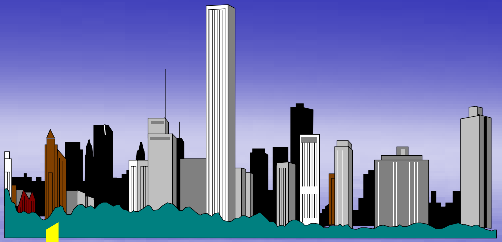


Cities of the Future

Integrated Sustainable Water and Landscape Management

Vladimir Novotny

Northeastern University Boston/AquaNova, Ltd, Newton, MA

Workshop Green City and Blue Water

Ritsumeikan University, Kyoto

July 7, 2010

Trinity of sustainability

Society

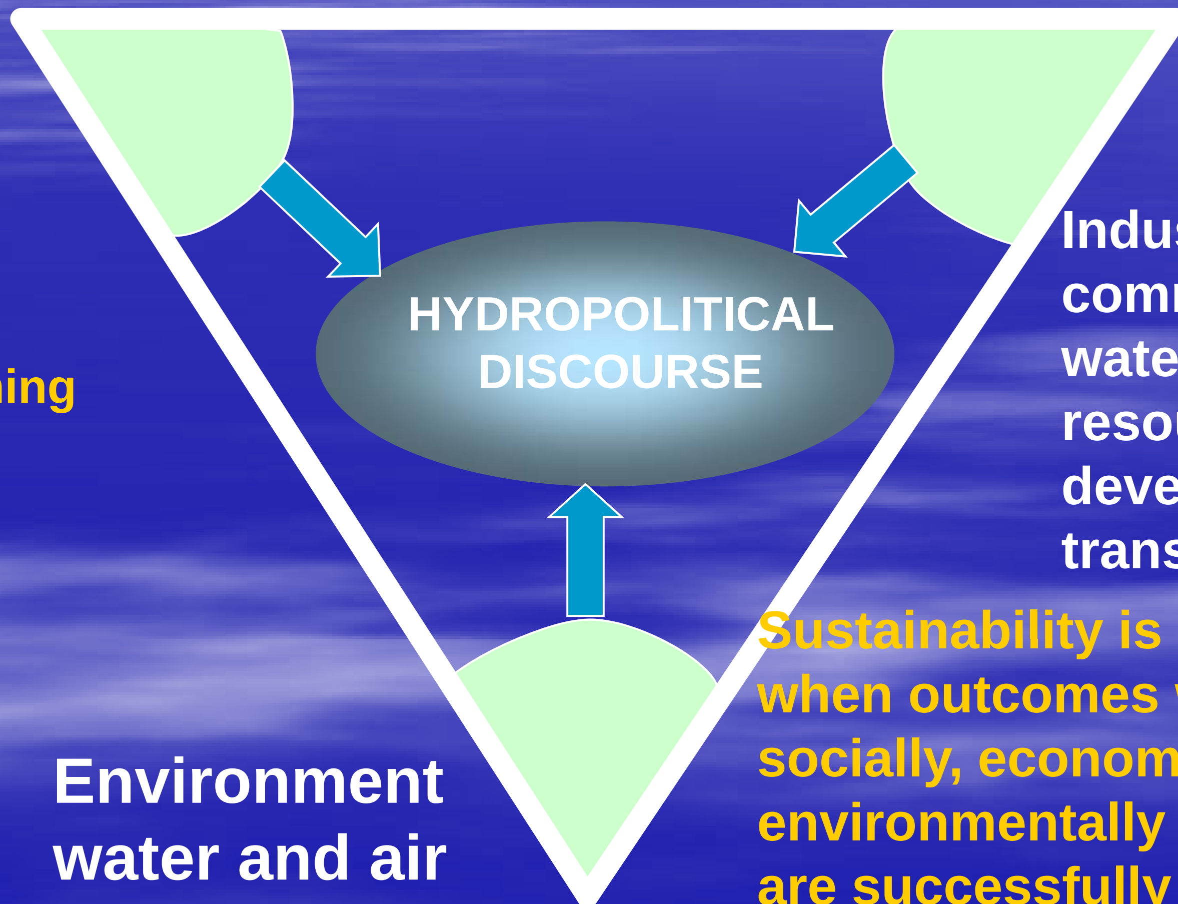
Domestic use, basic food production

Global warming

Economy

(Infrastructure)

Industrial and commercial use of water and water resources, land development, transportation



Environment water and air

Sustainability is achieved when outcomes which are socially, economically and environmentally sustainable, are successfully contended in the itergenerational context

PARADIGM

- A model and a set of rules how ideas are linked together and form a conceptual framework by which people build and operate the cities and manage their water resources
- It is based on logic, common sense, generational experience, and later, scientific knowledge
- It is derived by a discourse in the political domain; science or good engineering alone may not be the primary determinant of a paradigm
- A wrong or outdated paradigm may persist because of tradition, lack of information about the pros and cons of the outdated paradigm or lack of resources to change it

First paradigm of urban water/stormwater and used water management

Drainage of Agora in Athens 500 BC

In Pompeii in Italy in 79 AD the street was the drainage

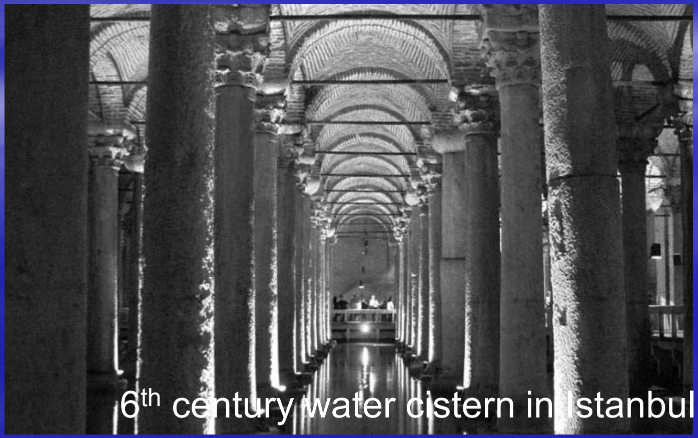
Wells for water supply , streets surface for drainage, night soil disposal

Paradigm II

II. **Long distance water transfers and storm water with some sewage drained by sewers**

Rainwater harvesting and storage has been used for thousands years

Pont du Gard



Paradigms of urban drainage have changed over millennia - Paradigm II

Long distance water transfers and storm water with some sewage drained by sewers

Pont du Gard

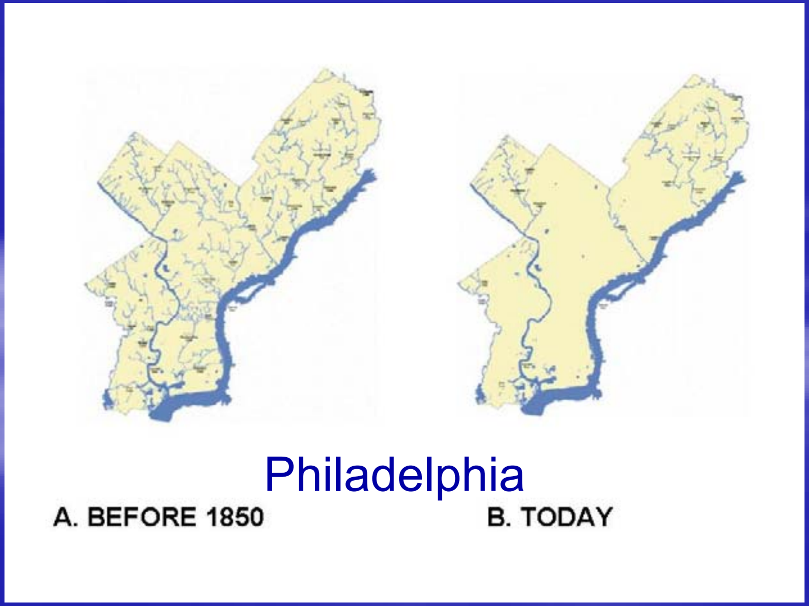
Lead (Rome) and wood pipes

Roman sewer Cloaka Maxima

Under the 3th Paradigm

- Surface streams disappeared from the surface and were converted to combined sewers

Mill Creek in Philadelphia



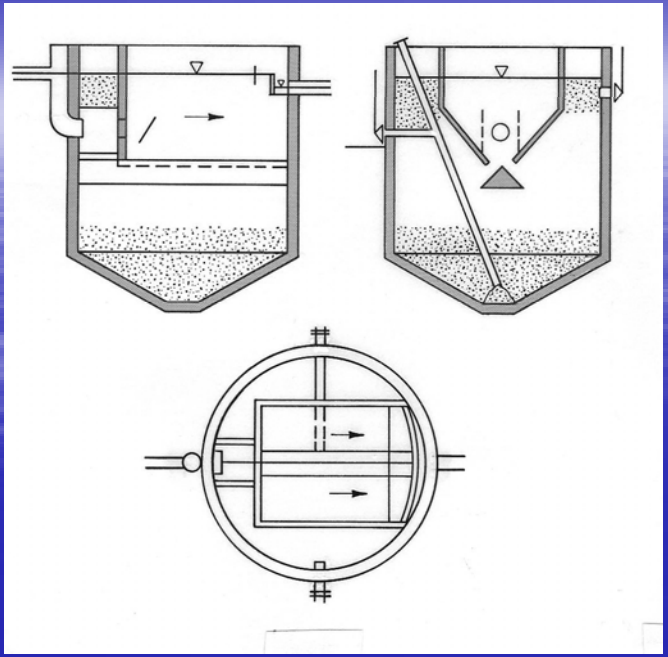
Credit Historic Archives of the Philadelphia Water Department

Paradigm IV

Control of CSOs in Milwaukee

Milwaukee has build 4 million m3 underground tunnel to store CSOs and by-passes from sanitary sewers. The tunnel reduced the frequency of overflows from about 40/year to 2/year. The target frequency was ordered by a court.

The tunnel was drilled 100 meter below surface in the dolomite formation (soft rock). Wall of the tunnel were grouted by epoxy grout to minimize groundwater infiltration.



