2.500 Desalination and Water Purification
Spring 2009

Water/Wastewater Literacy, "Sustainable Sanitation" and "Blue Development"

Guest Lecture for
Desalination and Water Purification (2.500)
April 30, 2009

Courtesy of Neil Tangri. Used with permission.

Susan Murcott, Senior Lecturer
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Water Supply and Distribution

Listed by the National Academy of Engineering as

4th Greatest Engineering Achievements of the 20th C.

(after…1. Electrification, 2. Automobile 3. Airplane)

http://www.greatachievements.org/

Family stories of waterborne diseases in Massachusetts several generations back…

Polio – 1909 (Beverly MA)

Typhoid – 1914 (Winthrop, MA)

Helen Hillary (1892 – 1978)

Edith Helen Coffman (1907 – 2004)

What are the Millennium Development Goals for water and sanitation?

Millennium Development Goal #7
"Ensure Environmental Sustainability"

Reduce by half the proportion of the global population that does not have access to improved drinking water and adequate sanitation by 2015. (Target 10)

Target population for water: 1.6 billion

Target population for sanitation: 2.1 billion

This will require:

- Improved water to 70,000 households per day (SEI, 2005)
- Basic sanitation to 95,000 households per day (SEI, 2005)

Millennium Development Goals & Targets

Goal 1: Eradicate extreme poverty and hunger -
Targets 1 & 2

Goal 2: Achieve universal primary education – *Target 3*

Goal 3: Promote gender equality and empower women –
Target 4

Goal 4: Reduce child mortality – *Target 5*

Goal 5: Improve maternal health – *Target 6*

Goal 6: Combat HIV/AIDS, malaria and other diseases –
Targets 7 & 8

Goal 7: Ensure environmental sustainability – *Targets 9, 10, 11*

Goal 8: Develop a global partnership for development –
Targets 12- 18

http://www.developmentgoals.org

How many people in the world lack “adequate” sanitation?

Improved Sanitation

- 2.6 billion people lack adequate sanitation

~ 40% of global population

- Many children worldwide attend school with no toilet facilities

What is the definition of “adequate” sanitation?

Definition of Adequate (a.k.a. “Improved”) Sanitation

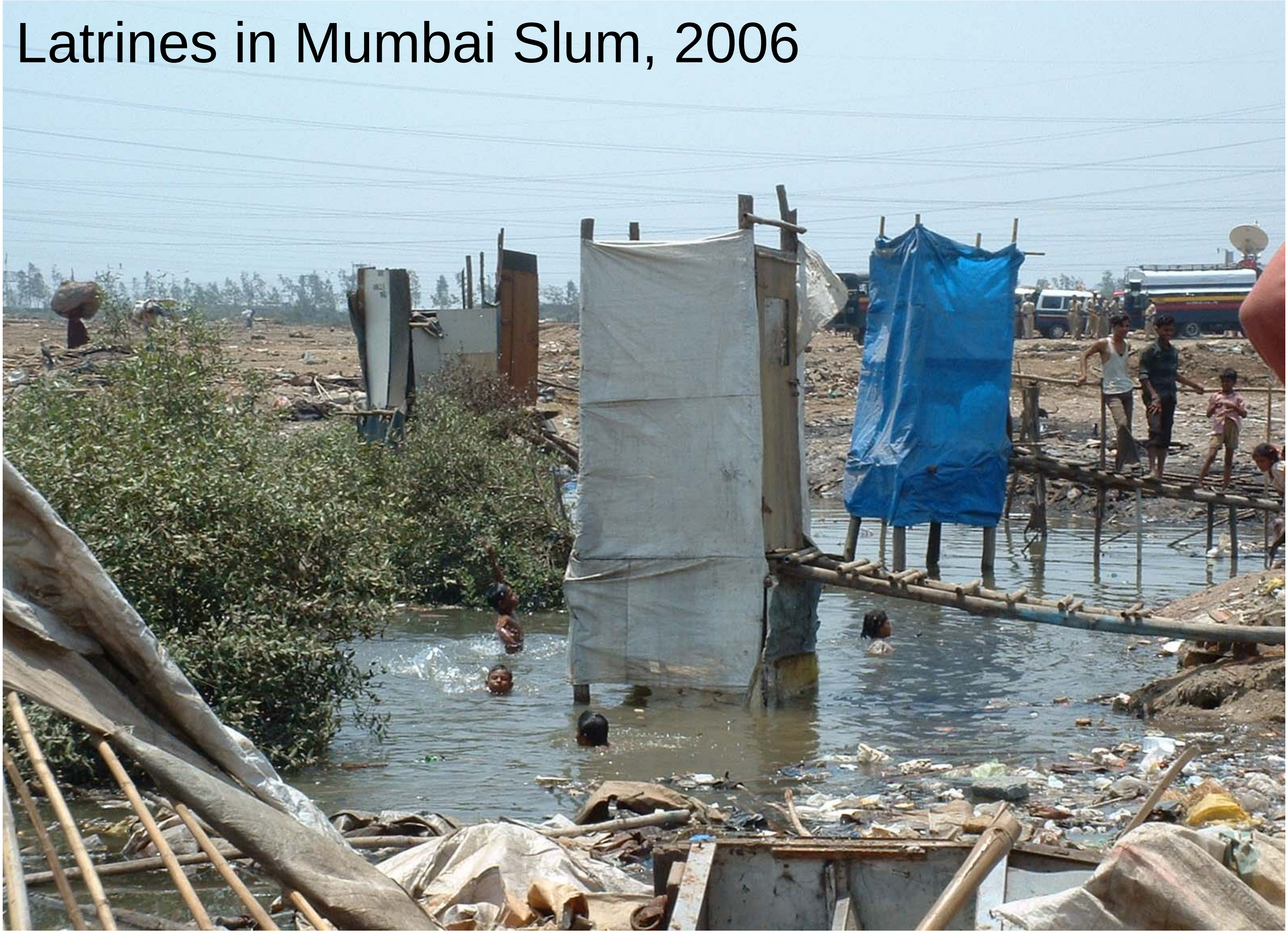
- **Improved**:
  - Connection to public sewer
  - Connection to septic system
  - Pour-flush latrine
  - Ventilated improved pit latrine
  - Simple pit latrine with slab
  - Compost latrine

- **Not improved**:
  - No sanitation (open defecation)
  - “Traditional latrines”
  - Open pit latrine
  - Bucket latrine
  - Shared (semi-public) and public latrines

No sanitation – "open defecation"

Poop

Latrines in Mumbai Slum, 2006



Courtesy of Neil Tangri. Used with permission.

Pit Latrine

Ventilated improved pit latrine (VIP)

A dry latrine system, with a screened vent pipe to trap flies and often with double pits to allow use on a permanent rotating basis. Considered a safe, hygienic means of excreta disposal.

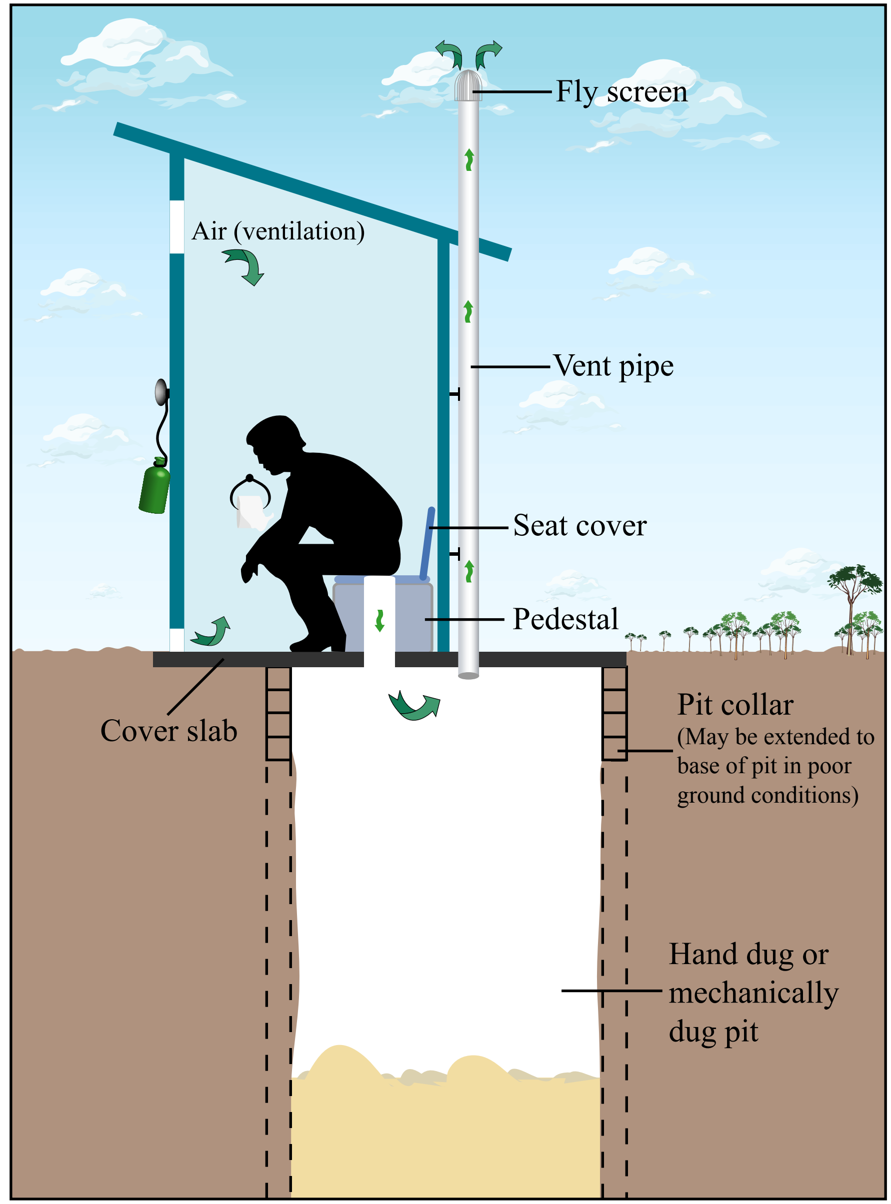


Figure by MIT OpenCourseWare.

http://web.mit.edu/urbanupgrading/

Sanitation Ladder

The 'sanitation ladder' presents sanitation coverage
as a four-step ladder that includes the proportion of the population:

- practicing open defecation
- using an unimproved sanitation facility
- using a shared sanitation facility
- using an improved sanitation facility.

Sanitation Ladder

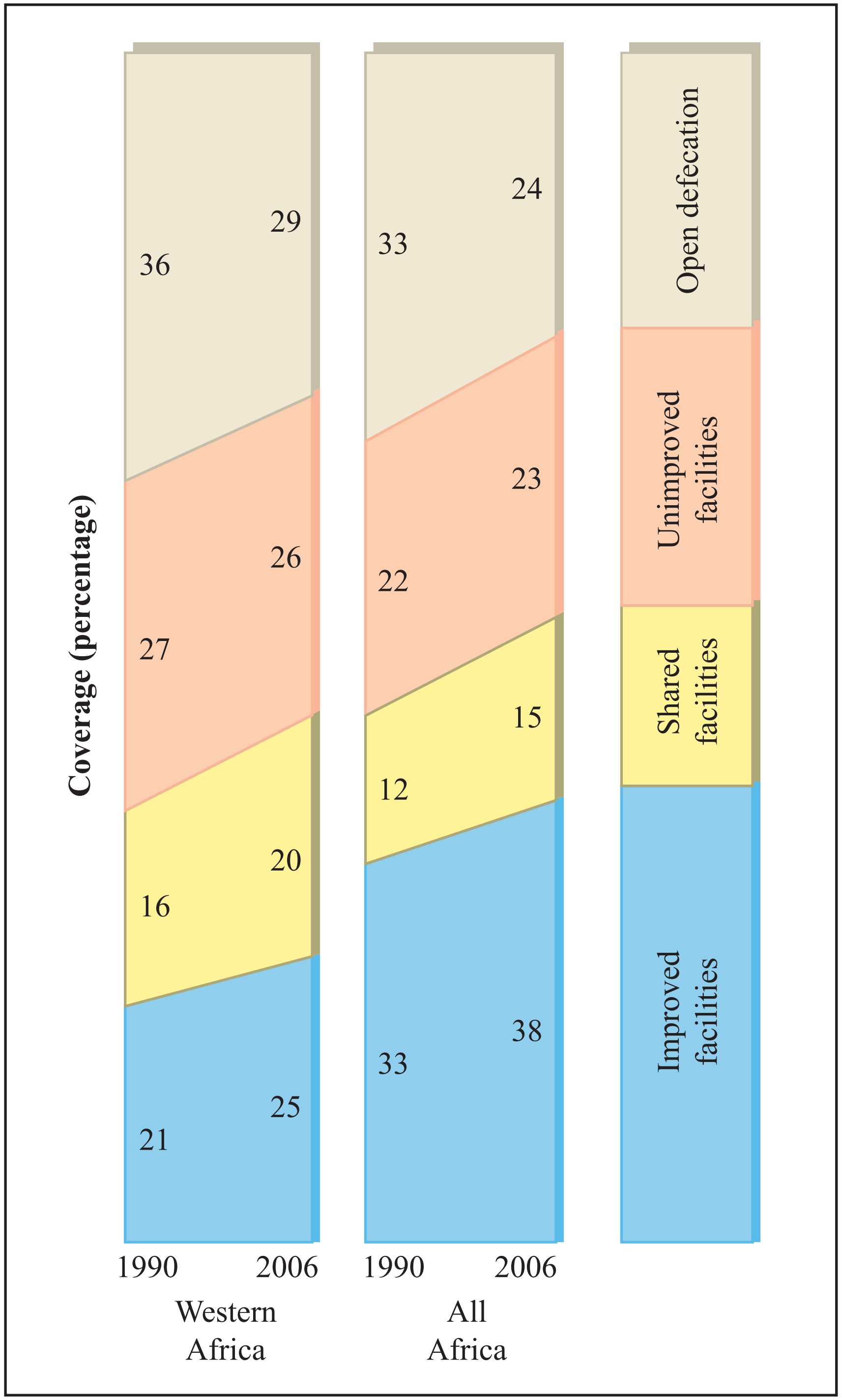


Figure by MIT OpenCourseWare.

Improved Sanitation and Income Level

- 2.6 Billion lack adequate sanitation
- 2.5 Billion people live on < $2 per day

(World Bank Annual Report, 2006)

http://go.worldbank.org/KQ3OFFED90

Women and Sanitation

(Slide Courtesy of Christine Moe, Emory University)

- In many parts of the world, women and girls are forced to wait until nightfall to defecate.
- In some countries, >50% of girls drop out of school because there are no toilets
- Ideal school latrines drawn by girls in Nyanza Province, Kenya, Summer 2007

What is the definition of of wastewater?

What's the definition of wastewater?

- Every community produces liquid and solid wastes and air emissions. Wastewater is the liquid or water-carried waste of the community after it has been used in a variety of applications.

- Wastewater is the combination of liquid or water-carried wastes removed from residences, institutions, commercial and industrial establishments, together with such groundwater, surface water and stormwater as may be present.

(Metcalf & Eddy 4th Ed. 2003)

What % of wastewater in the world is released to the environment without treatment?

95% of wastewater in the world is released to the environment without treatment

Niemczynowics, J.1997. “The Water Profession and Agenda 21.” *Water Quality International* 2. 9-11.

90% of cities and towns in developing countries lack sewage treatment
(Stockholm Environment Institute)

Guheshwori Wastewater Treatment Plant – improperly functioning facility in a developing country

Preliminary Treatment Stage

Final Treated Effluent Discharge Stage

Treated Wastewater Discharge to Bagmati River

Abandoned Imhoff Tank: Tank was abandoned after operator stopped being paid

Photo credit: Mahua Bhattacharya

Overflowing Imhoff Tank: Became clogged when adjacent earth wall collapsed into it during storm event.

Photo credit: Mahua Bhattacharya

Semi-functional Imhoff Tank: Missing control gates cause significant flow short-circuiting

Photo credit: Mahua Bhattacharya

How much water do we typically consume in the Boston per day on a per capita basis (assuming we include all residential, commercial, agricultural and industrial use)?

How much water do we consumer in Boston per person per day?

	Gallons per person per day	Cubic meters per person per day
Boston – residential, industrial, commercial	100	0.38 m^3
Boston (residential only)	65	0.25 m^3

MWRA – Facts

- What is populations served and current flow rates?
  - For the sewer system to Deer Island Treatment Facility (not including small plant in Clinton, MA)
  - 43 sewer service communities,
  - > 2 million customers,
  - 350 mgd = annual average wastewater flow
- What is the actual use/population served (gals/capita/day)?
  - 350 mgd / 2 million people = 175 gpcd;
  - this higher number than the 100 gpcd of the previous slide includes not only all residential, commercial, industrial and institutional sanitary flows, but also groundwater infiltration, storm water inflow, and combined sewer storm water flow tributary to Deer Island.

How much water do people consume (per person, per day) around the world?

Water Source	**Consumption liters/cap/day (m^3cd)**
Rural springs, surface waters, wells, etc.	2-25
Standpipes in cities/villages	10-50
Single tap in the home	15-90
Multiple taps in the home	30-300 (0.03 – 0.30)
United States	375 – 600 (0.38 – 0.6)

Virtual Water & Water Footprint

- Virtual water - Volume of water expended in the production of food, commercial goods & services

- Water footprint - sum of the volume of water an individual uses both directly and in the production of food, commercial goods and services.

