



Wastewater Reclamation/Reuse: Exploiting An Impaired-Quality (Unconventional) Water Resource

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Organization

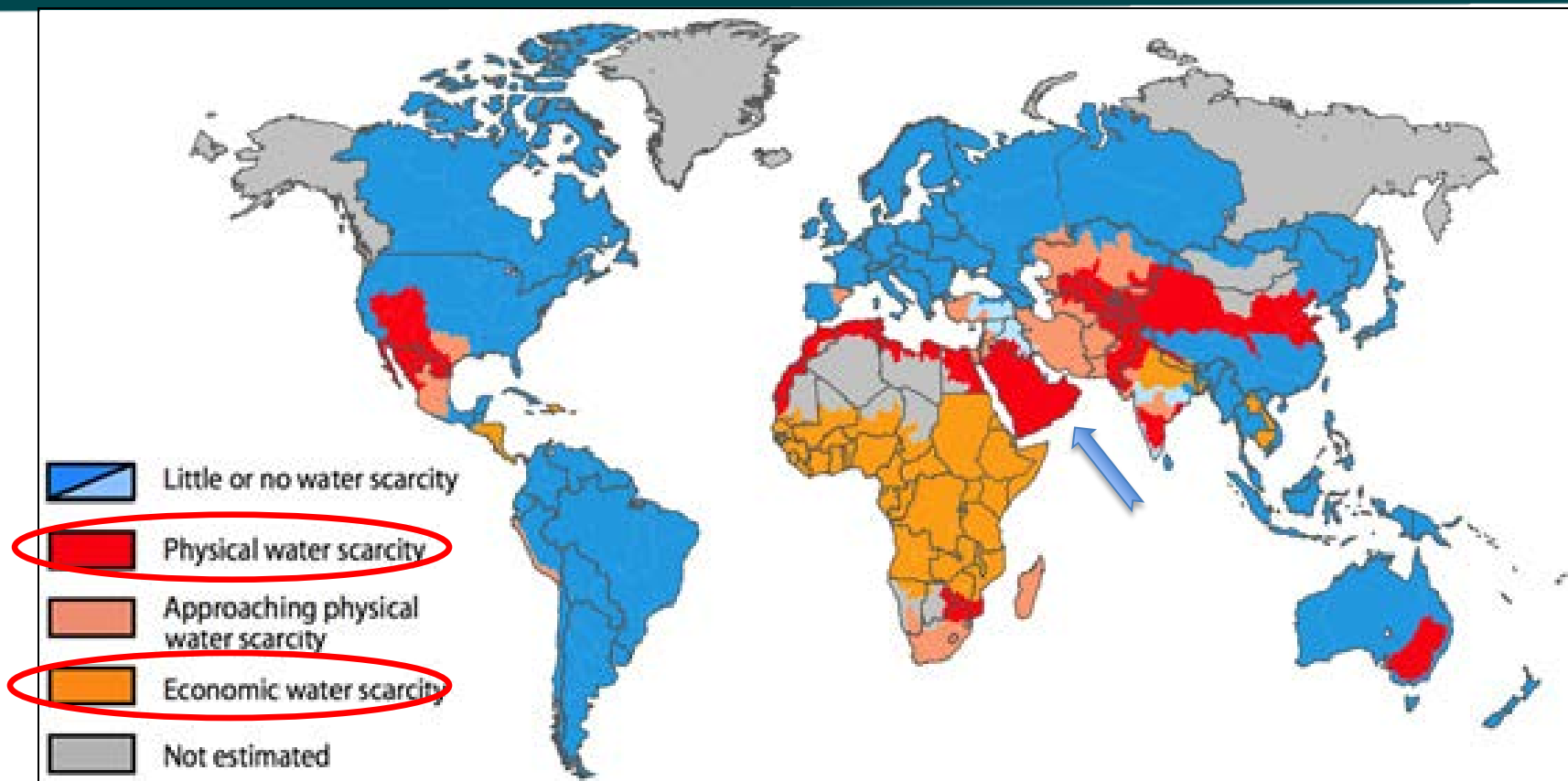
Part I: Water Reuse Practice and Water Quality Issues

Part II: Water Reuse Treatment Technologies



Part I: Water Reuse Practice and Water Quality Issues

Global Water Scarcity

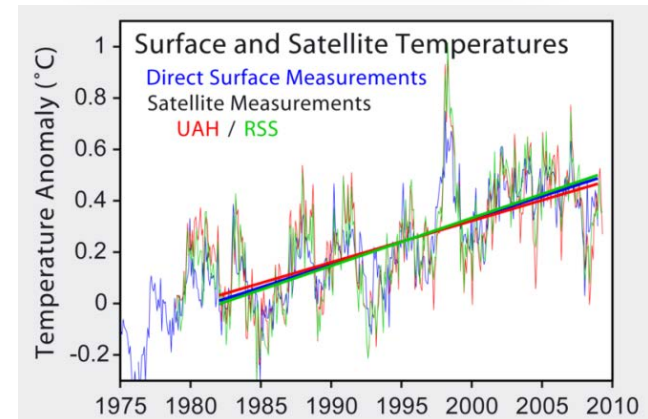


- GCC/MENA ⇒ one of the driest regions with **water scarcity** in the World
- Some countries have taken bold steps toward water resources/reuse
- **King Abdullah** has declared **water security** as equivalent to **national security**

Drivers for Changes in Water Availability (Owen, 2011)



- Urbanization
 - Increased Water Demand
 - Peri-Urban Growth
- Demographics
 - Population Shifts
 - Agricultural → Urban Water Needs
 - Improved Quality of Life
- Climate Change
 - Water Scarcity
 - Water Quality and Temperature



Water Scarcity $\Rightarrow$ Urbanization as a Driver (Reiter, 2008)

1950

World Cities exceeding
5 million residents

2000

World Cities exceeding
5 million residents

2015

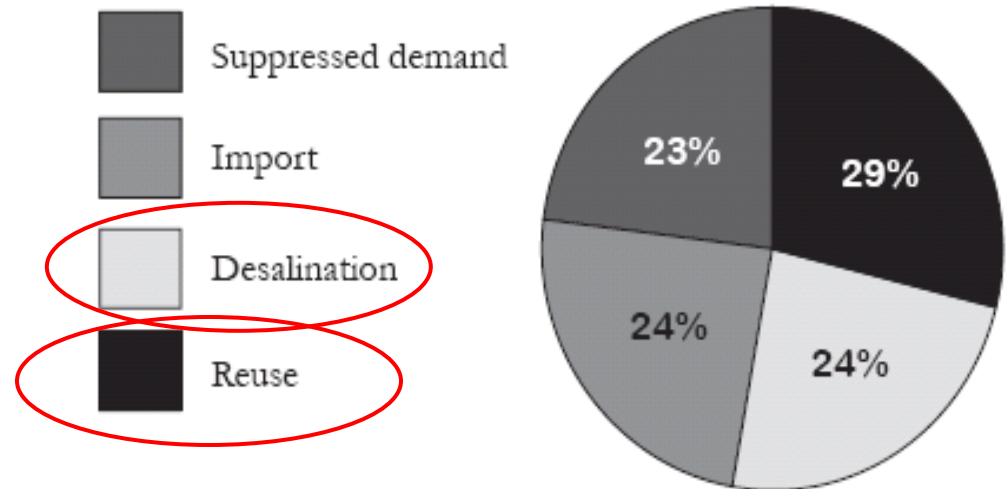
World Cities exceeding
5 million residents

- Urban Areas
Plus Peri-Urban Areas
(in Developing Countries)
- Almost 50 % of Global Population
within 100 km of an Ocean
(Role of Desalination)

Alternative Water Sources to Address Water Scarcity (Hoek, 2006)

- ◆ Water Transfers
- ◆ Dams / Diversion
- ◆ Conservation
- ◆ Reuse
- ◆ Desalination

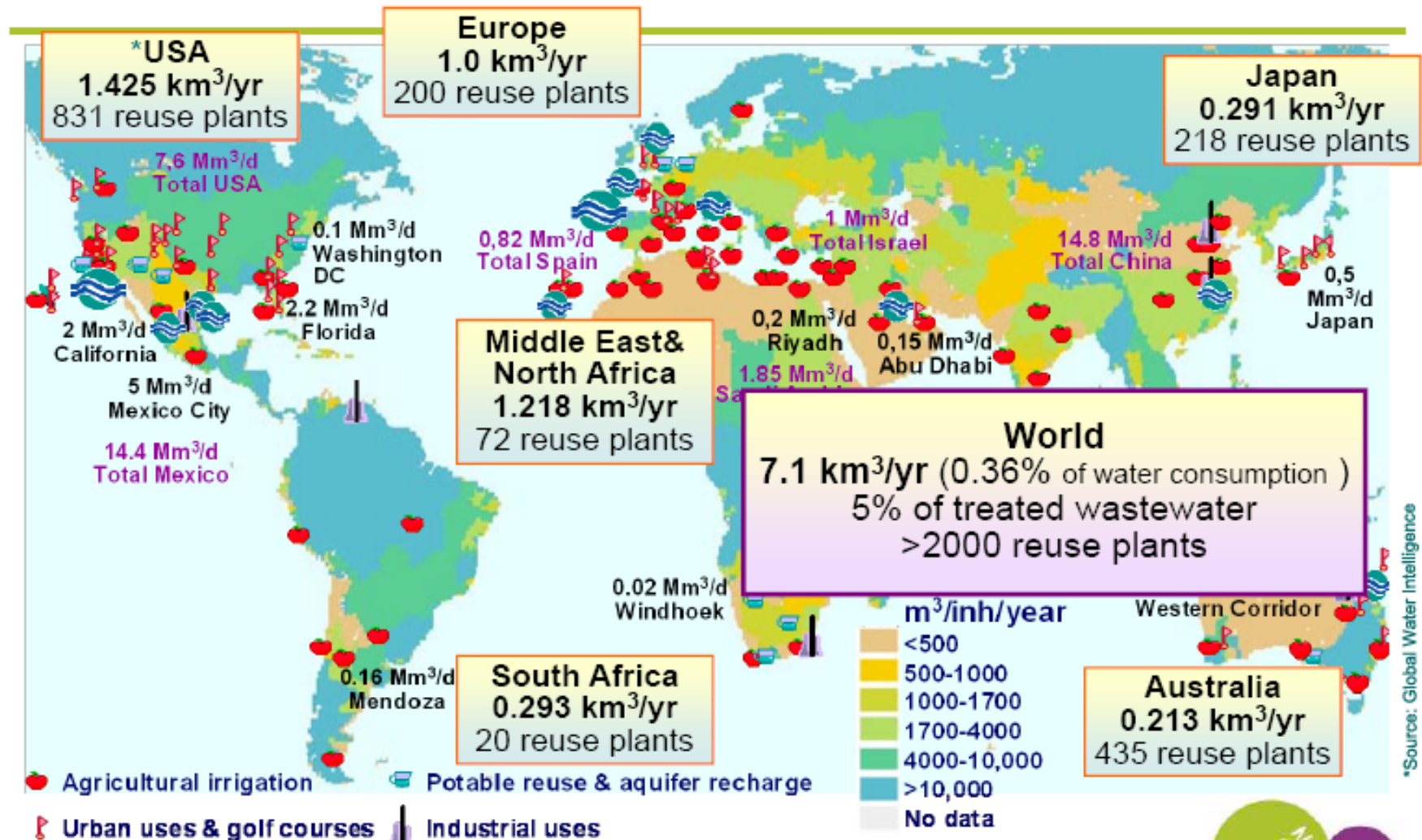
Reuse as proportion of total additional non-traditional water supply capacity (2005-2015)



- Most countries have first exploited water reuse (e.g., EU and USA)
⇒ more favorable economics
- In GCC/MENA, the opposite approach

Global Trends of Water Reuse

(Gislette, 2008)



Annual Water Consumption - KSA

2009



6%

Less Energy Intensive
Desalination



14%

Renewable water:
 $2.7 \times 10^9 \text{ m}^3/\text{yr.}$
(i.e., groundwater/surface water)



80%

Preserve Non-
Renewable
resources for future
generation by promoting
water Reuse

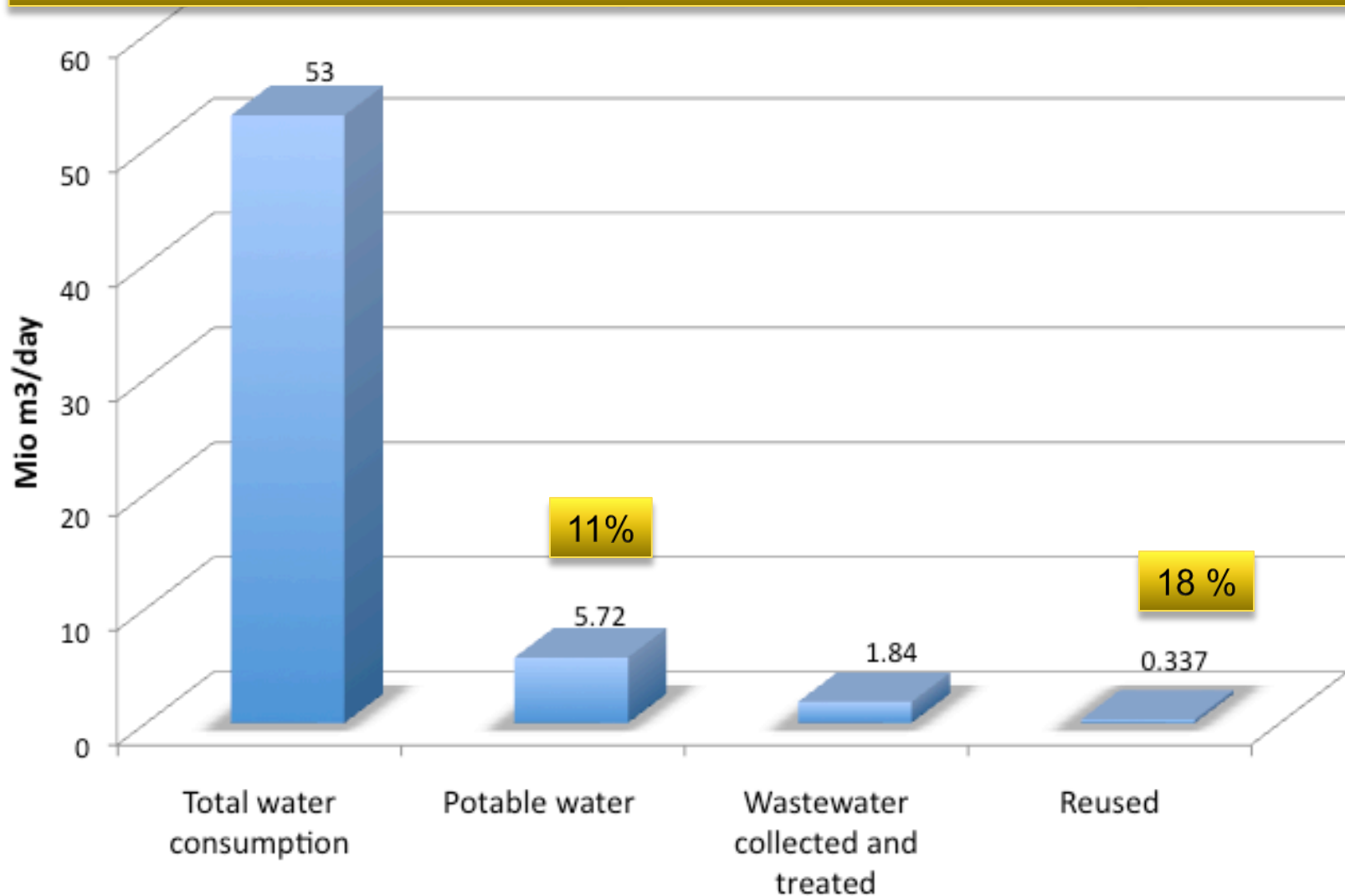
Total Water Annual Consumption: $19.2 \times 10^9 \text{ m}^3/\text{yr}$

(Al-Saud, 2010)

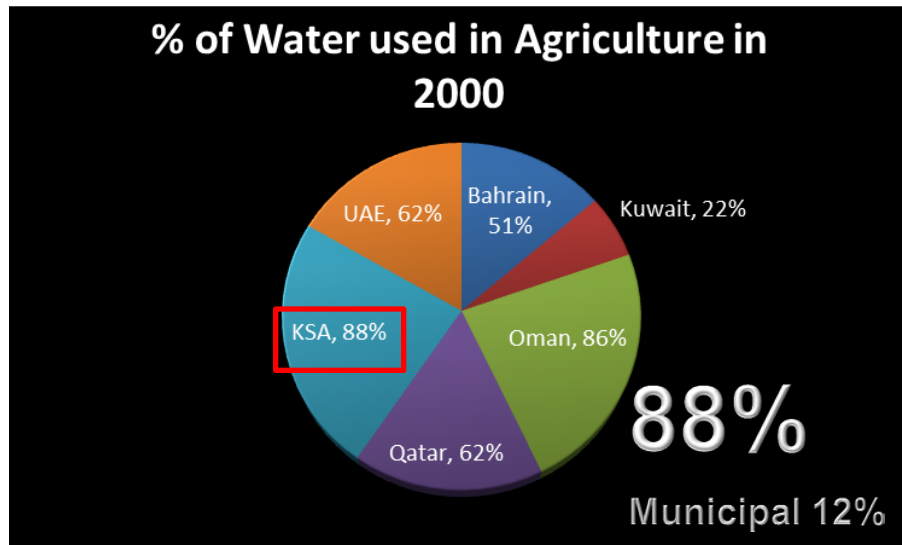
Current practice is not sustainable, require better management/technologies

KSA Annual Water Consumption

Total Water Annual Consumption 2009: $19.2 \times 10^9 \text{ m}^3/\text{yr} = 600 \text{ m}^3/\text{s}$