Simple treatment plants were built in the first half of the 20th century

Cuyahoga River in Cleveland on fire

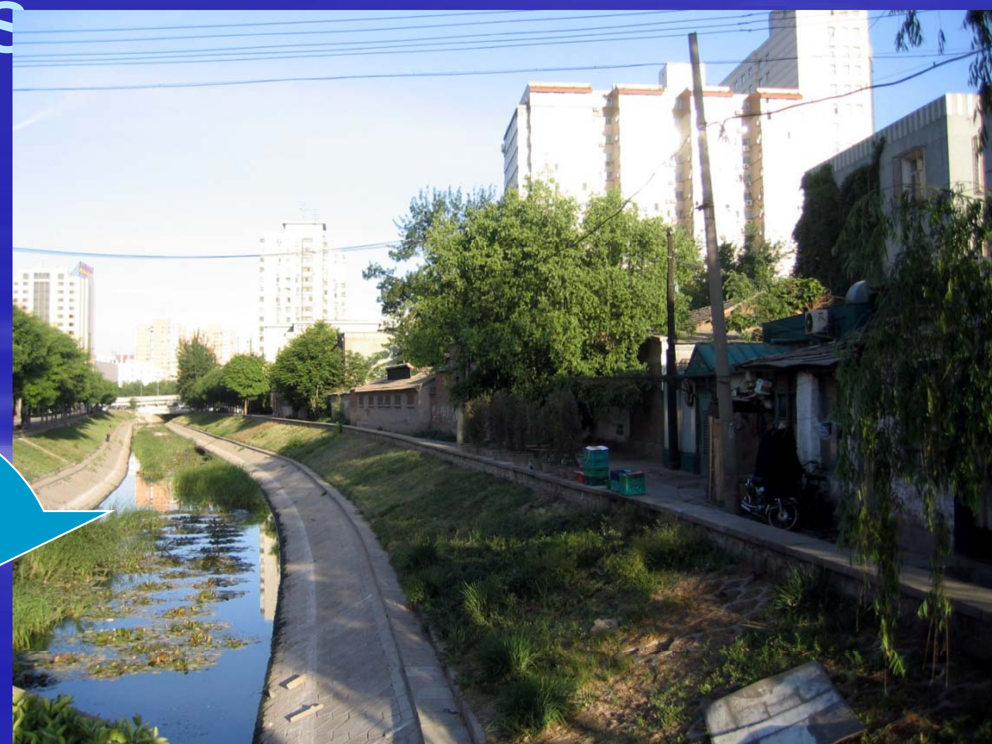
Gulf of Mexico on fire in May 2010

Courtesy Cleveland Press collection at Cleveland State University and Iowa DNR

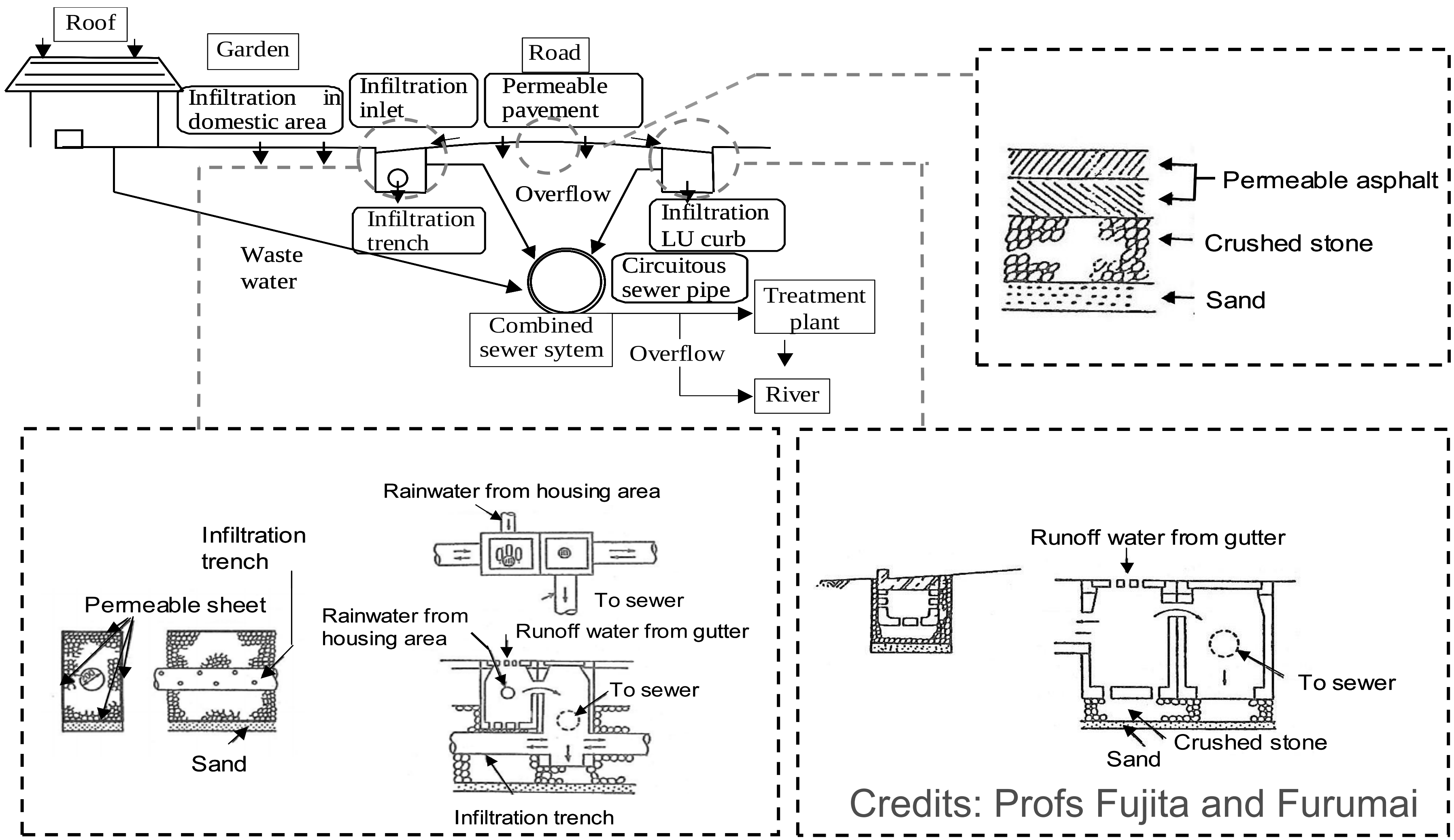
3^{rd} and 4^{th} Paradigms resulted in a perfect delivery of pollutants to receiving waters

Milwaukee (WI-US, 1990)

Beijing 2007



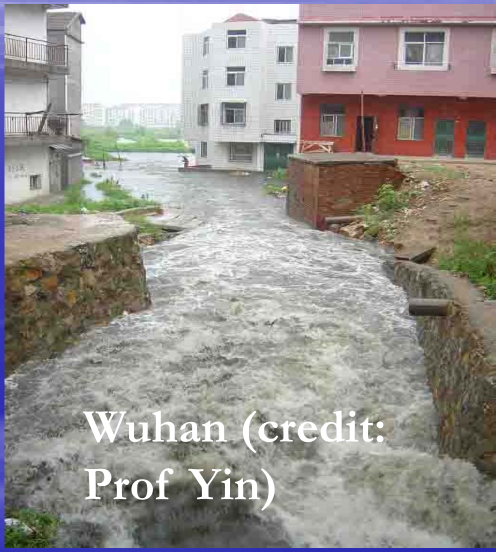
Ingenious drainage and infiltration system (EES Tokyo 1980s)



Credits: Profs Fujita and Furumai

PROBLEMS WITH THE 4th PARADIGM

- Natural hydrologic status of urban water bodies and watersheds has been modified by imperviousness, building sewers and stream modifications with the impacts on
  - Streams
    - Increased high flows (more flooding).
    - Peak flows increase by a factor of 4 to 10
    - Less base flow - not enough base flow to sustain viable fish population
    - Increased variability (flow, temperature, DO)
    - Increased stream bank erosion
  - Groundwater recharge is diminished
    - Effect on foundations (Boston, Venice, Mexico City, Philadelphia
    - Diminishing groundwater supply
    - Diminish base flow in river
  - The goals of the Clean Water Act and OPL goals cannot be attained using the IVth paradigm infrastructure heavy and energy demanding concepts



Wuhan (credit: Prof Yin)

Mexico City subsidence

Damages to Water Bodies

- **Wastewater disposal**
  - Effluent dominated – flow deprived streams
- **Urbanization effects other that wastewater**
  - Decreases base flow
    - Decreases water quality
  - Substrate degradation
    - Embeddedness
    - Habitat loss and fragmentation
  - Increases peak flow
    - Channel lining and cutting trees along the water body
    - Constricting channel by dikes and levees
    - Increases bank erosion
- **Loss of streams –conversion into sewers**

New Threats to Water Supplies and Ecology

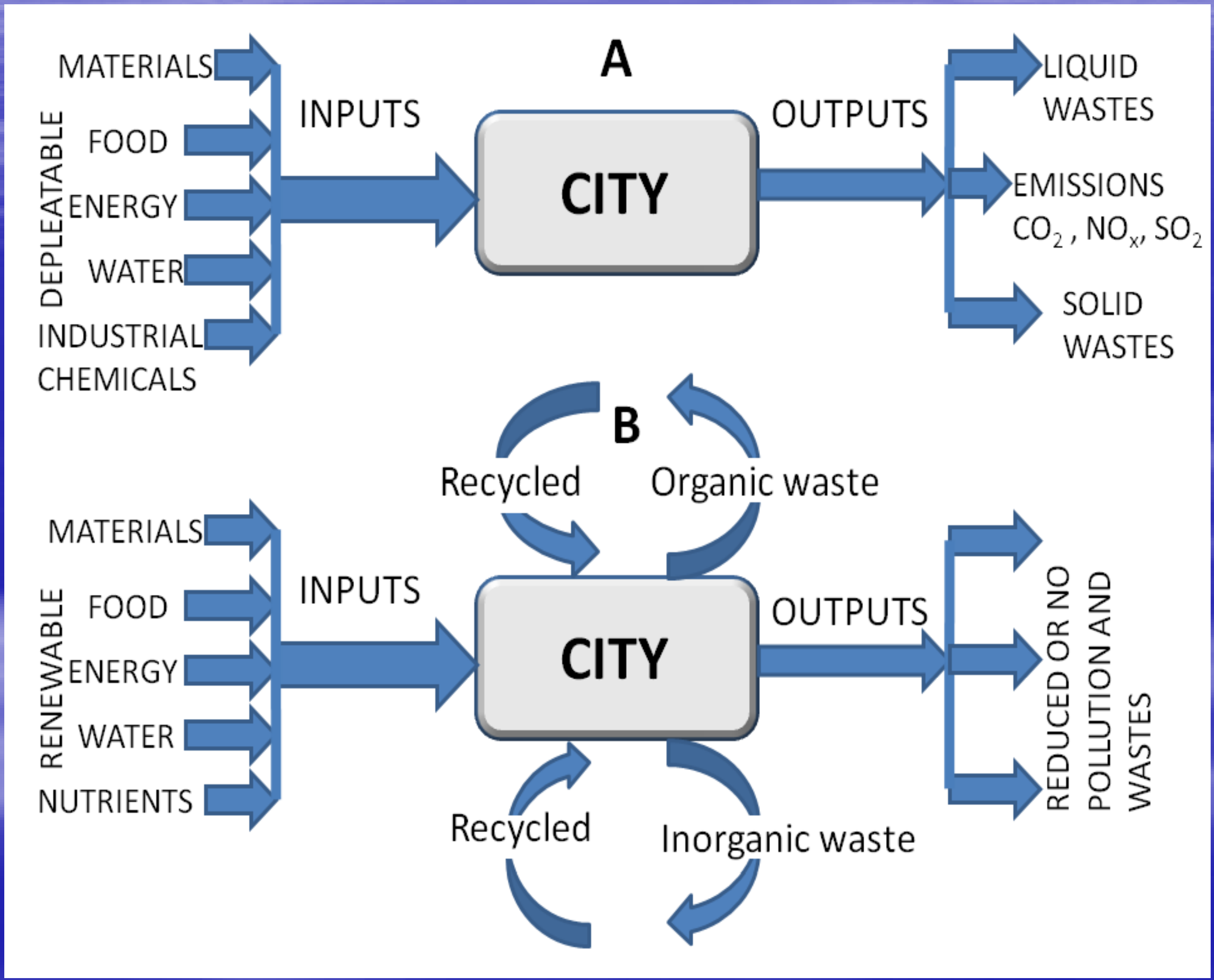
Urban pond in China

Reservoir supplying water for Prague

Severe problems with hypertrophy in China and Central Europe

- Hypertrophic water bodies (too much nutrient discharge causing extreme algal infestation – algal bloom)
  - Toxins
  - Loss of oxygen and biota
  - Loss of recreation
- New chemicals accumulate in the environment
  - Endocrine disruptors
  - Pharmaceutical
    - Antibiotics
  - Nanoparticles

Urban Metabolism



A Linear

B Cyclic

or

Hybrid

- Current urban systems are mostly linear
  - Excessive water volumes are withdrawn from mostly distant surface and groundwater sources
    - Inside the community water is used only once and wastefully, e.g., treated drinking water is used in landscape irrigation for growing grass
    - Great losses of water by leaks and evapotranspiration
  - Water is transferred underground to distant large wastewater treatment plants
    - The WTP use a lot of energy and emit carbon and often methane which are green house gases
    - The receiving water bodies become effluent dominated after discharge

Footprints

- A "footprint" is a quantitative measure showing the appropriation of natural resources by human beings
  - Ecological - a measure of the use of bio-productive space (e.g., hectares (acres) of productive land needed to support life in the cities)
  - Water - measures the total water use on site and also virtual water (usually expressed per capita)
  - Carbon - is a measure of the impact that human activities have on the environment in terms of the amount of GHG emissions measured in units of carbon dioxide

Ecological footprint

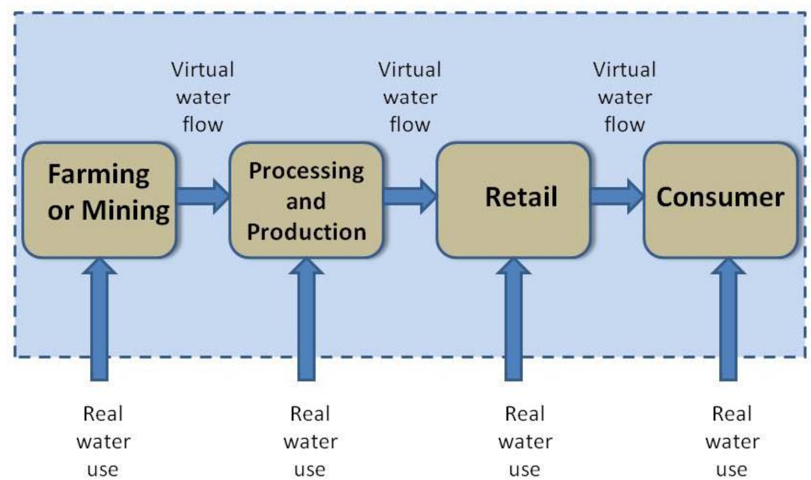
Year	World Population	Available productive land	
		Ha/person	Ac/person
1995	< 6 billion	1.5	3.6
2040	10 billion	<<1	2
Current ecological footprint			
Countries with 1 ha/cap or less		Most cities in undeveloped countries	
Countries with 2-3 ha/person		Japan and Republic of Korea (democratic)	
Countries with 3-4 ha/person		Austria, Belgium, United Kingdom, Denmark, France, Germany, Netherlands, Switzerland	
Countries with 4-5 ha/person		Australia, Canada and USA	

Imbalance

If the cities in the currently rapidly developing countries (China, India, Brazil) try to reach the same resource use as that in developed countries, conflicts may ensue

