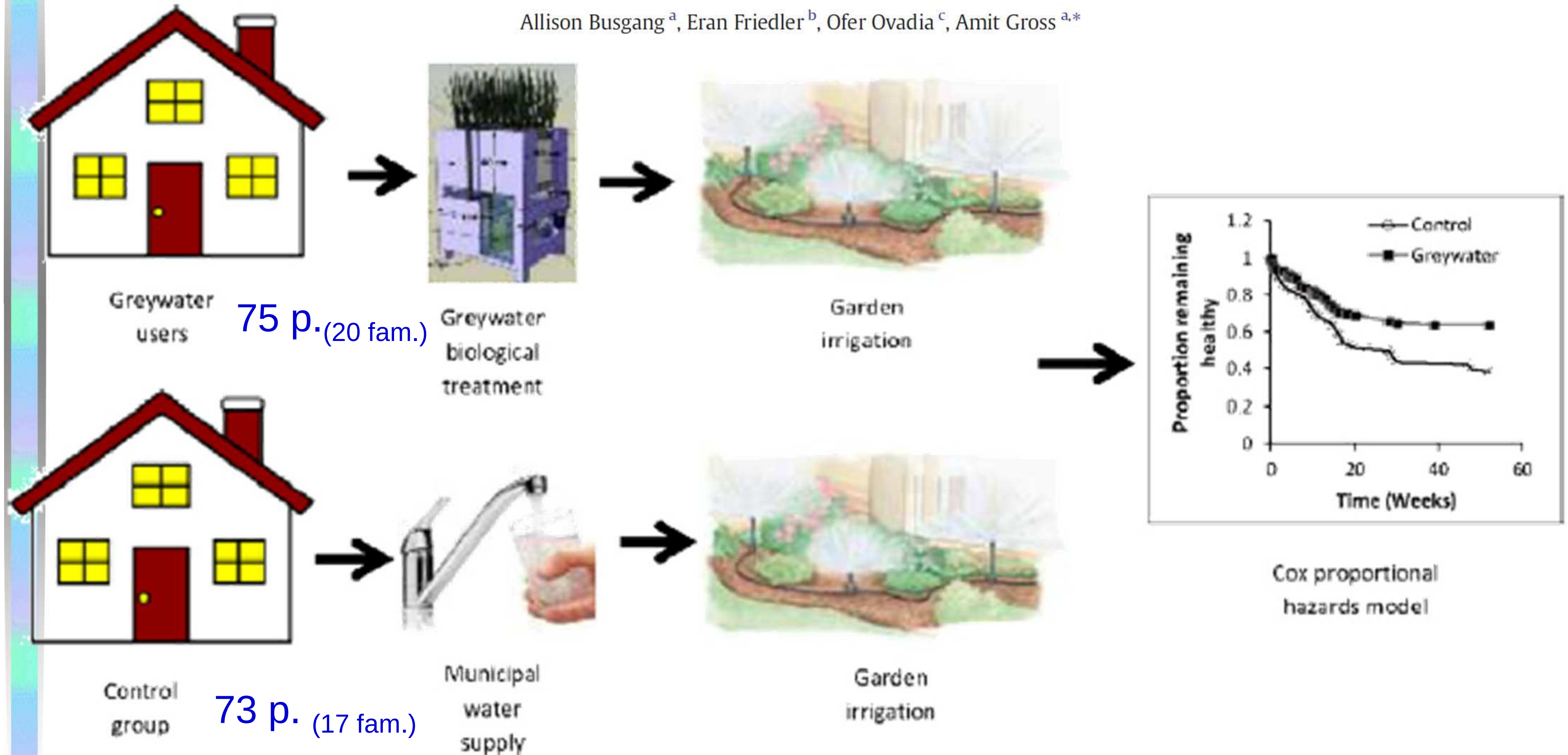
Epidemiological study for the assessment of health risks associated with graywater reuse for irrigation in arid regions

Allison Busgang [a], Eran Friedler [b], Ofer Ovadia [c], Amit Gross [a,*]



GW reuse for garden irrigation posed no additional health risk

- Opportunities
- Risks / Real world
- System approach

- Rainwater Harvesting
- Stormwater Harvesting

Urban Water Journal
Vol. 9, No. 3, June 2012, 137–148

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Evaluation of the effects of greywater reuse on domestic wastewater quality and quantity

Roni Penn[a], Matan Hadari[b] and Eran Friedler[a]*

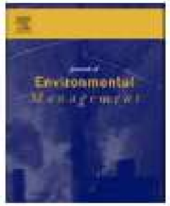
Journal of Environmental Management 114 (2013) 72–83