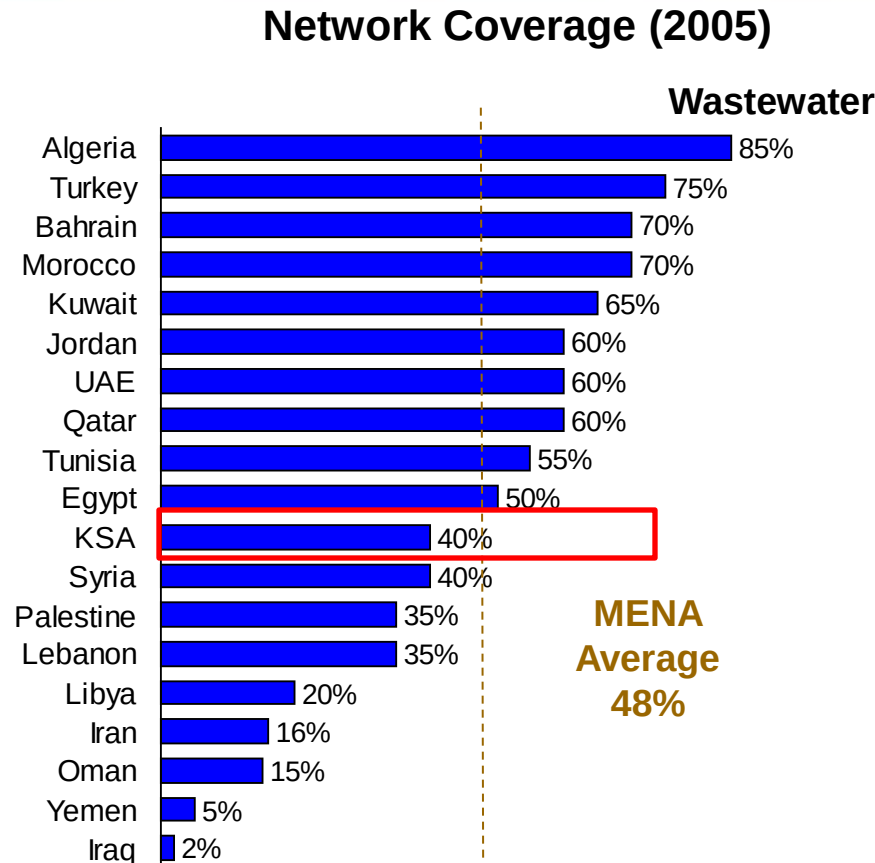


Water Usage in GCC Region



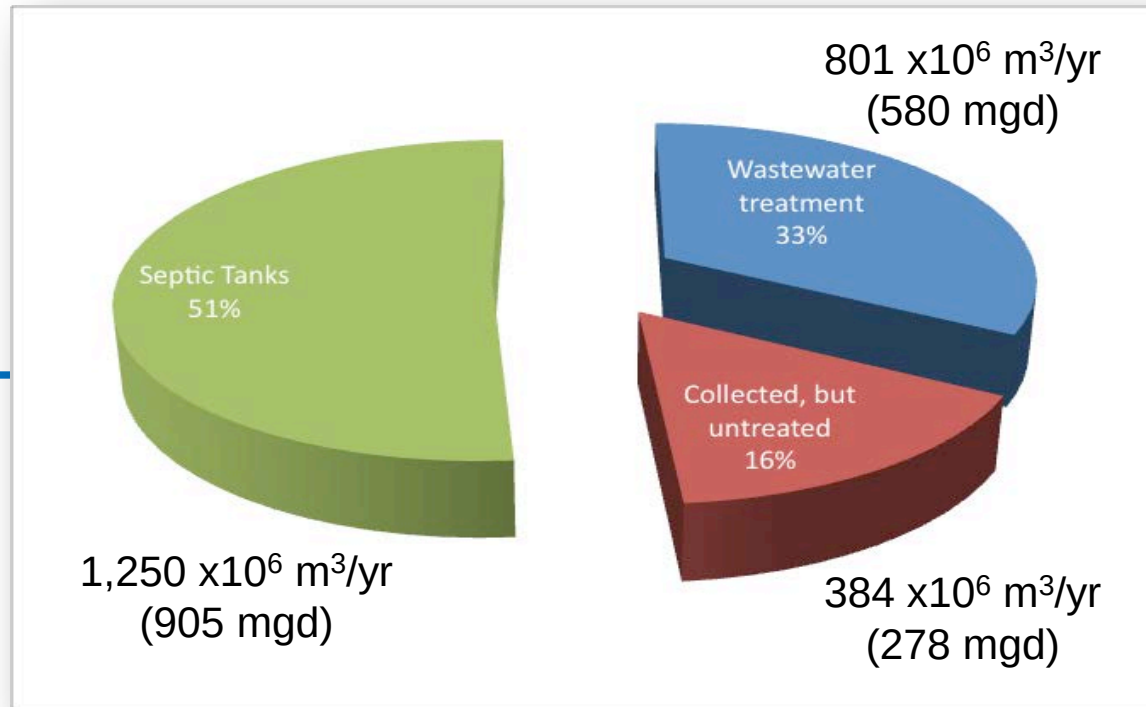
- Large portion of water is used for agriculture, small fraction for drinking – a practice which require (policy) changes
- Some governments in GCC, including KSA, have taken initiatives to reduce agriculture water usage to reduce withdrawal

Wastewater Services Coverage



- Wastewater (sewerage) coverage, especially for KSA is limited

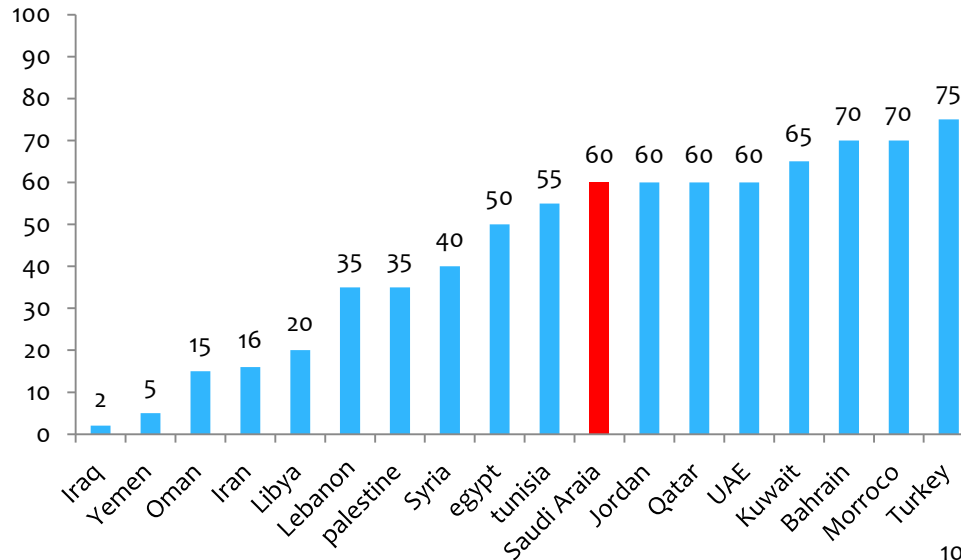
Wastewater Generation (KSA)



WWTP

- **About 51% of WW goes to septic/cesspool tanks-** not available for reuse
- **About 16% wastewater collected,** but not treated (wasted)
- **33% of WW collected is treated** at the WWTP (only **40% is reused**)
- Thus, **large portion (77%)** of the wastewater is not available; however, this portion (1.7×10^9 m³/year, large potential) could be available **for reuse**

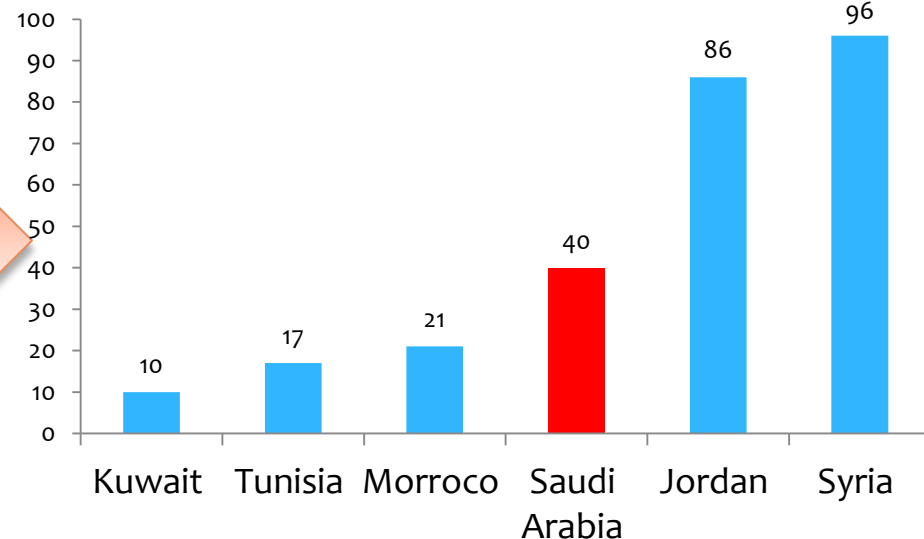
Wastewater Reuse in Arab and MENA Regions (Abderrahman, 2014)



**Sewerage coverage -
MENA Region**

Source : GWI -2013 and personal
contacts

**Treated Effluent
Reuse
(% of treated volume)**

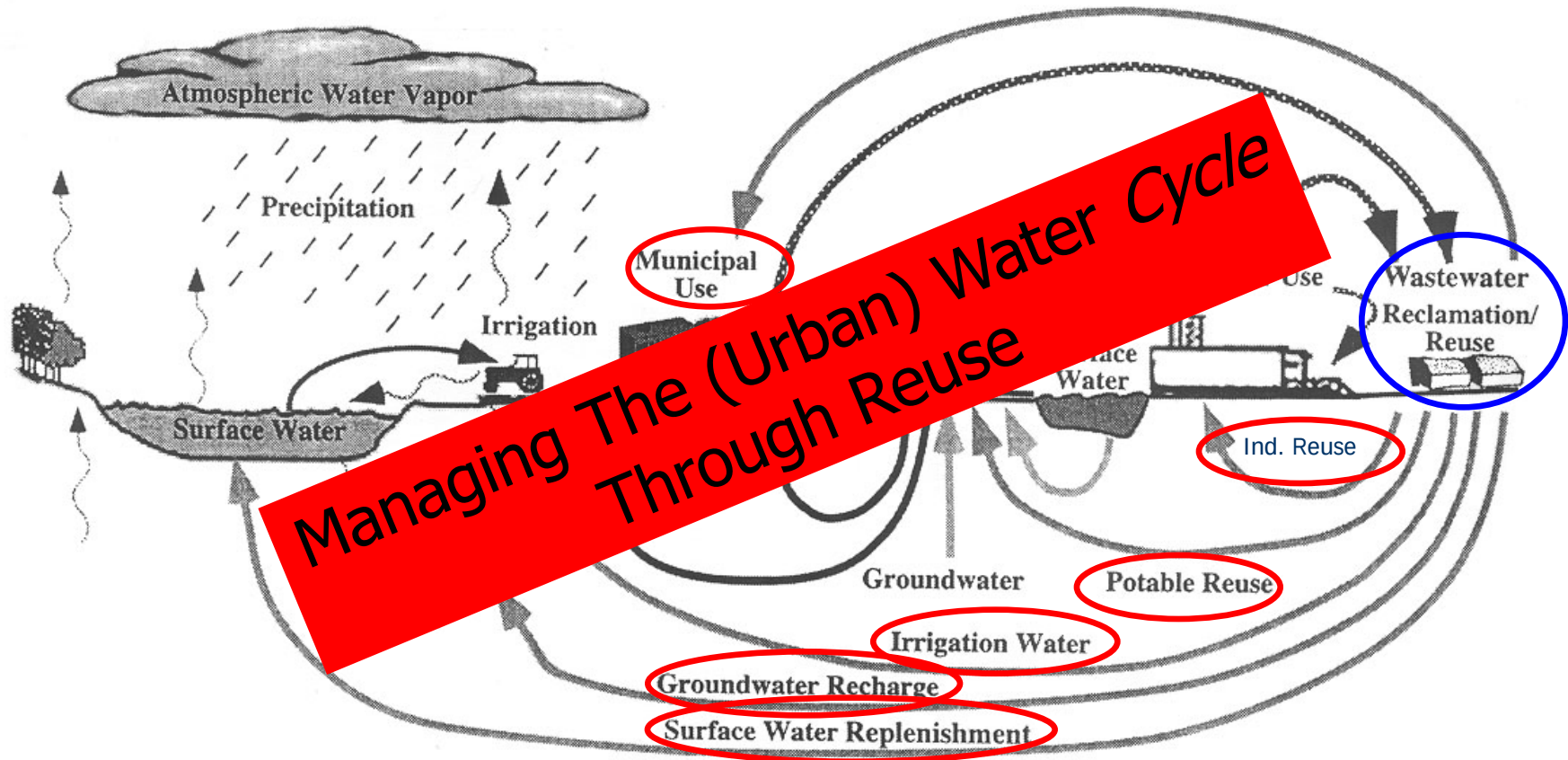


Some Basic Facts (Miller, 2008)



- All Water is Reused (no virgin water)
- Widespread *Unplanned/Unintended* Potable Reuse Along Major Rivers (Mississippi, Rhine, Seine, etc.)
- Drinking Water is a Manufactured Product
- Purity of Water Should Be Matched to its Intended (Re)Use
- In *Planned/Intended* (Potable) Reuse, Emulate Mother Nature with Technology (do it better and faster)
- Integrated Management of Urban Water Cycle
⇒ Target Potable (Highest) Quality
- Water Reuse is “Green” and “Eco-Friendly”

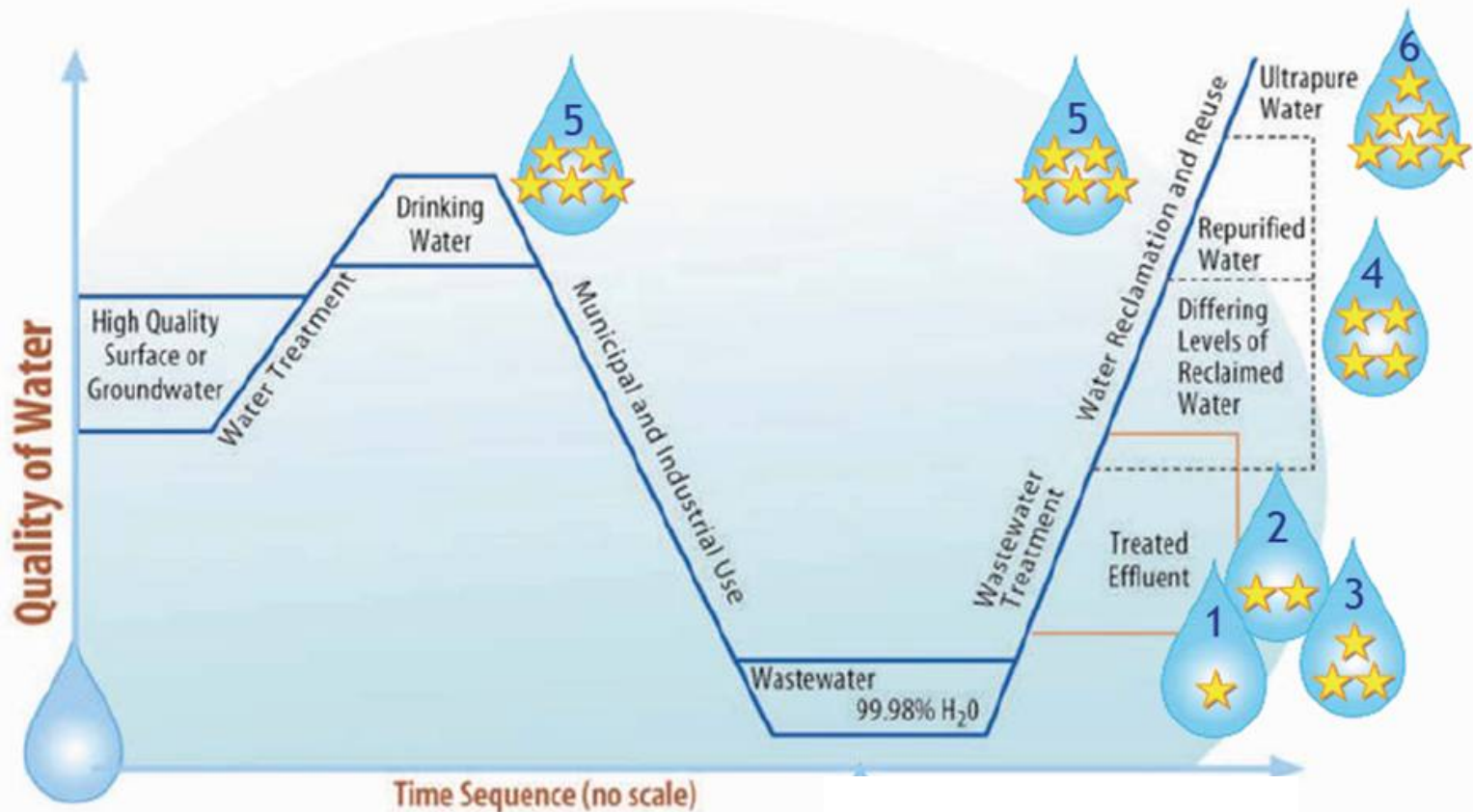
Role of Engineered Treatment, Reclamation, and Reuse Facilities in Cycling of Water through Hydrologic Cycle (Asano, 1998)



Water Quality as a Driver (Asano, 2006)

Understanding water quality determines how water can be safely used!

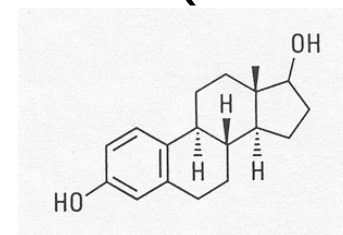
Singapore:
NeWater



Wastewater Effluent as a Water Resource



- Urban Hydrologic Cycle Perspective:
 - $Q_{WW} \approx 2/3 Q_{DW}$; Δ = Consumptive Use(s)
 - $\Delta TDS = 100 - 300 \text{ mg/L}$ (Salt Pick-Up)
 - $\Delta TOC = 5 - 10 \text{ mg/L}$ (Organic Matter Pick-Up)
- Wastewater Contaminants Constraining Reuse:
 - Effluent-Derived Trace Organic Compounds (TOrCs)
 - Microbials:
Indicator Organisms
and Pathogens (Viruses)
 - Nitrogen Species (Nitrate (NO_3^-), Ammonia (NH_3))



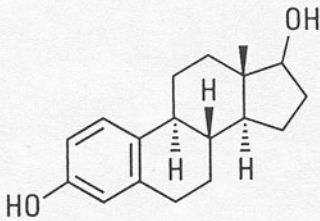
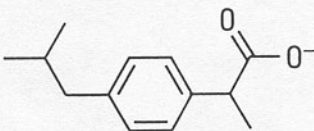
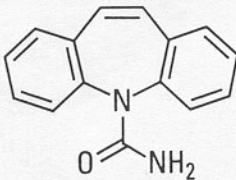
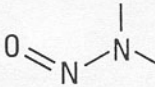
Unregulated Organic Micropollutants