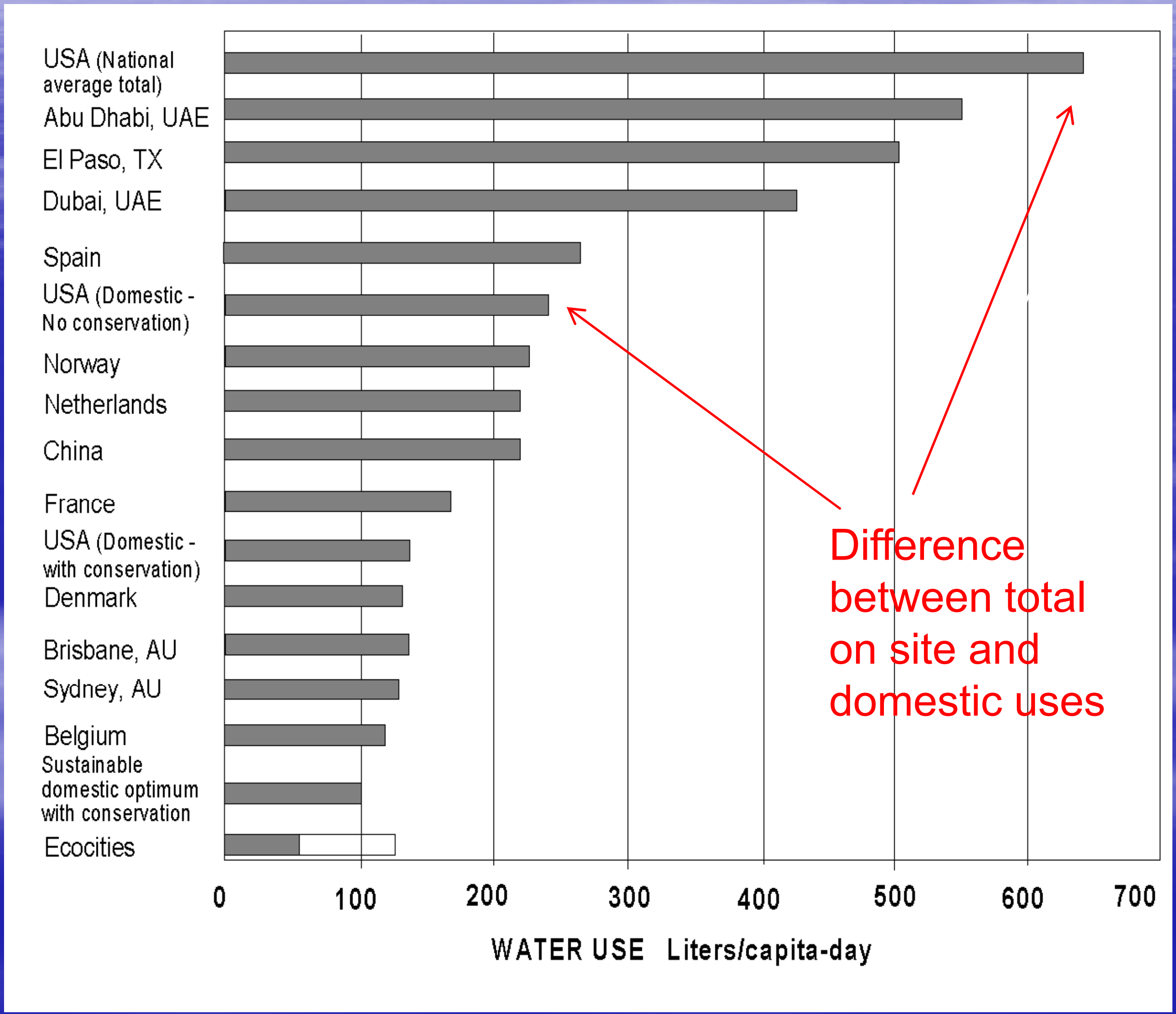
Water footprint

- On-site water use
  - Domestic
    - Indoor
    - Outdoor (irrigation)
  - Commercial
  - Public (fire, parks)
- Virtual
  - All water used in production in imported food and materials needed in the city



Source Hoekstra (2008)

Water use in some cities



VIRTUAL WATER

	l/cap-day
Food	1928
Electricity	53-73

	liter/kg
Beef	15,500
Corn	900
Milk	1,000

1 gallon=3.78 liters
1 kg = 2.2 lbs

GHG (carbon) Emission by Cities

Top ten countries in the CO_2 emissions in tons/person-year in 2006[1]									
Qatar	UAE	Kuwait	Bahrain	Aruba	Luxembourg	USA	Australia	Canada	Saudi Arabia
56.2	32.8	31.8	28.8	23.3	22.4	19.1	18.8	17.4	15.8
Selected world cities total emissions of CO_2 equivalent in tons/person-year[2]									
Washington DC	Glasgow UK	Toronto CA	Shanghai, China	New York City	Beijing China	London UK	Tokyo Japan	Seoul Korea	Barcelona Spain
19.7	8.4	8.2	8.1	7.1	6.9	6.2	4.8	3.8	3.4
Selected US cities domestic emissions of CO_2 equivalent in tons/person-year[3]									
San Diego CA	San Francisco	Boston MA	Portland OR	Chicago IL	Tampa FL	Atlanta GA	Tulsa OK	Austin TX	Memphis TN
7.2	4.5	8.7	8.9	9.3	9.3	10.4	9.9	12.6	11.06

[1]Wikipedia (2009); [2] Dodman (2009) ; [3]Gleaser and Kahn (2008)
[2,3] Values include transportation, heating, and electricity

GHG = Green House Gases (CO_2, methane, nitrogen oxides and other gases)

Vision of the Cities of the Future

Definition/Vision of an Ecocity:

An ecocity is a city or a part thereof that balances social, economic and environmental factors (triple bottom line) to achieve sustainable development. A sustainable city or ecocity is a city designed with consideration of environmental impact, inhabited by people dedicated to minimization of required inputs of energy, water and food, and waste output of heat, air pollution - CO2, methane, and water pollution. Ideally, a sustainable city powers itself with renewable sources of energy, creates the smallest possible ecological footprint, and produces the lowest quantity of pollution possible. It also uses land efficiently; composts used materials, recycle or convert waste-to-energy. If such practices are adapted, overall contribution of the city to climate change will be none or minimal below the resiliency threshold. Urban (green) infrastructure, resilient and hydrologically and ecologically functioning landscape, and water resources will constitute one system

Adapted from R. Register UC-Berkeley

What is a Water Centric Ecocity ?

Courtesy and credit W.P. Lucey, AquaTex Scientific Consulting, Victtoria, BC

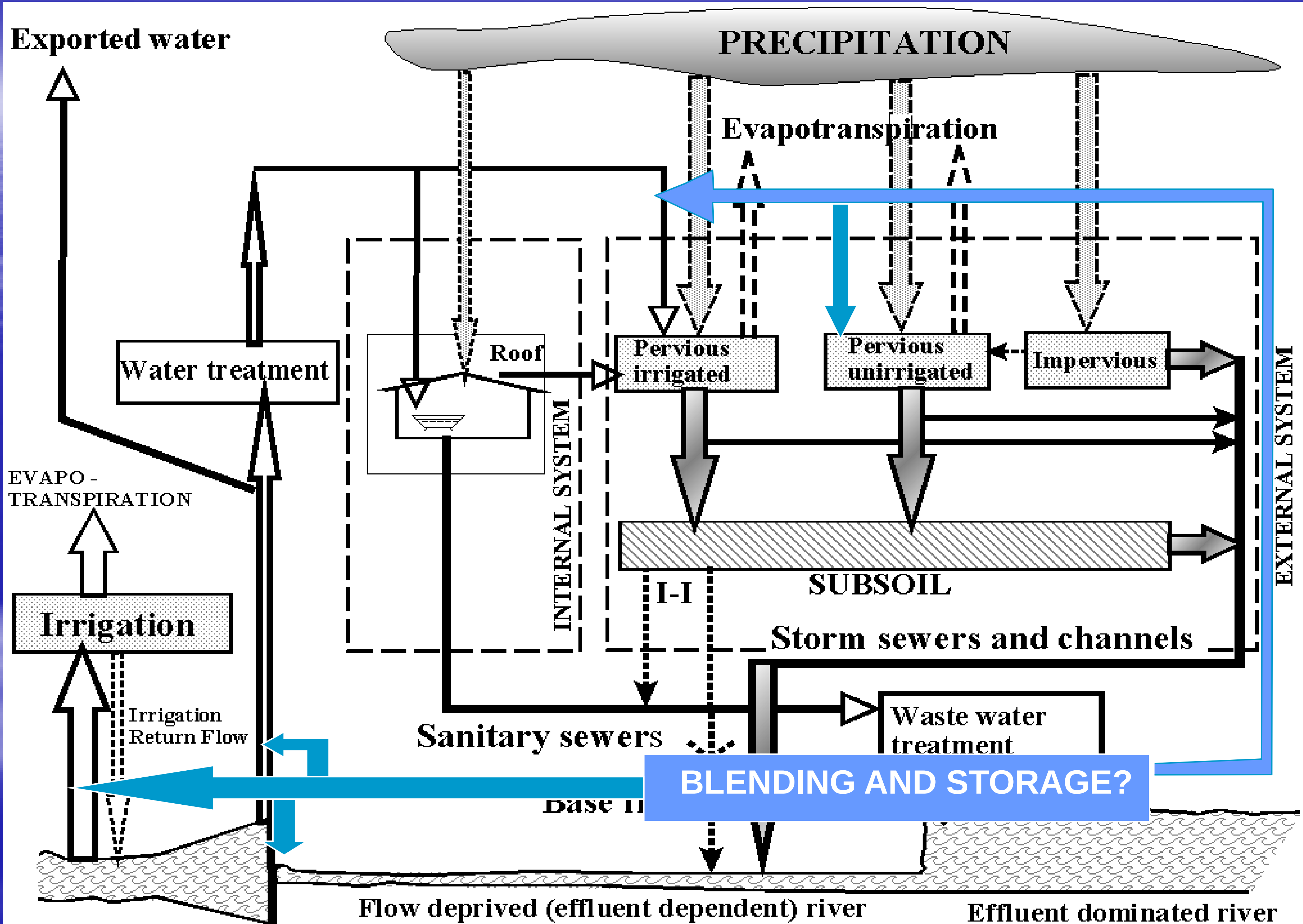
What is a Water Centric Ecocity ?

- **Water conservation**
- **Distributed stormwater management (surface)**
- **Distributed water treatment**
- **Water reclamation and reuse in buildings, irrigation and for ecologic stream flow**
- **Infiltration and repair of hydrology**
- **Stream restoration – multi-functional water bodies are a life line of the ecocity**
- **Heat and energy recovery**
- **Organic solids management for energy recovery**
- **Source separation**
- **Nutrient recovery**

Also

- **Renewable energy source (solar, wind, hydropower)**
- **Sustainable low carbon traffic emissions**
- **Recreation, walking, biking**
- **Suburban organic agriculture**

Need to close (fully or partially) Urban Hydrological Cycle



Total Hydrologic Balance

- Water supply, stormwater management, waste water disposal, groundwater levels and stream flow are components of the same system and should be harmoniously managed with ecological goals in focus
- Tools of management:
  - Water conservation
  - Capture, store and reuse rainwater and urban runoff
    - Groundwater recharge
    - Low flow augmentation
    - Local (house) irrigation (rain gardens)
  - Effluent reclamation and reuse
    - Irrigation
    - Toilet Flushing
    - Flow enhancement for aquatic life
    - Aesthetic enhancement of urban streams
    - Groundwater recharge
  - Stream Restoration
  - Decentralization and de-regionalization
  - Flow and pollutant load trading

Blending?

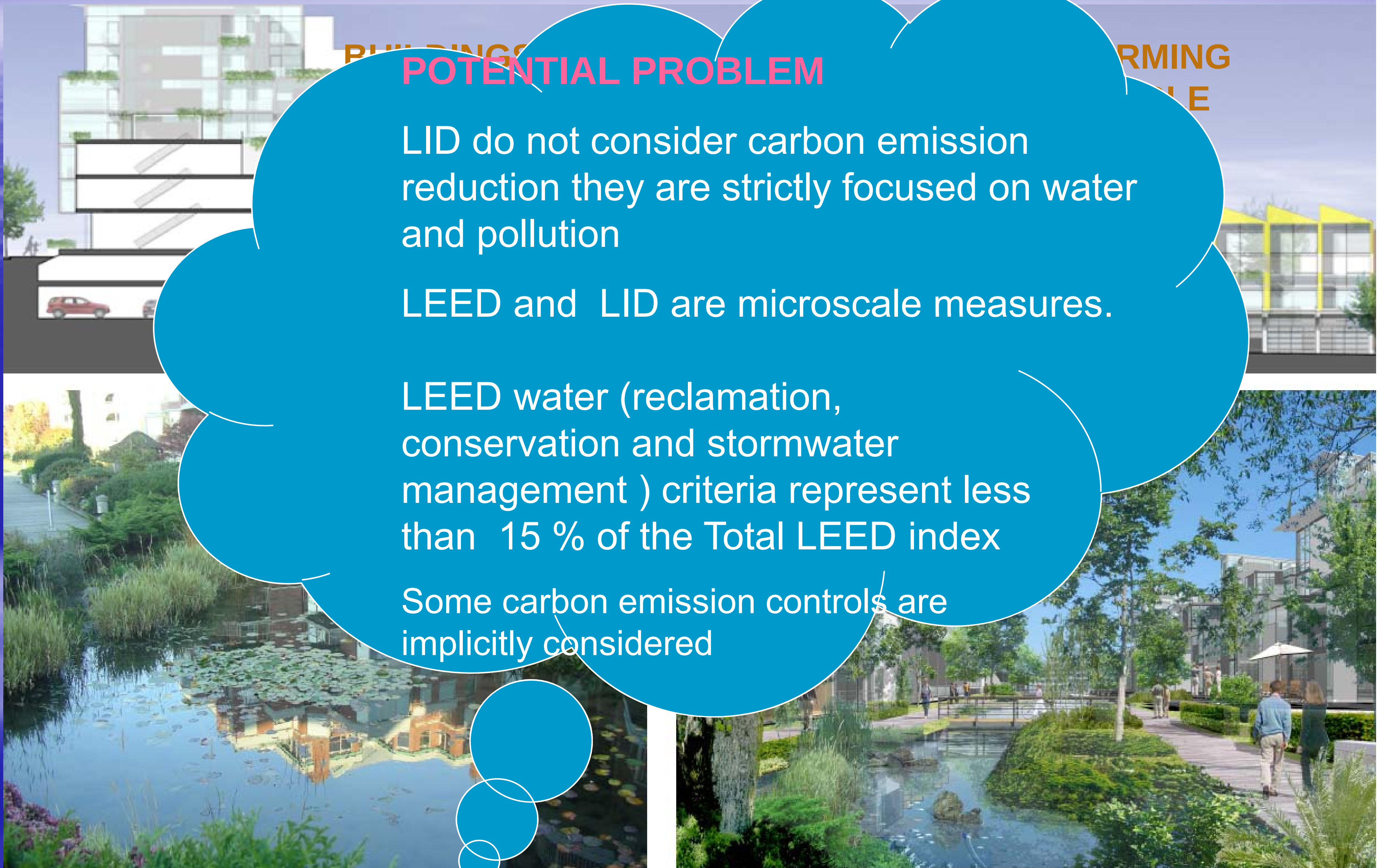
Integrated Water and Landscape Management