- See www.waterfootprint.org

- (My water footprint is 800 m3/year ~600 gallons/day)

Water Footprint

	Liters of water needed to produce
1 kg wheat	1,350
1 kg rice	3,000
1 kg corn	9,000
1 cup coffee	140
1 liter milk	1,000
1 kg beef	16,000

- The water footprint of China is about 700 cubic meter per year per capita. Only about 7% of the Chinese water footprint falls outside China.
- Japan with a footprint of 1150 cubic meter per year per capita, has about 65% of its total water footprint outside the borders of the country.
- The USA water footprint is 2500 cubic meter per year per capita.

Definitions – Virtual Water

- *Virtual water content* – The virtual-water content of a product (a commodity, good or service) is the volume of freshwater used to produce the product, measured at the place where the product was actually produced (production-site definition).
- It refers to the sum of the water use in the various steps of the production chain.
- The virtual-water content of a product can also be defined as the volume of water that would have been required to produce the product at the place where the product is consumed (consumption-site definition).
- (We recommend to use the production-site definition and to mention it explicitly when the consumption-site definition is used.)
- The adjective ‘virtual’ refers to the fact that most of the water used to produce a product is not contained in the product. The real-water content of products is generally negligible if compared to the virtual-water content.

www.waterfootprint.org

Three Colors of Virtual Water

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- *The three colors of a product's virtual water content* – The virtual-water content of a product consists of three components, namely a green, blue and gray component.

  - The **'green' virtual-water** content of a product is the volume of rainwater that evaporated during the production process. This is mainly relevant for agricultural products, where it refers to the total rainwater evaporation from the field during the growing period of the crop (including both transpiration by the plants and other forms of evaporation).

  - The **'blue' virtual-water** content of a product is the volume of surface water or groundwater that evaporated as a result of the production of the product. In the case of crop production, the blue water content of a crop is defined as the sum of the evaporation of irrigation water from the field and the evaporation of water from irrigation canals and artificial storage reservoirs. In the cases of industrial production and domestic water supply, the blue water content of the product or service is equal to the part of the water withdrawn from ground or surface water that evaporates and thus does not return to the system where it came from.

  - The **'gray' virtual-water** content of a product is the volume of water that becomes polluted during its production. This can be quantified by calculating the volume of water required to dilute pollutants emitted to the natural water system during its production process to such an extent that the quality of the ambient water remains beyond agreed water quality standards.

Relevance of the Colors of Water

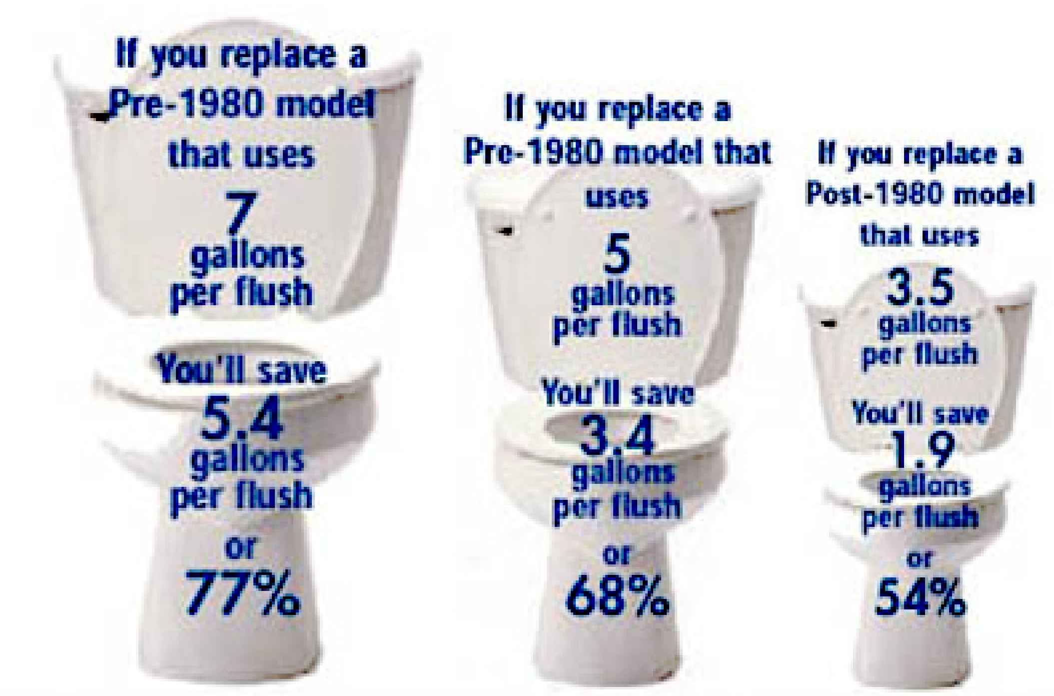
- It is relevant to know the ratio of green to blue water use, because the impacts on the hydrological cycle are different.
- Both the green and blue components in the total virtual-water content of a product refer to evaporation.
- The gray component in the total virtual-water content of a product refers to the volume of polluted water.
- Evaporated water and polluted water have in common that they are both ‘lost’, i.e. in first instance unavailable for other uses. We say ‘in first instance’ because evaporated water may come back as rainfall above land somewhere else and polluted water may become clean in the longer term, but these are considered here as secondary effects that will never take away the primary effects.

Virtual Water – Other Key Concepts

- *Virtual water flow* – The virtual-water flow between two nations or regions is the volume of virtual water that is being transferred from one place to another as a result of product trade.
- *Virtual water export* – The virtual-water export of a country or region is the volume of virtual water associated with the export of goods or services from the country or region. It is the total volume of water required to produce the products for export.
- *Virtual water import* – The virtual-water import of a country or region is the volume of virtual water associated with the import of goods or services into the country or region. It is the total volume of water used (in the export countries) to produce the products. Viewed from the perspective of the importing country, this water can be seen as an additional source of water that comes on top of the domestically available water resources.
- *Virtual water balance* – The virtual-water balance of a country over a certain time period is defined as the net import of virtual water over this period, which is equal to the gross import of virtual water minus the gross export. A positive virtual-water balance implies net inflow of virtual water to the country from other countries. A negative balance means net outflow of virtual water.
- *Water saving through trade* – A nation can preserve its domestic water resources by importing a water-intensive product instead of producing it domestically. International trade can save water globally if a water-intensive commodity is traded from an area where it is produced with high water productivity (resulting in products with low virtual-water content) to an area with lower water productivity.

How much water (and waste) is typically flushed down a conventional toilet versus a low-flow toilet?

Conventional vs. Low Flush Toilets



Courtesy of Massachusetts Water Resources Authority. Used with permission.

Massachusetts Water Resources Authority Ultra Low Flush Toilet Fact Sheet. http://www.mwra.com/publications/ulftoilets.pdf

Conventional Toilet Flush = 3.5 gallons

Images by herzogbr on Flickr.

Low Flush Toilet: 1.6 gallon

(U.S. regulation since 1992)

Image removed due to copyright restrictions. Please see any photo of the Toto Ultramax, such as http://www.vidavici.com/ProdImages/13217.jpg

Toto UltraMax #MS854114S

Dry (Water-Less) Toilets & Urinals

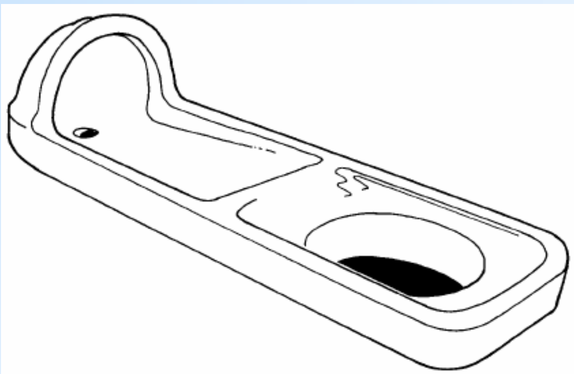
- The no-water alternatives

Ecological Sanitation

How Does It Work?

Decomposition by Dehydration

- Dry sanitation (<20% moisture)
- Addition of ash, soil, or lime
- Residence time: 6-12 months



Urine diversion
makes drying easier!

Ecosan in Kenya

Courtesy of Brian E. Robinson. Used with permission.

Nutrient Composition of Urine and Excreta

	Urine 	Feces 
Nitrogen	88 %	12 %
Phosphorus	67 %	33 %
Potassium	71 %	29 %
Wet Weight	90 %	10 %

Robinson, 2005, Adapted from Sida, 1997

What is the level of wastewater treatment at the Deer Island Wastewater Treatment Plant?

Secondary Treatment

Stages of Centralized Wastewater Treatment

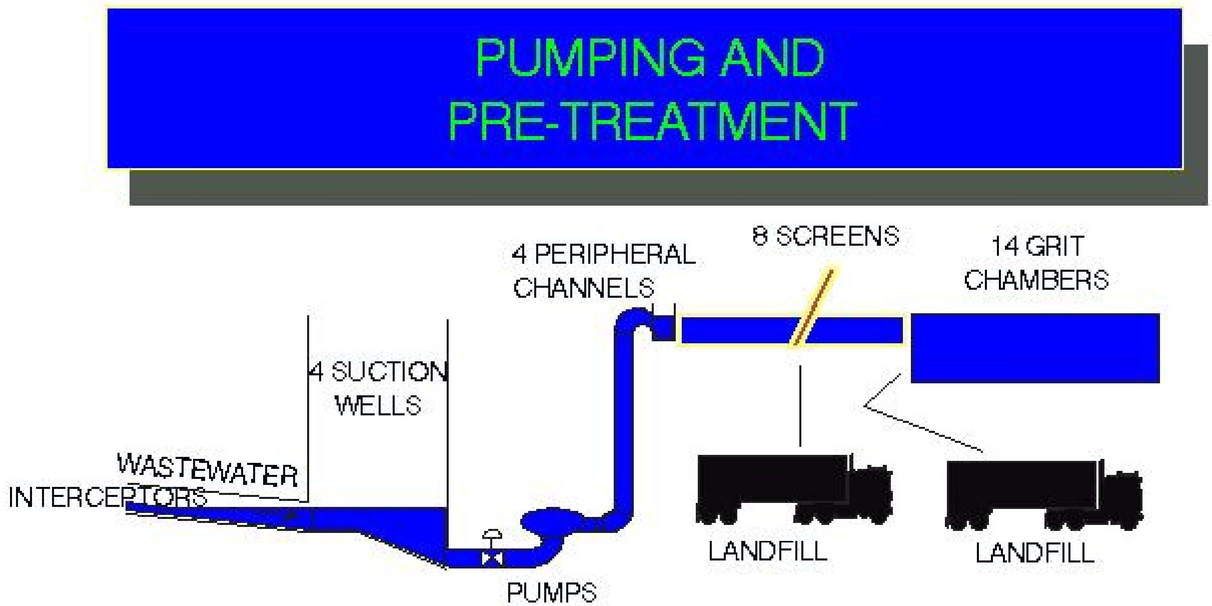
- LIQUID TREATMENT
- Preliminary Treatment
  - Physical Processes
- Primary Treatment
  - Physical processes
- *[Chemically Enhanced Primary (CEPT)]*
  - *Physical and chemical processes*
- Secondary
  - Biological processes
  - Chemical processes
- Tertiary (3rd)
  - Chemical processes
  - Biological processes

SLUDGE TREATMENT & DISPOSAL

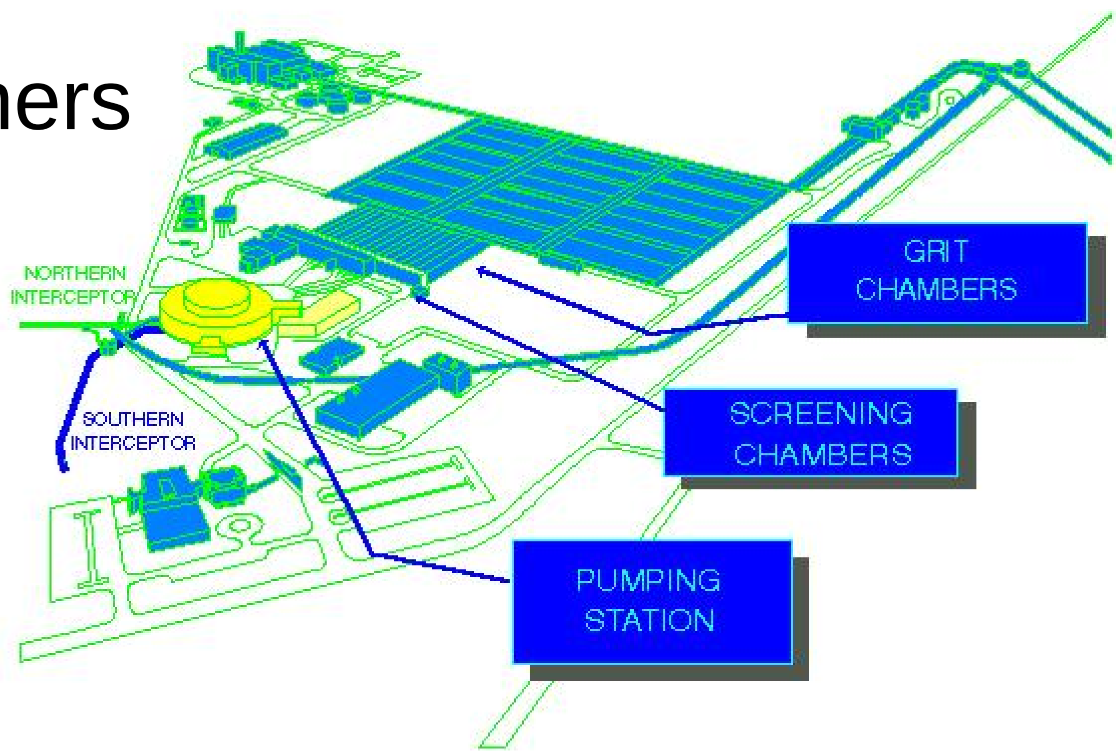
Preliminary Treatment

- Screening
- Comminutors (screeners & shredders)
- Grit Removal
- Scum Removal

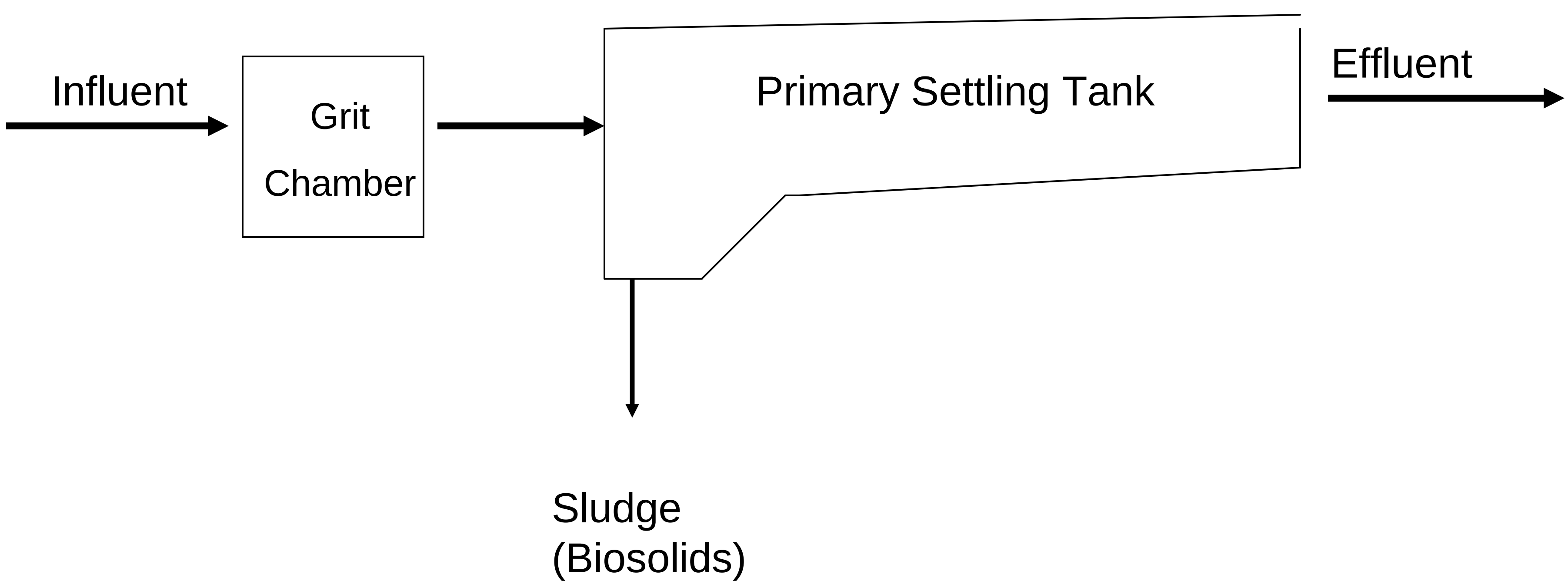
Preliminary Treatment



- Pumping
- Screening and/or comminutors (screeners & shredders)
- Grit Removal
- Scum Removal



Primary Treatment (physical settling by gravity)