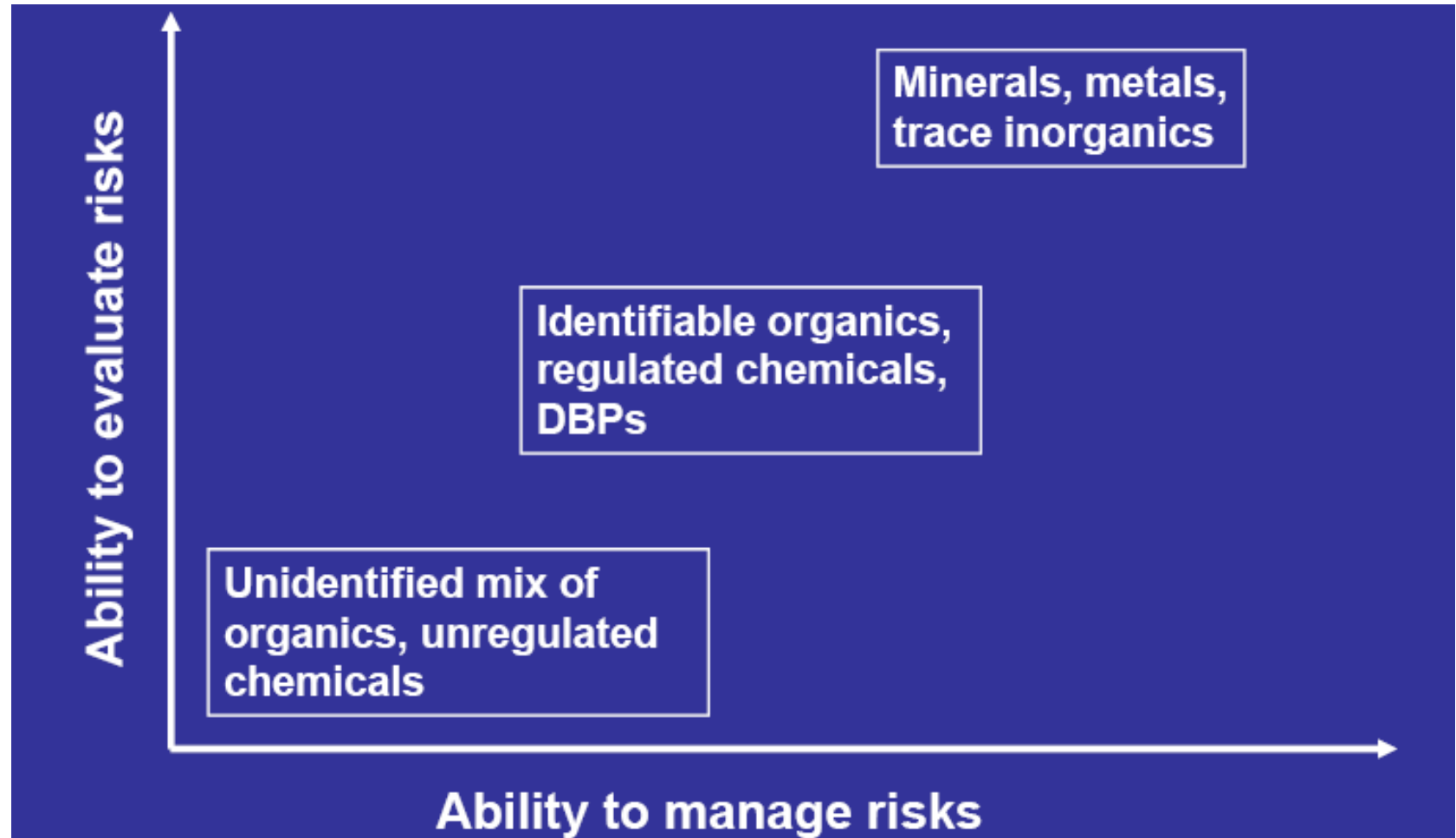
- Emerging disinfection by-products (e.g., NDMA)
- Endocrine disrupting compounds (EDCs)
 - Steroidal hormones (e.g., estrone, testosterone)
 - Industrial chemicals (e.g., Nonylphenol, Bisphenol A)
- Pharmaceutical active compounds (PhACs)
and personal care products (PCPs)
 - analgesics, antiepileptics, lipid regulators, antibiotics
 - flame retardants

Examples of Effluent-Derived Microcontaminants (Sedlak, 2000)



Compound	Structure	Log K_{ow}	Typical wastewater effluent concentration (ng/L)
17 β -estradiol		4.4	1.9 ^a
Ibuprofen		-0.4	370 ^b
Carbamazepine		2.5	2100 ^b
N-Nitrosodimethylamine		-0.6	200–1000 ^c

Chemical Constituents (Crook, 2008)

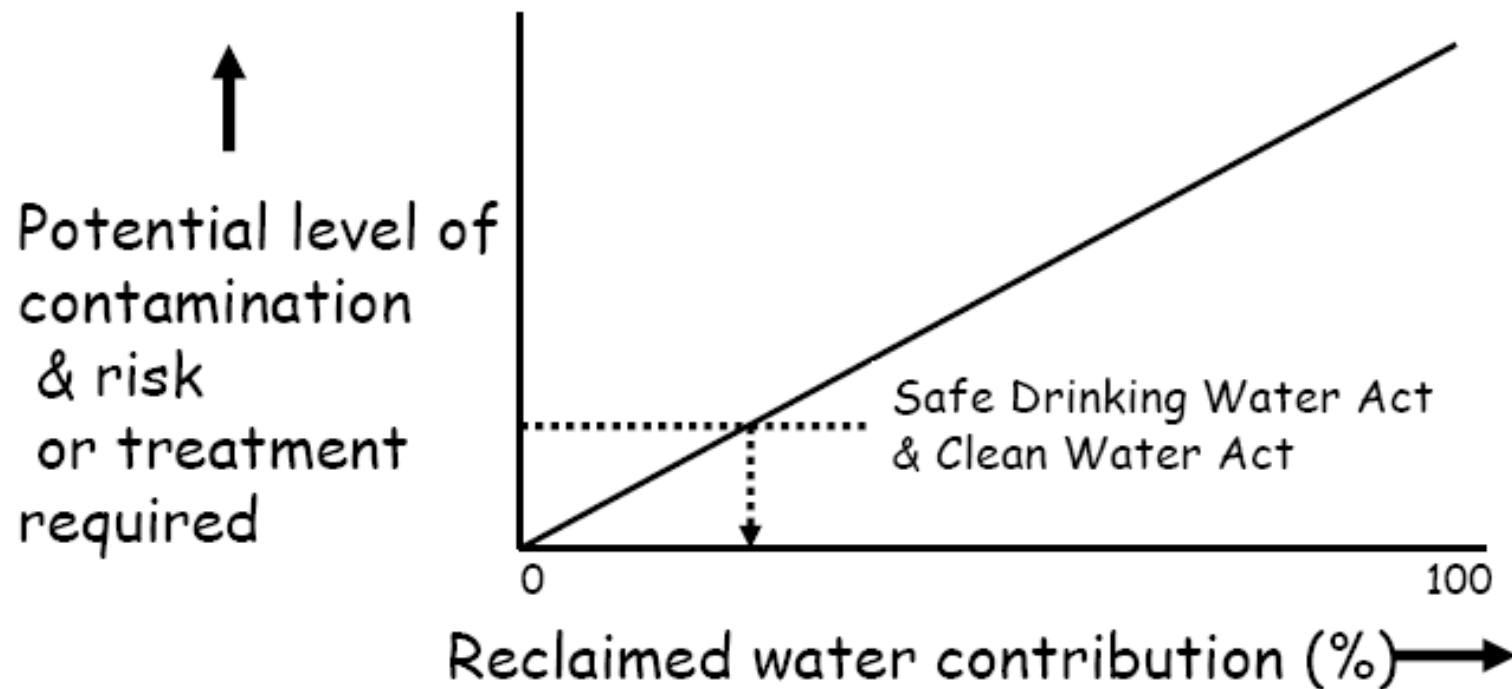




Pathogen Occurrence in WW

- Influential Factors
 - Source and Use of Water
 - General Health of Population
- Untreated Wastewater
 - Typical Pathogenic Bacteria Density: > 10 – 100 CFU/100 mL
 - Viruses: >1000 PFU/100 L
 - Protozoa: > 10/100 L
- Primary and Secondary Effluent/Treatment Efficiencies
 - Up to 2-log “Removal” vs. Inactivation
- Survival/Die-Off in Natural Waters
 - Temperature Effects
 - UV in Surface Waters
 - Aquifer Media Filtration

Degrees of Potable Reuse (Hultquist, 2008)



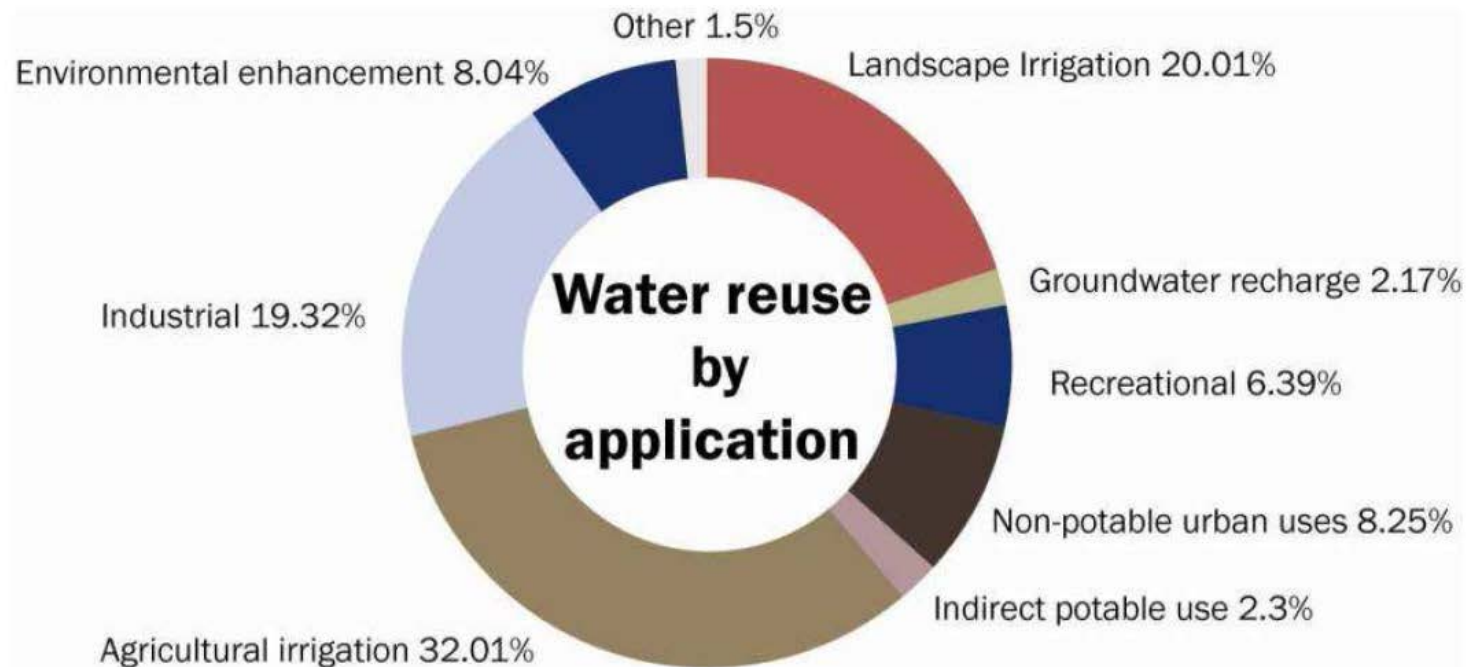
Categories of Reuse



- Definition Of Reclamation: Treatment for Reuse
- Planned/Intentional vs. Unplanned/Unintentional Reuse (e.g., Effluent-Dominated Rivers or Lakes)
- Non-Potable Reuses:
 - Agricultural Irrigation
 - Crops Intended for Human Consumption (raw versus cooked)
 - Animal Crops (fodder)
 - Urban (Landscape and Golf Course) Irrigation
 - Industrial Cooling and Process Water
 - Groundwater Recharge or Injection
- Potable vs. Non-Potable Reuse
 - Direct (Pipe-to-Pipe) Potable Reuse
 - Indirect (e.g., Groundwater or Reservoir) Potable Reuse



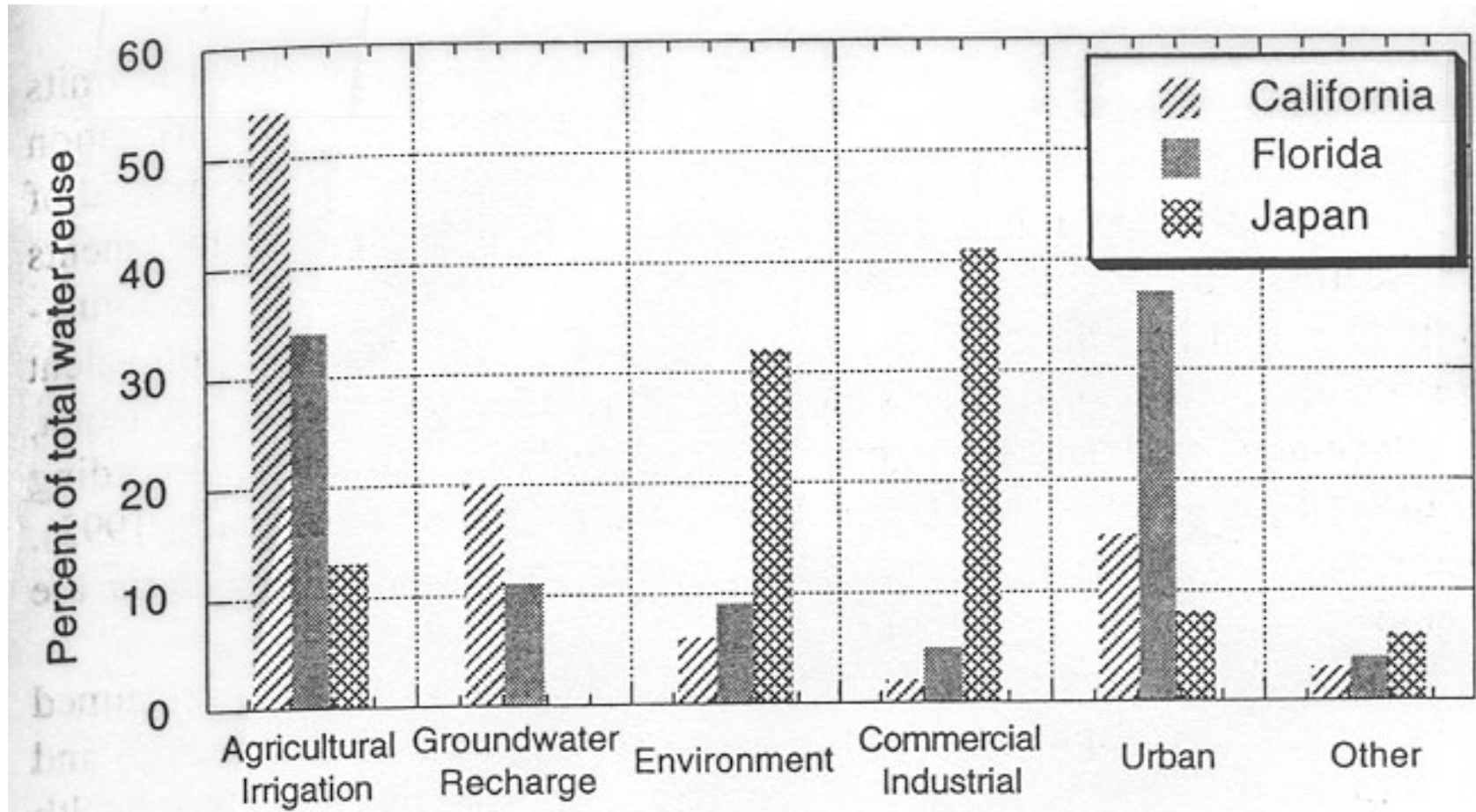
Water Reuse Applications (globally)



Source: GWI, 2010

- Agriculture, Landscape and industry are the major areas where most of the reuse water is used

Reclaimed Wastewater Applications in California, Florida, and Japan (Asano, 1998)



Constraints on Categories of Reuse



- ❑ Agricultural Reuse $\Rightarrow$ *Constrained by location, seasonality, need for transport system, need for winter storage*



- ❑ Industrial Reuse $\Rightarrow$ *Constrained by location, varying quality requirements, need for dual distribution system and storage*



- ❑ Landscape Irrigation $\Rightarrow$ *Constrained by dispersed nature of demand, need for dual (purple pipe) distribution system*



- ❑ Groundwater Recharge $\Rightarrow$ *Intent may vary (e.g., controlling salt water intrusion in coastal aquifers) but represents a salient feature of indirect potable reuse*

Urban Agriculture



- **Greenhouses:** Agriculture in urban setting, can provide safer, higher quality, and more environmentally friendly produces
- **Water Saving Technology:** Water saving technologies can reduce stress on limited water resources
- **Hydroponics:** Soil-less technology, is adaptable to urban farming to increase yield of year-round. Uses 10 - 20 times **less land** and 10 times **less water** than conventional agriculture



Direct Potable Reuse (McEwen, 1998)