- Effluent dominated – flow deprived streams
  - Loss of base flow – increased high flows
    - Nonpotable water
      - Irrigation
      - Toilet flushing
      - Baths (shower, bath and hot tub)
      - Street cleaning and flushing
    - Groundwater recharge

Microscale Assessment

- Microscale (buildings, neighborhoods, subdivision
  - Leadership in Energy and Environmental Design-LEED
    - Sustainability of the site – smart location
    - Green design
    - Energy efficiency
    - Indoor environmental quality
    - Innovation and design
    - Neighborhood patterns, etc.
  - Low Impact Development (LID)
    - Capture, storage and infiltration of precipitation, mimicking predevelopment hydrology
- Cities of the Future incorporate both LEED and LID principles and concepts but they are not traditional LID communities

CITY OF THE FUTURE



POTENTIAL PROBLEM

LID do not consider carbon emission reduction they are strictly focused on water and pollution

LEED and LID are microscale measures.

LEED water (reclamation, conservation and stormwater management) criteria represent less than 15 % of the Total LEED index

Some carbon emission controls are implicitly considered

Courtesy AquaTex

One Planet Living (WWF)

- zero net carbon emissions- 100% of the energy from renewable resources;
- zero solid waste
- sustainable transportation with zero carbon emission in the city;
- local and sustainable materials used throughout the construction;
- sustainable foods, outlets providing organic and or fair trade products;
- 50% reduction in water use from the national average,
- natural habitat and wildlife protection and preservation,
- preservation of local culture and heritage ;
- equity and fair trade with wages and working conditions; and
- health and happiness for every demographic group.

Best Management Practices are an integral part of the COFs

Green Roofs

Save energy and store water

Raingarderns

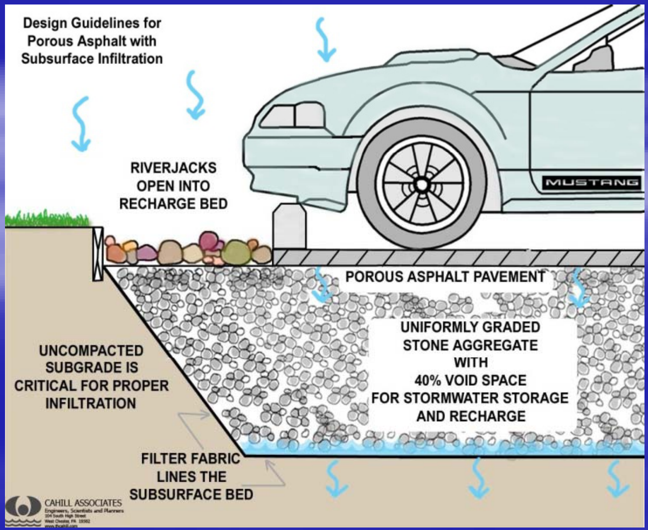
Infiltrate and treat runoff

Porous pavement

Infiltrate, store and treat runoff

Ponds and wetlands

Store, treat and infiltrate runoff



BMPs are not only for clean -up

- Mimic the Nature
- Repair Unsustainable Hydrology
- Provide and enhance surface drainage
- Provide pollutant removal for ecological flow
- Water Conservation
- Water Body Restoration
- Add to aesthetic qualities of the cities
- Enhance recreation
- Save money
- Save energy

NEW CONCEPT
Green and Sustainable

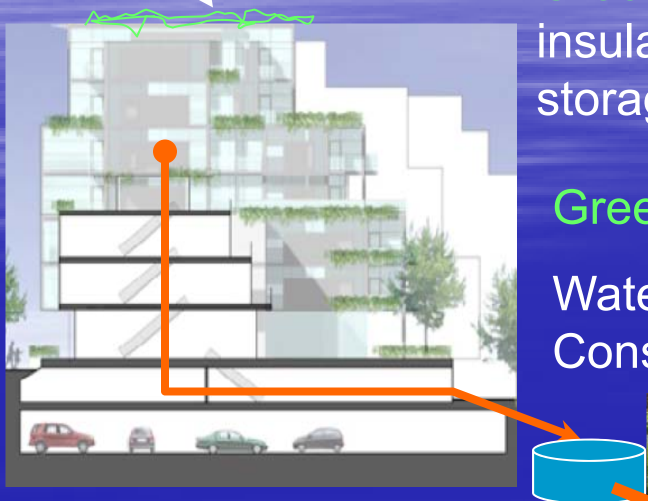
- Eco-mimicry for the landscape
  - Develop urban landscape that would mimic but not necessarily reproduce the predevelopment natural system
    - Xeriscape
  - Minimize imperviousness
  - Drainage service mostly on the surface
- Reduction of energy consumption
  - Public transportation, nonpolluting fuels, electric buses and light rail
  - Green buildings, passive energy savings, water saving appliances
- Green space for recreation along the rivers
  - Interconnected riparian buffers and wetlands
- Urban brown-field remediation and development
- Ecologically sound stream restoration and daylighting including base flow
- Resiliency to Extreme Meteorological Events

There is no waste – new sustainability terminology

- Waste water → Used water
- Treated wastewater that meets standards for discharge into receiving waters and other nonpotable uses → Reclaimed water
- Reclaimed water treated to potable water quality for reuse in buildings→ NEWater (Singapore terminology)
- Treatment plant with recovery of biogas, energy, nutrients, etc. → Integrated resource recovery facility

Components-pre -1st order ephemeral

Green roof
insulation, water storage



Green Building

Water &Energy Conservation

Pervious pavement –side roads

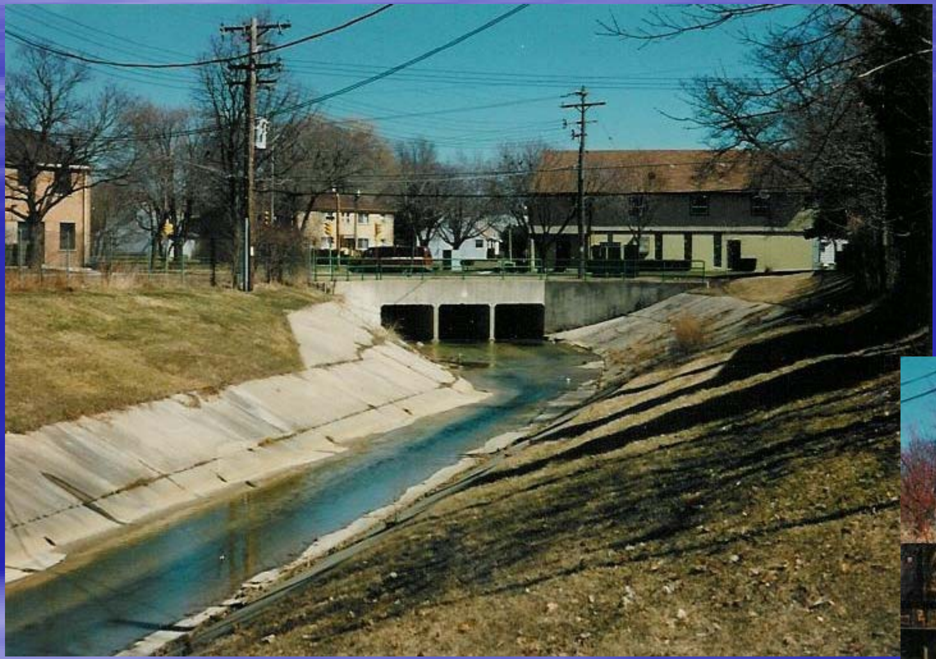
Raingardens with storage , e.g. , dry ponds

Pervious pavement - parking

How big is the flow and pollution load?

Natural systems	Nature mimicking Best Management Practices
Watershed with infiltration	Pervious pavements, green roofs with French well or rain garden infiltration of downspout excess water
Ephemeral pre-stream channels	Rain gardens, buffers sand filters connected to landscaped swales or dry storage ponds for flood water
1st order perennial streams with base water flow from o Springs o Headwater Wetlands o Headwater lakes	Daylighted, restored or created streams with base flow from o Groundwater infiltration, including dewatering basements o Decentralized high efficiency treatment plant effluents o Restored or created wetlands o Wet ponds with stored storm water
2nd order streams	Restored original streams with reclaimed floodplains and riparian wetlands; floodplain converted to recreational park and buffer zones; storage in lakes and ponds in the reclaimed flood plains
3rd and higher order streams	Removal of channelization and impoundments wherever possible, providing flood storage. Significant portion of flow may originate from upstream nonurbanizaed areas.