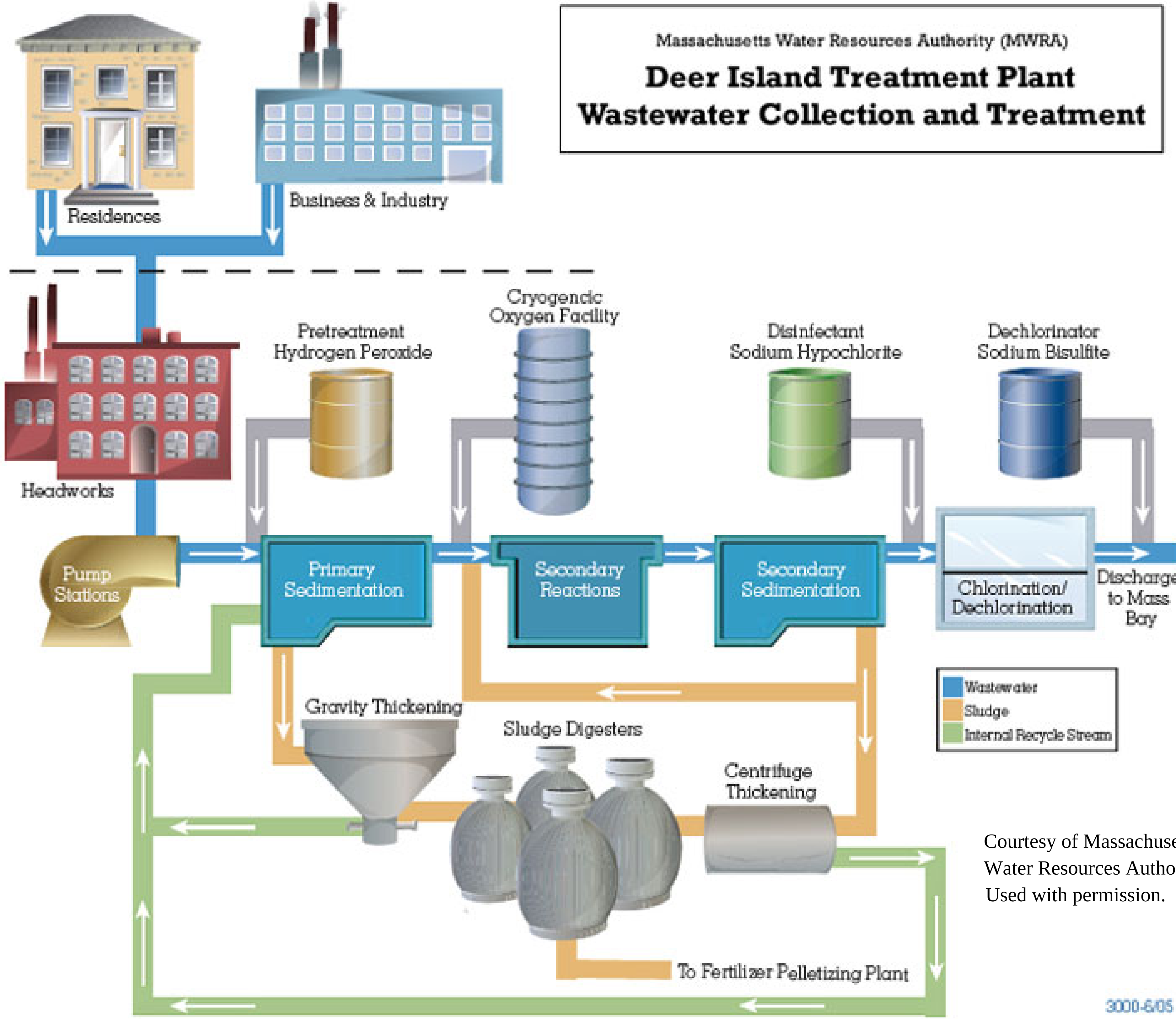


Primary Treatment – Kathmandu

Secondary Treatment

- Activated sludge
- Clarifiers
- Trickling filters (percolating filters)
- Rotating biological contactor (biodisk)

Conventional Primary + Activated Sludge Wastewater Treatment Flow Diagram



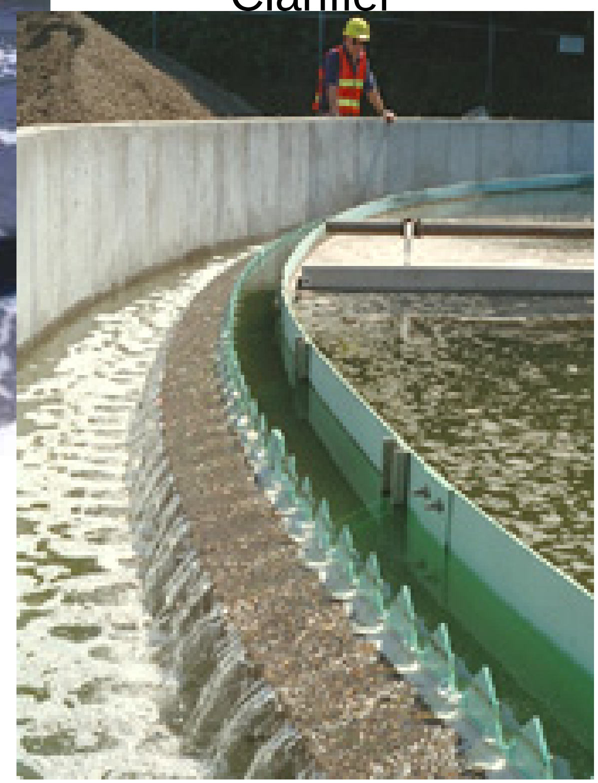
Courtesy of Massachusetts Water Resources Authority. Used with permission.

Activated Sludge

Surface Aerators in Aeration Tank

Secondary

Clarifier

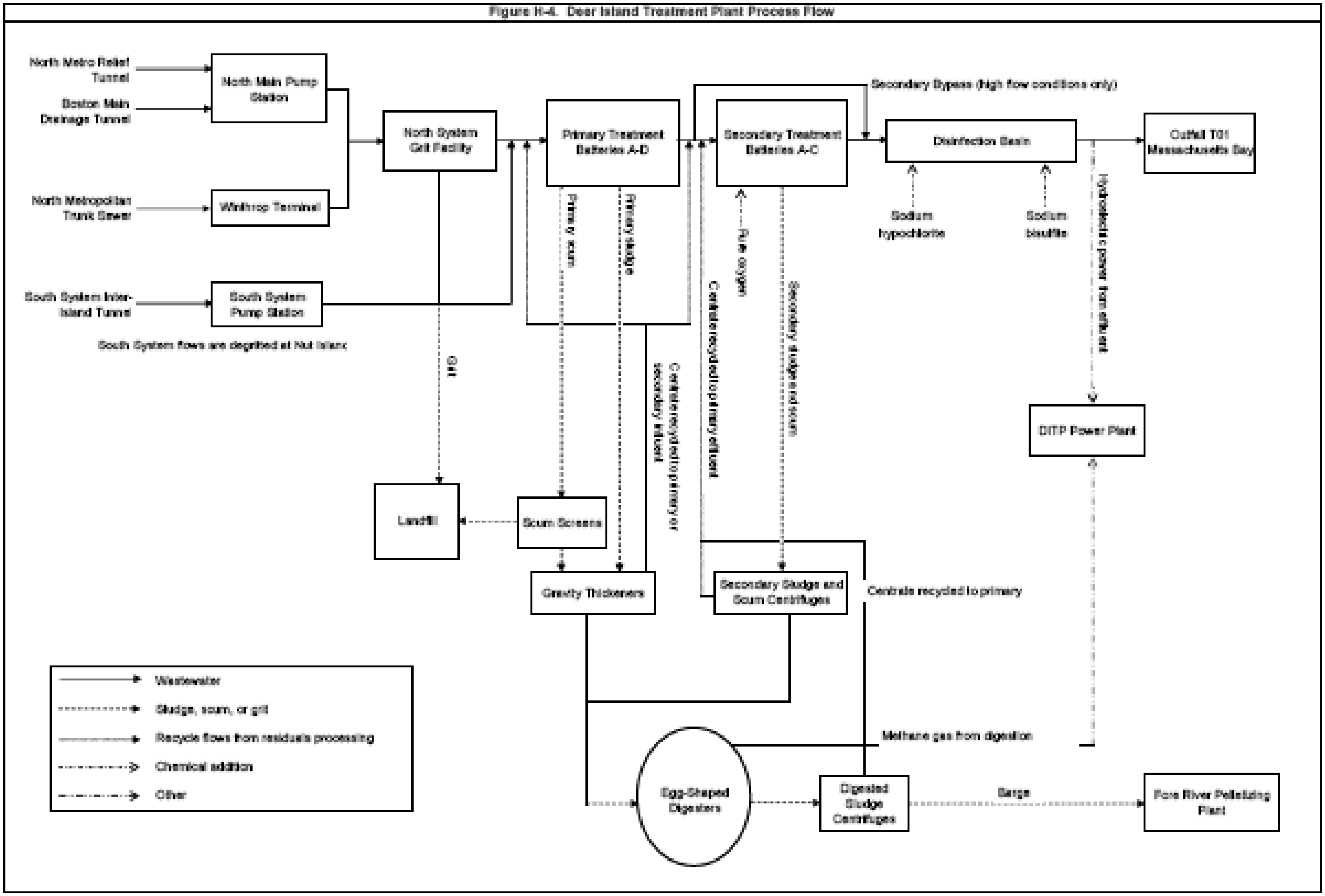


Boston's Deer Island Wastewater Treatment Plant

Deer Island Wastewater Disinfection Unit

Wastewater Effluent Discharged to Massachusetts Bay via a 14 mile outfall

MWRA - Schematic- Deer Island Wastewater Treatment Plant



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Deer Island Wastewater Treatment Plant Performance

Parameter	Theoretical % Removal for 2^{nd} Treatment	Actual % Removal at Deer Island
Total Suspended Solids	85%	94%
cBOD	85%	93%

MWRA Deer Island WWTP Performance

1994-2006

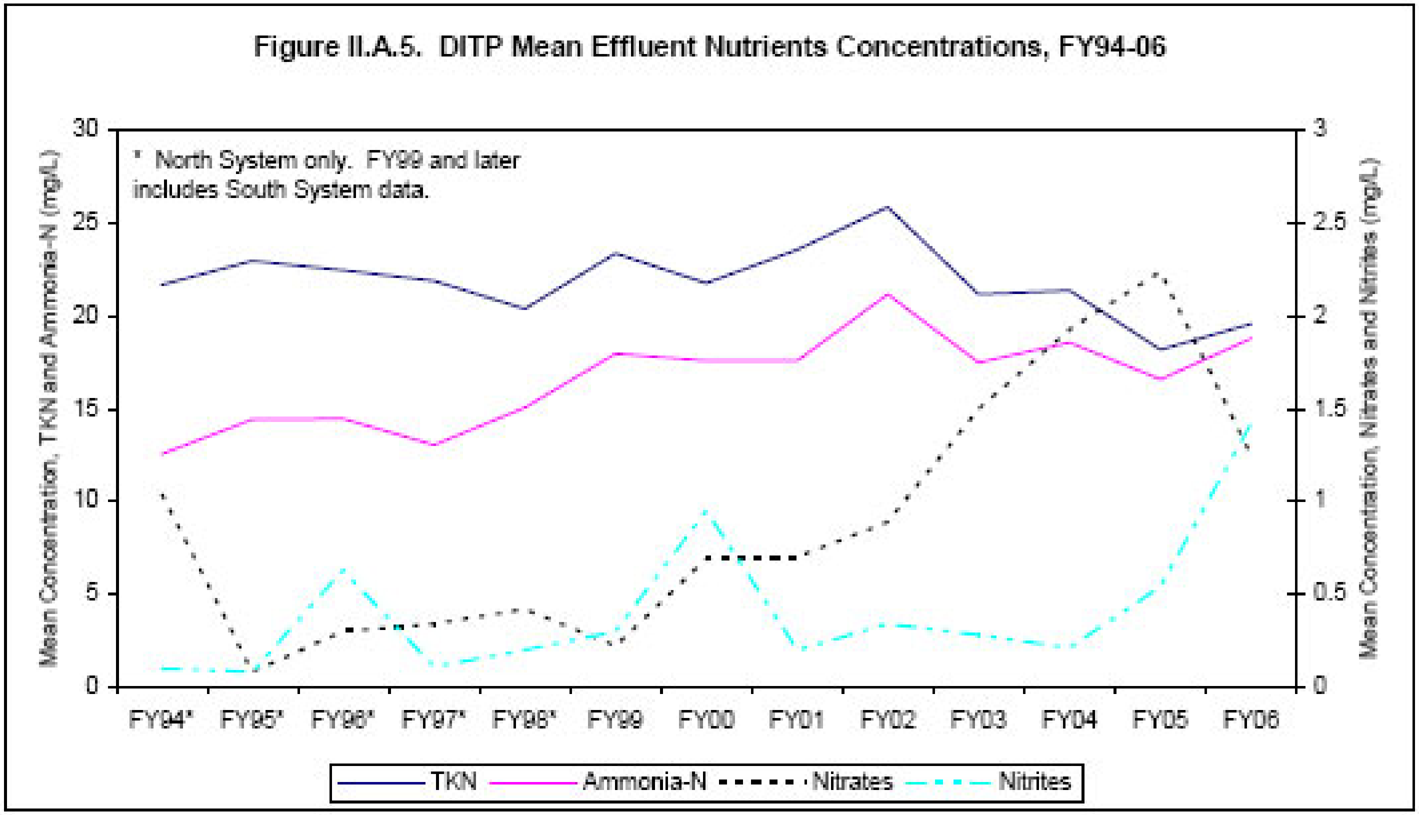
Table II.A.5. Deer Island Effluent Characterization, FY94-FY06

Parameter	FY94*	FY95*	FY96*	FY97*	FY98*	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
Flow (mgd)													
Minimum	171	167	147	167	159	237	219	260	222	238	246	243	229.4
Average	249	236	250	265	296	350	356	367	317	377	356	392	396
Maximum	528	565	526	649	917	757	900	1136	773	898	1132	871	1203
Total Suspended Solids (TSS)													
Min Conc (mg/L)	65	52	17	16	4	3	5	4	3	5	5	5	5
Avg Conc (mg/L)	73	65	44	41	25	22	18	15	16	18	17	15	9
Max Conc (mg/L)	86	90	136	100	140	69	62	47	43	132	78	62	61
Average Loading (tons/d)	52	45	27	29	17	14	26	24	21	28	25	25	16
Carbonaceous Biochemical Oxygen Demand (cBOD)													
Min Conc (mg/L)	**	**	**	**	**	**	**	4	3	3	3	2	2
Avg Conc (mg/L)	**	**	**	**	**	**	**	12	13	11	12	10	7
Max Conc (mg/L)	**	**	**	**	**	**	**	36	40	40	50	38	66
Average Loading (tons/d)	**	**	**	**	**	**	**	19	17	17	18	16	11
Settleable Solids													
Min Conc (mL/L)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Avg Conc (mL/L)	0.5	0.4	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Max Conc (mL/L)	0.9	0.7	2.0	1.6	7.0	3.0	3.1	1.9	3.0	3.0	6.0	1.2	1.0
Average Loading (tons/d)	0.4	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2
Total Kjeldahl Nitrogen													
Min Conc (mg/L)	12.8	13.7	10.6	10.9	9.1	11.2	8.2	12.2	15.1	9.7	11.0	6.6	5.8
Avg Conc (mg/L)	21.7	23.0	22.5	21.9	20.4	23.4	21.8	23.6	25.9	21.2	21.4	18.2	19.6
Max Conc (mg/L)	32.8	28.6	32.5	27.6	32.4	34.3	32.4	33.3	35.0	32.3	33.3	30.9	35.3
Average Loading (tons/d)	22.5	22.6	23.4	24.3	25.2	34.2	32.4	36.1	34.2	33.3	31.8	29.8	32.4
Ammonia-Nitrogen													
Min Conc (mg/L)	6.1	7.3	5.6	4.4	3.5	5.4	5.0	5.1	9.4	7.0	7.5	4.5	4.6
Avg Conc (mg/L)	12.6	14.4	14.5	13.1	15.1	18.0	17.6	17.6	21.2	17.5	18.6	16.6	18.8
Max Conc (mg/L)	18.5	19.6	21.9	18.0	22.7	26.4	25.2	24.9	32.0	28.0	28.0	28.7	45.2
Average Loading (tons/d)	9.0	10.0	8.9	9.1	10.0	11.9	26.2	27.0	28.0	27.5	27.6	27.1	31.0
Nitrates													
Min Conc (mg/L)	0.13	0.03	0.01	0.01	0.01	0.01	0.00	0.0	0.01	0.01	0.01	0.01	0.02
Avg Conc (mg/L)	1.04	0.08	0.30	0.34	0.42	0.22	0.69	0.7	0.89	1.50	1.93	2.24	1.25
Max Conc (mg/L)	5.98	0.28	1.95	2.58	1.49	1.93	2.96	4.2	2.86	5.07	3.88	5.77	4.8
Average Loading (tons/d)	0.74	0.06	0.18	0.23	0.28	0.15	1.03	1.1	1.2	2.4	2.9	3.7	2.1
Nitrites													
Min Conc (mg/L)	0.01	0.02	0.01	0.01	0.01	0.01	0.04	0.0	0.01	0.01	0.01	0.03	0.27
Avg Conc (mg/L)	0.10	0.08	0.63	0.11	0.20	0.30	0.95	0.2	0.34	0.28	0.21	0.54	1.42
Max Conc (mg/L)	0.26	0.22	1.90	0.62	1.15	1.99	3.06	1.1	1.26	0.91	0.69	0.71	2.74
Average Loading (tons/d)	0.07	0.06	0.39	0.08	0.13	0.20	1.41	0.3	0.4	0.4	0.3	0.9	2.3

* North System only. FY99 and later include South System data. ** Samples not collected.