City A
Water
Reclamation
Plant



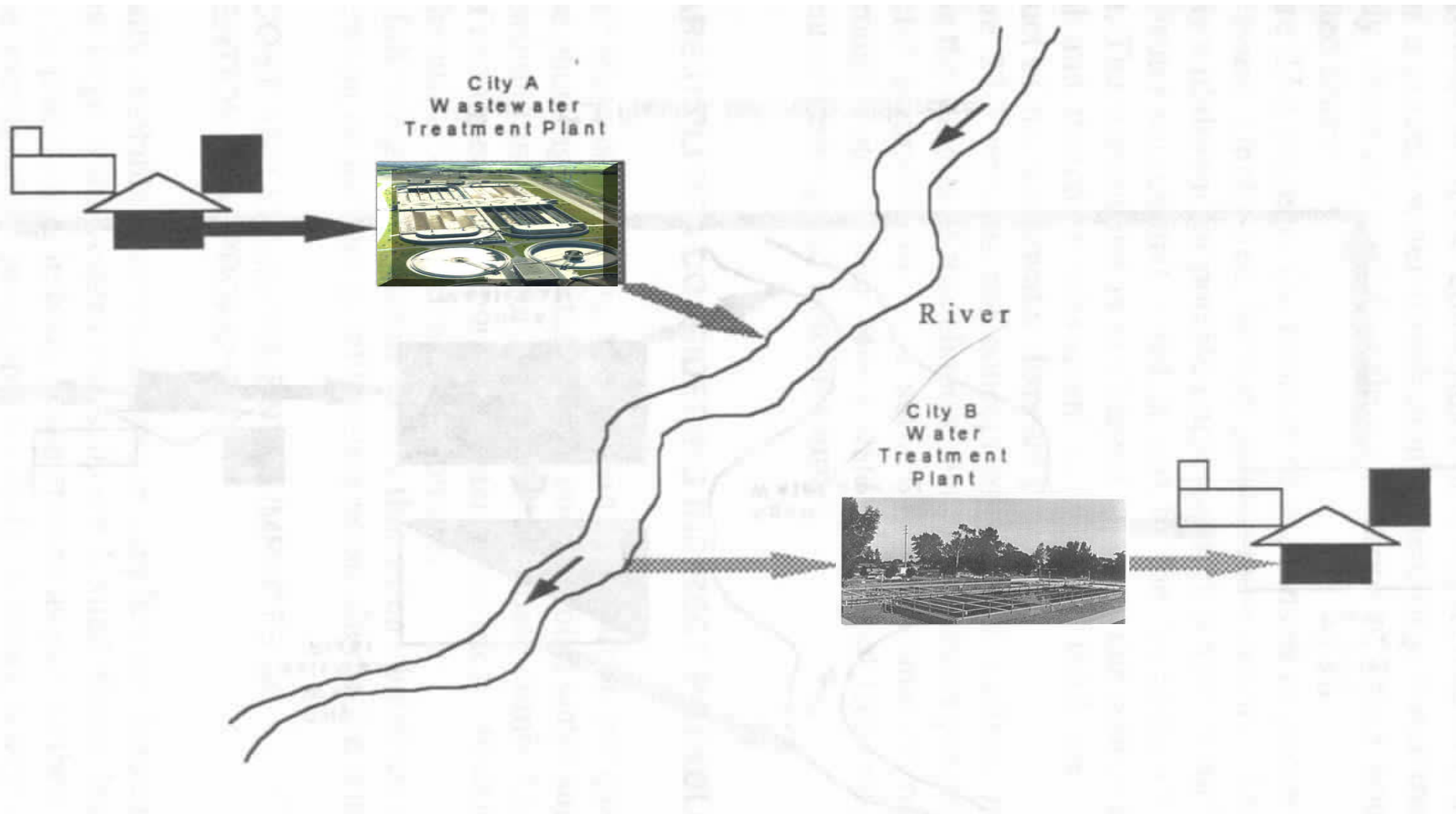
City A
Wastewater
Treatment
Plant

Aquifer or Surface
Water Source

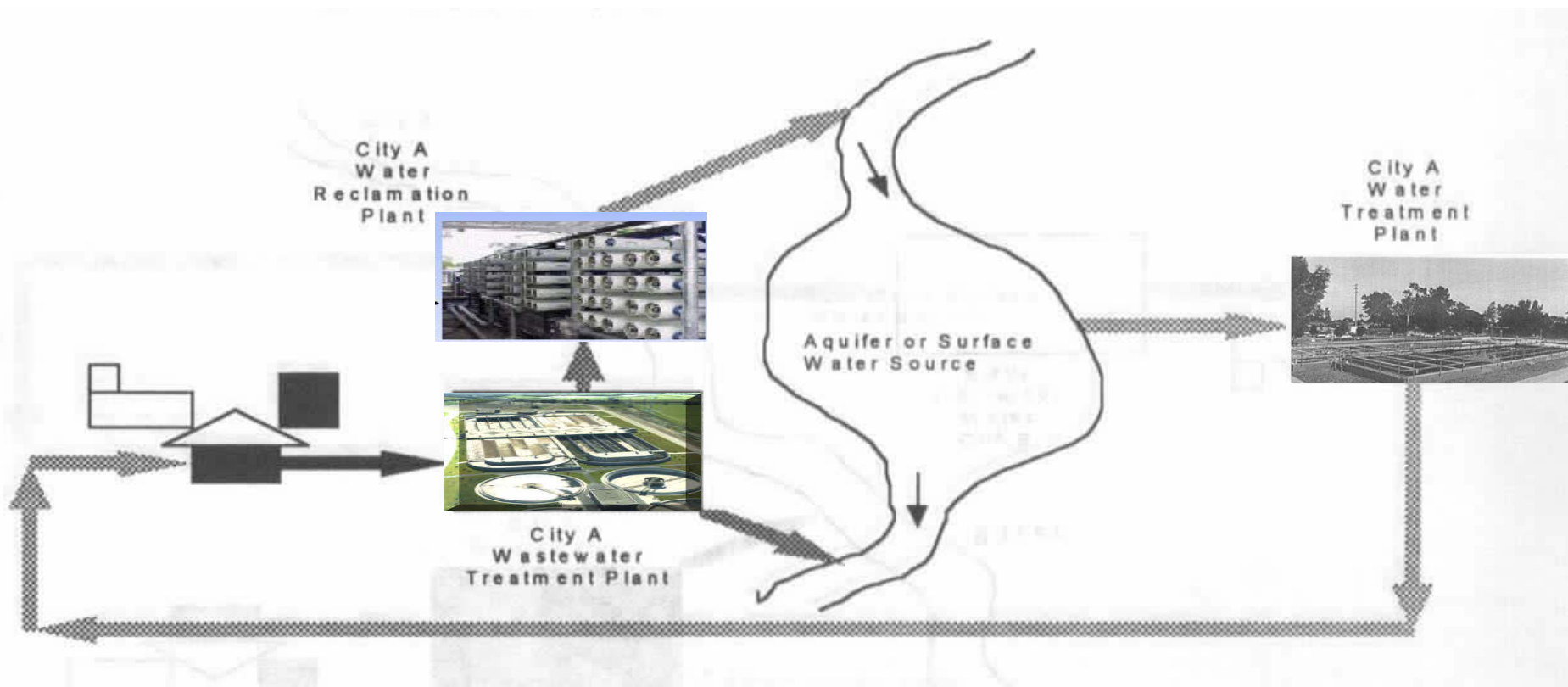
City A
Water
Treatment
Plant



Unplanned, Indirect Potable Reuse (McEwen, 1998)



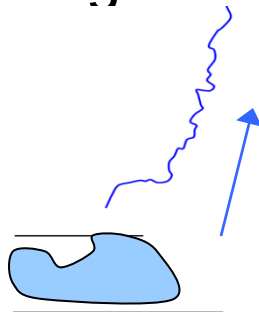
Planned, Indirect Potable Reuse (McEwen, 1998)



The Present Perspective



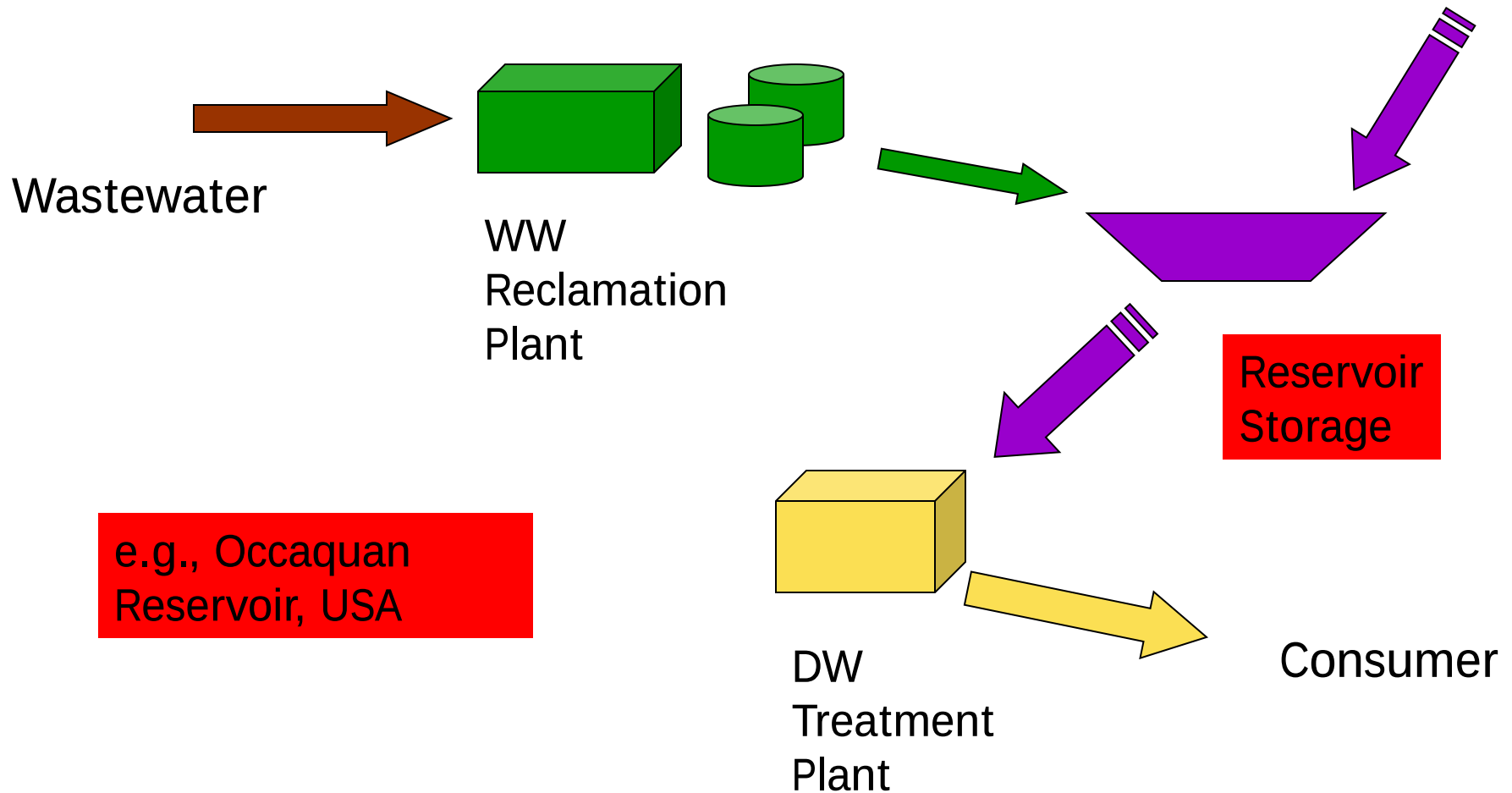
- Assess/Exploit Opportunities for Non-Potable Reuse First ✓
- Intentional/Planned Indirect Potable Reuse
- Augmentation of Existing Water Supply
 - Indirect via Infiltration/Injection into Aquifer
 - Storage Reservoir
 - Withdrawn as Mixture of Reclaimed Water and Raw Water Supply
 - Water Treatment of Mixture
- Two Dozen Cities in USA (population: 25,000 – 2,000,000);
Effluent-Dominated River/Stream:
> 50 % Effluent during Low Flow



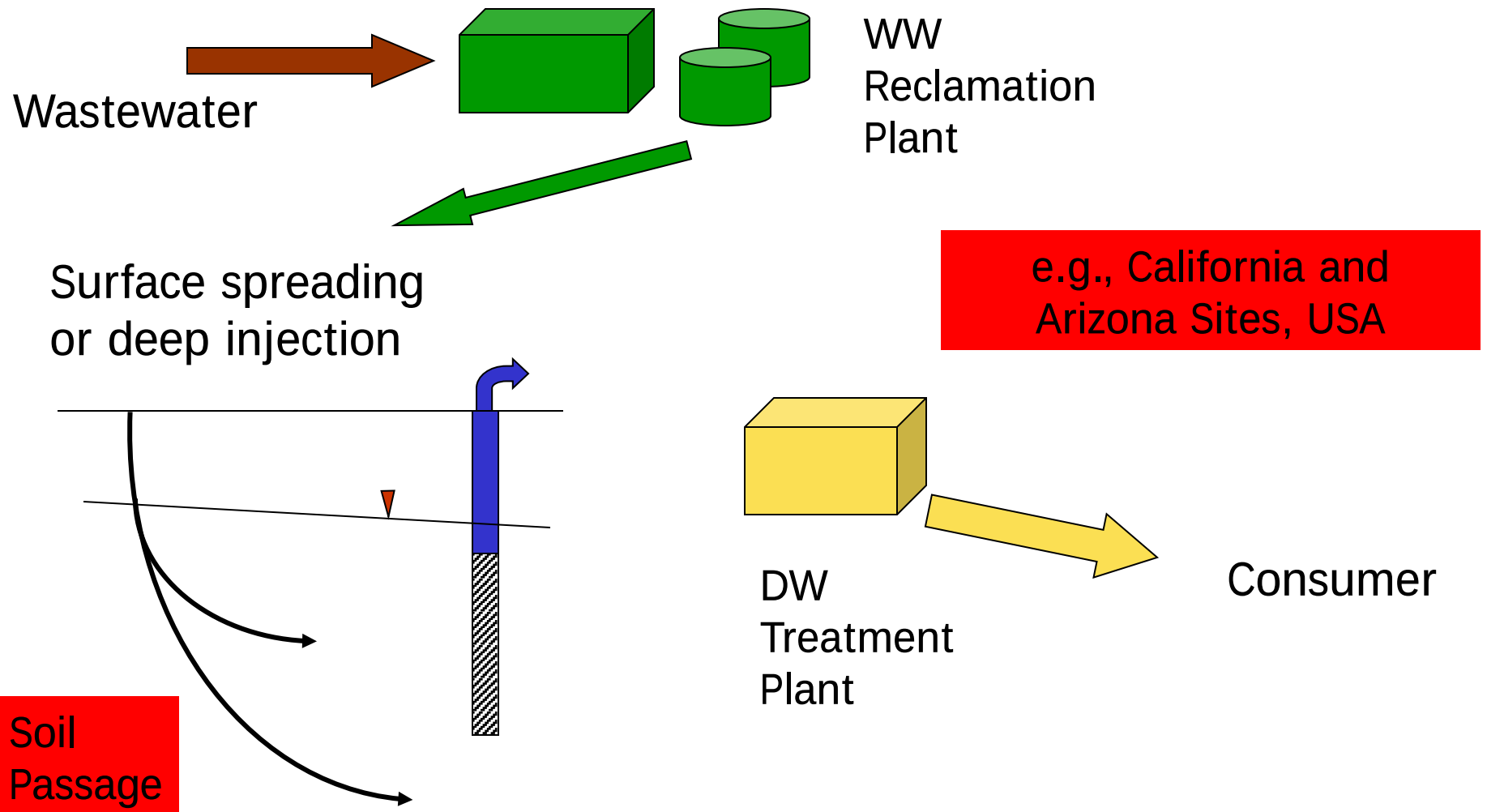
South Platte River: A WW Effluent Dominated River in North America!



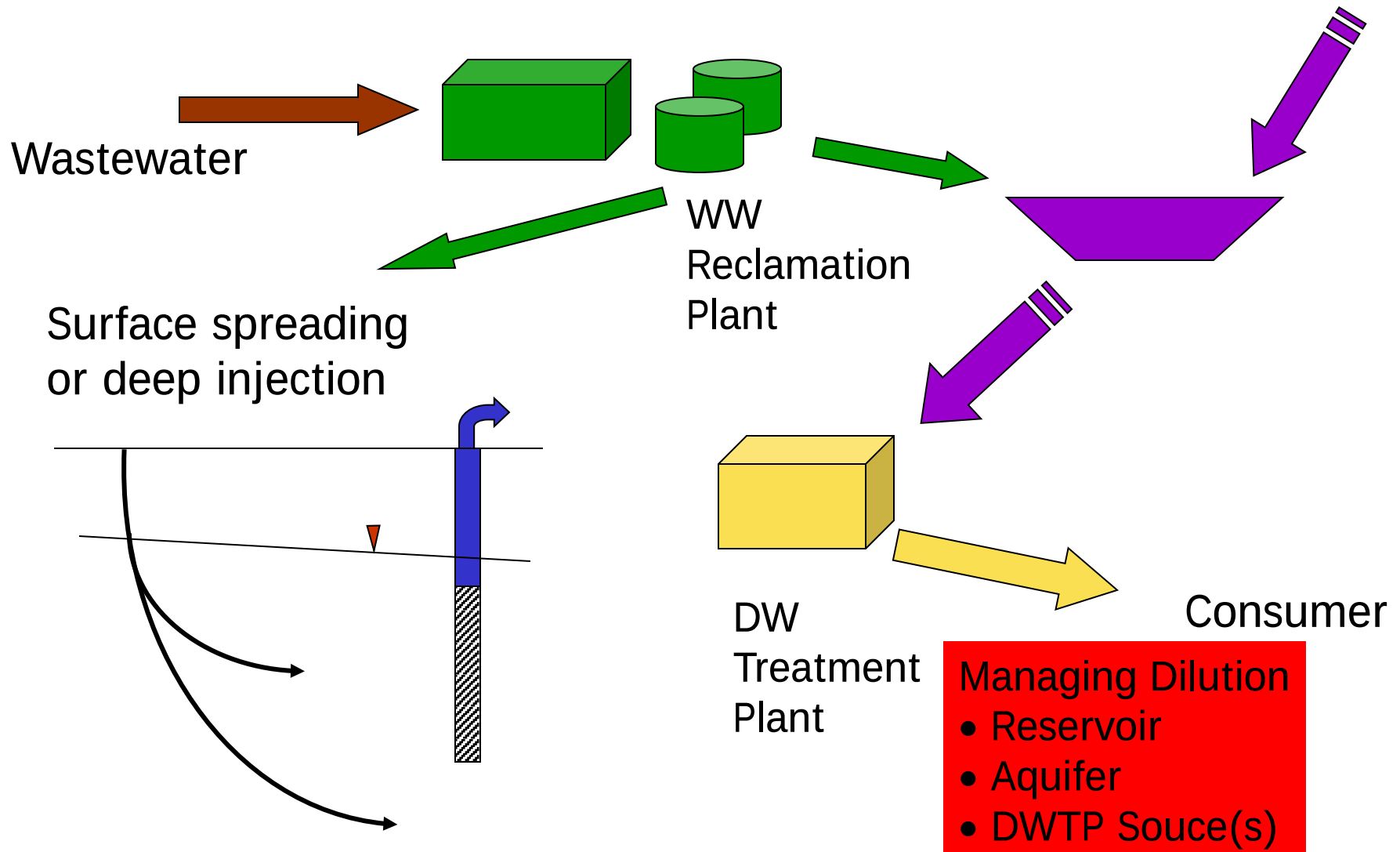
Indirect Potable Reuse



Indirect Potable Reuse



Indirect Potable Reuse



Environmental “Buffers”

- Inherent Component of Indirect Reuse
- Aquifer or Reservoir as Environmental “Buffer”
- Short-Circuiting?
- Retention Time (e.g., 6 – 12 months; Die-Off of Viruses)
- % Reclaimed Water
- Water Treatment of Mixture (minimal treatment for GW)
- (Above Ground) Treatment vs. Dilution;
- “Buffer” Treatment (Adsorption, Biodegradation✓)



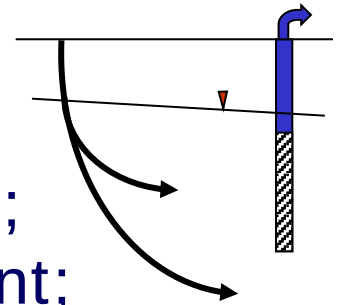
Groundwater Recharge

■ Applications:

- Replenishment of Over-Drafted Groundwater Basins
- Barrier Against Salt Water Intrusion
- Storage vs. Treatment

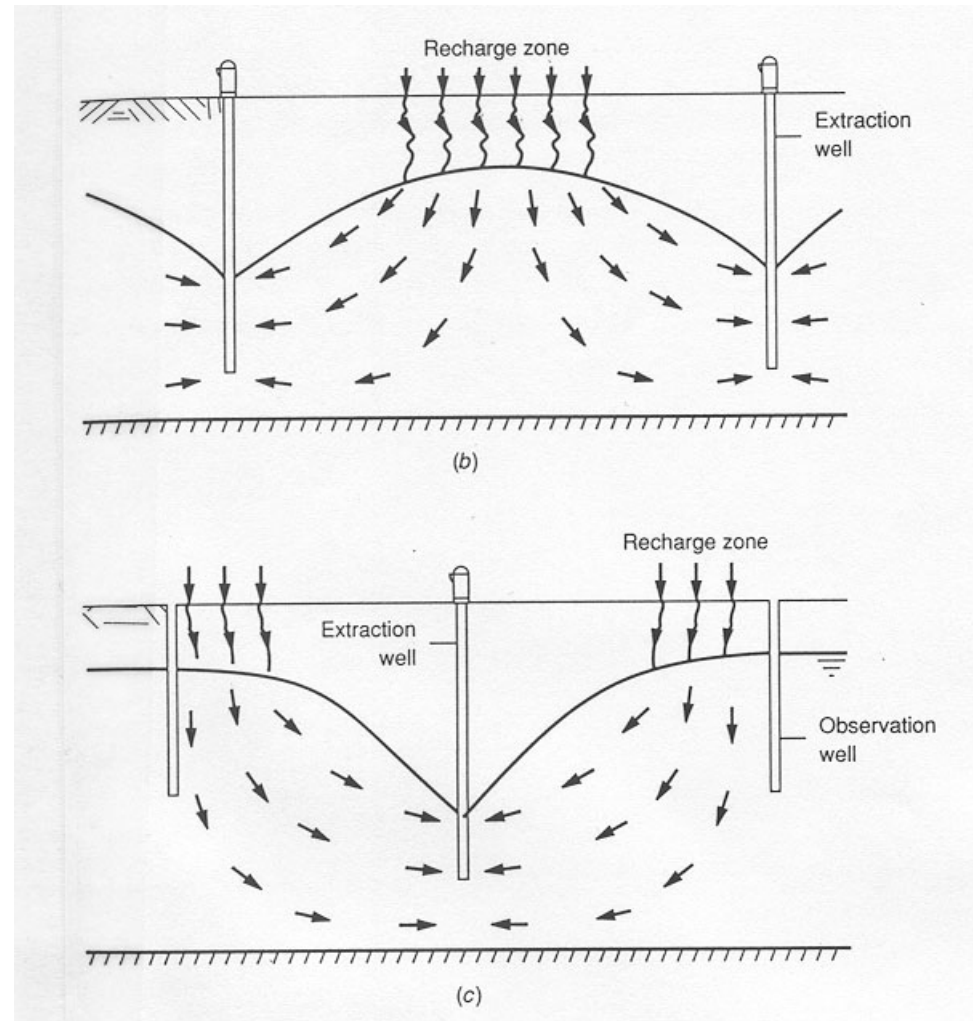
■ Methods:

- Surface Spreading/Infiltration Basins; Vadose (Unsaturated) Zone Treatment; Soil aquifer Treatment (SAT)
- Direct Injection via Injection Wells into Saturated Zone; Aquifer Storage and Recovery (ASR); No Land Requirements



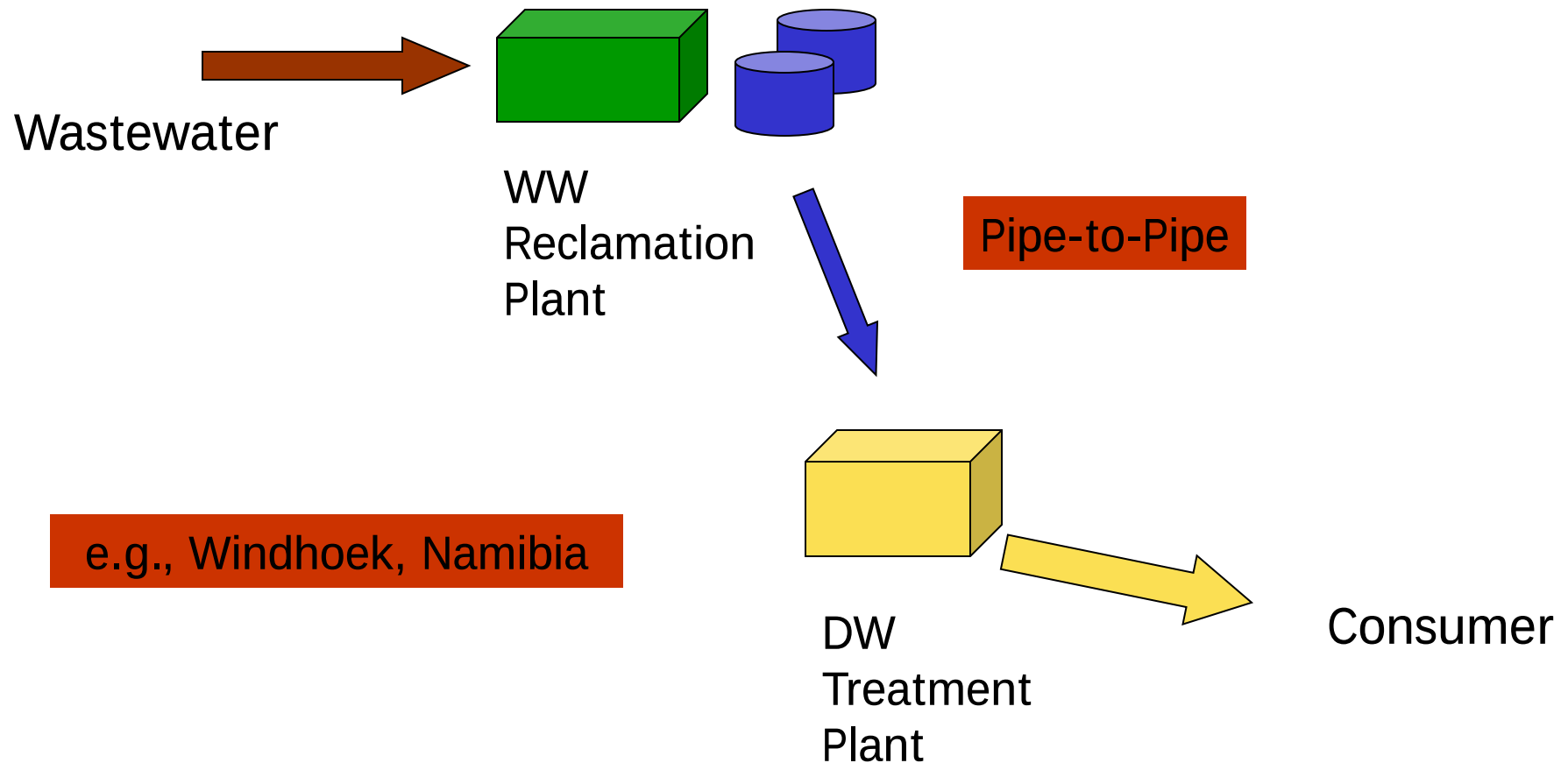
Schematic of Soil Aquifer Treatment (SAT): A Component in Indirect Reuse

(a) Well(s) surrounding
Recharge zone/basin(s)

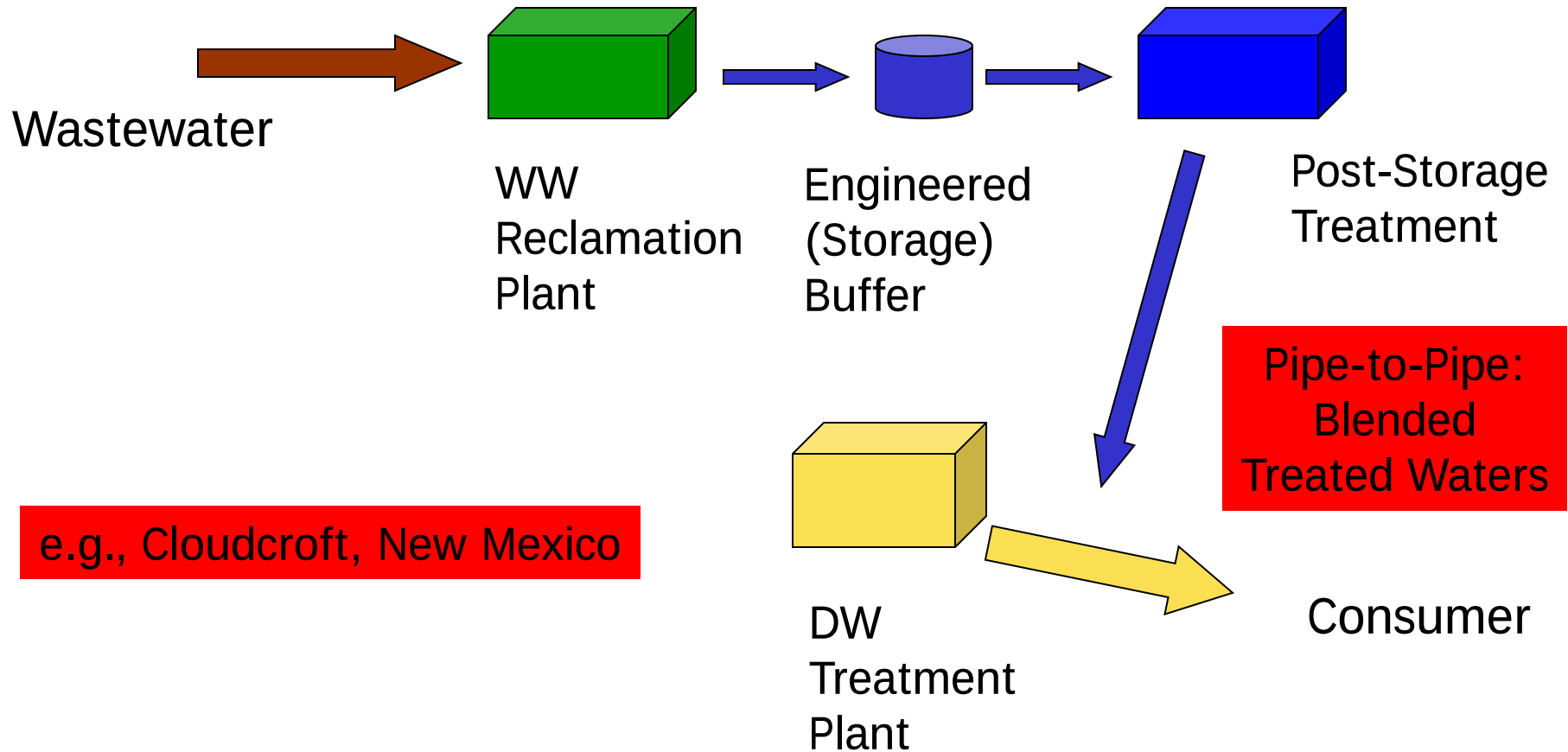


(b) Well(s) between
Recharge zone/basin(s)

Direct Potable Reuse



Direct Potable Reuse



Direct Potable Reuse (DPR)

Options

- Purified water (highly treated reclaimed wastewater) introduced directly into potable water supply distribution system
- Purified water introduced into raw-water supply immediately upstream of drinking water treatment plant

Needs

- Engineered (vs. Environmental) buffer
- Demonstrate efficacy of present *Industry Standard*
⇒ *MBR (or MF) – RO – AOP*

Regulatory Aspects

- Allowable Recycled Water Contribution (RWC)
⇒ *Loss of Identity*
- Multiple Barriers (redundancy)
- (Wastewater) Source Control (industry)

Why Consider DPR?

(Tchobanoglous et al, 2011)

Drivers

- Shortage of adequate storage (environmental buffer) in proximity to WWTP ⇒ Constrained by local hydrogeology and required (e.g., 6-month) residence time (California)
- Regulations mandating reduction in wastewater discharge into ocean (e.g., California, Florida)
- Limits to degree of non-potable (purple pipe/dual distribution system) reuse
- Considering tertiary treatment + transport, agricultural use may be more costly than DPR
- DPR (WWRO) is less costly than SWRO (desalination)
- Further increase the degree of WW reuse ⇒ increase market

Constraint

- Public (and Regulator) Acceptance

Reclamation System Components



- Collection, Treatment, Storage, Distribution
- Centralized vs. Satellite (Decentralized) Reclamation Facilities
- Segregated Collection Systems;
Gray Water (e.g., Showers) vs. Black Water (Toilets)
- Dual Distribution Systems (purple pipes);
Potable vs. Non-Potable Uses
- Environmental Buffers (Indirect System Component);
Also Serve as Storage
- On the Horizon: Separate Urine Separation
(Enriched in N, P); Treatment?

Water Quality Constraints To Reuse



■ Potable:

- Unknown Health Effects
- Microbial Risk (Viruses) ✓
- Chemical Risk (Organic Micropollutants)
- Nitrogen (N) Species (nitrate, ammonia)

■ Agricultural:

- TDS (Salt Toxicity)
- Specific Ion Toxicity (e.g., Boron (B))
- Attributes: Nutrients (N and P)

■ Cooling Water:

- TDS (Scaling Potential)

Attributes of a Potable Reclamation System



- Process and System Reliability
- Rigorous Monitoring System
- Multiple, Independent Barriers for Chemical and Microbial Contaminants; Redundancy
- Chemical Issues:
 - Implementation of Stringent Industrial Pretreatment and Source Control Measures for Synthetic Organic Chemicals and Heavy Metals
 - Control of Unidentifiable Contaminants; Reduce Contaminants Classes (TOC, TOX (organic halide))
- Microbial Issues
 - Inactivation by Strong Chemical Disinfectants (e.g., ozone)
 - and/or Physical Removal (SAT and Membranes) Processes

Reuse Regulations in USA



- No Federal Regulations; State Regulations (18 of 50)
- Degree of Treatment (e.g., Tertiary Sand Filtration, Disinfection)
- Contaminant Limits
(e.g., Coliform Bacteria, Viruses, Turbidity, TOC (California))
- Multiple Barriers Philosophy for Chemical and Biological Agents
- California:
 - Groundwater Recharge/Surface Spreading:
 - % Reclaimed Water Based on TOC ($< 20\%$);
 - Retention Time (12 months);
 - Horizontal Separation (300 ft);
 - Depth to Groundwater (6 – 15 ft);
 - Initial Percolation Rate (2 – 3 inches/min);
- Arizona Standard (Agricultural): 2.5 PFU/100 L (viruses);
2.5 Giardia cysts/100 L

WHO Guidelines for Agricultural Reuse

Type of irrigation	Health-based target for helminth eggs	Required pathogen reduction by treatment (log units)	Verification monitoring level (<i>E. coli</i> per 100 ml)	Notes
Unrestricted:	≤ 1 per litre (arithmetic mean) ^{b,c}	4	$\leq 10^3$	Root crops.
		3	$\leq 10^4$	Leaf crops.
	High-growing crops: ^{d,e} No recommendation	2	$\leq 10^5$	Drip irrigation of high-growing crops.
	Low-growing crops: ^d ≤ 1 per litre (arithmetic mean)	4	$\leq 10^3$	Drip irrigation of low-growing crops.
	E	6 or 7	$\leq 10^1$ or $\leq 10^0$	Verification level depends on the requirements of the local regulatory agency. ^a
Restricted:	F	3	$\leq 10^4$	Labour-intensive agriculture (protective of adults and children under 15).
	G	2	$\leq 10^5$	Highly mechanized agriculture.
	H	0.5	$\leq 10^6$	Pathogen removal in a septic tank.

Reuse Guidelines KSA: - Unrestricted Irrigation

Property		MCL (mg/L)	Property		MCL (mg/L)
Natural Properties	Floating Solids	None	Organic Chemical Properties	Oil and Grease	None
	TSS	10		Phenol	0.002
	pH	6-8.4		NH ₃ – N	5
Organic Chemical Properties	TDS	2500	Bacterial Properties	NO ₃ – N	10
	BOD ₅	10		Fecal bacteria	2.2 cells/100 mL
	Turbidity	5.00 NTU		Intestinal worms	1 egg/L

Health Effects and Assessment in WW Reclamation/Reuse



- Chemical and Biological Agents $\Rightarrow$ Risk
Long-Term Effects (e.g., Cancer) $\Rightarrow \Delta\text{Risk}$: e.g., $1/10^6$
Short-Term Effects (e.g., Reproductive)
- Infectious Diseases
Pathogenic Viruses, Bacteria, and Protozoa
 $\Rightarrow \text{Risk} \leq 10^{-4}$, i.e., one infection or less per 10,000 people per year
- Monitoring Specific Compounds vs. Bioassays
- Toxicity Testing vs. Epidemiological Studies
- Monitoring Indicator Organisms
(e.g., Bacteriophages) vs. Pathogens
- Risk Assessment:
Chemical vs. Microbial Risk; Incremental Risk

Risk Assessment and Risk Management in WW Reclamation/Reuse



- Risk Assessment
 - Hazard Identification
 - Exposure Assessment
 - Dose-Response
 - Acute vs. Chronic Effects
 - Short-Term vs. Long-Term Effects
- Risk Management
 - Source Control
 - Multi-Objective Process:
single process/multiple contaminants
 - Multi-Barrier Process Train:
multiple processes/single contaminant
 - Environmental Buffers

Markets for Reclaimed Wastewater



- Cost/Effectiveness + Environmental Considerations; Subsidies; Contractual Agreements; Revenue Plan
- Identify Potential Uses and Users at the beginning
- Forecasted Future Water Demand vs. Available Water Resources
- Customer Perspective: Required Quality, Required Quantity (Present, Future)
- Delivery Schedule (e.g., Seasonal Variations in Demand (Storage))
- Cost of Developing a New Water Resource (e.g. dam, well fields)
- Sole vs. Supplemental Supply



Issues in WW Reuse (Miller, 2008)

- Public acceptance
- Unknowns about chemical risk
- Poor differentiation by public and politicians of planned vs. unplanned reuse
- The media
- Lack of political support
- More cost-effective technologies
- Funding
- Better understanding of economics
- Energy/Water nexus
- Climate change

Constraints limiting water reuse (KSA)



- Water rates/value of water
- Lack of wastewater collection system
- Design and operation of appropriate wastewater treatment infrastructure
- Need for reclaimed water distribution system
- Implementing industrial source control program
- Legacy loads from leaking sewers, septic tanks, and discharge of raw sewage
- Public perception



Public Participation



- Coordinator (required, independent)
- Clear understanding of water reuse options
- Stakeholders, possible users
- Two-way communication, providing education and asking for meaningful input
- Building community support for a reuse program (e.g., Singapore)
- Understanding of possible alternatives



**“Water should not
be judged by its
history
but by its quality”**

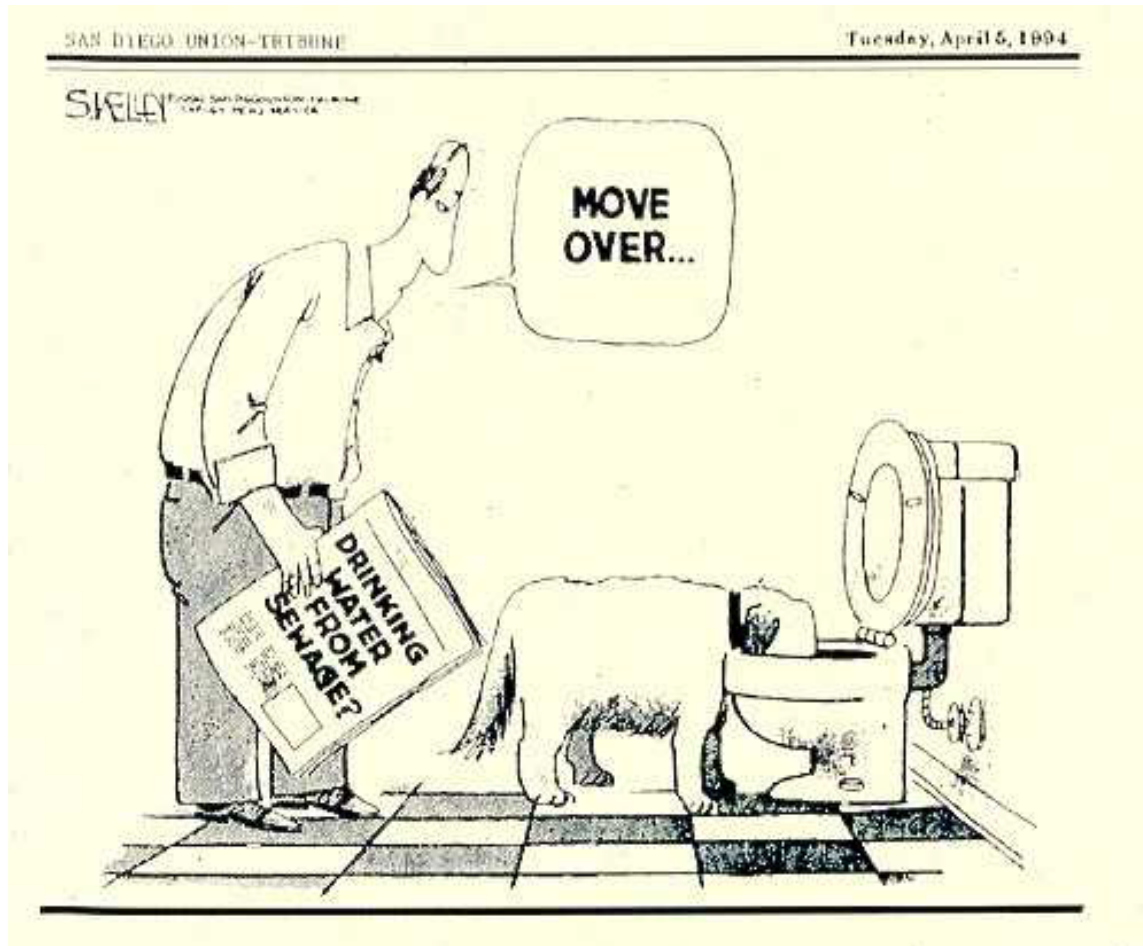
- Dr. Lucas van Vuuren

Most of us live
downstream.

Most of us drink
downstream.