ELSEVIER

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman



Modelling the effects of on-site greywater reuse and low flush toilets on municipal sewer systems

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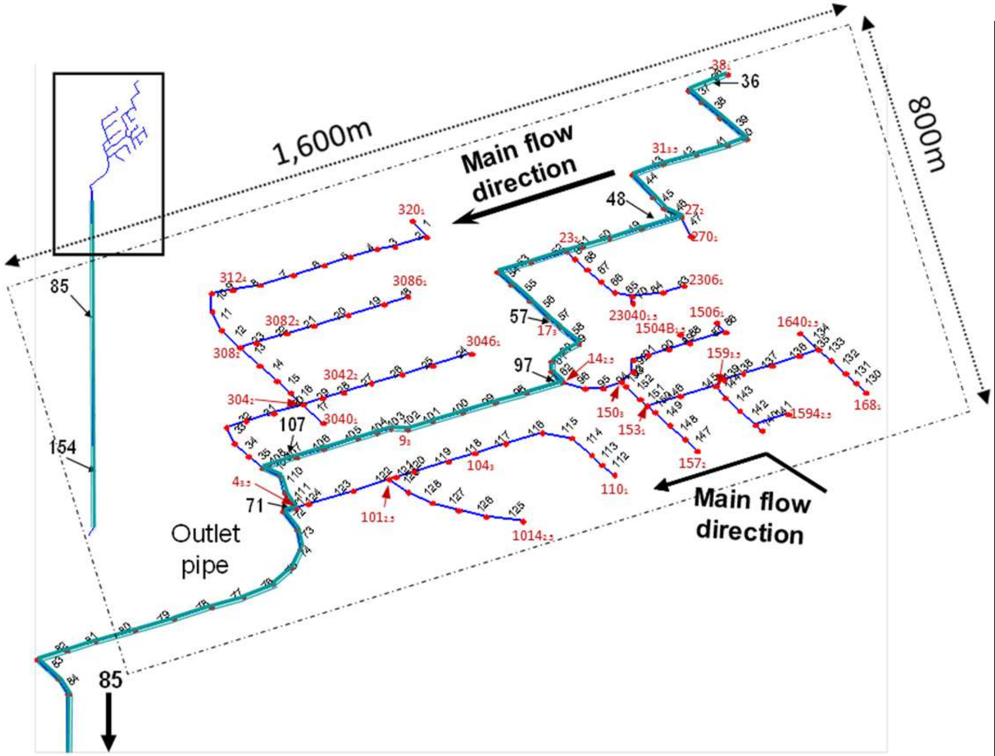
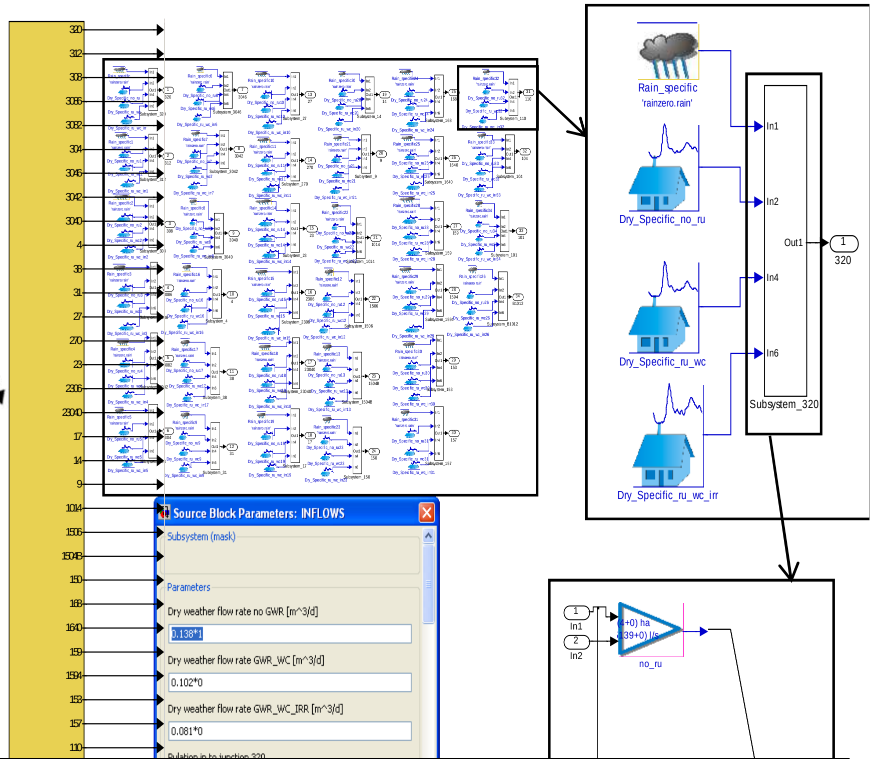
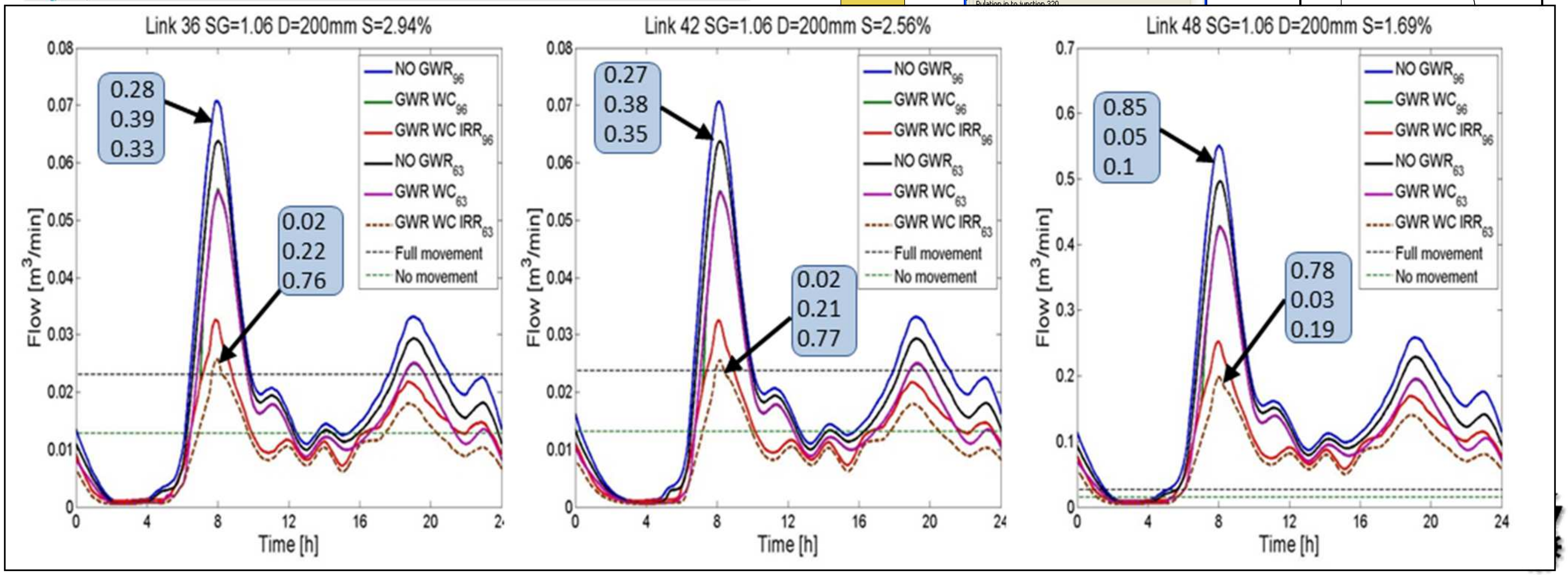
Assessment of the effects of greywater reuse on gross solids movement in sewer systems