Remove longitudinal and lateral fragmentation of urban ecosystems



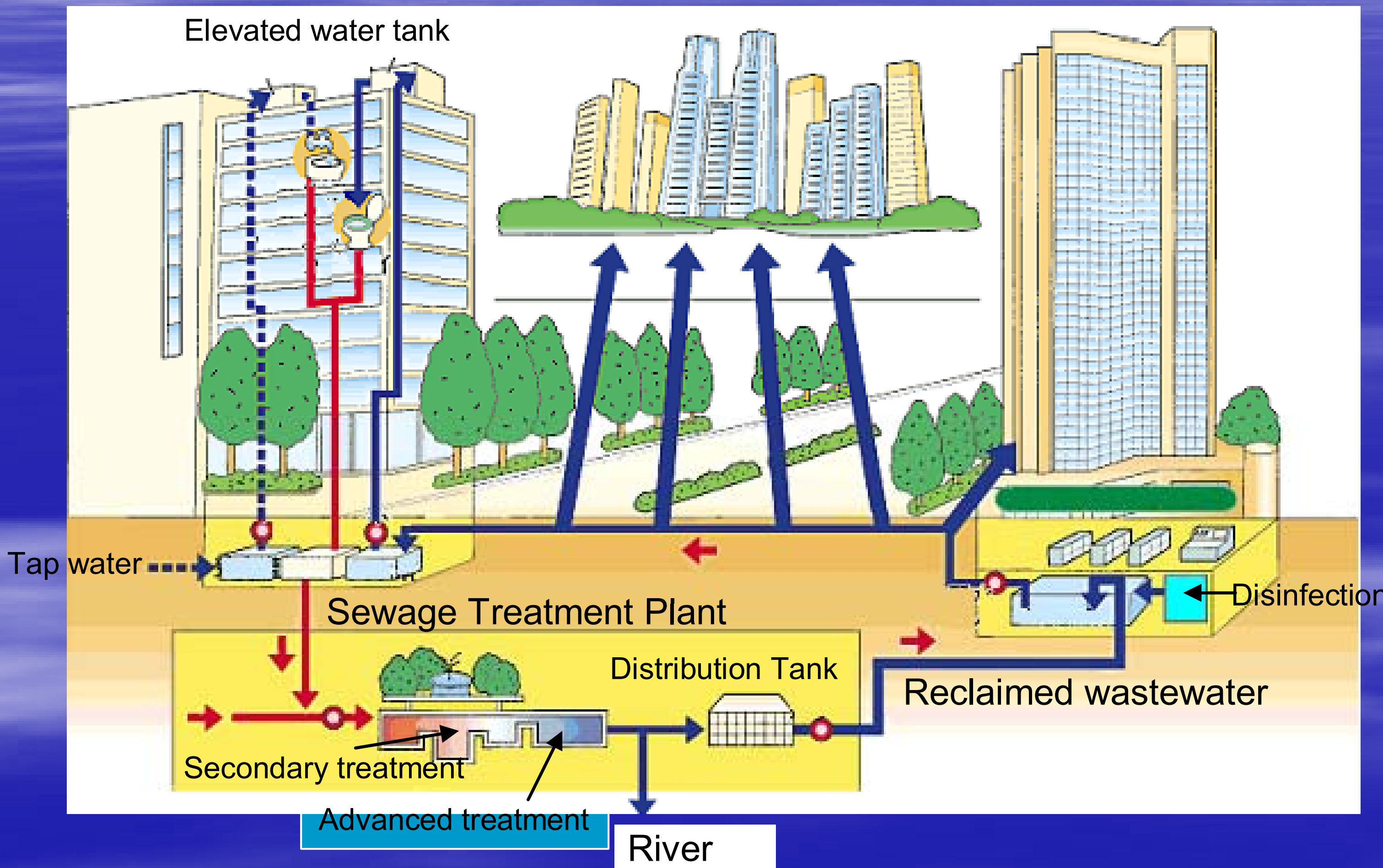
Impassable culvert

Drop structure

Rainwater harvesting requires minimum energy

Roof rainwater collecting tank in Orange District in Australia

Green Wastewater Reuse



Credit: Prof Furumai

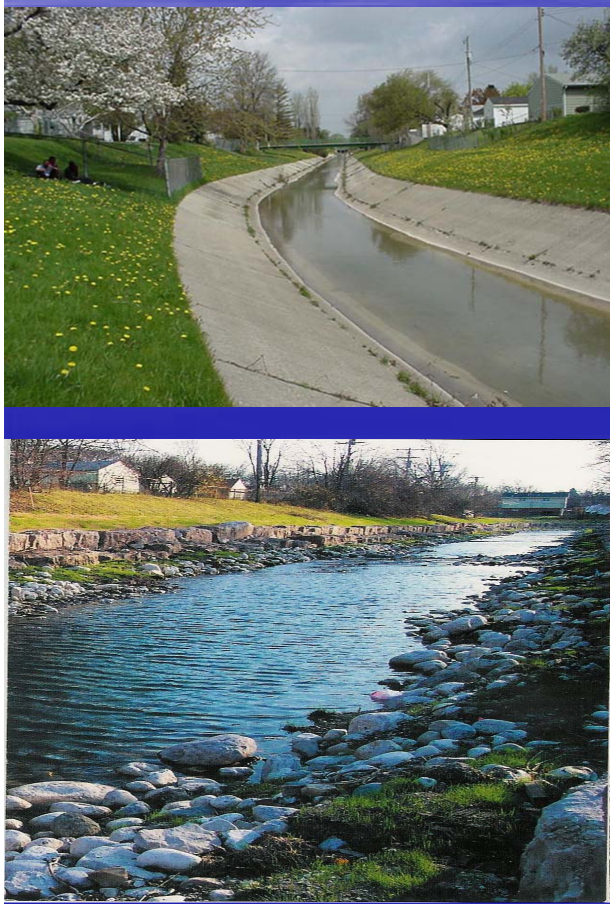
A water reclamation plant does not have to be far from the community

Courtesy AquaTex, Victoria, BC

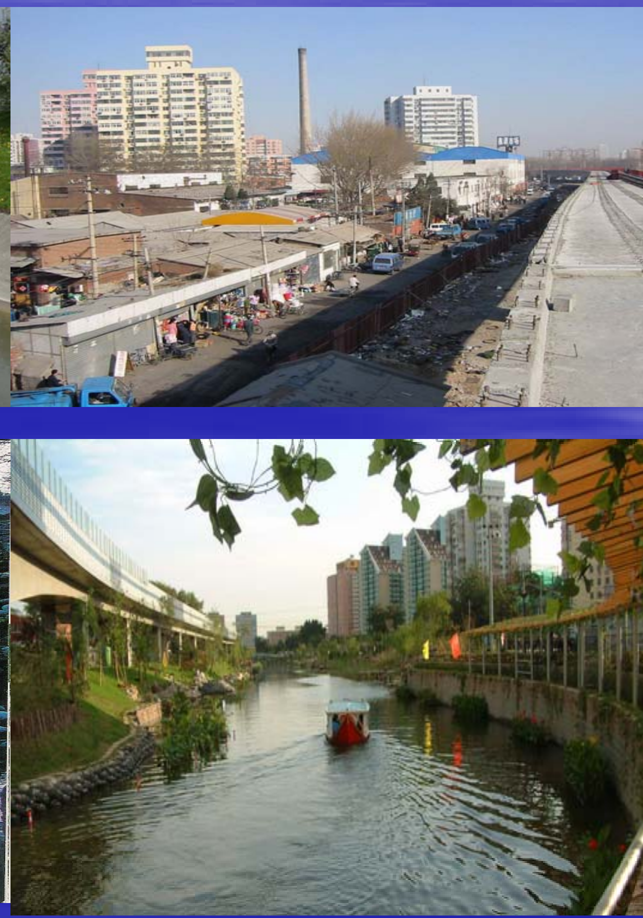
Decentralized Management Clusters and Ecoblocks

- A cluster (Ecoblock) is a semiautonomous part of the city that, for most part, has its own water/stormwater/wastewater management
  - Cluster may range in size from a high-rise building to a subdivision or a section of the city with thousands of inhabitants
  - Cluster infrastructure
    - Distributes water and practices water conservation and reuse
    - Implements energy saving in buildings (e.g., green roofs, solar energy)
    - Provides stormwater conveyance (mostly surface), storage and infiltration (groundwater recharge) and nature mimicking BMPs
    - Water reclamation units (high efficiency WWT)
    - Energy recovery from wastewater
  - Centralized or distributed biogas/Energy recovery
  - Ecologically and hydrologically functioning landscape
- Clusters are interconnected for increased resiliency

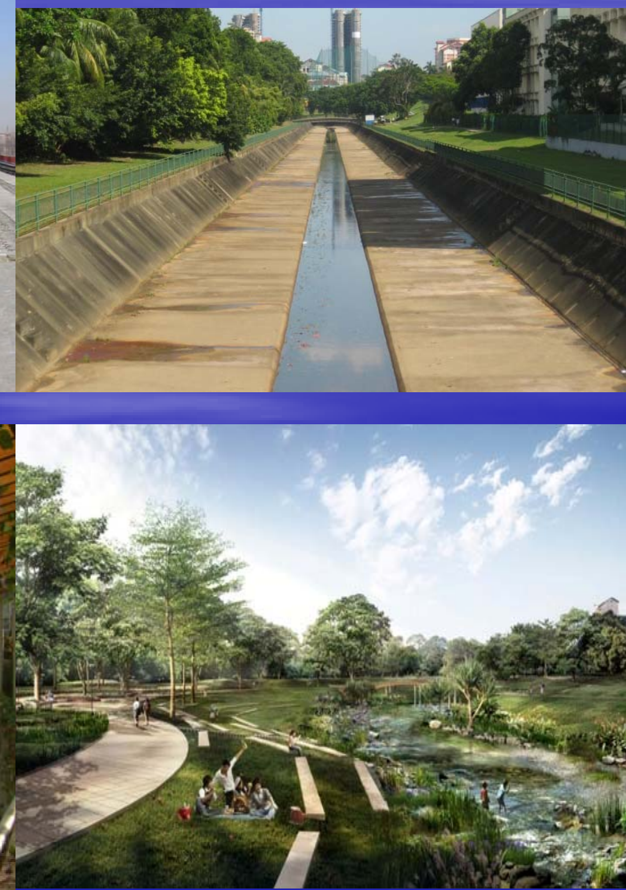
Urban water body restoration and daylighting is important