Macperson, 2008

Regulatory and Public Acceptance?



Through
Inspiration,
Discovery



Wadi Sanifah

Constructed wetland (CW),
water drainage, an unique
feature in dry region
(Riyadh, KSA)



Thank You

<http://www.mtplanners.com/mtpwadi.html>



Part II: Treatment Technologies



Conventional WW Treatment

- Conventional Activated Sludge (CAS)
w/o nitrification
- CAS + nitrification
- CAS + nitrification/denitrification
- + phosphorus removal
(biologically or chemically)
- + disinfection

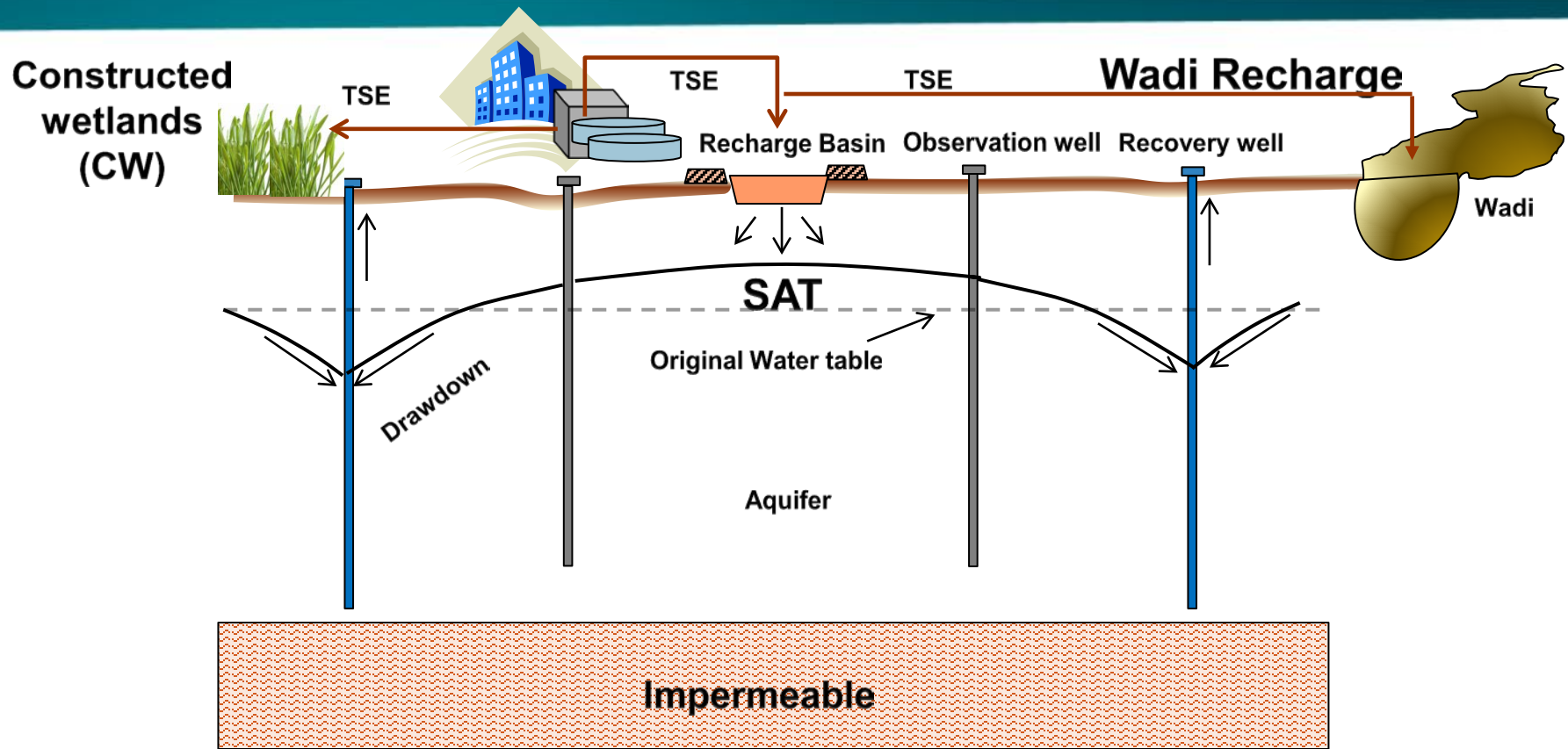
Advanced Treatment Processes for Potable Reuse



- Advanced Disinfection (UV Irradiation)
 - Difficult to Inactivate Microbes/Pathogens
 - *Constraint: Some UV-Resistant Viruses*
- Oxidation (Ozonation, Advanced Oxidation)
 - Organic Micropollutant (OMPs)
 - *Constraint: Metabolites (by-products)*
- Adsorption (Activated Carbon)
 - Organic Micropollutant (OMPS)
 - *Constraint: Polar OMPS*
- Membrane Separation (ultra- and nano-filtration)
 - (Physical) Removal of Microbes and OMPs
 - *Constraint: Removal of Small Microbes or OMPs*
- Aquifer Recharge and Recovery (ARR)
 - Removal of Microbes and Most OMPs
 - *An Advanced Process!*



Natural Treatment Processes



- **CW:** natural, low carbon footprint, sustainable, multi-contaminant removal
- **SAT:** infiltration of treated WW, percolation through soil, further treatment
- **Wadi Recharge:** dry riverbed, natural infiltration and treatment

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

Process/Parameter	BOD	COD (DOC)	Pathogens	SS	Turb.	PO ₄ ³⁻	NH ₃	NO ₃ ⁻	Trace Orgs.
Conv. Act. Sludge.									
Chlorination w/ Chloramines									
Chlorination w/ Chlorine									
Nitrification									
Nitrification-Denitrification									
Biological Phosphorus Removal									
UV Disinfection									
III-Filtration w/o Chemicals									
III-Filtration w/ Chemicals									
GAC									
Oxidation									
Low ΔP Membrane (MF or UF)									
Low ΔP Memb. w/ Coagulant									
Low ΔP Memb. w/ PAC									
High ΔP Membrane (RO or NF)									
IMS (MF + RO)									
MBR									

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

Process/Parameter	BOD	COD (DOC)	Pathogens	SS	Turb.	PO ₄ ³⁻	NH ₃	NO ₃ ⁻	Trace Orgs.
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Nitrification									
Nitrification-Denitrification									
Biological Phosphorus Removal									
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High ΔP Membrane (RO or NF)									
IMS (MF + RO)									
MBR									

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

[illegible]

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

[illegible]

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

Process/Parameter	BOD	COD (DOC)	Pathogens	SS	Turb.	PO ₄ ³⁻	NH ₃	NO ₃ ⁻	Trace Orgs.
Conv. Act. Sludge.	✓			?					
Chlorination w/ Chloramines									
Chlorination w/ Chlorine			✓						
Nitrification	✓	✓					✓		
Nitrification-Denitrification	✓	✓					✓	✓	
Biological Phosphorus Removal						✓			
UV Disinfection			✓						
III-Filtration w/o Chemicals				✓					
III-Filtration w/ Chemicals				✓	✓	✓			
GAC		✓							✓
Oxidation									✓

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

Process/Parameter	BOD	COD (DOC)	Pathogens	SS	Turb.	PO ₄ ³⁻	NH ₃	NO ₃ ⁻	Trace Orgs.
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Chlorination w/ Chloramines									
Chlorination w/ Chlorine			✓						
Nitrification	✓	✓					✓		
Nitrification-Denitrification	✓	✓					✓	✓	
Biological Phosphorus Removal						✓			
UV Disinfection			✓						
III-Filtration w/o Chemicals				✓					
III-Filtration w/ Chemicals				✓	✓	✓			
GAC		✓							✓
Oxidation									✓
Low ΔP Membrane (MF or UF)			✓	✓	✓				
Low ΔP Memb. w/ Coagulant		✓	✓	✓	✓	✓			
Low ΔP Memb. w/ PAC		✓	✓	✓	✓				✓
High ΔP Membrane (RO or NF)		✓							✓

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

Process/Parameter	BOD	COD (DOC)	Pathogens	SS	Turb.	PO ₄ ³⁻	NH ₃	NO ₃ ⁻	Trace Orgs.
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Chlorination w/ Chlorine			✓						
Nitrification	✓	✓					✓		
Nitrification-Denitrification	✓	✓					✓	✓	
Biological Phosphorus Removal						✓			
UV Disinfection			✓						
III-Filtration w/o Chemicals				✓					
III-Filtration w/ Chemicals				✓	✓	✓			
GAC		✓							✓
Oxidation									✓
Low ΔP Membrane (MF or UF)			✓	✓	✓				
Low ΔP Memb. w/ Coagulant		✓	✓	✓	✓	✓			
Low ΔP Memb. w/ PAC		✓	✓	✓	✓				✓
High ΔP Membrane (RO or NF)		✓				✓	?	✓	✓
IMS (MF + RO)		✓	✓	✓	✓	✓	?	✓	✓
MBR	✓	✓	✓	✓	✓	✓	✓	✓	?

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

Process/Parameter	BOD	COD (DOC)	Pathogens	SS	Turb.	PO ₄ ³⁻	NH ₃	NO ₃ ⁻	Trace Orgs.
Conv. Act. Sludge.	✓			?					
Chlorination w/ Chloramines									
Chlorination w/ Chlorine			✓						
Nitrification	✓	✓					✓		
Nitrification-Denitrification	✓	✓					✓	✓	
Biological Phosphorus Removal						✓			
UV Disinfection			✓						
III-Filtration w/o Chemicals				✓					
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Low ΔP Memb. w/ PAC		✓	✓	✓	✓				✓
High ΔP Membrane (RO or NF)		✓				✓	?	✓	✓
IMS (MF + RO)		✓	✓	✓	✓	✓	?	✓	✓
MBR	✓	✓	✓	✓	✓	✓	✓	✓	?

WW Treatment Processes for Reuse: Applicability and Targeted Contaminants

Process/Parameter	BOD	COD (DOC)	Pathogens	SS	Turb.	PO ₄ ³⁻	NH ₃	NO ₃ ⁻	Trace Orgs.
Conv. Act. Sludge.	✓			?					
Chlorination w/ Chloramines									
Chlorination w/ Chlorine			✓						
Nitrification	✓	✓					✓		
Nitrification-Denitrification	✓	✓					✓	✓	
Biological Phosphorus Removal						✓			
UV Disinfection			✓						
III-Filtration w/o Chemicals				✓					
III-Filtration w/ Chemicals				✓	✓	✓			
GAC		✓							✓
Oxidation									✓
Low ΔP Membrane (MF or UF)			✓	✓	✓				
Low ΔP Memb. w/ Coagulant		✓	✓	✓	✓	✓			
Low ΔP Memb. w/ PAC		✓	✓	✓	✓				✓
High ΔP Membrane (RO or NF)		✓				✓	?	✓	✓
IMS (MF + RO)		✓	✓	✓	✓	✓	?	✓	✓
MBR	✓	✓	✓	✓	✓	✓	✓	✓	?

Natural Treatment Processes for Reuse: Applicability and Targeted Contaminants

[illegible]

General Performance Comparison

Parameter	ARR/SAT	Engineered Process
Turbidity (NTU)	≤ 1 NTU	≤ 1 NTU
DOC Removal	≥ 50 %	≥ 50 %
Biostability: BDOC Removal	$< \text{MDL}$	$< \text{MDL}$
Trace Organics Removal	≥ 50 % (except for few persistent PhACs)	≥ 50 % (except for few persistent PhACs)
(Total) Nitrogen Achievable	≤ 2 mg/L	≤ 2 mg/L
Microbial Removal (Viruses)	$\geq 4\text{-log}$	$\geq 4\text{-log}$

Performance of Drinking Water Treatment Processes for Removal of PhACs and EDCs (Janex-Habibi, 2007)

Process	Acidic compounds	Neutral compounds	X-ray contrast media	Antibiotics	Estrogens, EE2	Detergents, NPEO, NP, OPEO, OP
ARR/SAT	50 - >90%	<10%	50 - 90%	50 - 90%	>90%	
Flocculation	<10%	<10%	<10%	<10%	<20%	10 - 50%
Ozonation	10 - >90%	10 - >90%	10 - 50%	>90%	>90%	50 - 90%
GAC, PAC	>90%	>90%	50 - 90%	50 - >90%	>90%	>90%
PAC/UF	>90%	>90%	50 - 90%	50 - >90%	>90%	>90%
NF	>90%	>90%	>90%	>90%	>90%	>90%
UV	<10%	10 - 50%	10 - 50%	10 - 50%	<10%	40 - 90%
Chlorine	<10 - 90%	<10%	<10%	50 - 90%	50 - 90%	<20%
Chlorine dioxyde	<10 - >90%	<10%	<10%	50 - 90%	>90%	<20%

- ARR: A Generally Robust Process (a few refractory OMPs)
- RO and GAC: Poor Retention of low MW polar compounds (e.g., NDMA)
- AOP: Slow Oxidation of Chlorinated Flame Retardants

Microbial Removals



Microbe	ARR/SAT	MF Membrane	UF Membrane	Ozonation
Total Coliforms	100 % (nd)	4.8 – 5.9 log	100 % (nd)	2.3 – 4.1 log
	24 m	0.2 um	100 kD	0.3 – 6.3 mg/L-min
	Weiss, 2005	Farahbakhsh, 2004	Bourgeois, 2001	Owens, 2000
Giardia Cysts	>1.9 log	4.6 – 5.2 log	4.7 – 5.2 log	1.5 – 2.7 log
	24 m	0.1 – 0.2 um	100 – 500 kD	0.3 – 1.0 mg/L-min
	Weiss, 2005	Jacangelo, 1997	Jacangelo, 1997	Owens, 2000
Crypto Occysts	>1.5 log	> 7 log	> 7 log	0.6 – 2.7 log
	24 m	0.25 um	13 kD	2.6 – 7.2 mg/L-min
	Weiss, 2005	Hirata, 1998	Hirata, 1998	Owens, 2000
MS2 Phage	8 log	0.2 – 1 log	1.7 - > 7 log	3 log
	30 m	0.1 – 0.2 um	100 – 500 kD	0.03 mg/L-min
	Medema, 2002	Jacangelo, 1997	Jacangelp, 1997	Oh, 2007

ARR: Equivalent to Other Processes if Adequate Time/Distance

The Water Industry Standard for Indirect Potable Reuse

e.g., California (OCWD)



Secondary
treatment



Tertiary
filtration



Disinfection



Microfiltration
(or MBR)



Reverse Osmosis



AOP

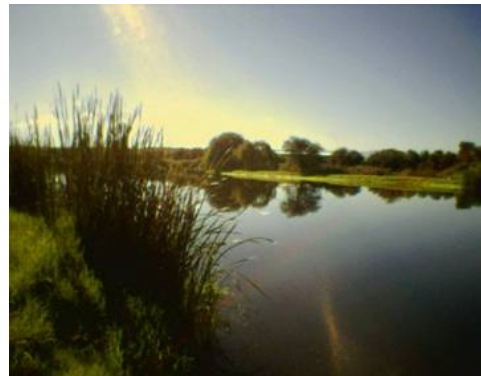
ARR (Direct
Injection or
Infiltration)



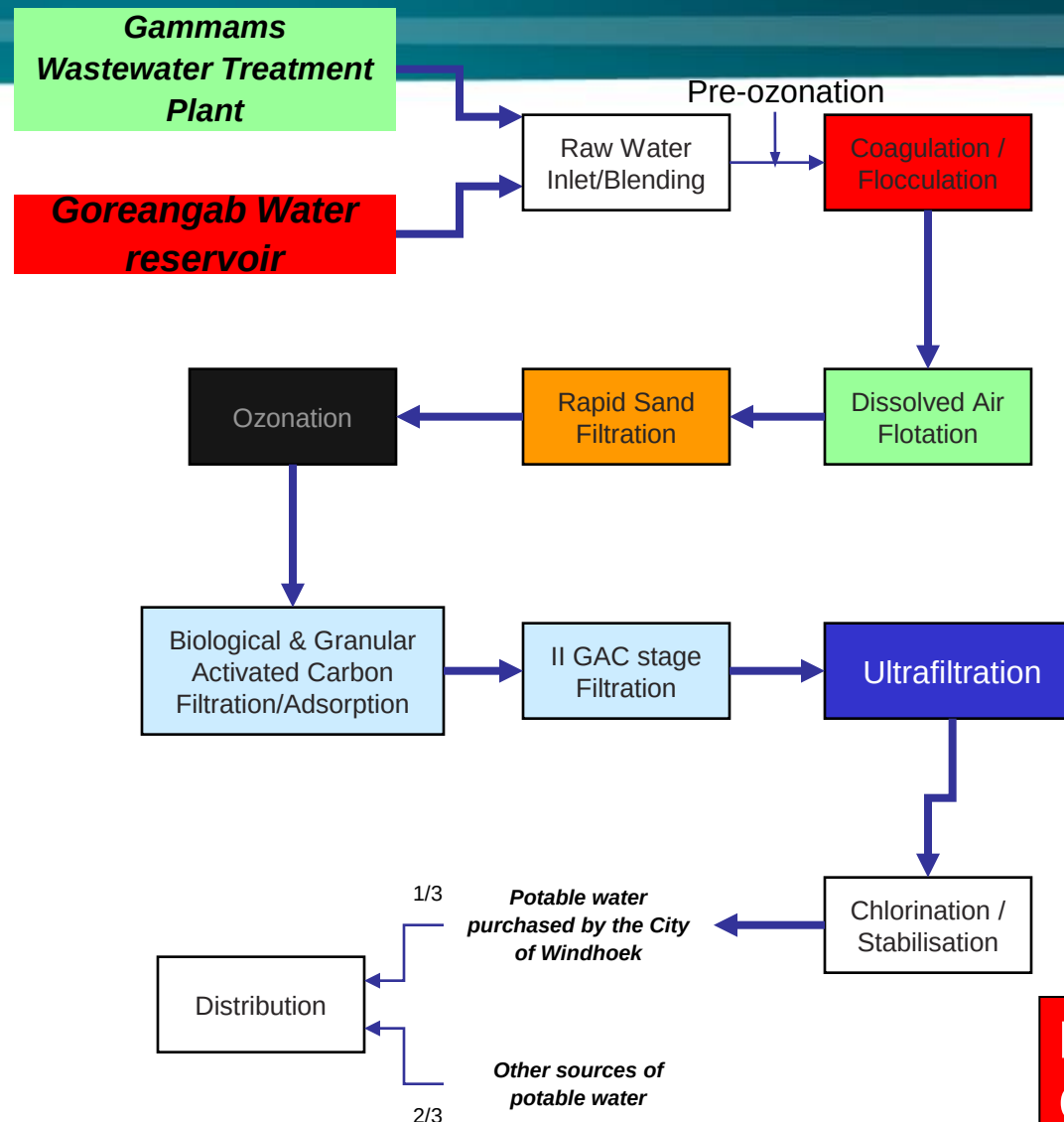
The Windhoek Approach



**Direct Potable Reuse:
Mixture of Wastewater
Plus
Reservoir Water;
Influent to Drinking
Water Treatment Plant**



Windhoek DW Treatment Plant



**Multi-Process
Complexity +
Expense**

- Advanced Processes: O_3 , GAC, UF (but no RO!)
- Direct blending of reclaimed water with potable water

Possible Engineered Buffer Systems in DPR (Tchobanoglous et al, 2011)