MWRA Deer Island WWTP Performance

Effluent Nitrogen Concentrations 1994-2006



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Because activated sludge (2nd treatment) process uses bacteria to breakdown wastes, it changes nutrient concentrations. Total Kjeldahl nitrogen (TKN) consists of NH3-N plus organic nitrogen. Increased levels of NH3-N are characteristic of the activated sludge process, while TKN is relatively stable.

MWRA

National Pollutant Discharge Elimination Standards (NPDES) Permit Testing Requirements

Table J-2. NPDES Permit Application Testing Requirements
40 CFR 122, Appendix D, Tables II and III

Volatile Organics	Organic Pesticides	Organic Base/Neutrals
acrolein acrylonitrile benzene bromoform carbon tetrachloride chlorobenzene chlorodibromomethane chloroethane 2-chloroethylvinyl ether chloroform dichlorobromomethane 1,1-dichloroethane 1,2-dichloroethane 1,1-dichloroethylene 1,2-dichloropropane 1,3-dichloropropylene ethyl benzene methyl bromide methyl chloride methylene chloride 1,1,2,2-tetrachloroethane tetrachloroethylene toluene 1,2-trans-dichloroethylene 1,1,1-trichloroethane 1,1,2-trichloroethane trichloroethylene vinyl chloride	aldrin alpha-BHC beta-BHC gamma-BHC delta-BHC chlordane 4,4'-DDT 4,4'-DDE 4,4'-DDD dieldrin alpha-endosulfan beta-endosulfan endosulfan sulfate endrin endrin aldehyde heptachlor heptachlor epoxide PCB-1242 PCB-1254 PCB-1221 PCB-1232 PCB-1248 PCB-1260 PCB-1016 toxaphene	acenaphthene acenaphthylene anthracene benzidine benzo(a)anthracene benzo(a)pyrene 3,4-benzofluoranthracene benzo(ghi)perylene benzo(k)fluoranthene bis(2-chloroethoxy)methane bis(2-chloroethyl)ether bis(2-ethylhexyl)phthalate 4-bromophenyl phenyl ether butylbenzyl phthalate 2-chloronaphthalene 4-chlorophenyl phenyl ether chrysene dibenzo(a,h)anthracene 1,2-dichlorobenzene 1,3-dichlorobenzene 1,4-dichlorobenzene 3-3'-dichlorobenzidine diethyl phthalate dimethyl phthalate di-n-butyl phthalate 2,4-dinitrotoluene 2,6-dinitrotoluene di-n-octyl phthalate 1,2-diphenylhydrazine fluoranthene fluorene hexachlorobenzene hexachlorobutadiene hexachlorocyclopentadiene hexachloroethane indeno(1,2,3-cd)pyrene isophorone napthalene nitrobenzene N-nitrosodimethylamine N-nitrosodi-n-propylamine N-nitrosodiphenylamine phenanthrene pyrene 1,2,4-trichlorobenzene
Organic Acids	**Metals**	**Cyanide and Phenols**
2-chlorophenol 2,4-dichlorophenol 2,4-dimethylphenol 4,6-dinitro-o-cresol (2-methyl-4,6-dinitrophenol) 2,4-dinitrophenol 2-nitrophenol 4-nitrophenol p-chloro-m-cresol (4-chloro-m-cresol) pentachlorophenol phenol 2,4,6-trichlorophenol	antimony, total arsenic, total beryllium, total cadmium, total chromium, total copper, total lead, total mercury, total nickel, total selenium, total silver, total thallium, total zinc, total cyanide, total phenols, total	cyanide, total phenol, total

MWRW List of Parameters Tested

Table I-1. List of Parameters Tested

Parameter	EPA Method Number	MWRA MDL (µg/L)	MWRA QL (µg/L)
Metals			
Aluminum	200.7	90	<90
Antimony	200.7	0.8	<0.9
Arsenic	206.2	0.8	<0.8
	200.7	43.8	<45
Beryllium	200.7	0.3	<0.5
Boron	200.7	9.5	<250
Cadmium	200.7	1.1	<2
	213.2	.03	<0.03
Chromium	200.7	4.0	<4
	218.2	0.7	<0.7
Copper	200.7	10.5	<10
	220.2	0.6	<1
	200.8	[1]	[1]
Hexavalent Chromium	SM 3500-CR D[2]	1.8	<5
Iron	200.7	[3]	<30
Lead	200.7	12.0	<15
	239.2	2.4	<2.4
Mercury	245.2	0.01	<0.01
	1631	[1]	[1]
Molybdenum	200.7	3.4	<5
	246.2	1.2	<1
Nickel	200.7	3.0	<3
	249.2	0.7	<0.7
Selenium	200.7	48.2	<50
	270.2	0.9	<0.9
Silver	200.7	1.4	<2
	272.2	0.09	<0.09
Thallium	200.7	58.3	<60
	279.2	1.0	<1
Zinc	200.7	5.7	<6
Other Inorganic Chemicals[4]			
Cyanide	335.2	0.004	<0.01
Fats, Oil, and Grease (mg/L)	1664A	2.0	<7
Petroleum hydrocarbons (mg/L)		[1]	[1]
Phenol (mg/L)	420.2 MO	0.003	<0.01
Sulfate (mg/L)	300.0	0.2	<1
Total Organic Carbon (mg/L)	415.1	0.06	<0.3
Surfactants (mg/L)	425.1	0.03	<0.03
Pesticides (ng/L)			
4,4'-DDD	608	6.8	<20
4-4'-DDE	608	8.8	<20
4-4'-DDT	608	15.8	<20
Aldrin	608	3.5	<20
alpha-BHC	608	6.3	<20
alpha-Chlordane	608	3.6	<20
beta-BHC	608	6.3	<20
Chlordane (Technical)	608	[1]	[1]
delta-BHC	608	6.7	<20
Dieldrin	608	5.5	<20
Endosulfan I	608	5.3	<20
Endosulfan II	608	4.0	<20
Endosulfan sulfate	608	16.7	<20
Endrin	608	13.7	<20
Endrin aldehyde	608	9.1	<20
Endrin ketone	608	5.4	<20
gamma-BHC (Lindane)	608	4.2	<20
Heptachlor	608	9.7	<20
Heptachlor epoxide	608	6.8	<20
Hexachlorobenzene	612	[1]	[1]
Methoxychlor	608	52.0	<200
Toxaphene	608	[1]	[1]

Table I-1. List of Parameters Tested (cont.)

PCBs (all in ng/L)			
Arochlor-1016	608	31.0	<500
Arochlor-1221	608	21.0	<1000
Arochlor-1232	608	14.0	<500
Arochlor-1242	608	[1]	[1]
Arochlor-1248	608	[1]	[1]
Arochlor-1254	608	10.0	<500
Arochlor-1260	608	32.0	<500
Volatile Organics			
1,1,1-trichloroethane	624	1.0	<5
1,1,2,2-tetrachloroethane	624	1.3	<5
1,1,2-trichloroethane	624	0.6	<5
1,1-dichloroethane	624	0.8	<5
1,1-dichloroethene	624	1.3	<5
1,2-dichlorobenzene	624	0.4	<5
1,2-dichloroethane	624	0.6	<5
1,2-dichloropropane	624	0.4	<5
1,3-dichlorobenzene	624	0.5	<5
1,4-dichlorobenzene	624	0.4	<5
2-butanone	624	1.8	<5
2-chloroethylvinylether	624	0.8	<5
2-hexanone	624	1.5	<5
4-methyl-2-pentanone	624	1.3	<5
Acetone	624	16	<5
Acrolein	624	5.4	<5
Acrylonitrile	624	4.2	<5
Benzene	624	0.5	<5
Bromodichloromethane	624	0.4	<5
Bromoform	624	0.4	<5
Bromomethane	624	1.1	<5
Carbon disulfide	624	1.4	<5
Carbon tetrachloride	624	1.0	<5
Chlorobenzene	624	0.4	<5
Chloroethane	624	1.0	<5
Chloroform	624	0.5	<5
Chloromethane	624	0.7	<5
cis-1,2-dichloroethene	624	0.5	<5
cis-1,3-dichloropropane	624	0.3	<5
Dibromochloromethane	624	0.6	<5
Ethylbenzene	624	0.5	<5
m,p-xylene	624	1.4	<5
Methylene chloride	624	0.6	<5
o-xylene	624	0.5	<5
Styrene	624	0.4	<5
Tetrachloroethene	624	0.8	<5
Toluene	624	0.5	<5
trans-1,2-dichloroethene	624	1.1	<5
trans-1,3-dichloropropene	624	0.3	<5
Trichloroethene	624	1.0	<5
Trichlorofluoromethane	624	0.8	<5
Vinyl acetate	624	0.8	<5
Vinyl chloride	624	1.0	<5
Semi-Volatiles			
1,2,4-trichlorobenzene	625	6.1	<10
1,2-dichlorobenzene	625	3.7	<10
1,2-diphenylhydrazine	625	8.7	<10
1,3-dichlorobenzene	625	2.9	<10
1,4-dichlorobenzene	625	3.2	<10
2,2'-oxybis(1-chloropropane)	625	3.9	<10
2,4,5-trichlorophenol	625	8.4	<10
2,4,6-trichlorophenol	625	9.6	<10
2,4-dichlorophenol	625	9.0	<10
2,4-dimethylphenol	625	8.1	<10
2,4-dinitrophenol	625	12.4	<20

MWRA List of Parameters Tested (cont…)

Table I-1. List of Parameters Tested (cont.)

Semi-Volatiles (cont.)			
2,4-dinitrotoluene	625	7.6	<10
2,6-dinitrotoluene	625	10.0	<10
2-chloronaphthalene	625	9.2	<10
2-chlorophenol	625	4.2	<10
2-methyl-4,6-dinitrophenol	625	7.9	<100
2-methylnaphthalene	625	4.5	<10
2-methylphenol	625	7.5	<10
2-nitroaniline	625	6.9	<10
2-nitrophenol	625	6.2	<10
3-3'-dichlorobenzidine	625	8.4	<20
3-nitroaniline	625	8.6	<10
4-bromophenyl phenyl ether	625	7.8	<10
4-chloro-3-methylphenol	625	7.4	<10
4-chloroaniline	625	8.2	<10
4-chlorophenyl phenyl ether	625	9.0	<10
4-methylphenol (includes 3-methylphenol)	625	7.2	<10
4-nitroaniline	625	8.0	<10
4-nitrophenol	625	6.3	<20
Acenaphthene	625	6.8	<10
Acenaphthylene	625	7.2	<10
Aniline	625	6.6	<10
Anthracene	625	5.8	<10
Benzidine	625	0.5	<10
Benzo(a)anthracene	625	5.4	<10
Benzo(a)pyrene	625	5.4	<10
Benzo(b)fluoranthene	625	7.8	<10
Benzo(ghi)perylene	625	6.2	<10
Benzo(k)fluoranthene	625	4.1	<10
Benzoic acid	625	7.2	<20
Benzyl alcohol	625	5.8	<10
bis(2-chloroethoxy) methane	625	6.7	<10
bis(2-chloroethyl) ether	625	4.1	<10
bis(2-ethylhexyl) phthalate	625	4.9	<10
Butyl benzyl phthalate	625	6.6	<10
Chrysene	625	6.2	<10
di-n-butylphthalate	625	5.4	<10
di-n-octylphthalate	625	4.6	<10
Dibenzo(a,h)anthracene	625	5.2	<10
Dibenzofuran	625	6.8	<10
Diethyl phthalate	625	9.1	<10
Dimethyl phthalate	625	9.9	<10
Fluoranthene	625	5.1	<10
Fluorene	625	6.1	<10
Hexachlorobenzene	625	8.8	<10
Hexachlorobutadiene	625	6.2	<10
Hexachlorocyclopentadiene	625	10.7	<50
Hexachoroethane	625	3.5	<10
Indeno(1,2,3-cd) pyrene	625	6.4	<10
Isophrone	625	7.5	<10
n-nitroso-di-n-propylamine	625	3.1	<10
n-nitrosodimethylamine	625	4.3	<10
n-nitrosodiphenylamine	625	7.9	<10
Naphthalene	625	5.7	<10
Nitrobenzene	625	6.3	<10
Pentachlorophenol	625	6.9	<30
Phenanthrene	625	5.8	<1
Phenol	625	2.2	<20
Pyrene	625	6.0	<10

[1] Data unavailable.
[2] Standard Methods.
[3] Native concentration too high for MDL determination.
[4] Some expressed in mg/L as noted.

US EPA

126 Priority Pollutants

Courtesy of Massachusetts Water Resources Authority. Used with permission.

Table J-1. EPA List of 126 Priority Pollutants

Chlorinated Benzenes Chlorobenzene 1,2-dichlorobenzene 1,3-dichlorobenzene 1,4-dichlorobenzene 1,2,4-trichlorobenzene Hexachlorobenzene	**Chlorinated Ethanes** Chloroethane 1,1-dichloroethane 1,2-dichloroethane 1,1,1-trichloroethane 1,1,2,2-tetrachloroethane Hexachloroethane	**Chlorinated Phenols** 2-chlorophenol 2,4-dichlorophenol 2,4,6-trichlorophenol Parametachlorocresol (4-chloro-3-methyl phenol)
DDT and Metabolites 4,4-DDT 4,4-DDE (p,p-DDX) 4,4-DDD (p,p-DDE)	**Haloethers** 4-chlorophenyl phenyl ether 2-bromophenyl phenyl ether Bis(2-chloroisopropyl) ether	**Halomethanes** Methylene chloride (dichloromethane) Methyl chloride (chloromethane) Methyl bromide (bromomethane) Bromoform (tribromomethane) Dichlorobromomethane Chlorodibromomethane
Inorganics Antimony Arsenic Asbestos Beryllium Cadmium Chromium (III) Chromium (VI) Copper Cyanide, total Lead Mercury Nickel Selenium Silver Thallium Zinc	**Nitroamines** N-nitrosodimethylamine N-nitrosodiphenylamine N-nitrosodi-n-propylamine	**Pesticides and Metabolites** Aldrin Dieldrin Chlordane (technical mixture and metabolites) Alpha-endosulfan Beta-endosulfan Endosulfan sulfate Endrin Endrin aldehyde Heptachlor Heptachlor epoxide (BHC-hexachlorocyclohexane) Alpha-BHC Beta-BHC Gamma-BHC (Lindane) Delta-BHC Toxaphene
Phenols (other than chlorinated) 2-nitrophenol 4-nitrophenol 2,4-dinitrophenol 4,6-dinitro-o-cresol (4,6-dinitro-2-methylphenol) Pentachlorophenol Phenol 2,4-dimethylphenol	**Phthalate Esters** Bis(2-ethylhexyl)phthalate Butyl benzyl phthalate Di-n-butyl phthalate Di-n-octyl phthalate Diethyl phthalate Dimethyl phthalate	**Polychlorinated Biphenyls (PCBs)** PCB-1242 (Arochlor 1242) PCB-1254 (Arochlor 1254) PCB-1221 (Arochlor 1221) PCB-1232 (Arochlor 1232) PCB-1248 (Arochlor 1248) PCB-1260 (Arochlor 1260) PCB-1016 (Arochlor 1016)
Polynuclear Aromatic Hydrocarbons (PAHs) Acenaphthene 1,2-benzanthracene (benzo(a)anthracene) Benzo(a)pyrene (3,4-benzo-pyrene) 3,4-benzofluoranthene (benzo(b)fluoranthene) 11,12-benzofluoranthene (benzo(k)fluoranthene) Chrysene Acenaphthylene Anthracene 1,12-benzoperylene (benzo(ghi)perylene) Fluorene Fluoranthene Phenanthrene 1,2,5,6-dibenzanthracene (dibenzo(a,h)anthracene) Indeno (1,2,3-cd) pyrene (2,3-o-phenylene pyrene) Pyrene	**Other Chlorinated Organics** Chloroform (trichloromethane) Carbon tetrachloride (tetrachloromethane) Bis(2-chloroethoxy)methane Bis(2-chloroethyl)ether 2-chloroethyl vinyl ether (mixed) 2-chloronaphthalene 3,3'-dichlorobenzidine 1,1-dichlorethylene 1,2-trans-dichloroethylene 1,2-dichloropropane 1,2-dichloropropylene (1,3-dichloropropene) Tetrachloroethylene Trichloroethylene Vinyl chloride (chloroethylene) Hexachlorobutadiene Hexachlorocyclopentadiene 2,3,7,8-tetrachloro-dibenzo-p-dioxin (TCDD)	**Other Organics** Acrolein Acrylonitrile Benzene Benzidine 2,4-dinitrotoluene 2,6-dinitrotoluene Ethylbenzene Isophrone Naphthalene Nitrobenzene Toluene

When was the core technology that is used at the Deer Island Wastewater Treatment Plant first invented and installed?

1916: The first activated sludge plant was built in Worcester, England.

(Ujang & Henze, 2006)

How much do we pay per household per year for water and wastewater treatment in Boston?