R. Penn, M. Schütze and E. Friedler


1,600m
800m
Main flow direction
Main flow direction
Outlet pipe
85
154
107
97
57
48
36
71


Source Block Parameters: INFLOWS
Subsystem (mask)
Parameters
Dry weather flow rate no GWR [m^3/d]
0.138*1
Dry weather flow rate GWR_WC [m^3/d]
0.102*0
Dry weather flow rate GWR_WC_IRR [m^3/d]
0.081*0
Rain_specific
'rainzero.rain'
Dry_Specific_no_ru
Dry_Specific_ru_wc
Dry_Specific_ru_wc_irr
Subsystem_320
Out1
320
no_ru


Link 36 SG=1.06 D=200mm S=2.94%
Link 42 SG=1.06 D=200mm S=2.56%
Link 48 SG=1.06 D=200mm S=1.69%
Flow [m^3/min]
Time [h]
NO GWR96
GWR WC96
GWR WC IRR96
NO GWR63
GWR WC63
GWR WC IRR63
Full movement
No movement
0.28 0.39 0.33
0.02 0.22 0.76
0.27 0.38 0.35
0.02 0.21 0.77
0.85 0.05 0.1
0.78 0.03 0.19

Urban Water Journal, 2015
http://dx.doi.org/10.1080/1573062X.2015.1036084

Taylor & Francis
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RESEARCH ARTICLE

Reducing inventory data requirements for scenario representation in comparative life cycle assessment (LCA), demonstrated on the urban wastewater system

Tamar Opher* and Eran Friedler

Table 1. Main characteristics distinguishing between the four alternatives.