(a) above ground tanks



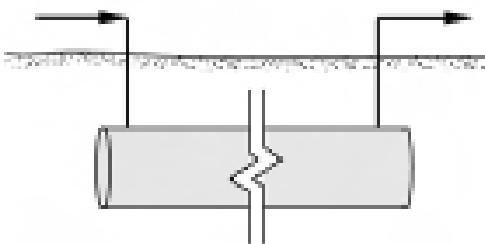
(d) enclosed subsurface storage reservoirs



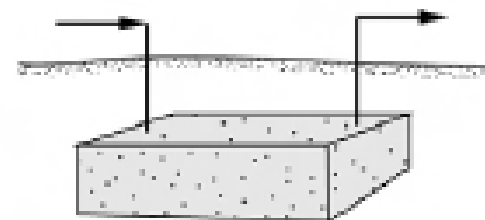
(b) covered and lined surface storage reservoirs



(e) confined aquifers

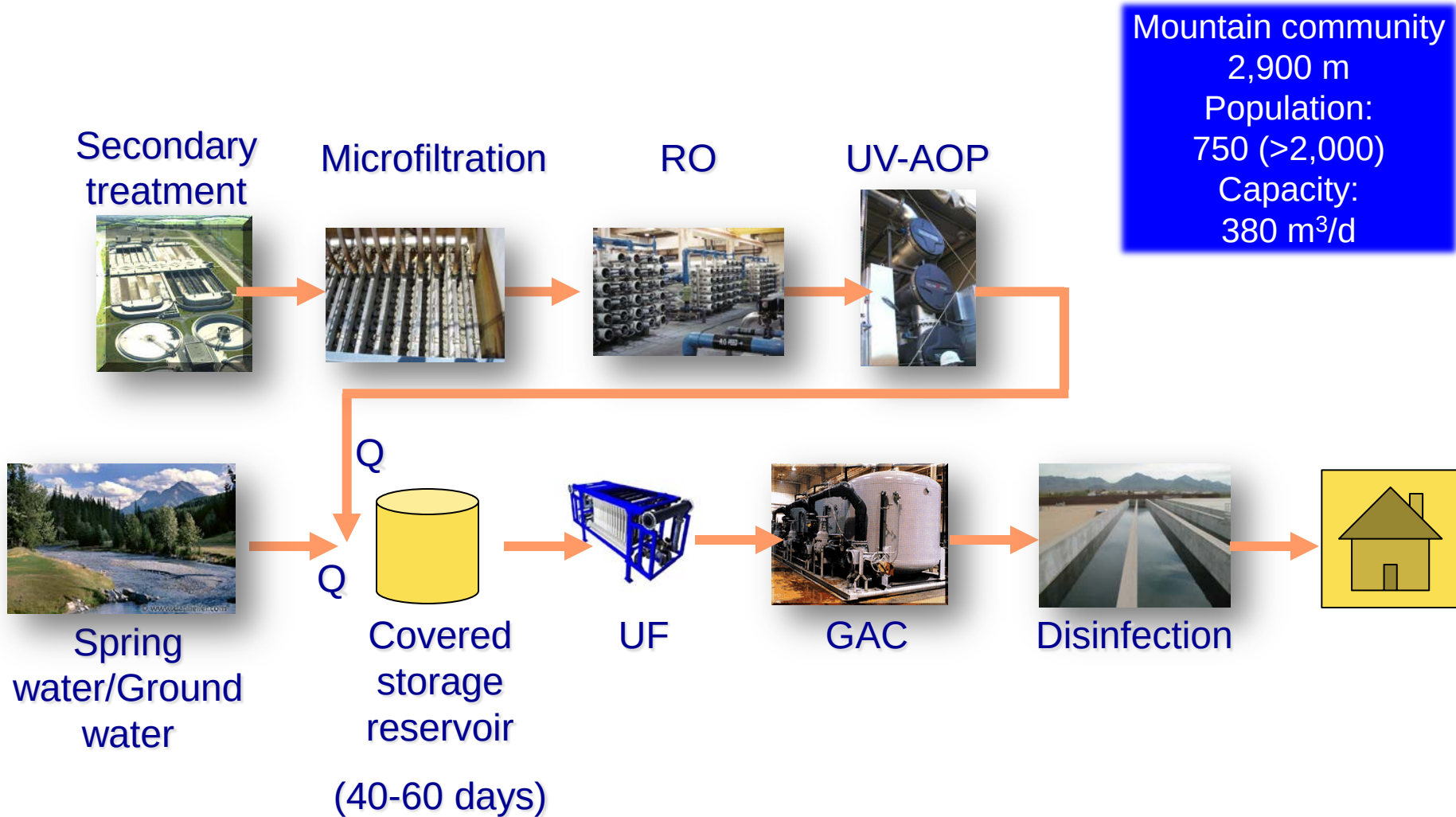


(c) large diameter subsurface pipelines



(f) engineered subsurface aquifers

Direct Potable Reuse: Cloudcroft, New Mexico (USA)



Diversification of Water Reuse

Increase of Recycle Water Quality and Value



Agriculture



Landscaping



Industrial



Aquifer Recharge

West Basin, CA, USA (2007)

40%

35%

25%

Costs (\$/m3)*

\$0.30

\$0.42

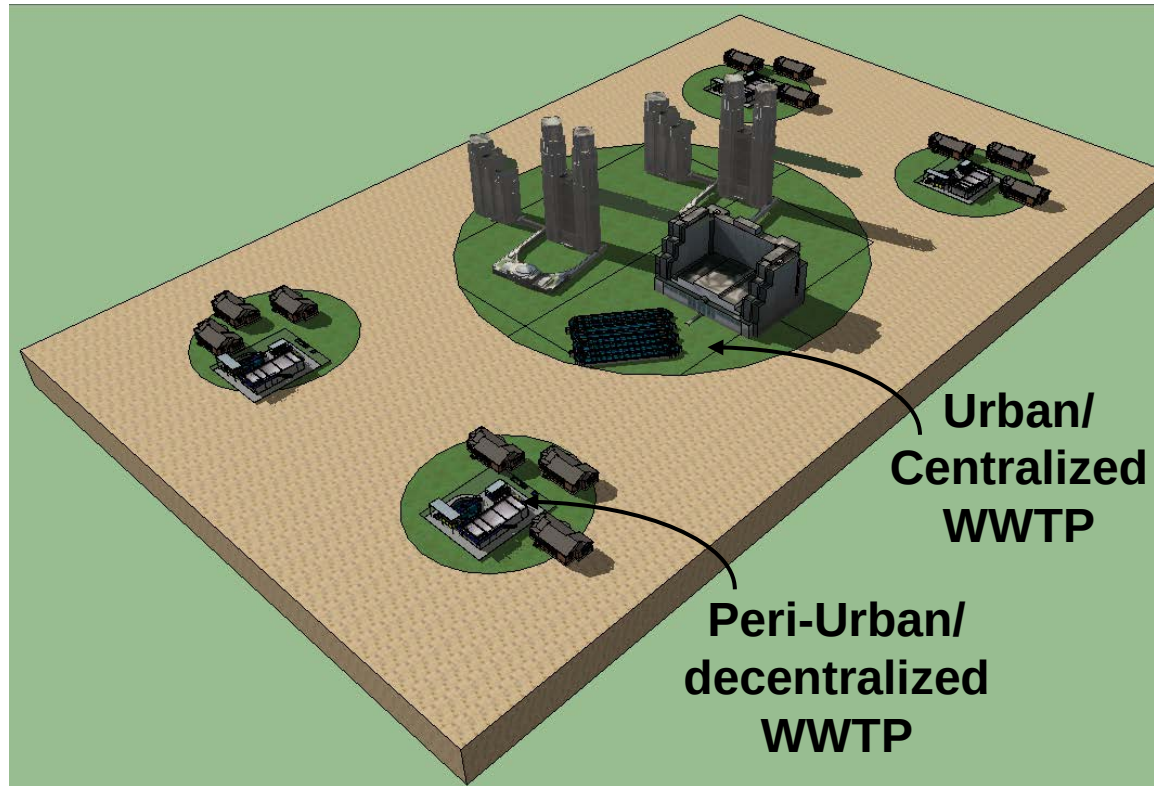
\$0.95

Agriculture/TSE

Soften RO

Single/Double RO

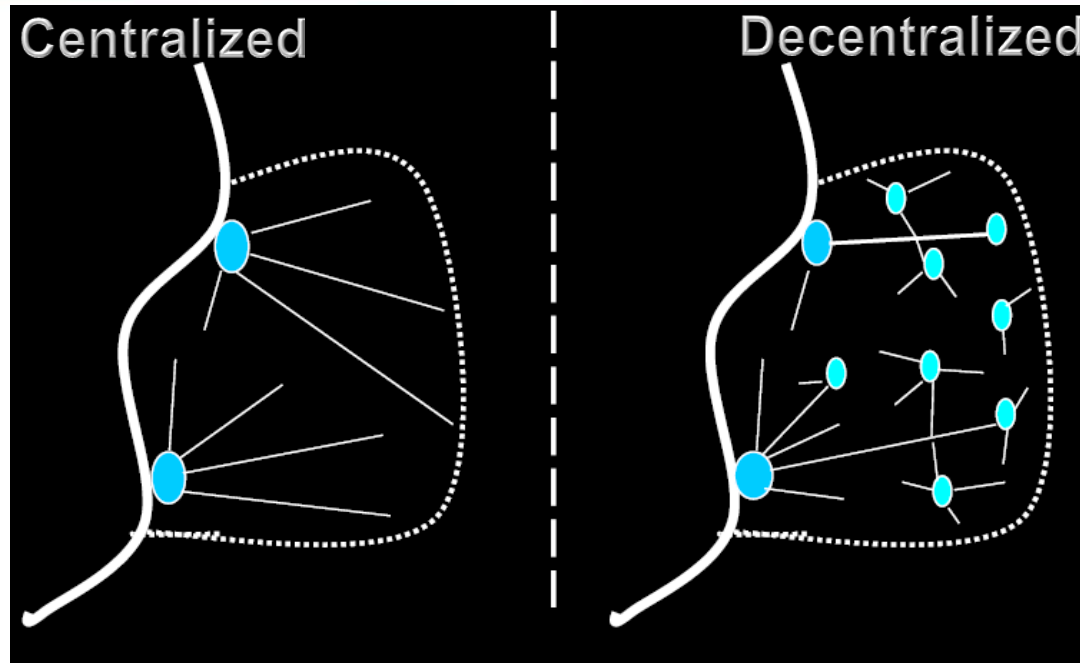
Decentralized Treatment



There are several advantages of this decentralized treatment in comparison to centralized treatment, but will require a comprehensive cost-benefit analysis (CBA)

- When WW collection system **not available**
- Located **away from the centralized** treatment
- **Satellite, small WW** treatment (MBR) could promote reuse and recycling
- Can provide opportunity for **peri-urban agriculture**
- Requires **urban planning and land-use** consideration

Moving from a Centralized to a Nodal System (Reiter, 2008)



Centralized treatment system - WW is conveyed away from homes for treatment to community's larger treatment facility

Decentralized treatment system – WW goes to onsite treatment systems and/or a network of smaller wastewater treatment plants, serving several households (clusters)



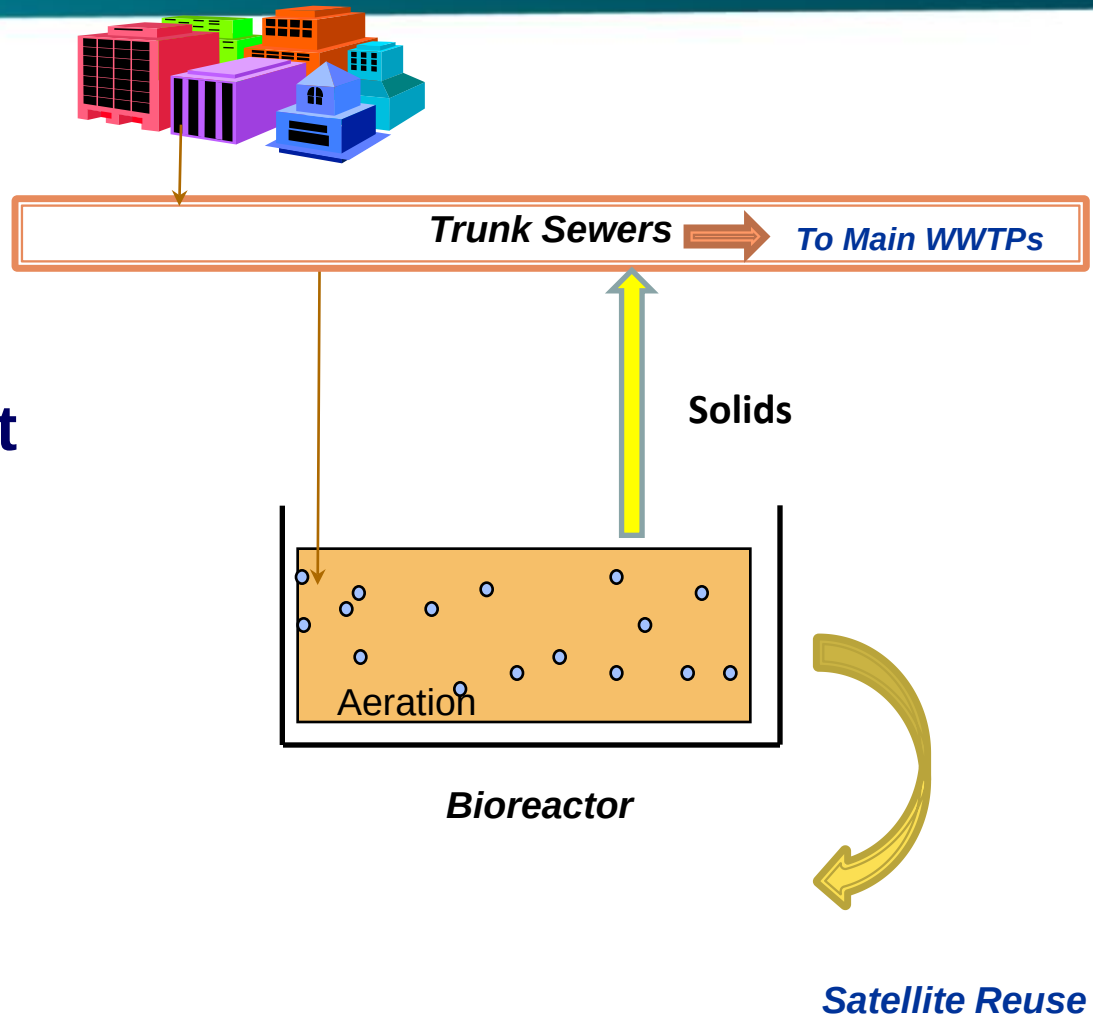
- **Infrastructure unavailable** (Centralized WWTP), then capture wastewater locally (Decentralized WWTP)
 - **Costs** of Supporting Infrastructure and transporting wastewater long distance - is reduced
 - **Energy** needed to pump and **transporting back** treated WW long distance for reuse - is reduced
- **Hydraulic load** to centralized WWTP – is reduced
- **Promotes** opportunities for enhanced local reuse
- **Tailored water quality** for water reuse
 - ✓ Landscape, golf course irrigation, **urban agriculture**
 - ✓ Groundwater recharge, enhancing water resources
- **Automated** system to handle variation in WW loading and flow

Decentralized Options

Sewer Mining

Peri-Urban Areas (cost
of trunk sewer
extension vs.
localized
treatment/reuse)

Household Level
(grey water)





Sewer mining can reduce water demand by using recycled water made available through sewer mining processes

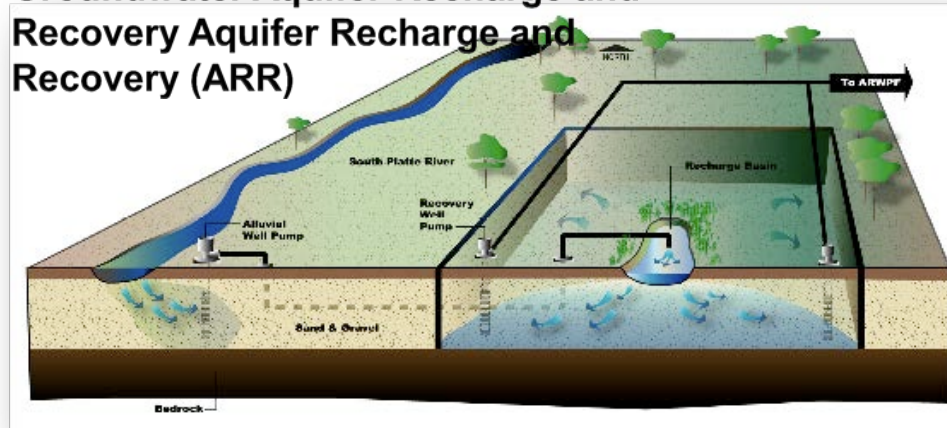
- **Sewer mining** is tapping into a WW transmission line
- Tap into the raw sewer line, treat locally with MBR, **treated sewer mining** by-products (waste solids) could be acceptable for return to the WW system
- If **treated sewer line available**, tap and use directly in irrigating sports fields, parks and golf courses and for agriculture



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Role of Natural Systems in Reuse

Groundwater Aquifer Recharge and Recovery (ARR)

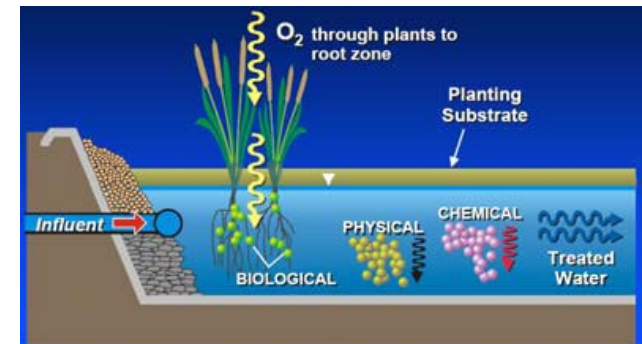


Attributes:

- Low energy/cost
- Low carbon footprint
- No chemical demand
- No residual generation
- Sustainable operation
- Multi-objective treatment
- Provides storage

What do we need to know to “engineer” natural systems?