Boston – Mass. Water Resources Authority (MWRA) Rates (2009)

Cost per household per year ($1,185)

- $737 = average household retail wastewater/sewer cost
- $448 = average household retail water cost

Greater Boston (MWRA) Water and Wastewater Costs

	Cost ($)
Integrated Water Supply Improvement Program	$ 1.7 billion
Deer Island Wastewater Treatment Plan	$ 3.8 billion
Total	5.5
Population served	2.25 million

Amount Spent on Water

Region	Water & San Expenditure
Madagascar	0.3% gov't expenditure, 95% on drinking water. $0.0005 per person for sanitation
Typical developing country	1%
Europe	4.5%
US & Canada	3.6%
Africa	0.2%
Middle East	0.2%

About $1 trillion per year on existing water/WW infrastructure is needed = about 1.5% of global GDP or $120 per capita

(Rogers, P. 2008 citing Booz Allen Hamilton)

Net Present Value of Urban Wastewater Treatment Options

(Total Costs = Capital + O&M)*

	Cost ($\$/m^3$)
Primary	0.14 – 0.17
CEPT	0.17 – 0.21
Primary + Secondary	0.28 – 0.35
Tertiary (Nutrient Removal)	0.40 – 0.75
Tertiary + Hi Lime + GAC	0.90 – 1.1
Tertiary + Hi Lime + GAC + Reverse Osmosis	1.4 – 1.7

* Assumes 20 year project life and interest rate of 8%. Land costs not included.
(National Research Council, 1993)

Cost of Water Treatment - MWRA

- 10 year $1.7 Billion Integrated Water Supply Improvement Program
  - $700 million (est.) for MetroWest Tunnel
  - $370 million (est.) for Carroll Treatment Plant
  - $200 million (est.) for Covered Storage
  - $135 million (est.) for Land Acquisition
  - $30 million (est.) per year for Pipeline Improvements
- Overall Value of System
  - Estimated $6 billion in water assets
  - Estimated $6 billion in wastewater assets

Net Present Value (NPV) costs associated with the provision of safe drinking water and sanitation (Whittington, D., 2004).

	Minimum Cost	Low Range Cost	High Range Cost
	($/m^3)	($/m^3)	($/m^3)
Opportunity Cost of Raw Water Supply	0.00[a]	0.05	0.20
Storage and Transmission to Treatment Plant	0.10[b]	0.15	0.20
Treatment to Drinking Water Standards	0.05[c]	0.15	0.20
Distribution of Water to Households	0.30[d]	0.50	0.70
Collection of Wastewater from Homes & Conveyance to WWTP	0.35[e]	0.80	1.05
WWTP (Wastewater Treatment Plant)	0.20[f]	0.30	0.50
Damages Associated with Discharge of Treated Wastewater	0.00[g]	0.05	0.20
TOTAL	**1.00**	**2.00**	**3.05**

Assumptions for minimum cost estimates: a.Steal it; b. Minimal storage; c.Simple chlorination; d.AquaTerra + PVC pipes; e.Condominial systems; f.Simple lagoon; g.No damages

Reference: Whittington, Dale. Guest Lecture to “Water and Sanitation Infrastructure Planning in Developing Countries” (11.479), MIT, Cambridge MA. April 15, 2004.

Desalinated Water Cost

- Best Reverse Osmosis plants - $0.52/m3
- Inefficient thermal plants - $2/m3 and higher

Estimates from John Lienhard,
MIT, 2.500

What are some major principles of “Blue Development” where “Blue Development” is to water/wastewater/watershed systems what “Green Development” is to environmental design generally?

“Blue Design” Principles of Water / Wastewater/Watershed System Management

- Imitate nature - close water loops
- Reduce, reuse, recycle water
- Eliminate the concept of waste – approach the state of natural systems, in which there is no waste
- Life cycle analysis of technologies and unit processes
- LEED Certification “Water Efficiency” ratings
- Energy generation – hydropower, biogas
- Energy conservation in water/wastewater systems design

- CAN YOU THINK OF OTHERS???

The Hydrologic Cycle

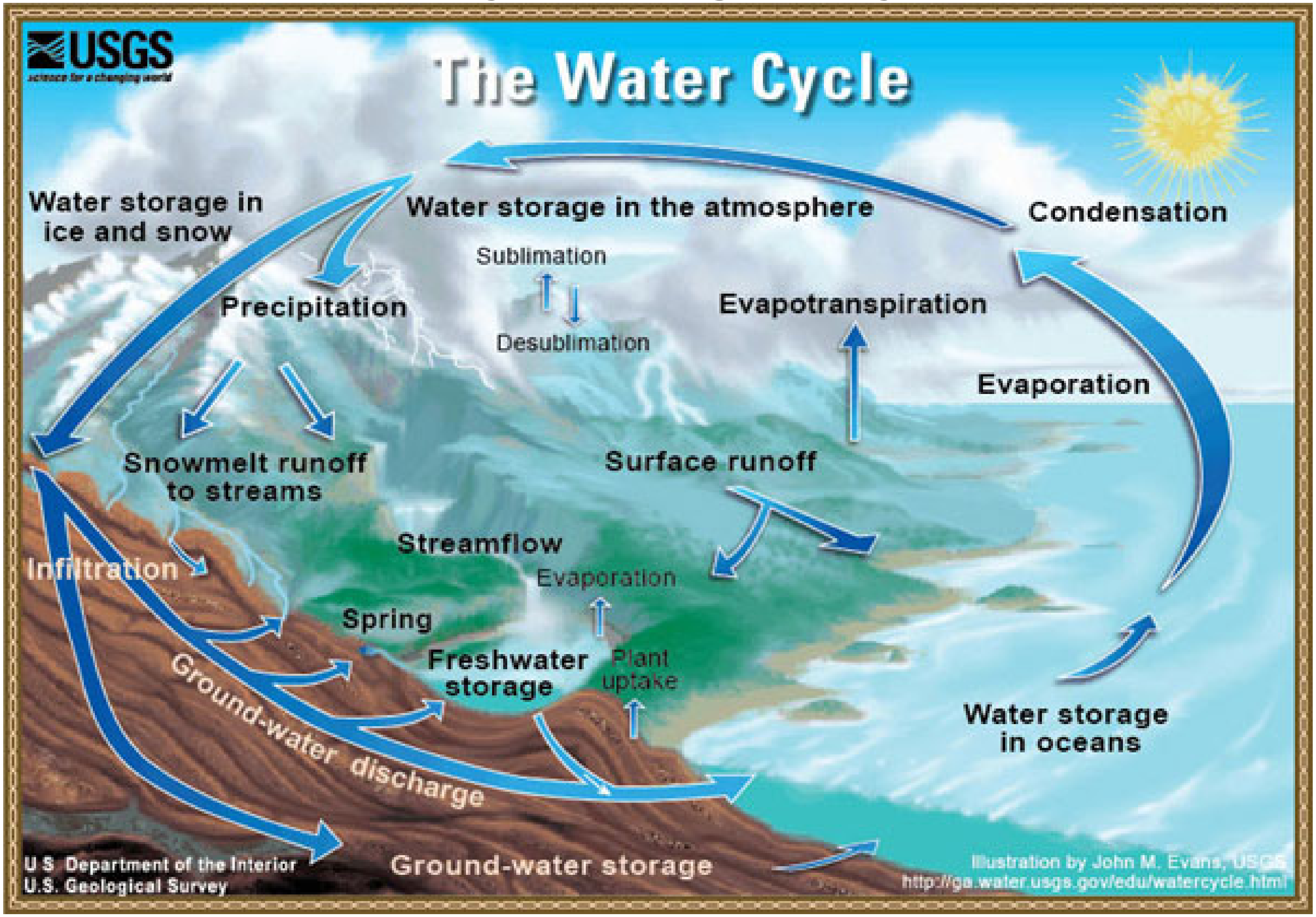


Image by John Evans, USGS.

How do we manage human water/wastewater systems in balance with hydrological and ecological systems

Conventional Industrialized Sanitation

Linear Flow

Images removed due to copyright restrictions: a straight line arrow goes from a sewer outfall, to a wastewater treatment plant, to a body of water where effluent is discharged.

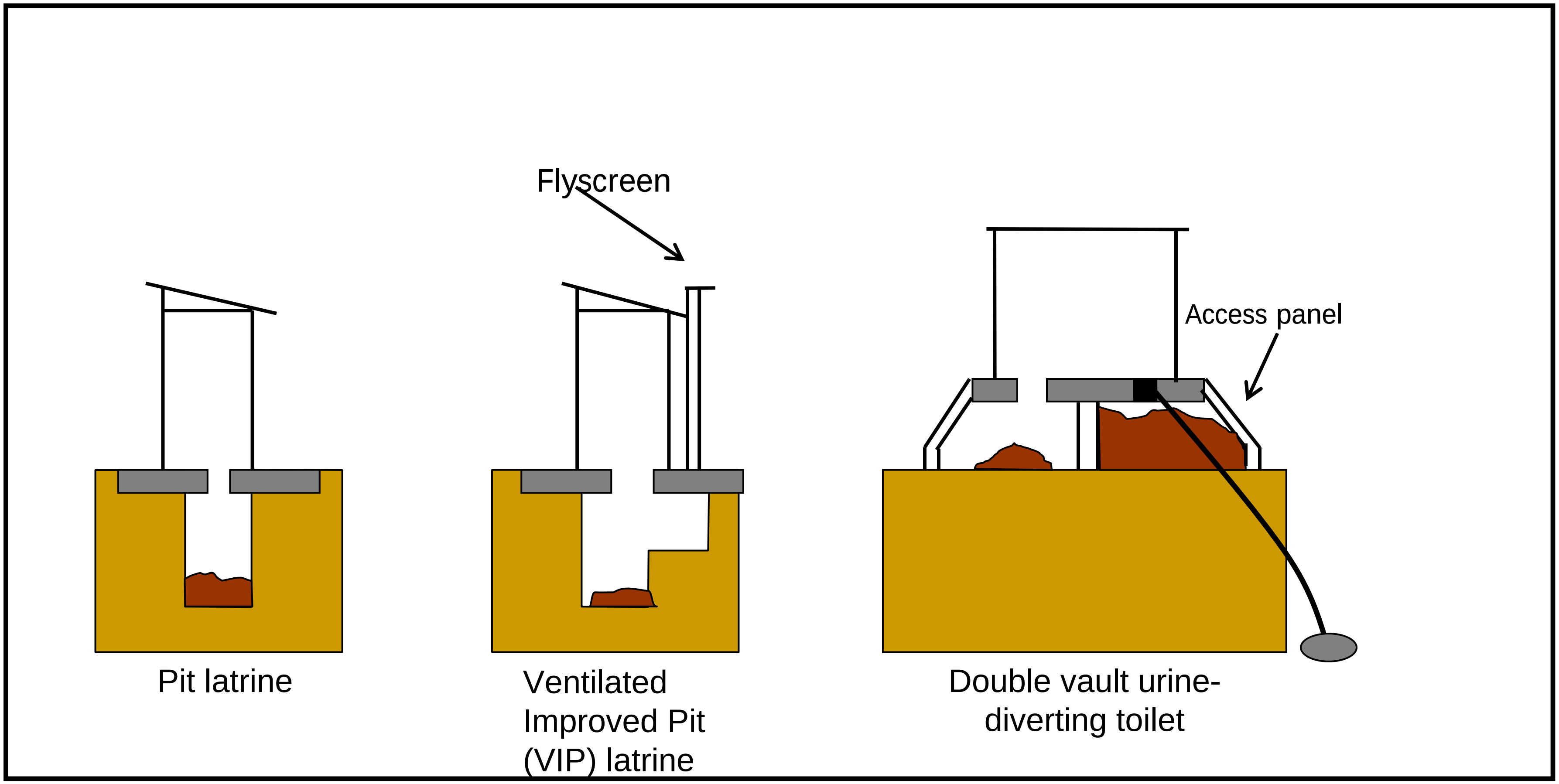
(Slide by Brian Robinson)

Ecological Sanitation, ("Sustainable Sanitation")

"Closed Loop"

Images removed due to copyright restrictions: two arrows in a loop, connecting a drawing of an outhouse, crop fields fertilized with human waste, and fully grown corn.

Progressive Improvements in On-site Dry Sanitation Options



Slide courtesy of Christine Moe, Guest Lecture, MIT 4-28-09

WATER AND WASTEWATER TECHNOLOGY, Hammer and Hammer, 6th ed.

Image removed due to copyright restrictions. Please see:
The inside cover of Hammer, Mark J. Sr., and Mark J. Hammer, Jr.
Water and Wastewater Technology. Upper Saddle River, NJ: Pearson/Prentice Hall, 2008.

Slide courtesy of Peter Rogers

MIT Guest Lecture

"Water & Sanitation Infrastructure in Developing Countries

April 23, 2009

Water Efficiency (Leed v3, 2009)
New Construction & Major Renovation

• Water Use Reduction	Required
• Water Efficient Landscaping	2 - 4
– Reduce by 50%	2
– No potable water use or irrigation	4
• Innovative Wastewater Treatment	2
• Water Use Reduction	2 - 4
– Reduce by 30%	2
– Reduce by 35%	3
– Reduce by 40%	4

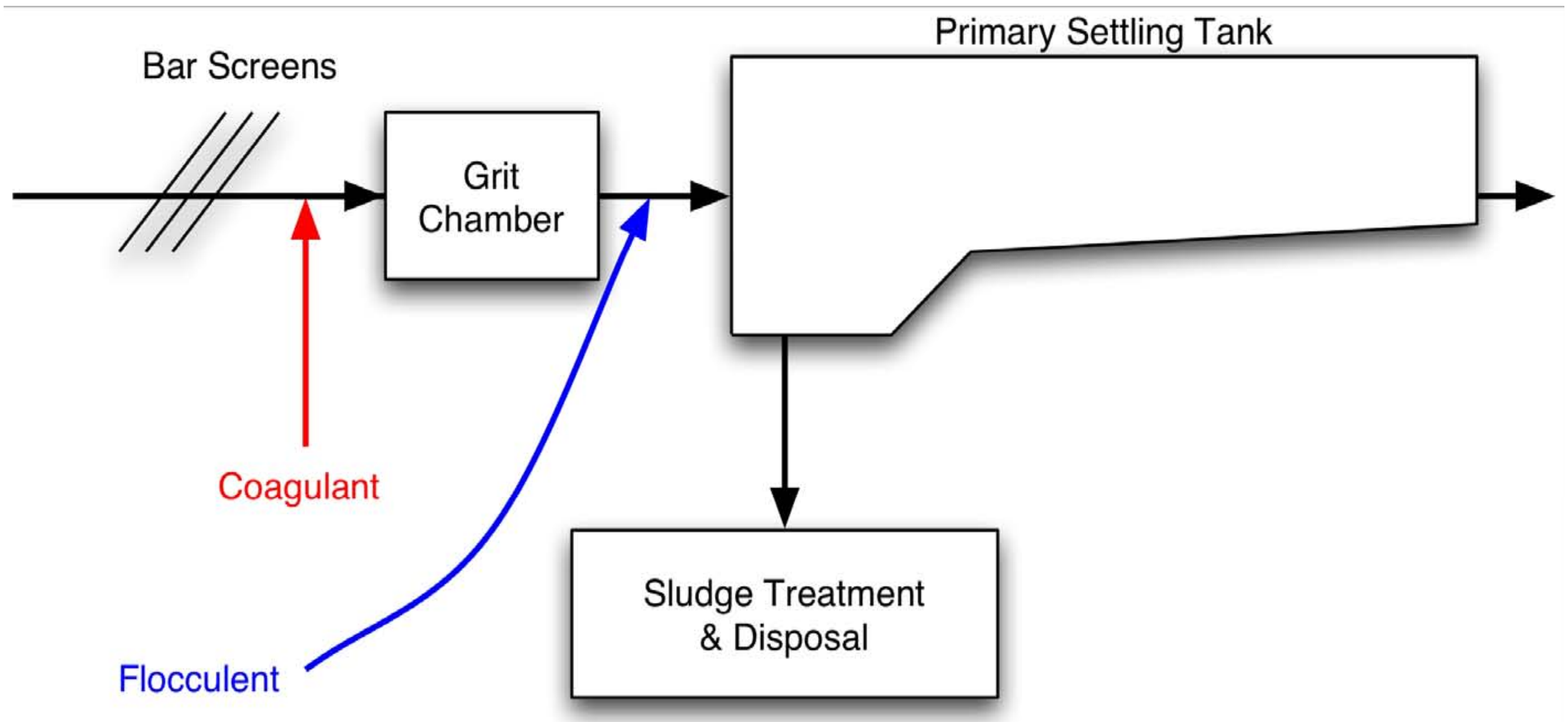
Chemically Enhanced Primary Treatment

Slides courtesy of D.Harlemen, F. Chagnon and S. Murcott

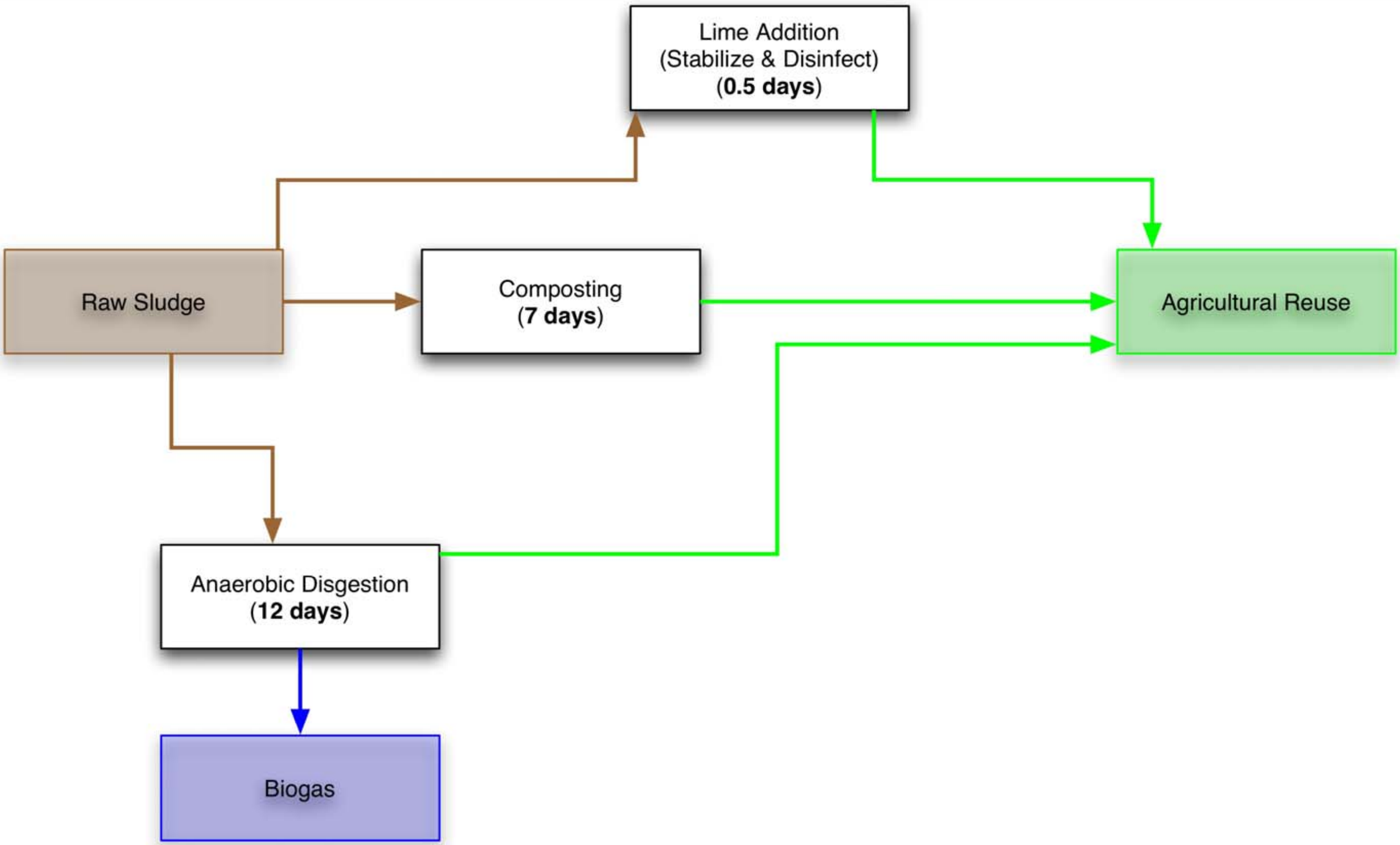
What is Chemically Enhanced Primary Treatment?