Scenario	Greywater treatment	Urban reuse
0	Central WWTP	None
1	Central WWTP	Toilet flushing, private gardening, municipal park irrigation
2	Cluster RBC	Toilet flushing, private gardening
3	On-site RBC	Toilet flushing, private gardening

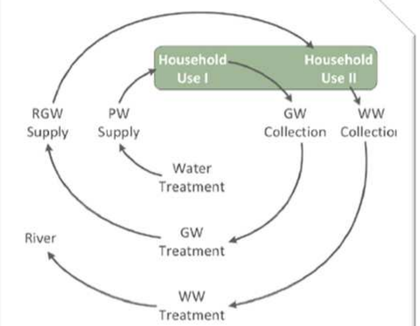
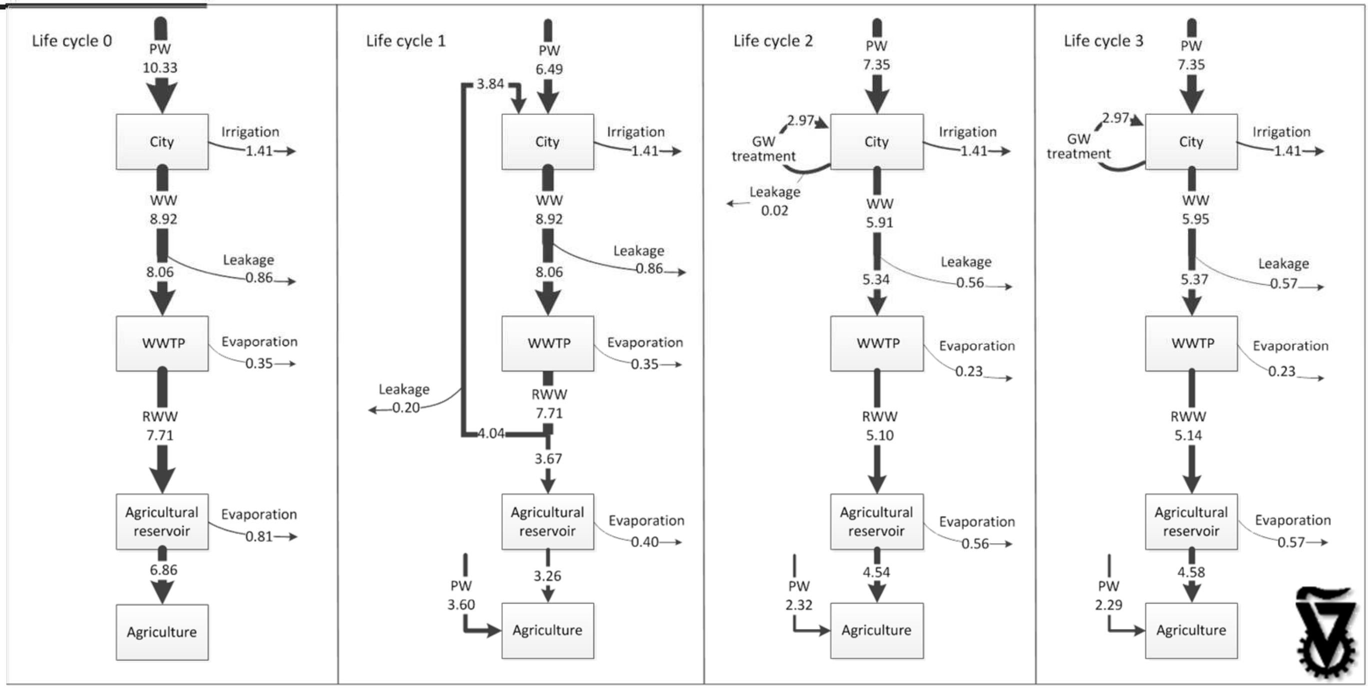


Figure 1: Open loop recycling of domestic water.
PW = potable water; GW = greywater;
WW = wastewater; RGW = reclaimed GW;