Lincoln Creek in Milwaukee

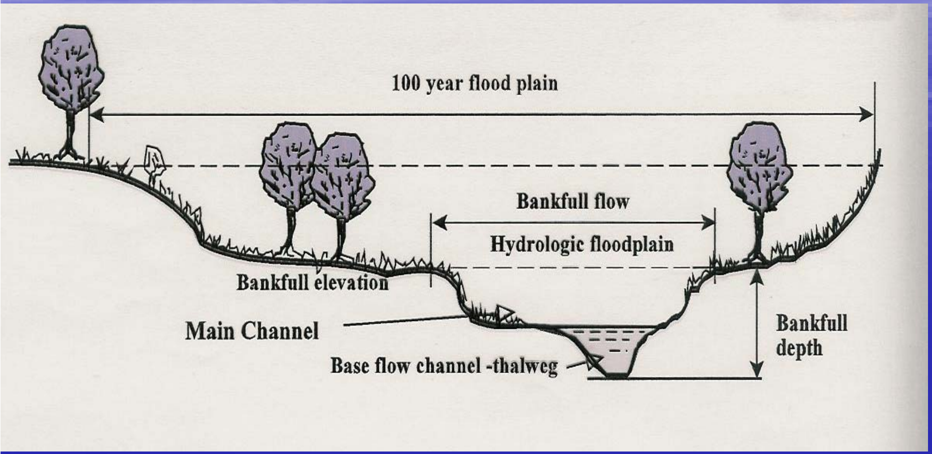


Zhuan River in Beijing

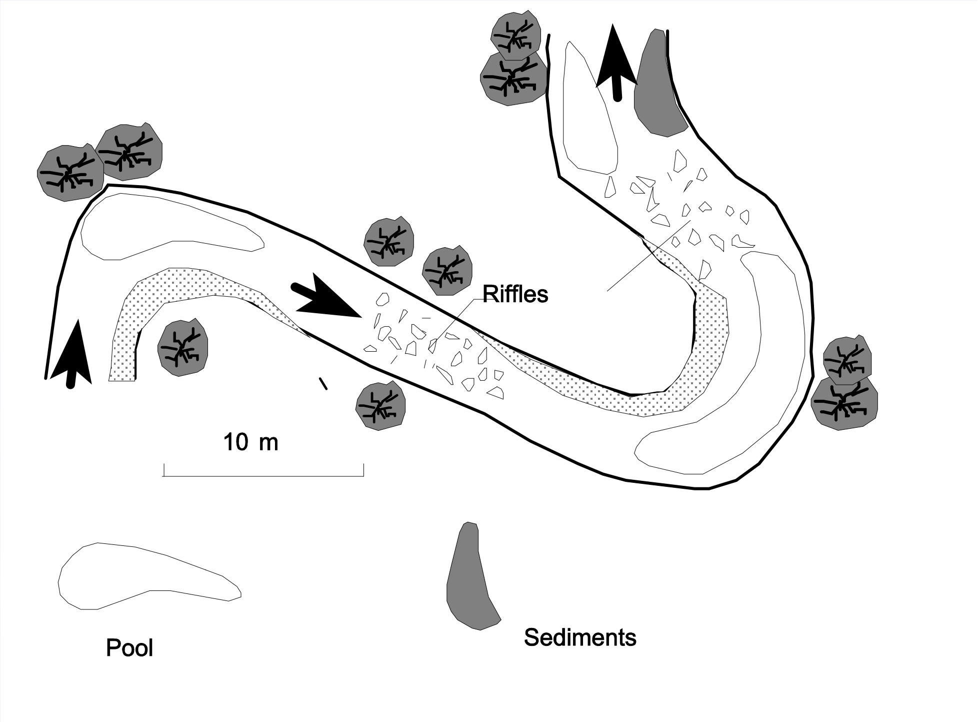


Kallong River in Singapore

Natural Channel

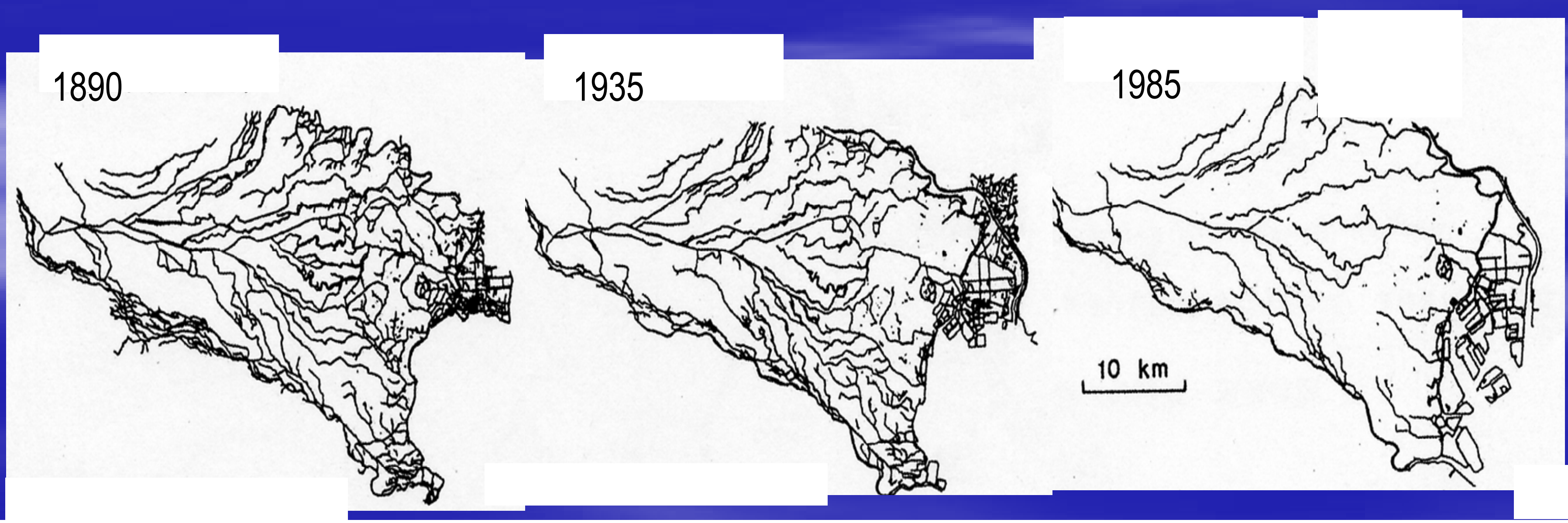


Cross-section



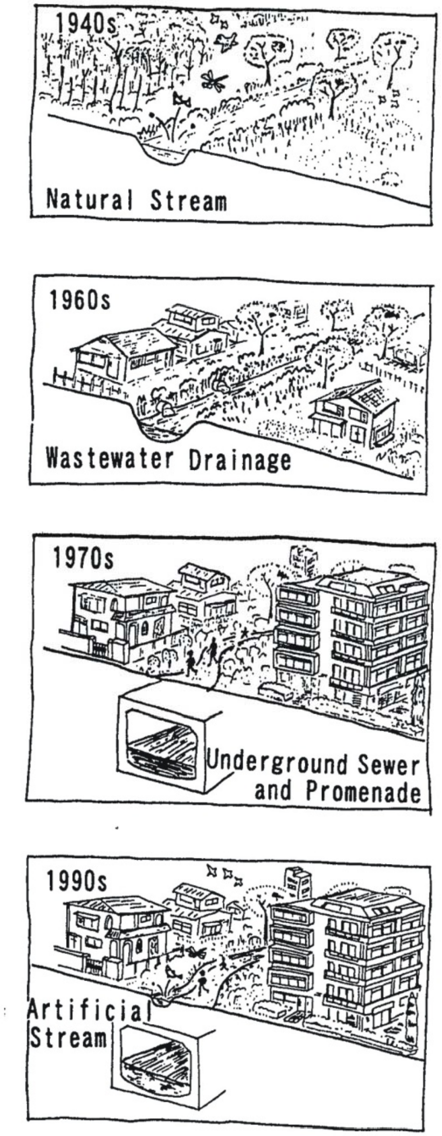
DAYLIGTHING

- With the high degree of treatment required in the new cities it does not make sense to use sewers for conveyance; they were invented and used for conveyance of highly polluted urban wastewater and urban runoff
- Streams covered, converted to culverts or combined sewers can be brought to the surface
- A new stream can be recreated in a place where the old stream is irreversibly lost



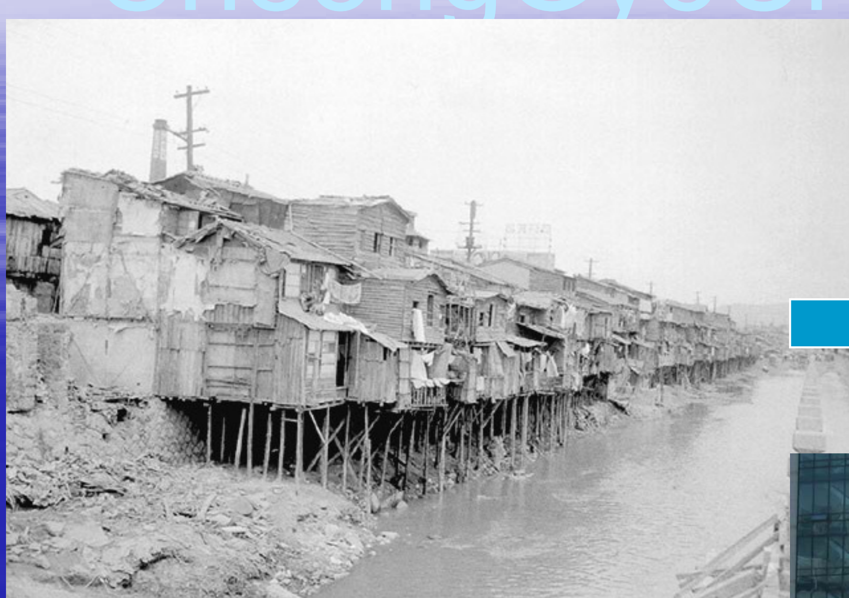
KITAZAWA STREAM IN TOKYO

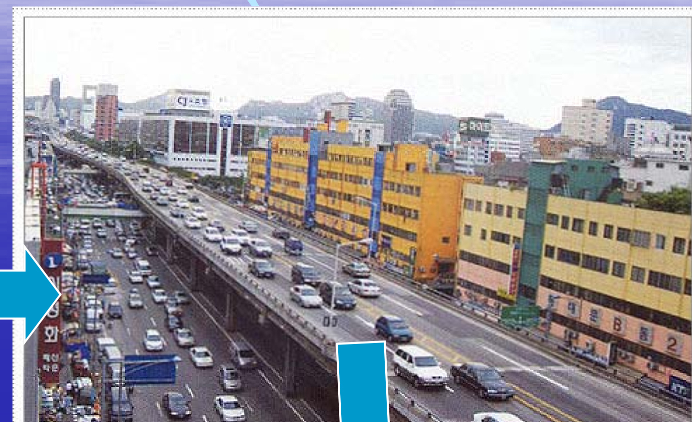
- Flow in the "upper" stream is provided by a highly treated effluent from a nearby treatment plant
- Fish is living in the stream and looks healthy



The history of Kitazawa Stream

CheongGyeCheon (Seoul, KR)





Benefits ++++

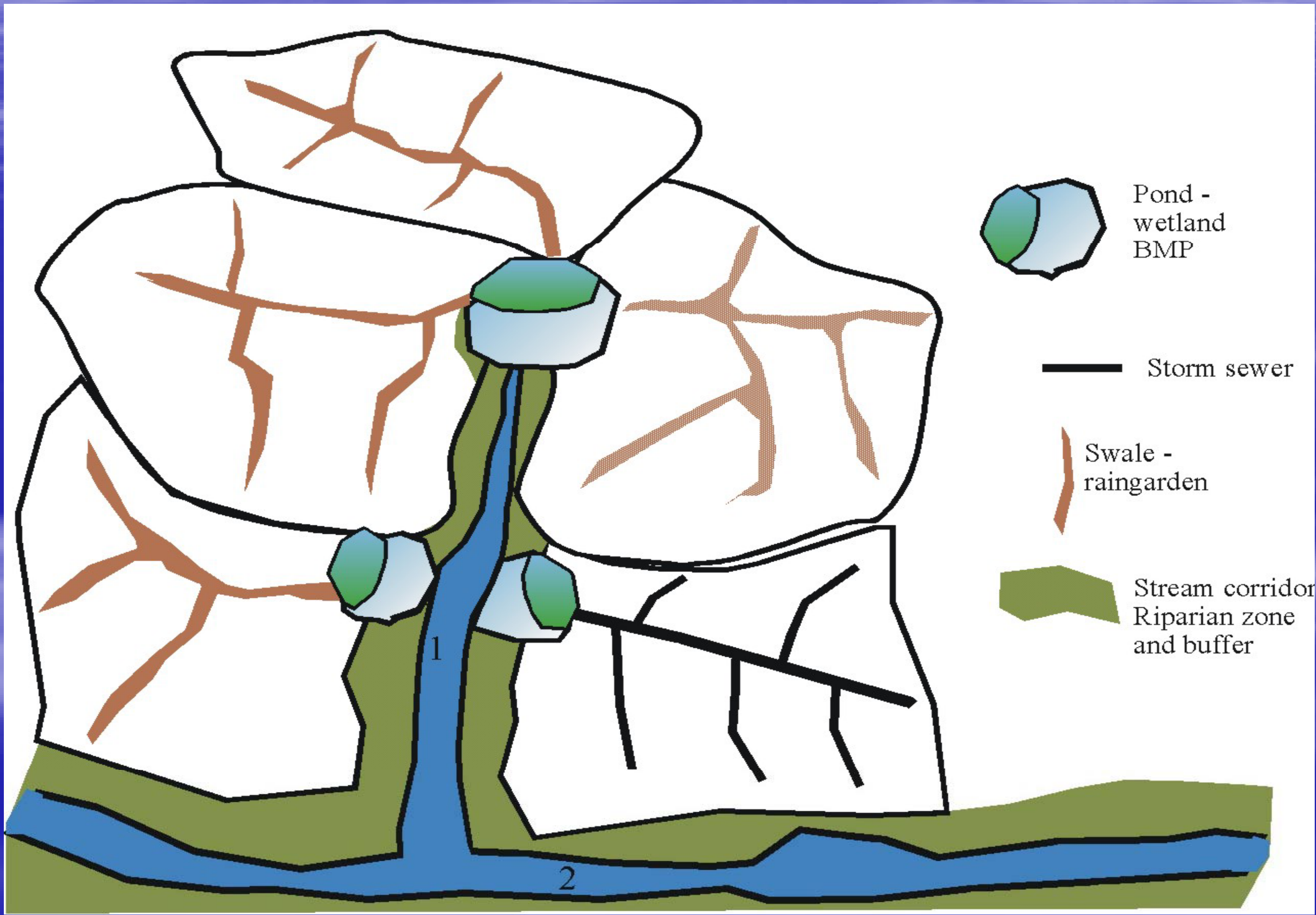
City revitalization, Aesthetic

Flood control, Ecology

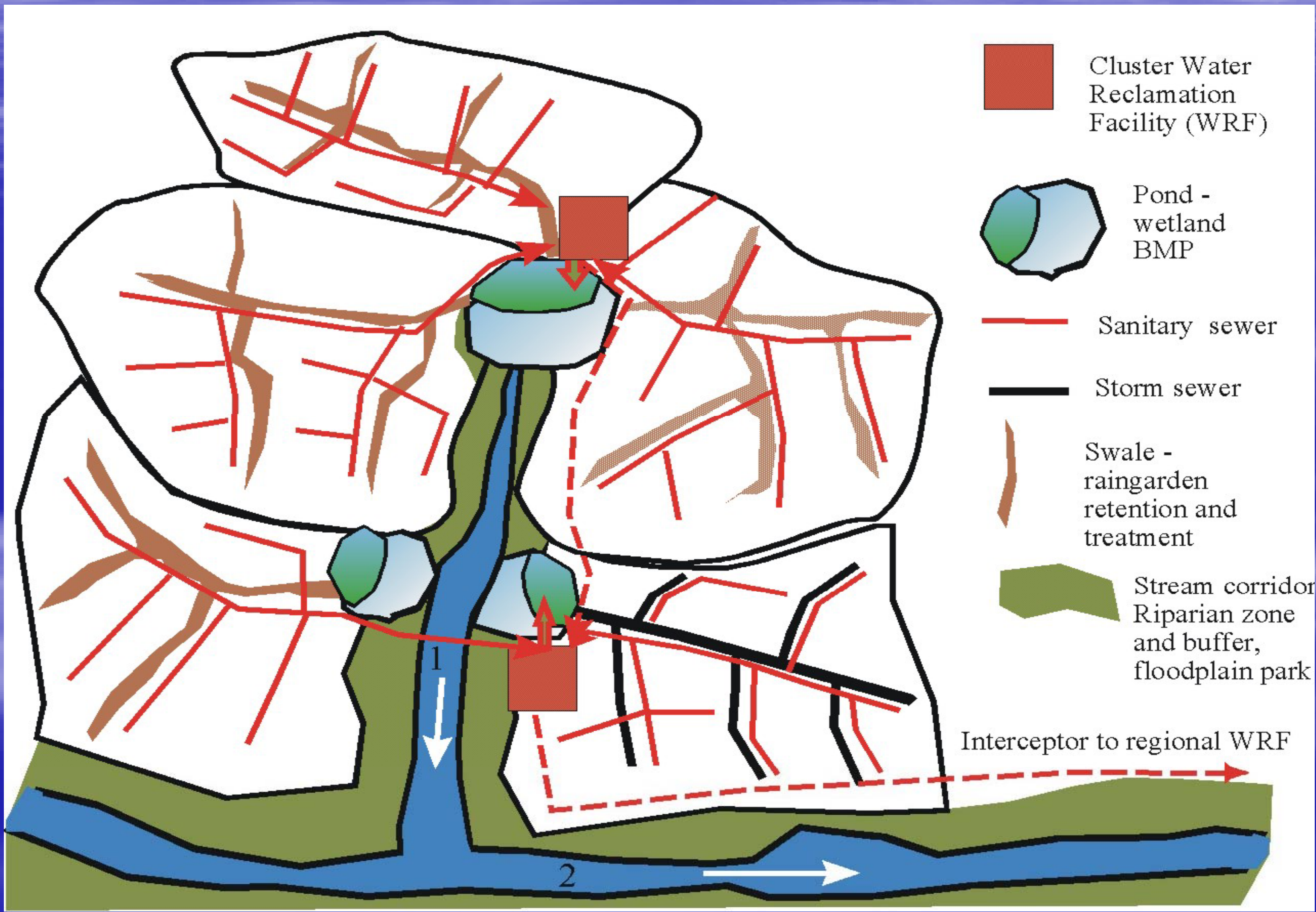
Sustainability -

No water reclamation, water is pumped from a larger river downstream, carbon negative