- Low dose of metal salts (e.g., FeCl3 or AlSO4) added to primary treatment stage.
- Possible (optional) addition of organic polymer
- Coagulation and flocculation form larger particles that causes enhanced settling.
- Higher rate (“surface overflow rate), hence more water can go through faster, hence smaller plant footprint
- Simple, low-cost, low-tech
- Effluent can be effectively disinfected

CEPT Schematic



CEPT Sludge



Lime Addition
(Stabilize & Disinfect)
(0.5 days)
Raw Sludge
Composting
(7 days)
Agricultural Reuse
Anaerobic Disgestion
(12 days)
Biogas

Sludge Reuse Example

1. Sludge removal is ~10% more than solids removed (1/3 in form of ferric phosphate precipitate, and 2/3 in form of ferric hydroxide precipitate)
2. CEPT sludge has a 4~6% solids content
3. Lime stabilization/disinfection (2 hours contact time at a pH>12)
4. Gravity thickening
5. Sludge drying beds
6. Agricultural application

Bench-Scale CEPT

Courtesy of Donald Harleman and Frederic Chagnon. Used with permission.

Coagulation / Flocculation

- Coagulation / flocculation is standard practice in municipal drinking water treatment plants

- Extensive research at MIT in the 1980s and 1990s led to “CEPT.”

Advantages of CEPT as 1st Stage Treatment

- 1. Rate: 2x-3x conventional primary surface overflow rate reduces size of subsequent treatment

- 2. Performance
  - Intermediate performance between primary treatment and secondary biological treatment. Almost identical secondary treatment removal efficiencies for TSS, but intermediate efficiencies for BOD or COD.
  - Much higher phosphorus removal than secondary treatment
  - Disinfection: CEPT effluent, unlike primary treatment effluent, can be disinfected. <u>It is the minimal level of treatment to effectively disinfect.</u>

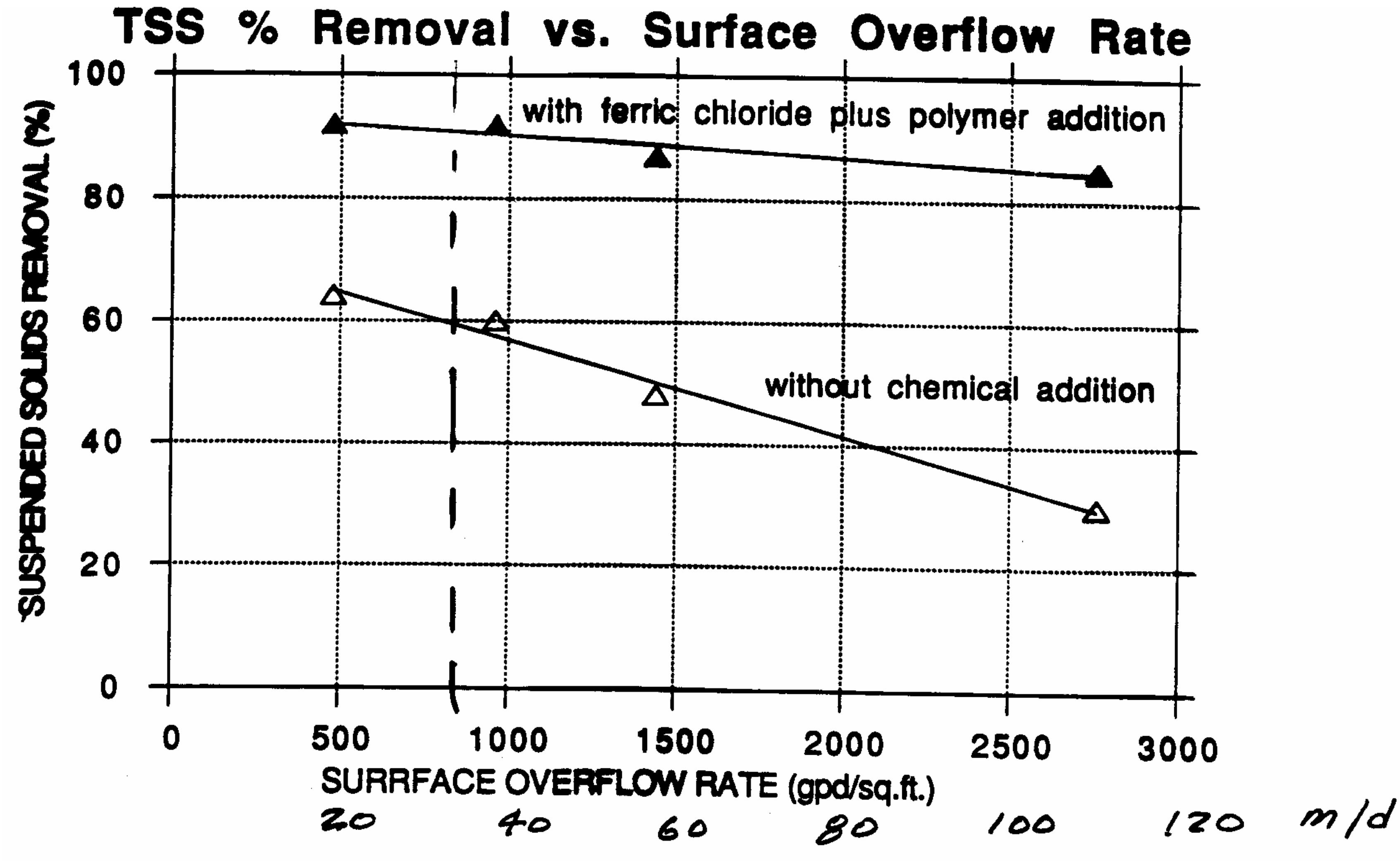
Advantages of CEPT as a 1st Stage Treatment

- 3. Energy Savings: Large energy savings compared to secondary biological treatment
- 4. Cost – Capital and O&M costs for CEPT are 55% the cost of conventional primary + activated sludge secondary treatment, including sludge handling (based on Mexico City data)

OVERFLOW RATE

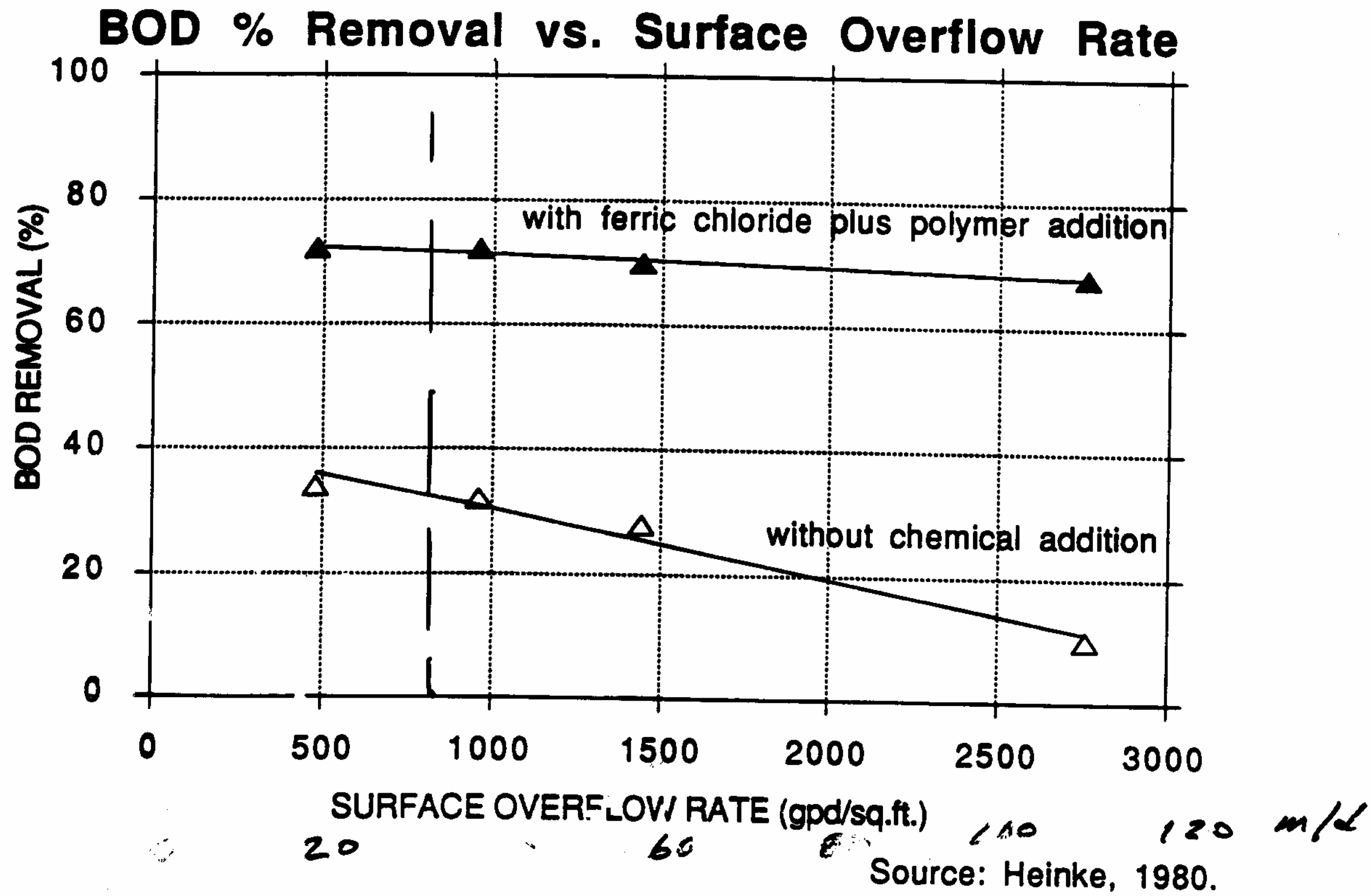
ADVANTAGE

CEPT: TSS vs. Overflow Rate



Courtesy of Donald Harleman and Frederic Chagnon. Used with permission.

CEPT: BOD vs. Overflow Rate



Rate Comparisons

	Hydraulic Retention Time (hours)
Stabilization Ponds (Lagoons)	48-120
Biological Secondary Activated Sludge (Extended Aeration)	20-30
Upflow Anaerobic Sludge Blanket (UASB)	8-10
CEPT	< 2

Applications

- Existing treatment plant upgrade: Increased capacity allows inexpensive way to upgrade existing wastewater treatment plants
- New plants: able to increase the throughput and therefore, reduce the number of tanks needed (When Stonecutters Island, Hong Kong switched from conventional primary to CEPT, the number of settling tanks was reduced by 2/3rds.
- Staged Development: CEPT is an effective 1st stage of treatment. It may be followed by biological treatment if desired. Subsequent biological treatment will be smaller and more efficient because of reduced organic load and increased solubility of the CEPT effluent

PERFORMANCE

ADVANTAGE

Level of Treatment and Results

Treatment Type	TSS % Removed	BOD % Removed	P % Removed	Sludge Produced (Dry wt./day)
Primary*	55%	30%	38%	**X**
CEPT (date from previous slide)	81%	60%	87%	1.33 **X** (TSS) 0.12 **X** (Chemicals) 1.45 **X** (Total)
Primary + Activated Sludge*	85%	85%	38%	1.42 **X** (TSS) 0.48 **X** (New biomass) 1.90 **X** (Total)

From: National Research Council (1993): Averages based on a survey of > 100 US public municipal wastewater treatment plants

Removal of Contaminants with CEPT: USA, Canada, Norway

	Flow (M. m3/day)	TSS%	BOD%	P%	Toxics %
Los Angeles-Hyperion	1.4	83	52	80	
Los Angeles – JWPCP	1.5	78	42		
Orange Cty #1	0.2	65	38		
Orange Cty #2	0.7	71	47		
San Diego – Pt. Loma	0.7	80	57	80	
Tacoma, WA	0.02	96	85	90	73
Sarnia, Canada	0.04	80	50		
Oslo, Norway	0.4	92	85	95	
Norway (ave. of 23 plants)		84	81	90	
AVERAGE	**0.6**	**81**	**60**	**87**	**73**

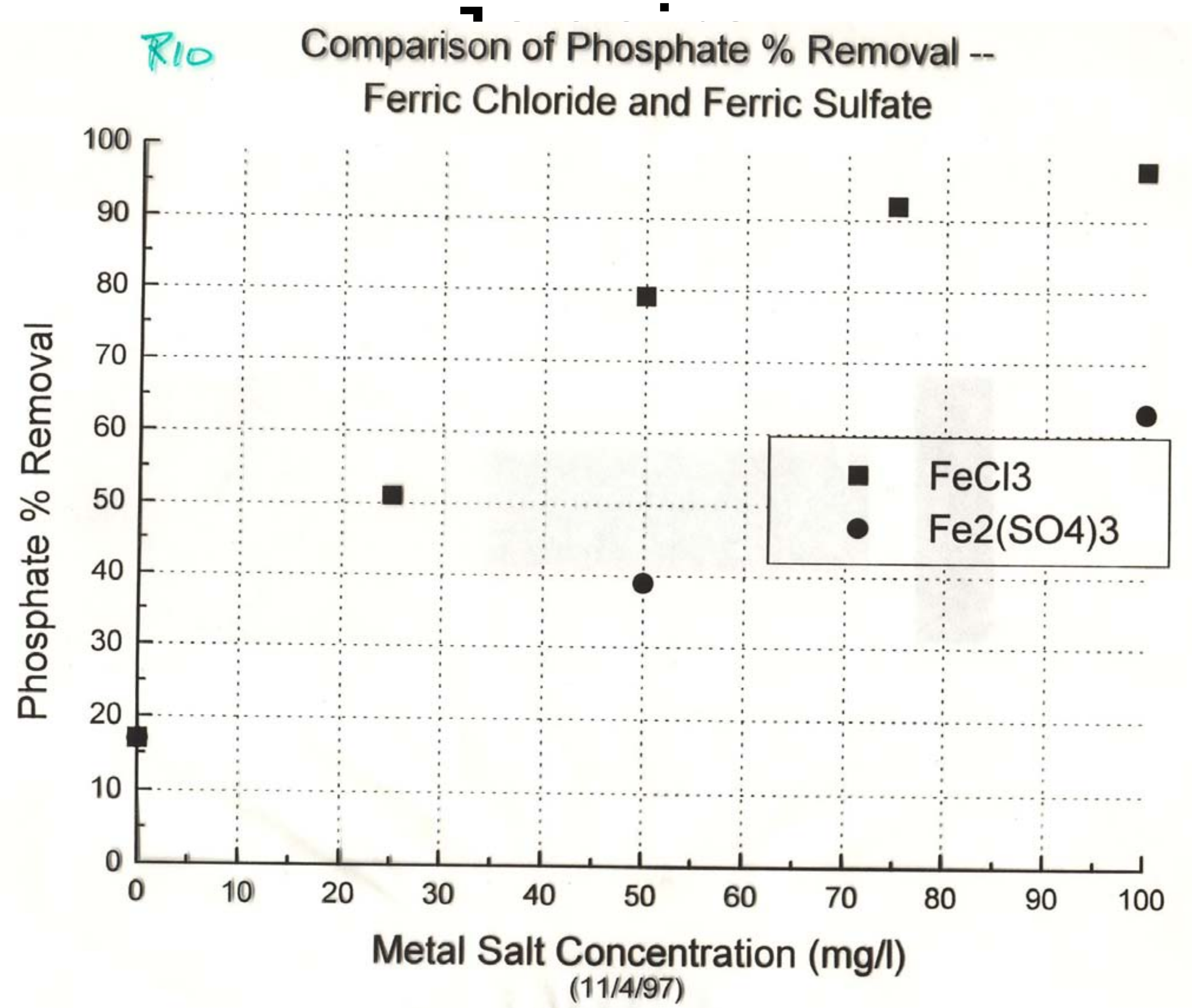
TSS Performance vs. Cost

Image removed due to copyright restrictions.