- Opportunities
- Risks / Real world
- System approach

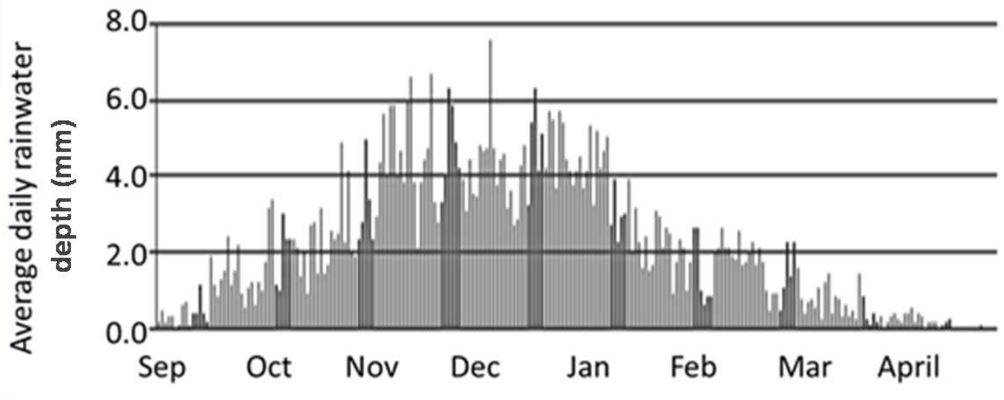
- Rainwater Harvesting
- Stormwater Harvesting

Study area (Haifa – Israel)

Dry period 151 d (105-220)

Rainy season

- Rainfall – 538 mm/y (292-925)
- 50 (rainy d)/y (35-69)
- Time between consecutive events
  - 4.1 d (S.D. 6.2)
  - Median 1 d
  - 75% ≤ 5 d
- 151dry days (105-220)



Rain is highly stochastic - challenge

$$R(t) = Max \begin{Bmatrix} a_t \cdot P(t)^6 + b_t \cdot P(t)^5 + c_t \cdot P(t)^4 + d_t \cdot P(t)^3 + e_t \cdot P(t)^2 + f_t \cdot P(t) + g_t \\ 0 \end{Bmatrix}$$