Integrated System-Drainage



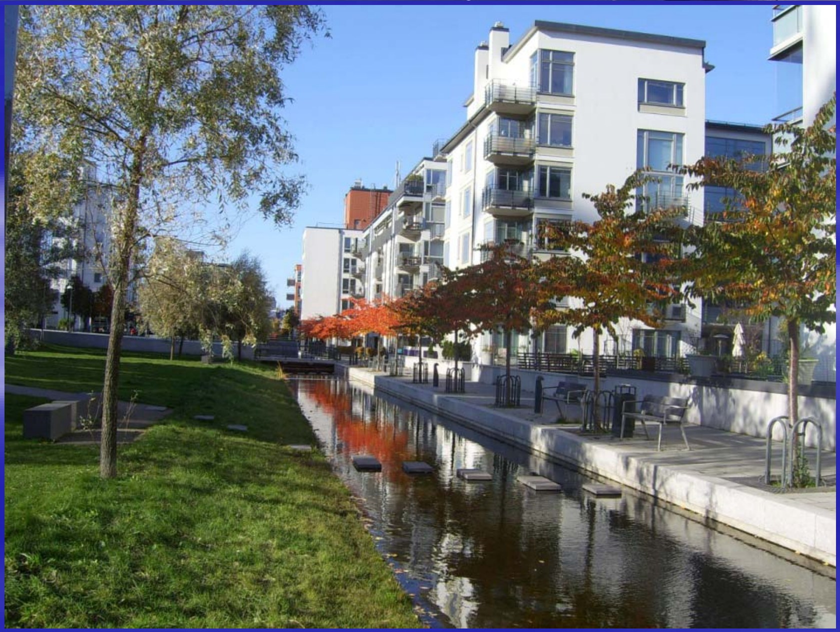
Integrated System with Reuse



Seven Cities Ecocities Review

Hammarby Sjőstad
Dongtan
Qingdao
Tianjin
Masdar
Treasure Island
Sonoma Valley

Water Centric Hammarby Sjostad




BEIJING
TIANJIN
Tianjin
ecocity
Qingdao
North Ko
Shaanxi
XI'AN
Dongtan
Shanghai
© 2008 ZENRIN
© 2008 Europa Technologies
© 2008 Kingway Ltd.
© 2008 NFGIS
©2006 Google
Pointer 36°15'53.60" N 116°35'42.81" E
Streaming |||||||||| 100%
Eye alt 891.93 mi

Dongtan

Venice -type ecocity on Yangzee River

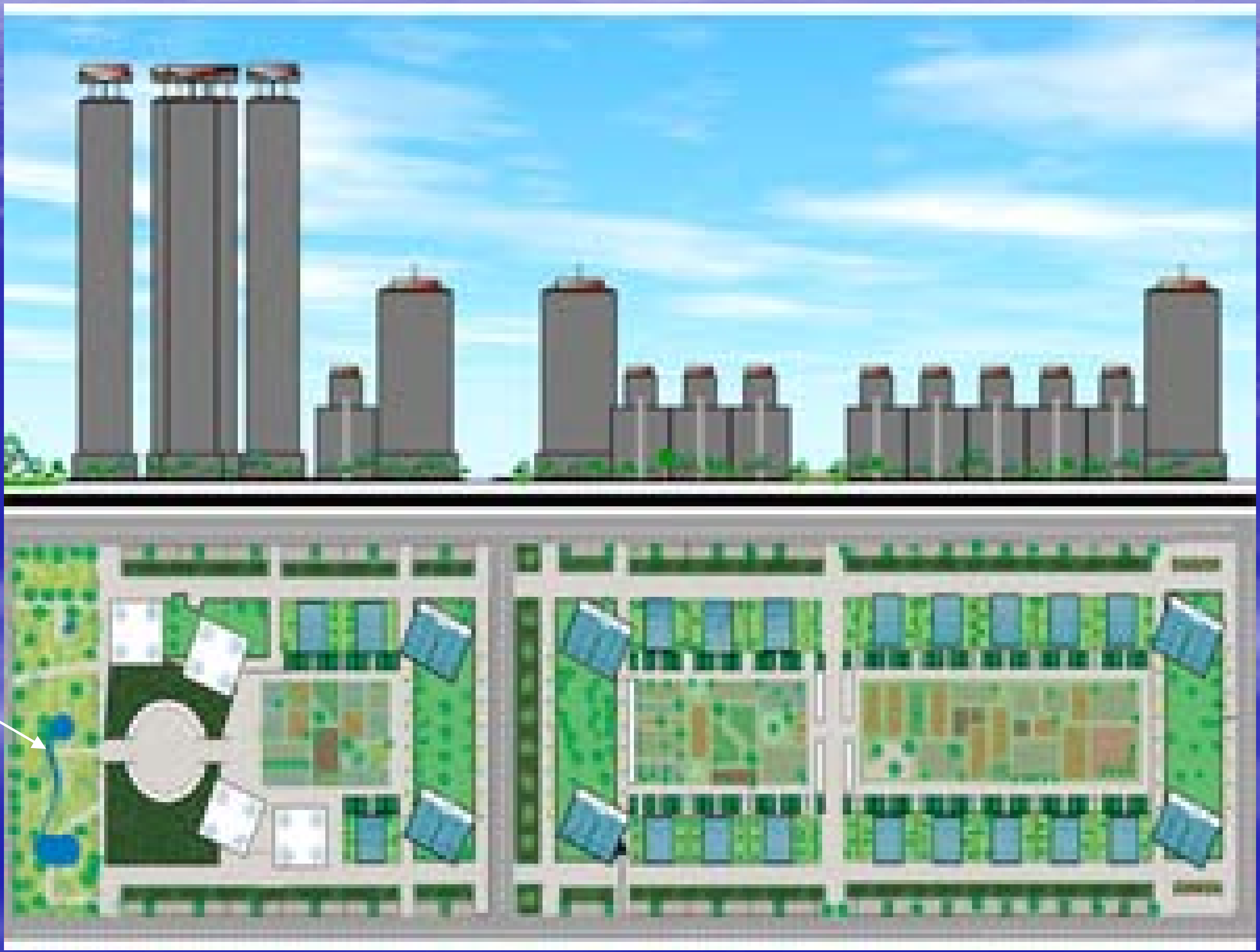
Water centric

QINGDAO (China) Ecoblock

Size 3.5 ha

1530-1800 pop

Treatment wetland



Source Harrison Fraker and ARUP

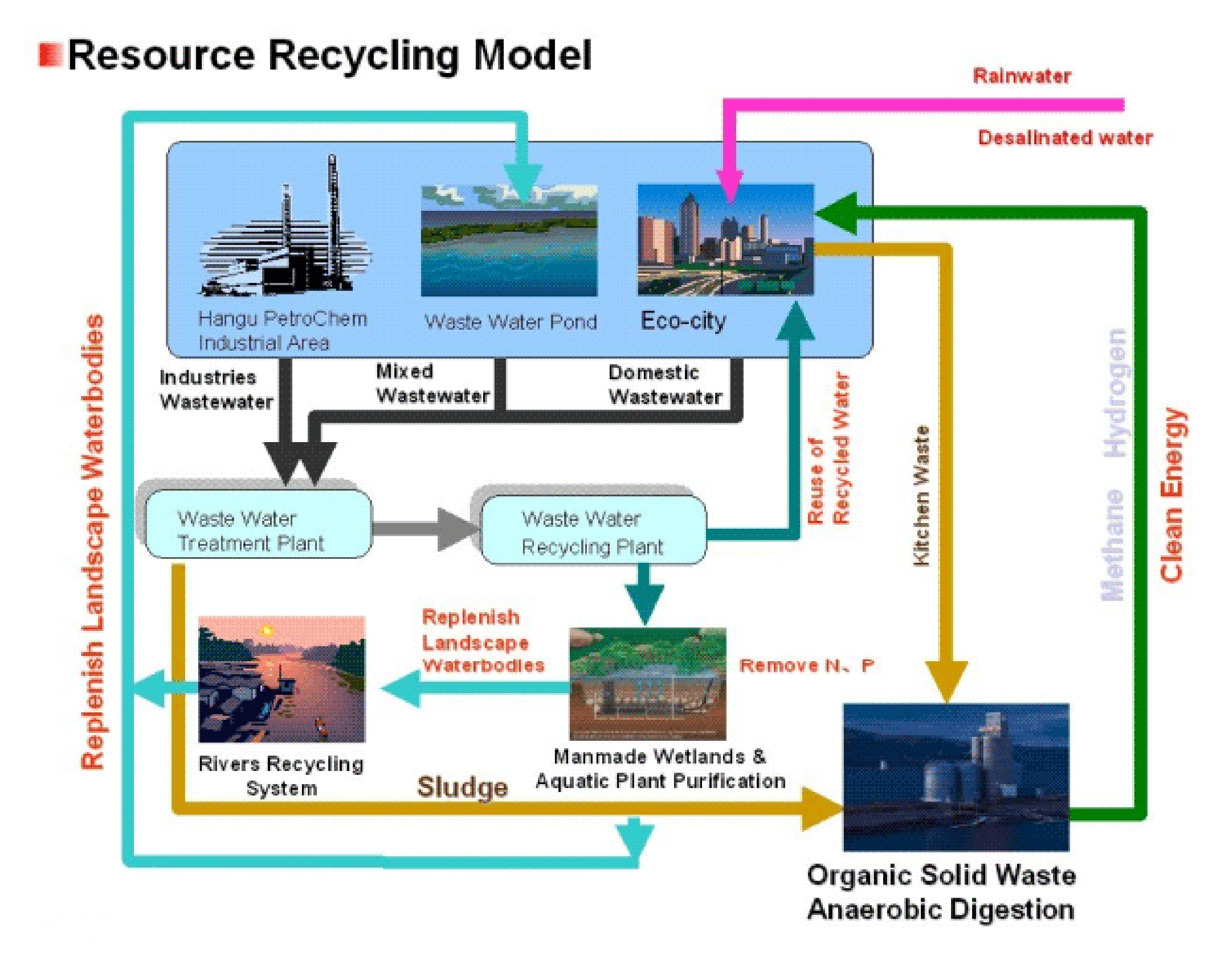
600 units on 2.7 ha (6.5 acres)

Sino-Singapore Ecocity Tianjin

Cooperation:
Singapore
US (CH2M-Hill)
Germany (Atelier Dreiseitl)
China

Zhanjiavo near
Tianjin by Dreiseitl

Tianjin Water Cycles



Credit
Sino-Singapore
Development
Consortium

Masdar (UAE)

Cooperation:

UK – Foster and Associates
USA – CH2M-Hill
United Arab Emirates

Siemens

Courtesy: Masdar Development Corporation/CH2M-HILL

Treasure Island (CA)

Location
San Francisco Bay, California
Developer City of San Francisco

Sonoma Mountain Village (CA)

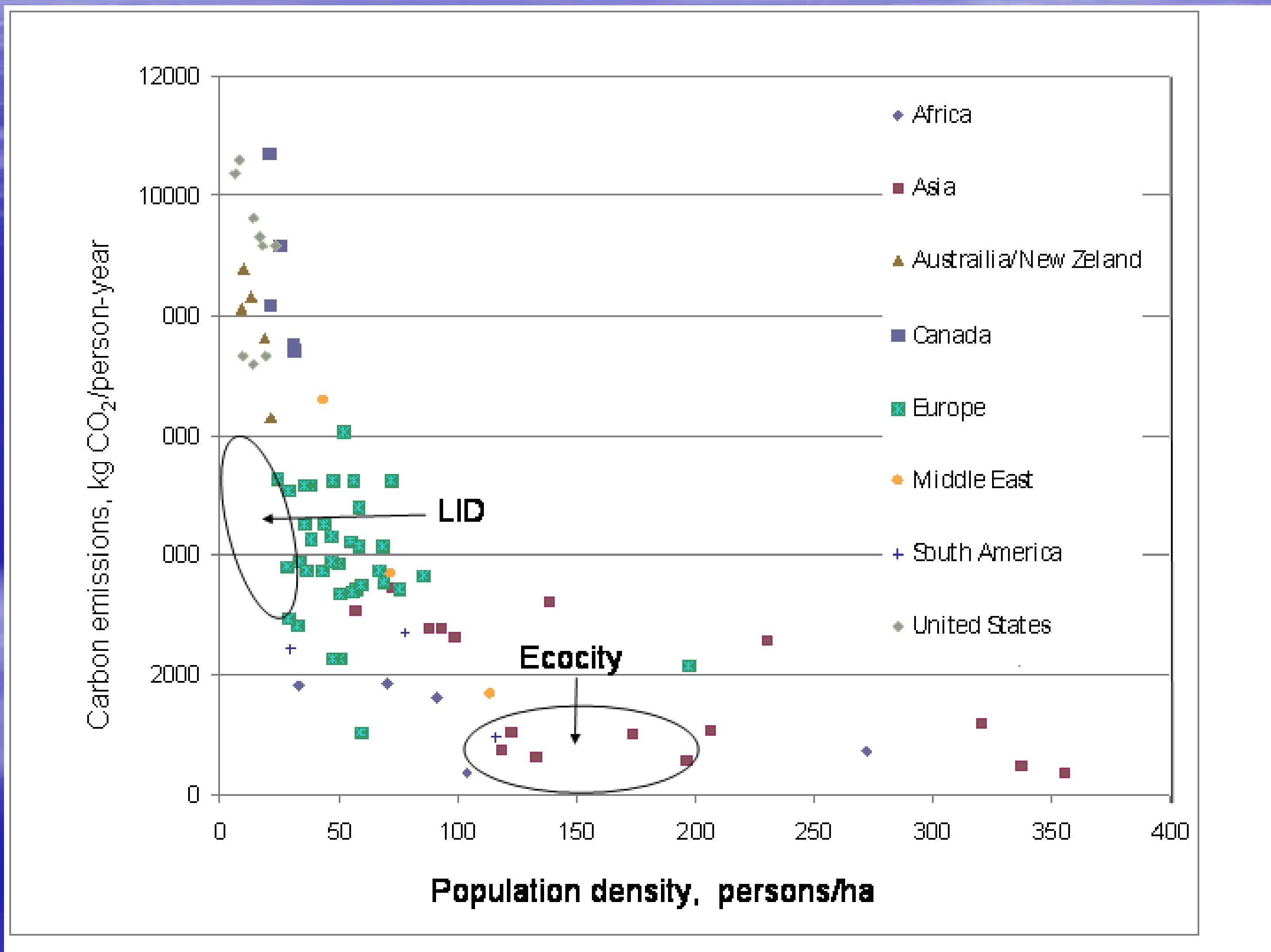
What have we learned?