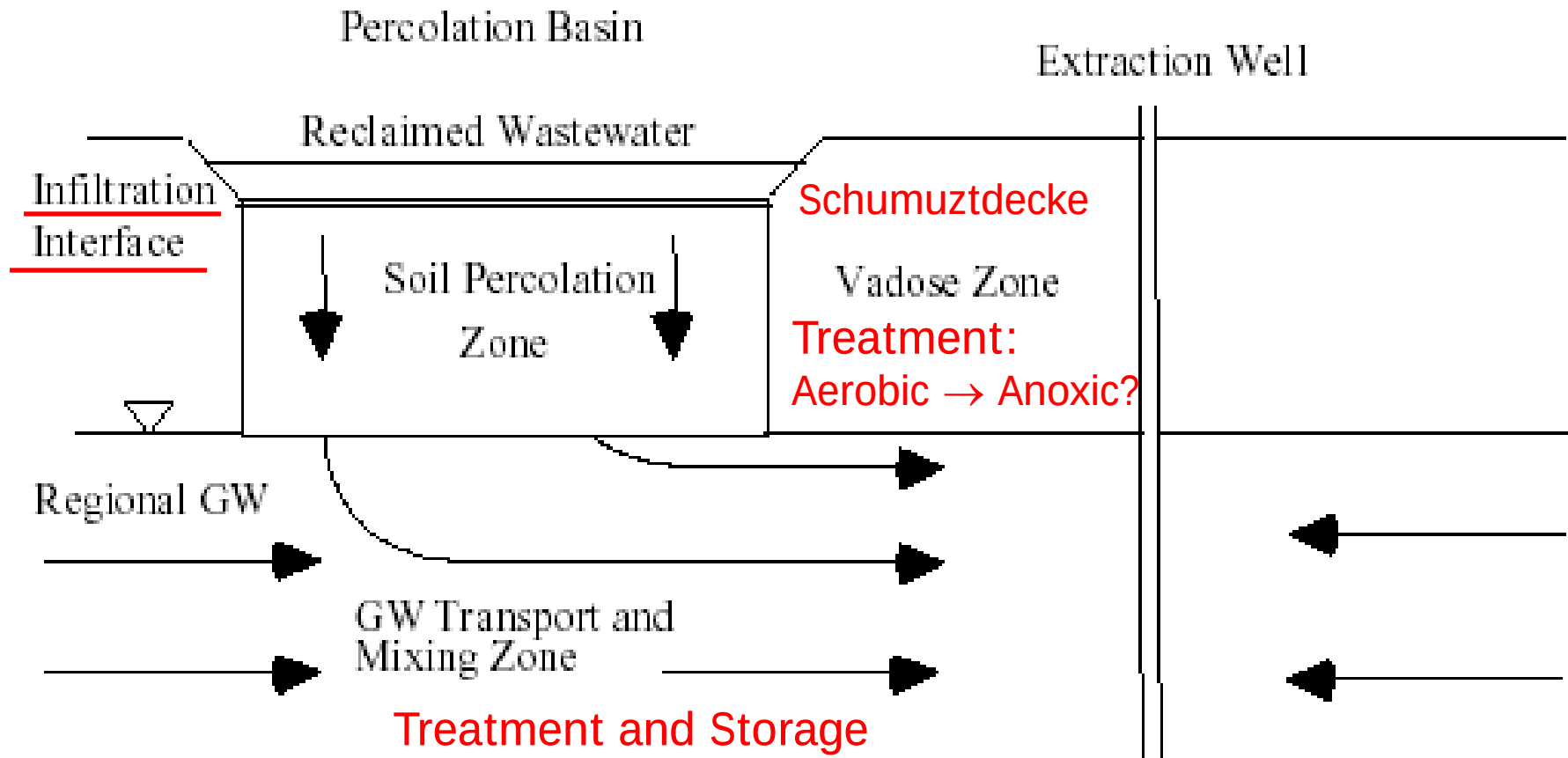
Constructed wetlands (CW)



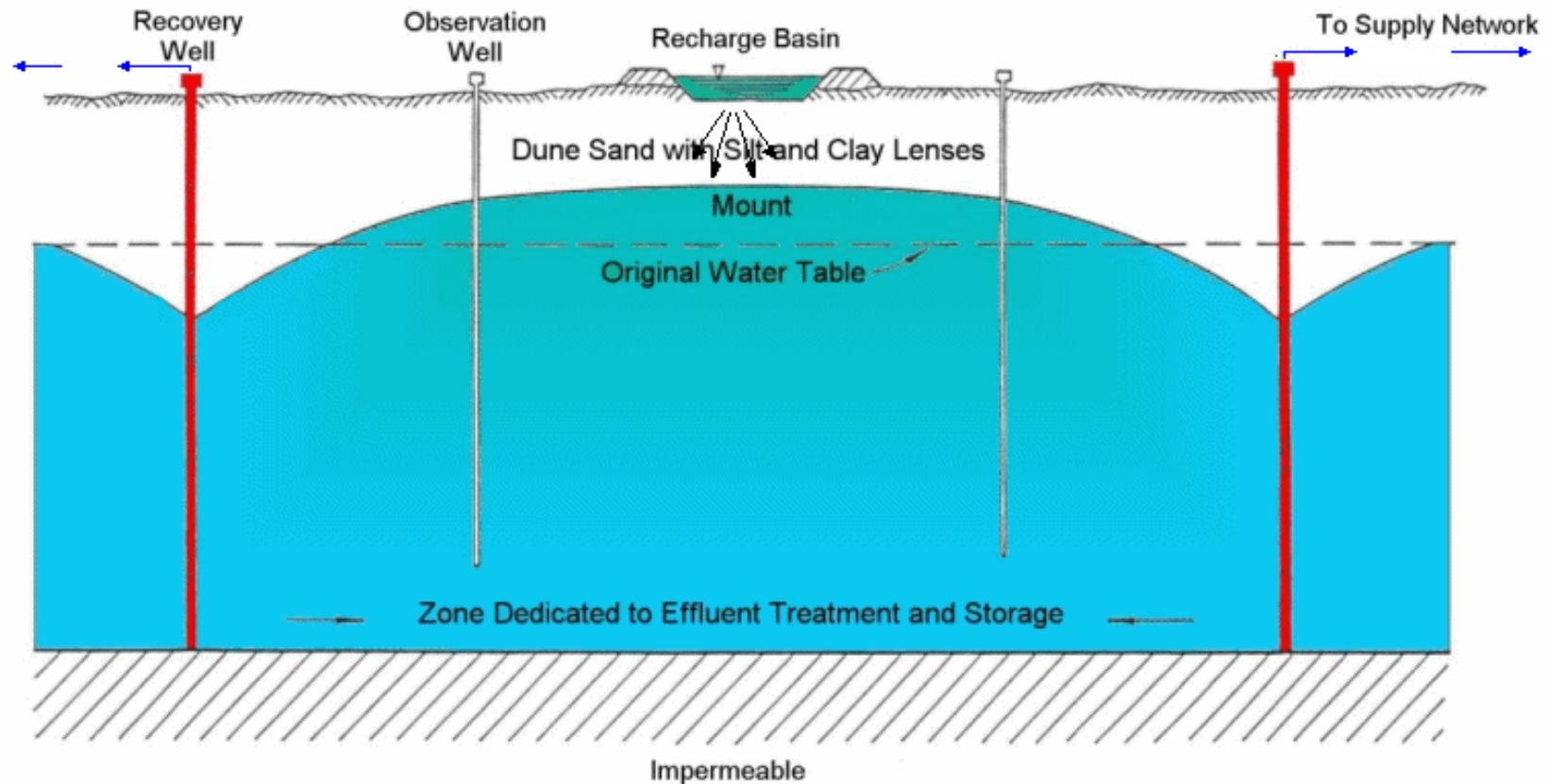
Soil Aquifer Treatment (SAT)



Soil Aquifer Treatment (SAT)



SAT: Infiltration to Recovery (Cikurel, 2004)



Recharge - Recovery Scheme

Montebello Forebay Infiltration Basins

Los Angeles, California USA

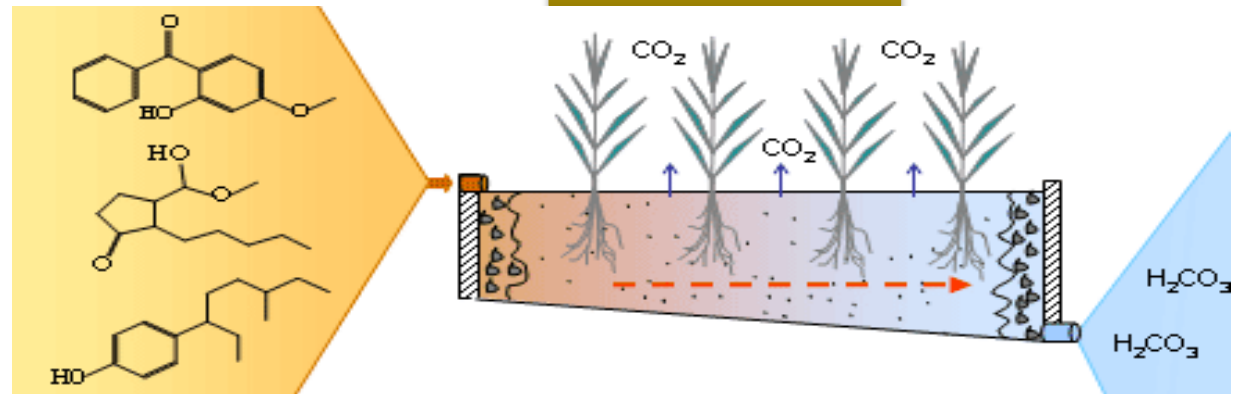
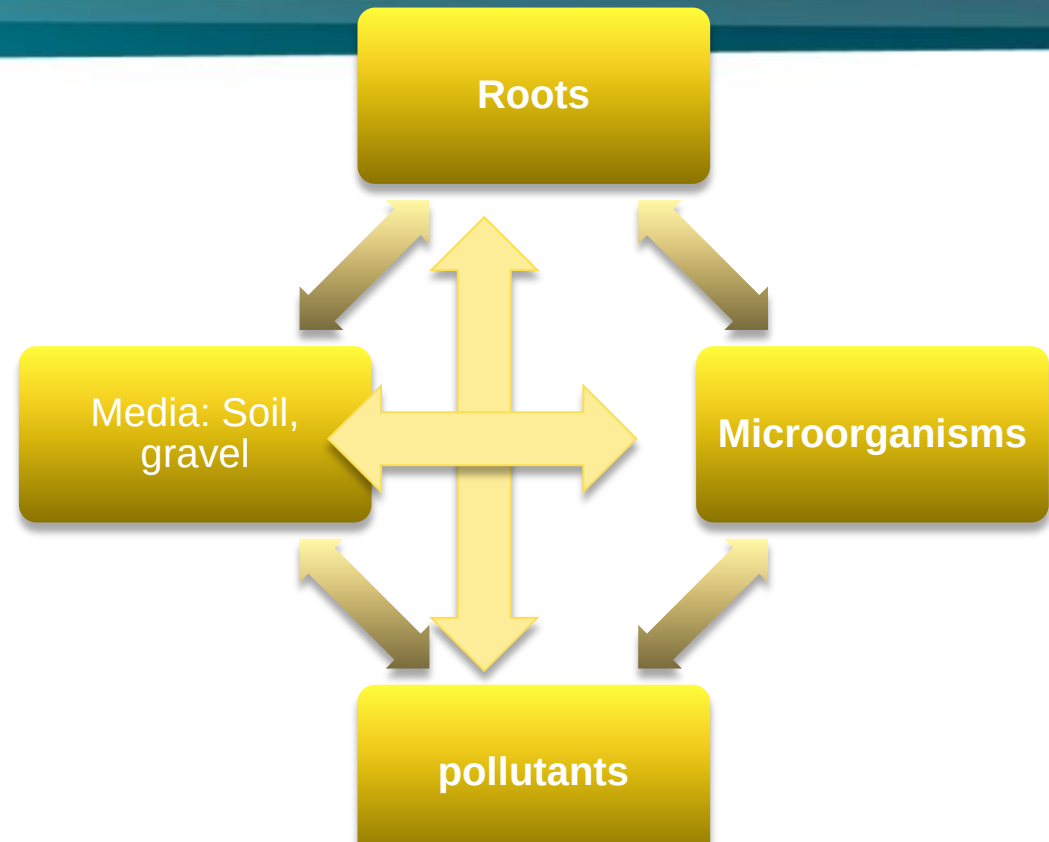


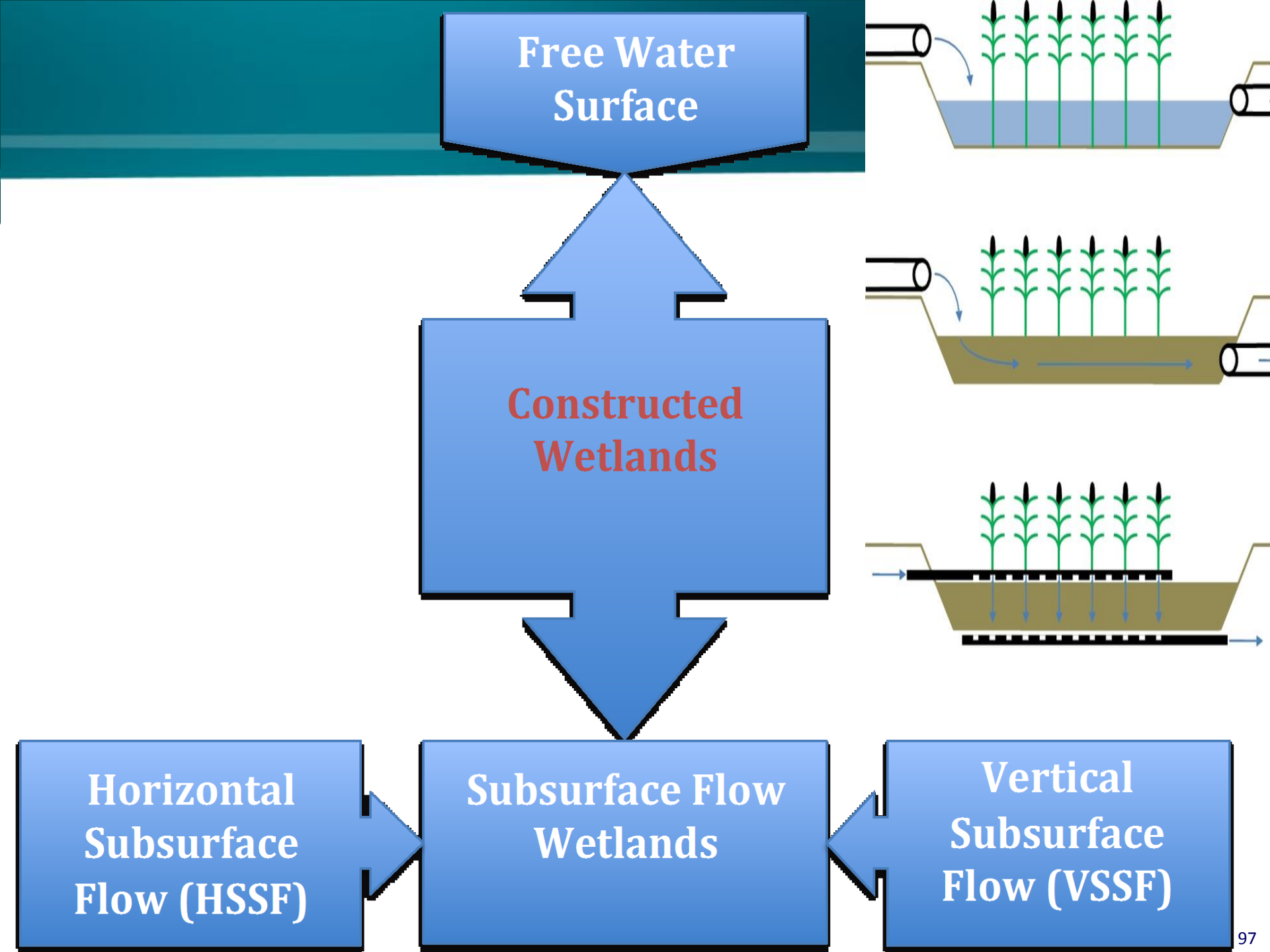
Constructed Wetlands



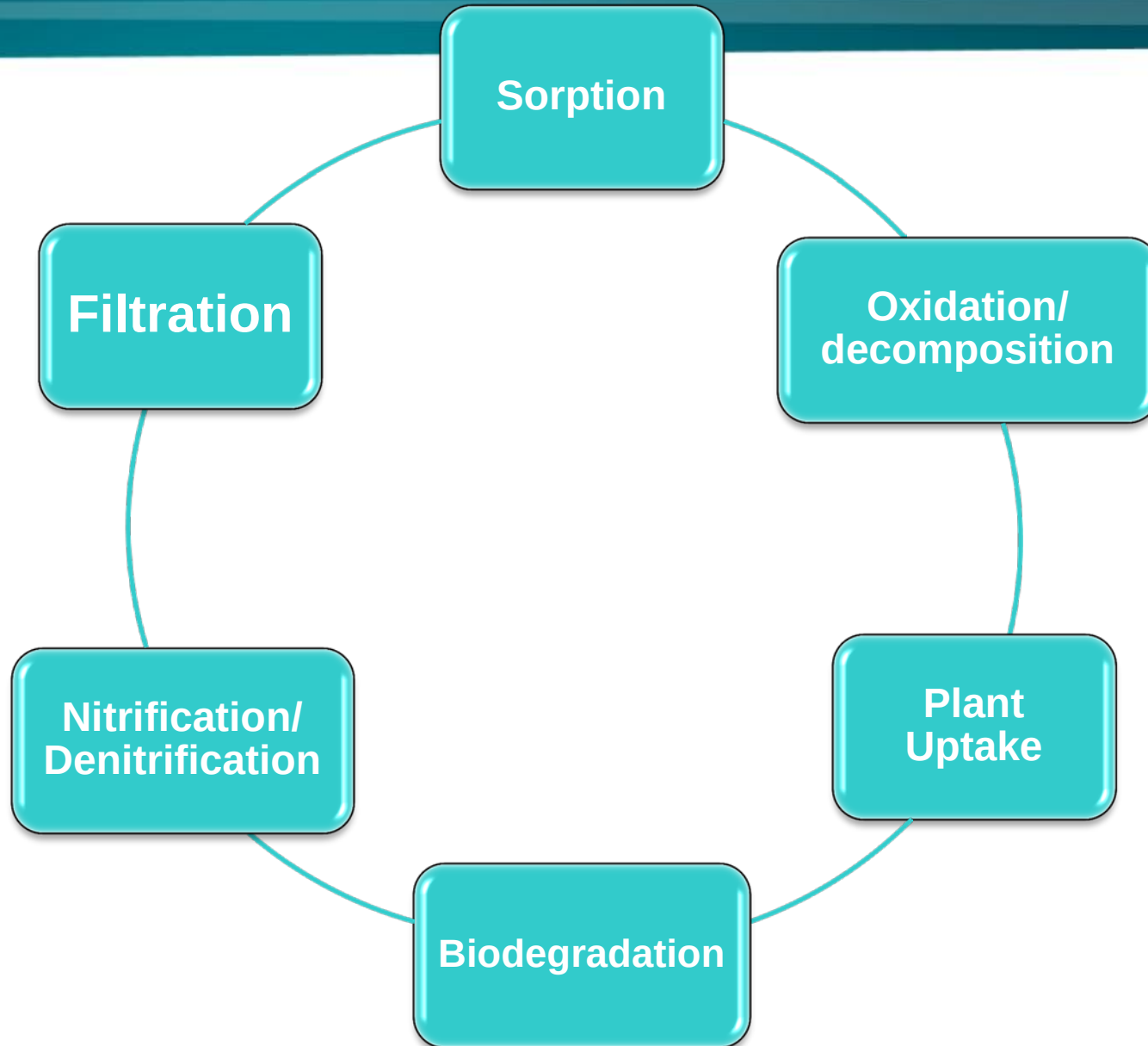
Constructed Wetlands (CWs)

CWs are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and associated microbial assemblages to assist in treating wastewaters





Treatment processes in CWs



Business Opportunities in KSA and GCC/MENA Region: Key Technologies

- Membrane Technologies
 - Niches in Tailored Water Quality (Designer Water)
 - Improved (Performance) Membranes
 - New Membrane Processes (e.g., forward osmosis (FO))
 - New Concepts and Applications of MBRs
 - Anaerobic MBR: Energy-Neutral Wastewater Treatment
- Aquifer Recharge and Recovery
 - Secondary or Tertiary Treatment Process
 - Indirect Potable Reuse
- Unique KSA Conditions
 - < 50 % Sewer Coverage
 - Industrial Areas/Cities

Acknowledgements

- **Dr. Shahnawaz Sinha, WDRC, KAUST**
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جامعة الملك عبد الله
للعلوم والتقنية
King Abdullah University of
Science and Technology



Water Desalination and
Reuse Center

Thanks for your attention