Please see Fig. D.4a in *Managing Wastewater in Coastal Urban Areas*.

Washington, DC: National Academies Press, 1993.

Phosphate Removal in Rio de Janeiro



ENERGY

ADVANTAGE

Wastewater Treatment & Energy Use

- US publicly owned wastewater treatment works (POTWs) are **net consumers of energy**. They consume 0.32 % of total national energy use, or about 4% of total national electricity use.
- Wastewater treatment works typically account for 15% or more of a municipality's energy budget.
- Inefficiencies means that there are significant opportunities for energy conservation and demand-side management.

Primary and Secondary Energy

- Primary energy is the energy employed in operation of a facility, such as electricity used in various processes, heat. The major primary energy sources are electric power, natural gas, diesel fuel, gasoline.
- Secondary energy is the energy needed in the manufacture of materials to construct the facility, the construction itself, and the energy associated with chemical use, labor, transportation.

Wastewater Treatment & Energy Use

- The energy use associated with operating a wastewater treatment plant depends on the level of treatment, plant size, location, pumping needs and other factors.
- <u>Pumping</u> is often the largest energy consuming process.
- <u>Aeration</u> also consumes huge amounts of energy

Kwh/Million Gallons Treated for Urban Water/Wastewater - California

California Energy Commission, 2005 CE-700-2005-001-SF

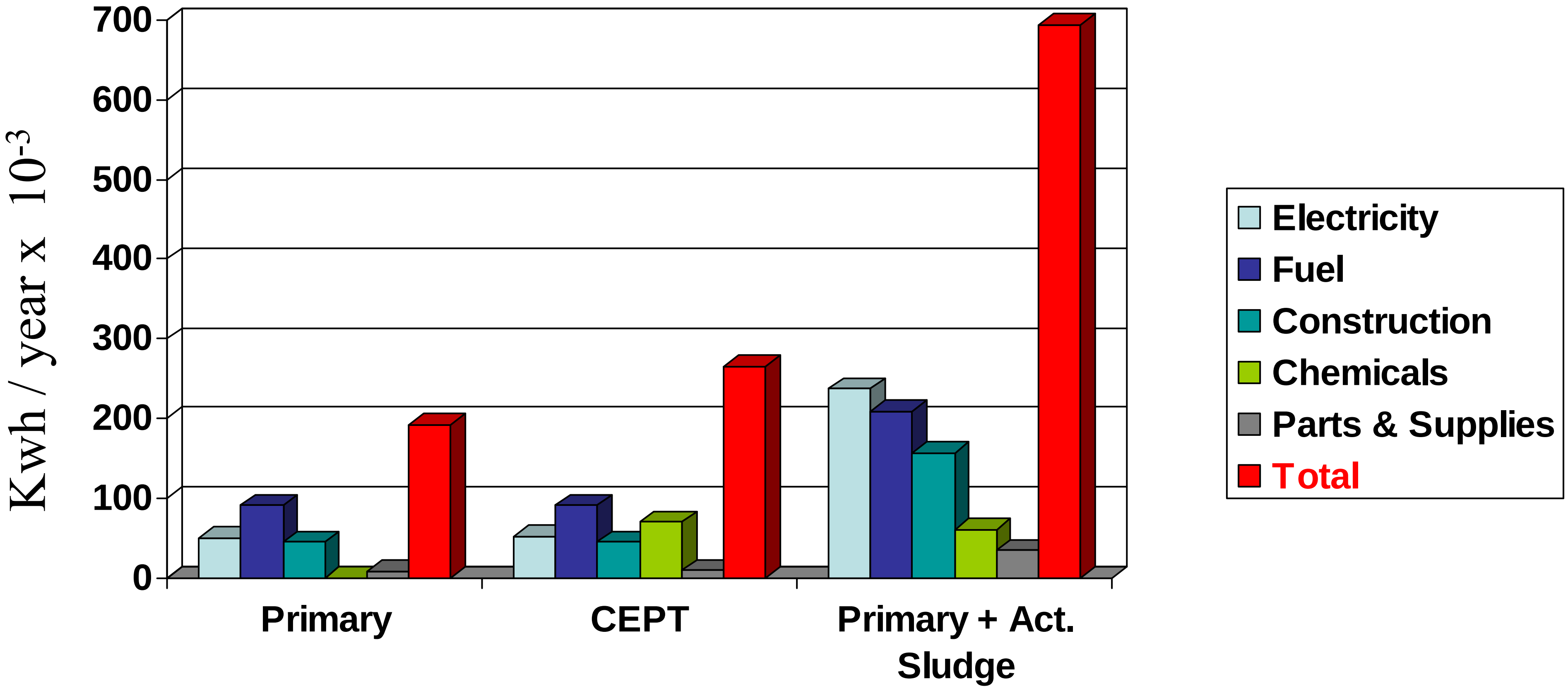
	North		South	
Supply & Conveyance	150	(4%)	8,900	(70%)
Water Treatment	100	(3%)	100	(1%)
Water Distribution	1,200	(30%)	1,200	(9%)
Wastewater Treatment*	2,500	(63%)	2,500	(20%)
Total	3,950	(100%)	12,700	(100%)

* Mainly for aeration in biological secondary treatment

Energy Usage for 3 Treatment Systems

for a 4,000 m3/day plant

(kwh / yr x 10^{-3})



(Adapted from Tchobanoglous, 1985)

COST

ADVANTAGE

Mexico City Cost Comparison

	Construction (US$/Capita)	O&M (US$/yr/capita)
Primary Treatment	*10*	*0.1*
CEPT	*5.5*	*1.3*
TOTAL CEPT	**56.3**	**3.5**
TOTAL Primary + 2nd Biological Act. Sl.	**103.9**	**5.7**

Per capita costs based on estimate of 1.5M people served

Examples

CEPT Treatment Plants

or

CEPT Pilot Treatment Plant Studies

Hong Kong Stonecutters Island

Courtesy of Donald Harleman and Frederic Chagnon. Used with permission.

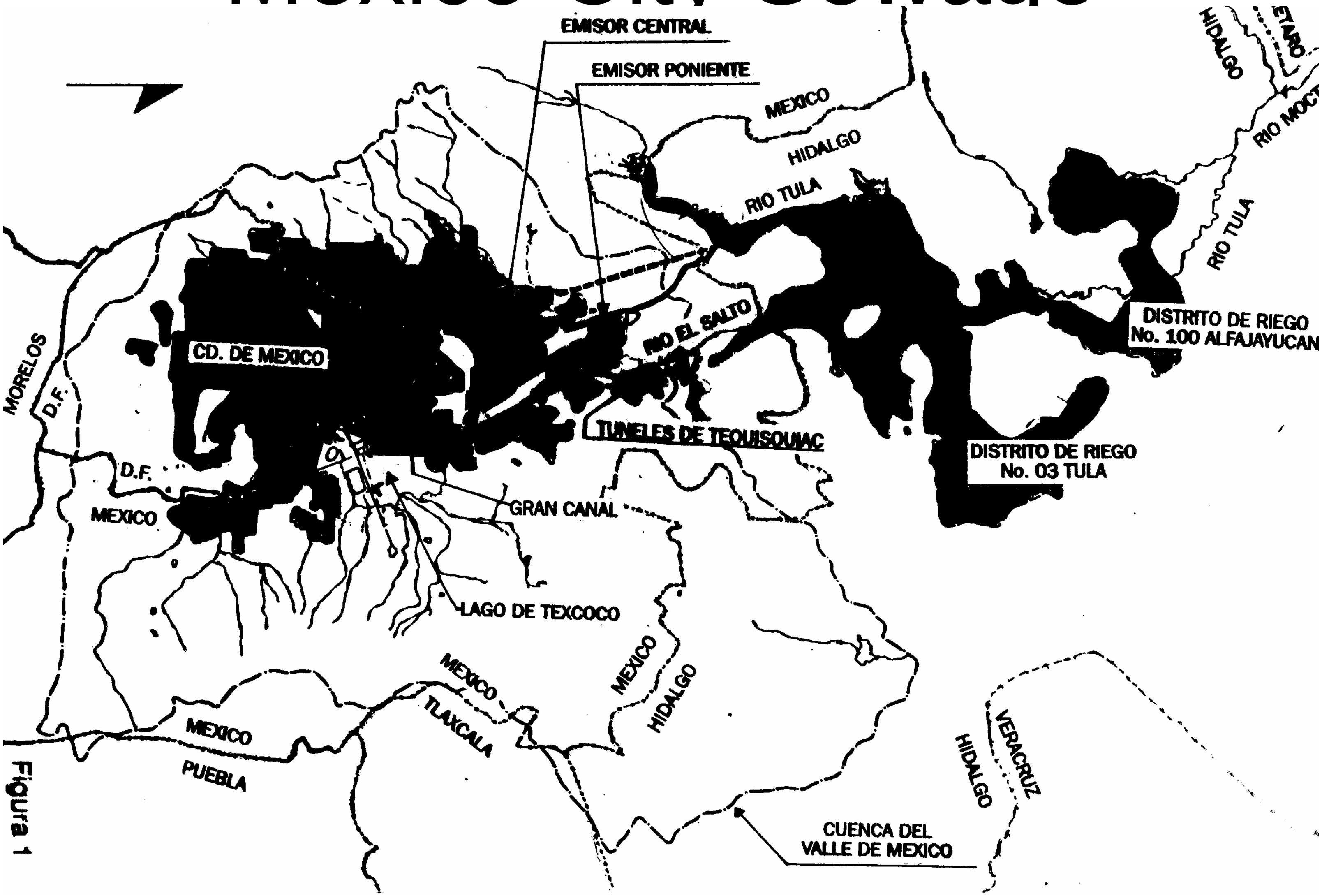
Stonecutters Island, Hong Kong Wastewater Treatment Plant

Largest CEPT Plants in Operation

- Hong-Kong - Stonecutters Island
  - 40 m^3/s capacity.; 3 million people (16m^3/s avg. flow)
  - 10 mg/L $FeCl_3$ + 0.15 mg/L Anionic Polymer
  - 80% TSS; 70% BOD Overflow rate = 85 m/d
  - Presence of seawater in sewage – may assist in coagulation/flocculation

- San Diego - Point Loma = largest US CEPT Plant
  - 10 m^3/s; 1 million people
  - 35 mg/L $FeCl_3$ + 0.25 mg/L anionic polymer
  - 80% TSS, 60% BOD

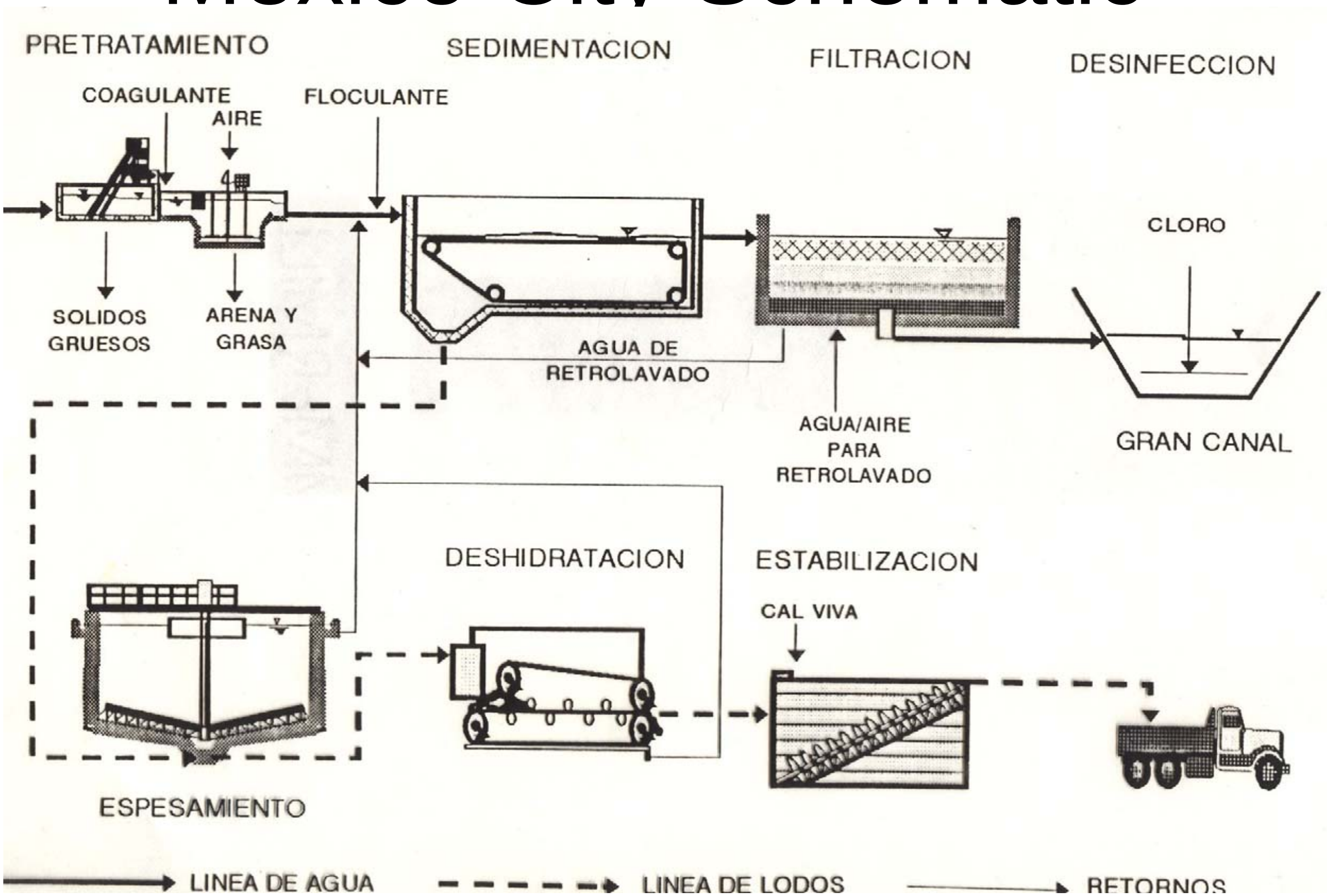
Mexico City Sewage



Ascaris Infection Risk

ZONE	Individual Studied	# of infected	%	Relative Frequency
In children from 0 to 4 years old / Population over 5 years old				
Dry Season				
Tula	341 / 759	34 / 94	10 / 12.4	18 / 12.7
Alfajayucan	327 / 809	2 / 8	0.6 / 1.0	1 / 1
Rainy Season				
Tula	335 / 698	46 / 115	13.7 / 16.5	5.7 / 14.4
Alfajayucan	356 / 855	9 / 10	2.5 / 1.2	1 / 1

Mexico City Schematic



Courtesy of Donald Harleman and Frederic Chagnon. Used with permission.