$$P(t) = Random(0-1)$$

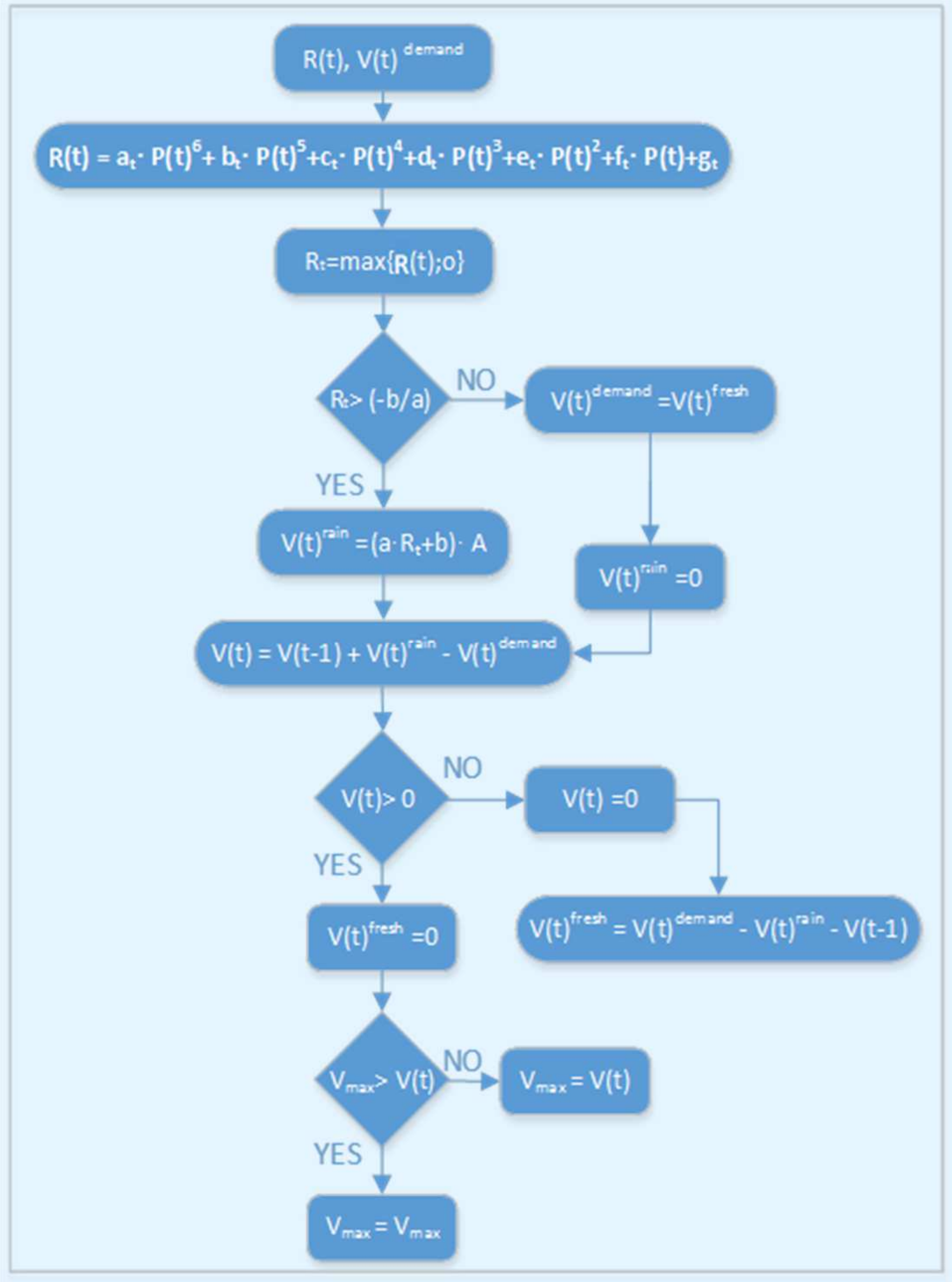
Main Algorithm for V_{max} calculation

Rain

Roof runoff

Mass balance

V_{max}



- Daily time-steps
- Random simulations
- 100 y

Model Input

- **Roof type:** Concrete, Steel-sheets, Tiles
- **Roof size:** 75, 100, 150, 200, 400 m^2
- **No. of residents:** 4, 8, 12, 24, 48, 64
- **Water demand:** 68 L/(c·d) (44% of in-house demand)

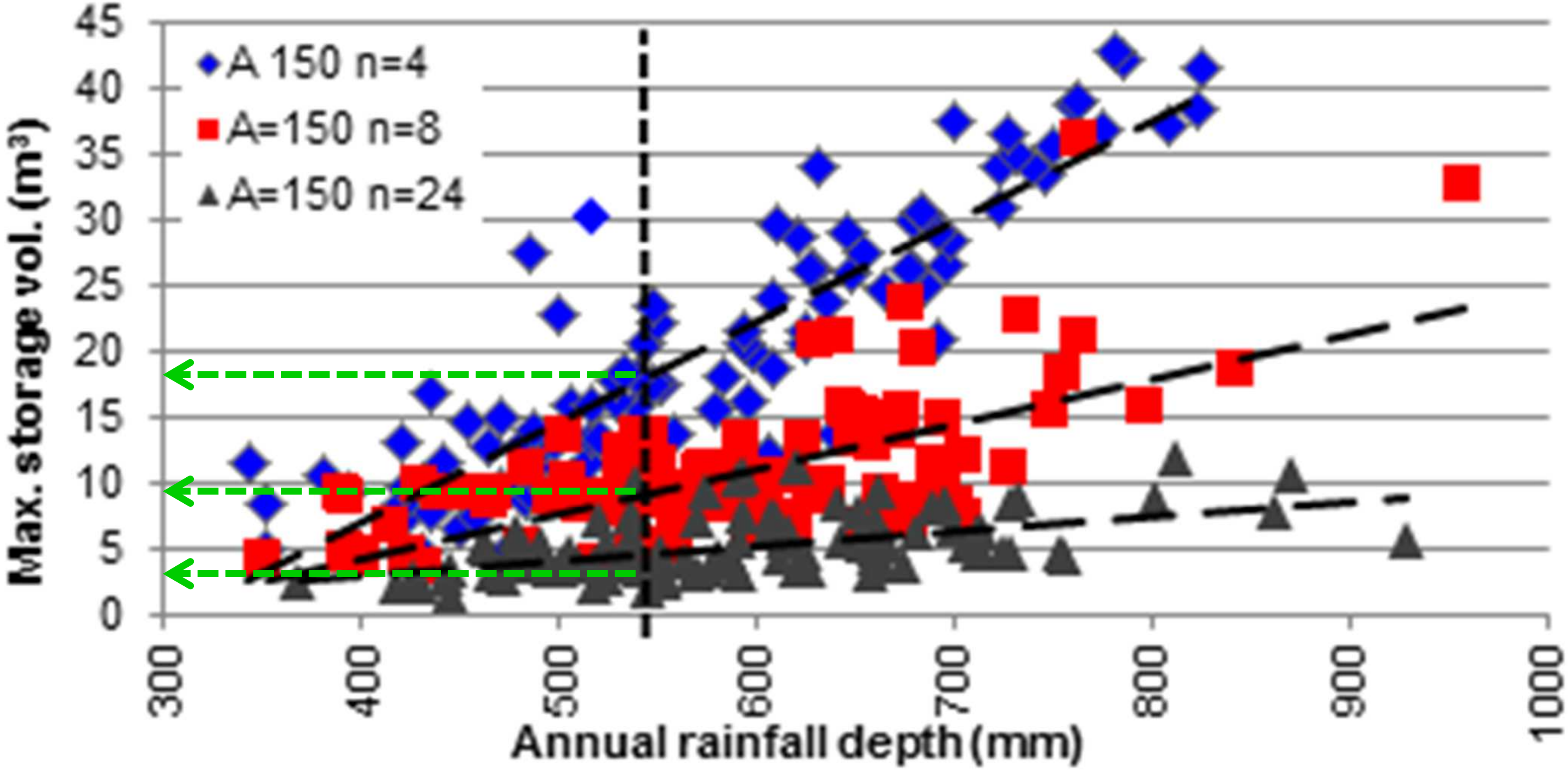
  WC 55 L/(c·d)

  WM 13 L/(c·d)

Roof type	a L/(mm·m^2)	b l/(m^2·d)	$R_{(y=0)}$ * mm	n**
Concrete	**0.78**	**-1.8**	**2.3**	47
Steel sheets	**0.80**	**-0.033**	**0.041**	45
Tiles	**0.91**	**-0.34**	**0.37**	36

$$d_{i(t)}^{runoff} = \mathrm{Max}\begin{Bmatrix} a_i \cdot \mathrm{R(t)} + b_i \\ 0 \end{Bmatrix}$$

Maximum storage tank volume



RUE = 100%

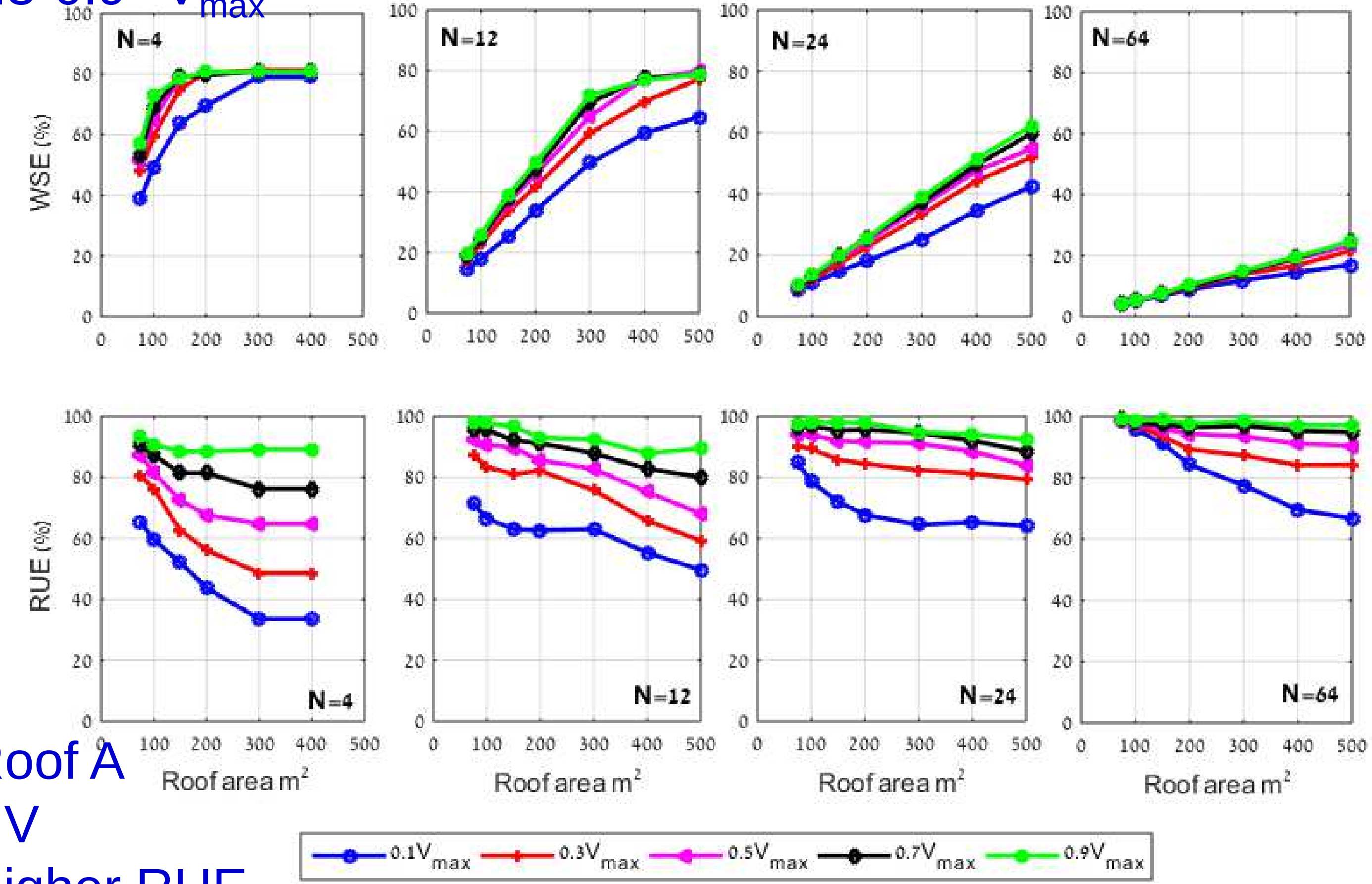
100 stochastic simulation runs

Stochastic modelling of the performance of an onsite rainwater harvesting system in Mediterranean climates – North Israel as a case study