Agricultural Reuse of Wastewater from Mexico City to Hidalgo is best accomplished by CEPT (low helminth, mid-organics, mid-nutrients, low cost

Process	Effluent Helminth (egg/l)	Organic Matter Concentration	Nutrient Concentration	Cost
Influent	250	High	High	N/A
Primary	40	High	High	Low
CEPT	1-5	Moderate	Moderate	Low-Mod
Primary +2nd Biol	1-3	Low	Mod-Low	High
PT+2nd Biological +Sand Filters	<1	Low	Low	Very high

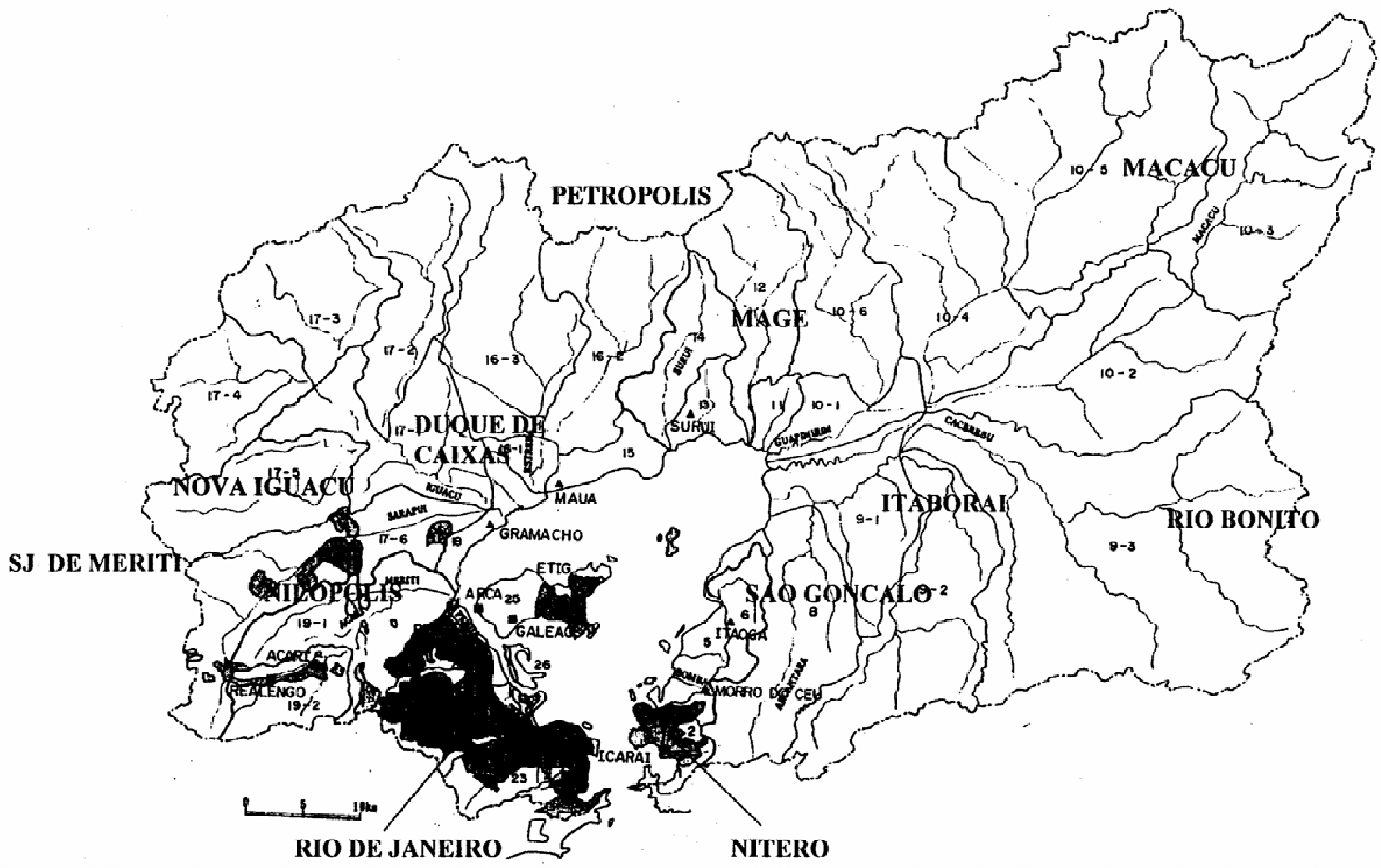
Mexico City Cost Comparison

	Construction (US$/Capita)	O&M (US$/yr/capita)
CEPT Tank	*5.5*	*1.3*
Primary Treatment	*10*	*0.1*
TOTAL CEPT	**56.3**	**3.5**
TOTAL Primary + 2nd Biological Act. Sl.	**103.9**	**5.7**

Per Capita costs based on estimate of 1.5M people served

CEPT in Rio de Janeiro

Figure 1. Guanabara bay, its watershed and municipalities (after Kokusai Kogyoco, 1994)
(shadowed area - seweraged regions; ■ wastewater treatment plants; ▲ solid waste disposal sites)



Courtesy of Donald Harleman and Frederic Chagnon. Used with permission.

2 CEPT Plants in Rio de Janeiro

<u>**Pavuna and Sarapui**</u>

– Two wastewater plants of 1.5 m3/sec

– Treat 30% of Rio's wastewater

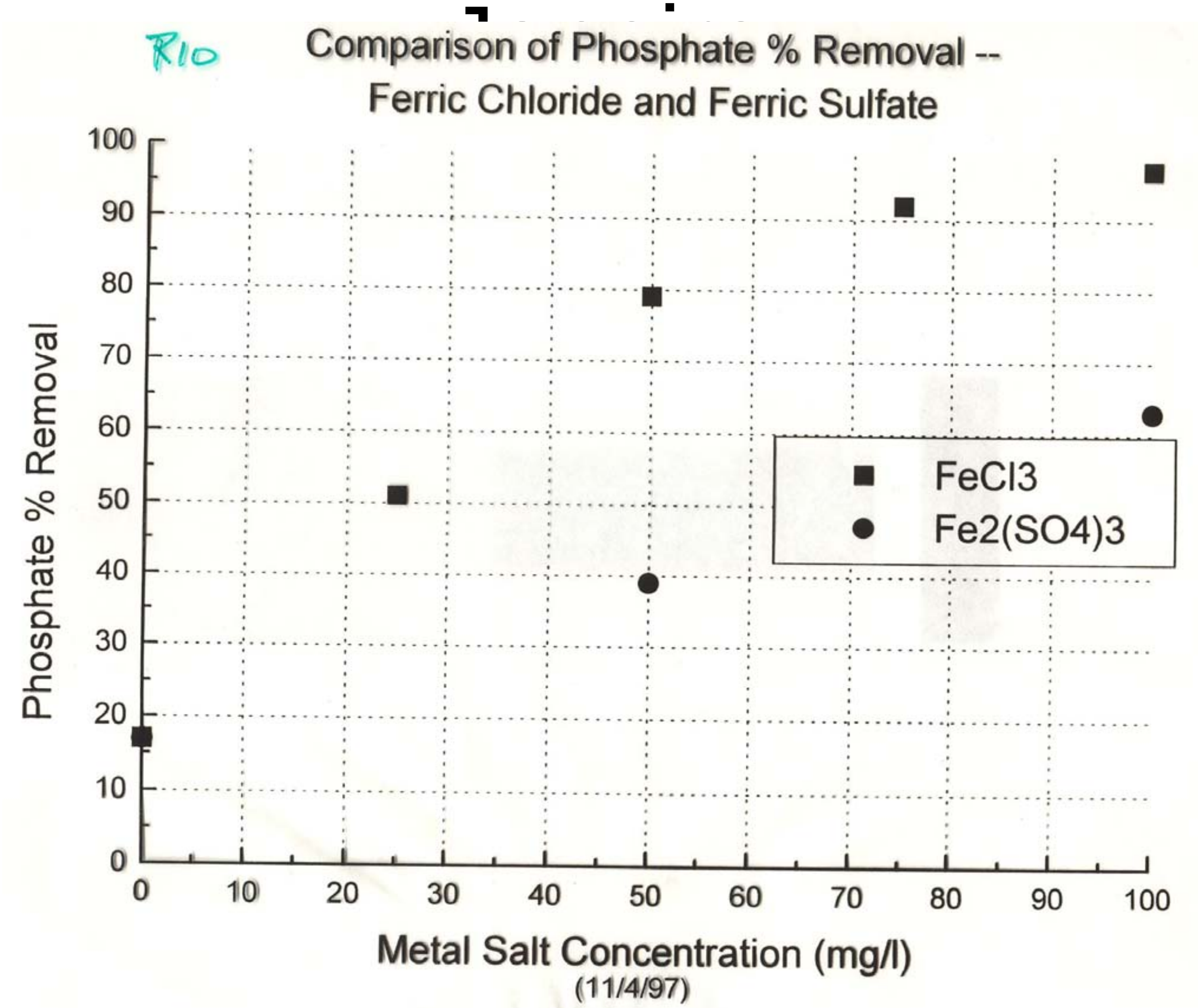
– Biological Treatment "on hold" due to success of these CEPT plants

Parameter	TSS	BOD	COD
% Removal	70%	60%	70%

Rio CEPT Results

Month (1999)	BOD Removal (%)		TSS Removal (%)	
	Pavuna STP	Sarapuí STP	Pavuna STP	Sarapuí STP
June	63.3	-	78.5	67.1
July	69.9	42.7	62.9	65.0
August	60.8	39.0	65.4	82.1
September	69.6	42.1	70.4	85.1
October	59.7	41.1	55.3	75.1
November	63.2	43.0	52.6	65.1
December	50.0	-	67.7	65.0
AVERAGE	**64**	**41.5**	**65**	**72**

Phosphate Removal in Rio de



Rio Sludge Treatment Costs

Sludge Treatment	CEPT
Anaerobic Digestion	R$M 18
Chemical Stabilization (Lime)	R$M 10

Potential Treatment after CEPT

- Activated sludge is suboptimal

- Biological aerated filters (BAF)

or

- Waste Stabilization Ponds (facultative or aerated lagoons)

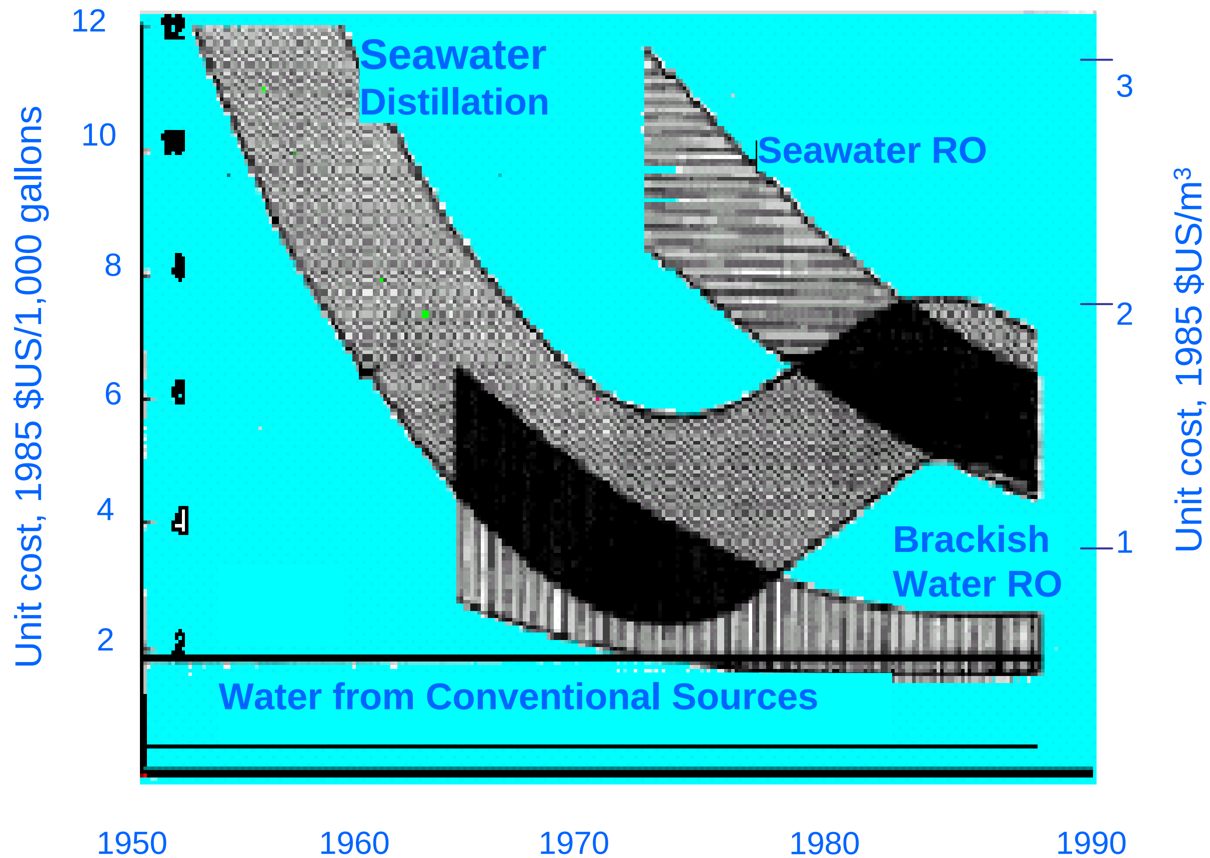
RO in developing nations

- Traditional large central system → for large cities
- Small system with hand pumps, or solar energy → for small villages

Advantages	Disadvantages
Good water quality	$$
Small footprint	Membrane fouling
modular	What do you do with brine? If dead end, more fouling
	Energy intensive
	Need specialized personal

Cost of desalination

- Steady unit cost decrease over time due to larger scale plants, technological advances, and integrated power-desalination projects
- But still expensive

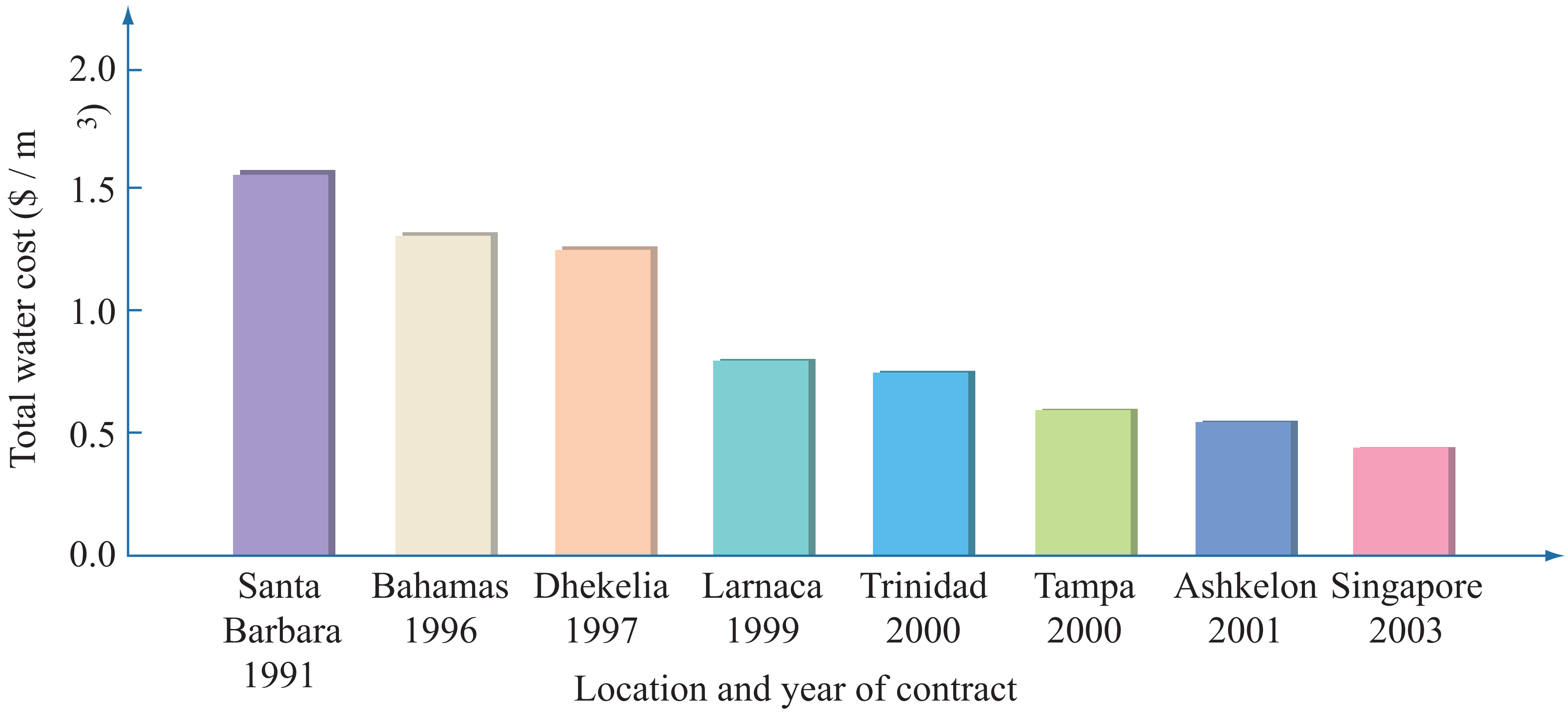


Courtesy of Shahid Chaudhry. Used with permission.

Source: Chaudhry, 2003

Sophie Walewijk, Stanford University

Unit cost of RO desalination over time



Total water cost for seawater RO membrane projects (1991-2003).

Figure by MIT OpenCourseWare.

RO Achilles' heal: membrane fouling

Images removed due to copyright restrictions. Please see:
Fig. 6a in Zhu, Xiaohua, and Menachem Elimelech. "Fouling of Reverse Osmosis Membranes by Aluminum Oxide Colloids." *Journal of Environmental Engineering* 121 (December 1995): 884-892.

and

Fig. 3e and 4b in Tang, Chuyang Y., Young-Nam Kwon, and James O. Leckie. "Characterization of Humic Acid Fouled Reverse Osmosis and Nanofiltration Membranes by Transmission Electron Microscopy and Streaming Potential Measurements." *Environmental Science and Technology* 41 (2007): 942-949.

0.1 M NaCl, pH 5.6 – 6.0
Source: Fouling of RO by Al2O3 colloids
(Zhu et al, 1995)

Effect of pH on organic fouling
(humic acids)
Soure: Tang et al. Environmental Science and Technology – 41 (2007) 942-949

Energy use for desalination

Range of Energy Use of different Desalination Technologies

Technology	Energy Use **kJ/kg**
MSF	**95-299**
MED	**95-275**
VC	**14-120**
RO (seawater)	**11-61**
RO (brackish)	**7.2-11**
ED (brackish)	**0.4-4**

source: Miller, 2003. From CEE 265C lecture notes

Research areas:

- energy sources: hand pumps, solar, wave energy
- materials: cheaper and less fouling
- reduction of energy with energy recovery system (a standard today)

Sophie Walewijk, Stanford University

Brine disposal

- 75% recovery means there is 25% concentrated waste → what do you do with this?
  - Back into the sea
  - Dry it and dispose of it
  - …

Some alternatives to RO

- Rain water harvesting
- Solar Distillation: will remove salt
- Blending waters

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http://www.indiatogether.org/photo/2004/images/env-rwhsaree.jpg
http://www.yp-connect.net/~hannagan/images/still.gif

Forward Osmosis for disaster relief

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