H. Muklada[1], Y. Gilboa[1], E. Friedler[1]*

WSE

- Increases with roof A
- No sig. diff. $V = 0.3\text{-}0.9 \times V_{max}$
- More people
  Lower WSE



RUE

- Decreases with Roof A
- More sensitive to V
- More people → Higher RUE

Science of the Total Environment 407 (2009) 4490–4496

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journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

A preliminary coupled MT–GA model for the prediction of highway runoff quality

Tamar Opher, Eran Friedler *

Table 1
MT–GA attributes and coefficients (genes).

Attribute	Equation	Description	Gene
AADT	$\alpha_1 \cdot AADT$	Linear	α_1
ADP	$1-\exp(-\alpha_2 \cdot \mathrm{ADP})$	Saturation curve (Driscoll et al., 1990)	α_2
Rainfall	$\frac{\mathrm{Rainfall}}{\alpha_3} \cdot \exp\left(1-\frac{\mathrm{Rainfall}}{\alpha_3}\right)$	Early maximum then fading	α_3
Max. rain intensity	$\mathrm{MaxIntensity}^{\alpha_4}$	Power function (Yuan et al., 2001; Francey et al., 2004)	α_4
Ant. rainfall	$\mathrm{AntRain}^{-\alpha_5}$	Negative power function	α_5

Table 4
Models' selected attributes performance.

	AADT	ADP	Rainfall	Maximum intensity	Antecedent rainfall	R^2_{MT}	R^2_{MT-GA}
Cr_{Total}	▪	▪		▪	▪	0.17	0.33
Pb_{Total}	▪	▪	▪		▪	0.30	0.87
Zn_{Total}	▪	▪	▪			0.32	0.41
TOC		▪		▪	▪	0.05	0.69
TSS	▪	▪	▪			0.27	0.33

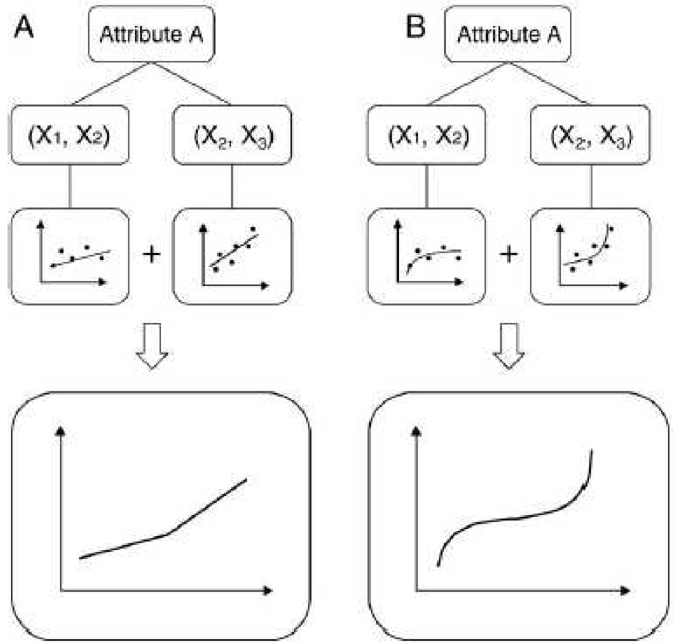

Fig. 1. Linear leaf nodes in an MT model (A) vs. non-linear leaf nodes of a coupled MT–GA model (B).

My current research

✓ **A multi-objective LCA-based model for sustainability assessment of urban water reuse alternatives of varying centralisation scales**

✓ ***Impacts of onsite greywater reuse on urban wastewater systems***

✓ **Personal care products (PCPs) as source for micropollutants in Greywater – Identification, quantification and on-site treatment (biological + UV-AOP)**

✓ ***Urban stormwater harvesting & reuse***

✓ ***Atmospheric moisture harvesting***

Collaboration Welcomed

Thank you for

your attention

Special thanks to my Collaborators, Students

… and Funders

Website: **http://www.technion.ac.il/~civil/friedler/**

Email: **eranf@technion.ac.il**

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