Courtesy: Sonoma Mountain Village - SOMO

City	Population Total	Population Density #/ha	Water use L/cap-day	% water recycle	Water System	% Energy savings renewable	Green area m^2/cap	Cost US$/unit*
Hammarby Sjőstad	30,000	133	100	0	Linear	50	40	200,000
Dongtan	500,000 (80,000)++	160	200	43	Linear	100	100	~40,000
Qingdao	1500+	430 - 515	160	85	Closed loop	100	~15	?
Tianjin	350,000 (50,000)++	117	160	60	Partially closed	15	15	60,000 – 70,000
Masdar	50,000	135	160	80	Closed loop	100	<10	1 million
Treasure Island	13,500	170	264	25	Mostly Linear	60	75	550,000
Sonoma Valley	5,000	62	185	22	Linear	100	20	525,000

+ ecoblock only, an ecocity may consist of many interconnected ecoblocks

Population density matters



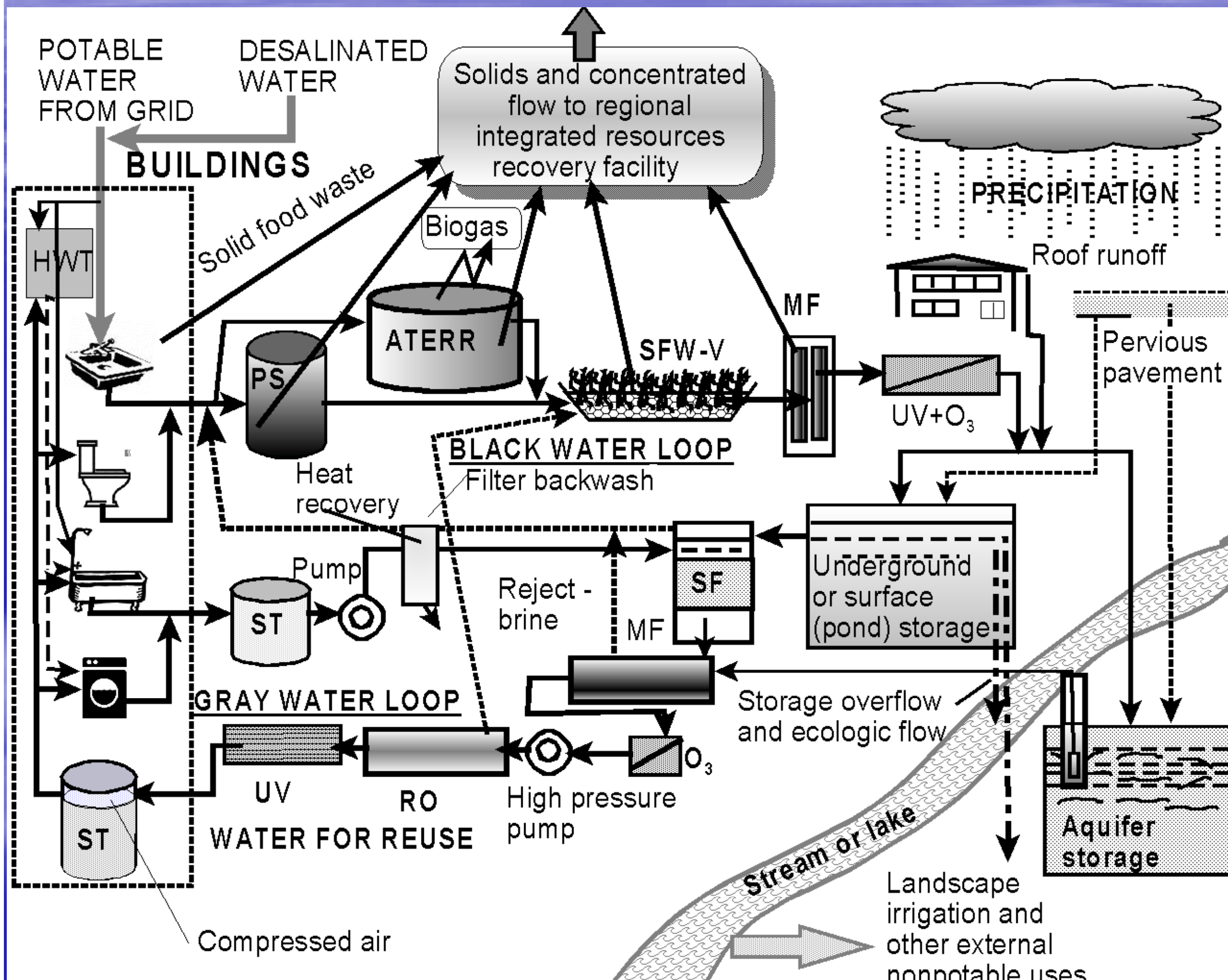
Difficult to compare US cities with Asian Cities or countries with different economic levels

Based on Newman and various other sources

Qingdao

The recycle needs urban runoff

Losses by evapotranspiration, ecological flow and reject water



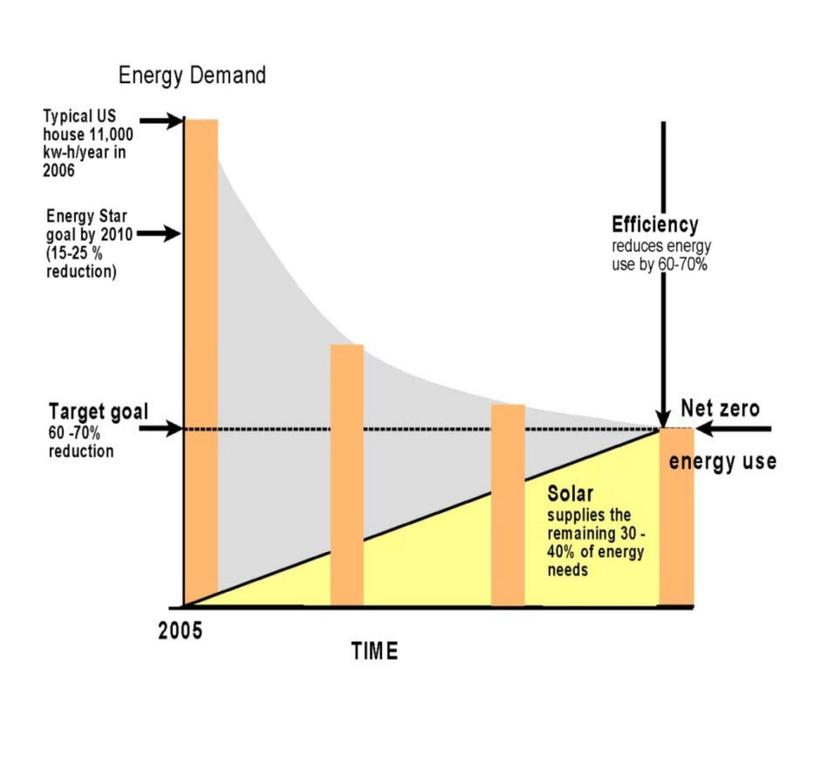
The number of cycles without make up water is very limited.

Make up water comes mainly from treated (and stored) storm water

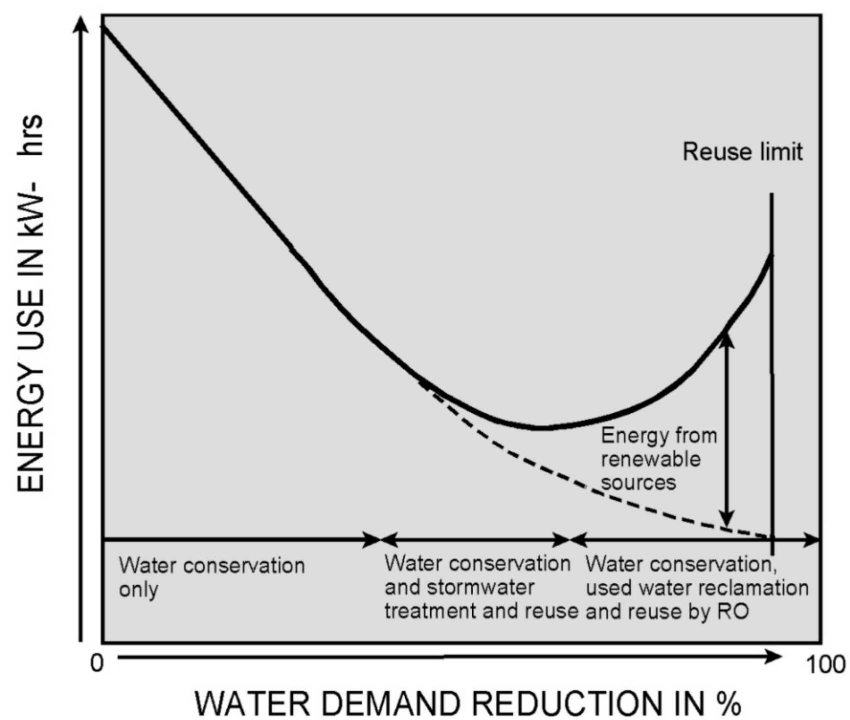
- PS – primary settler
- MF microfiltration
- UV ultraviolet disinfection
- ST storage
- RO reverse osmosis
- SFW – subsurface flow wetland
- SF – sand filter
- ATERR –anaerobic treatment and energy recovery reactor

Water Energy Nexus

Incorporating energy into landscape



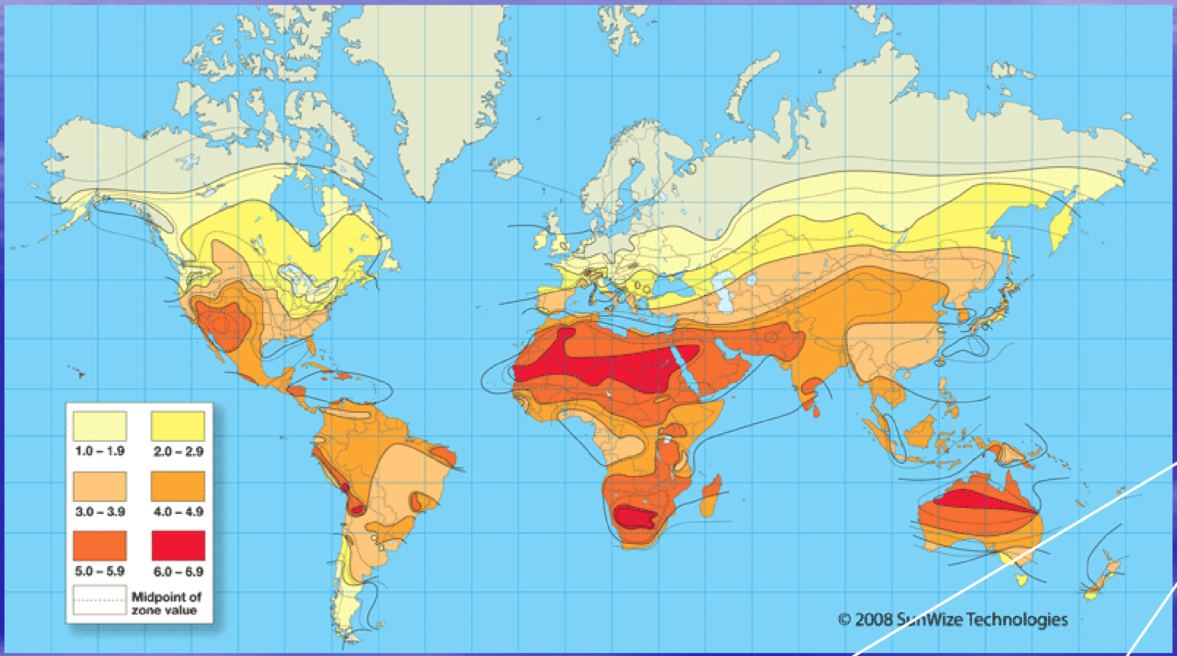
National Science & Technology Council (2008) of the US President



Energy delivered from the grid

1 kW-hr = 0.6 kg CO_2 emissions

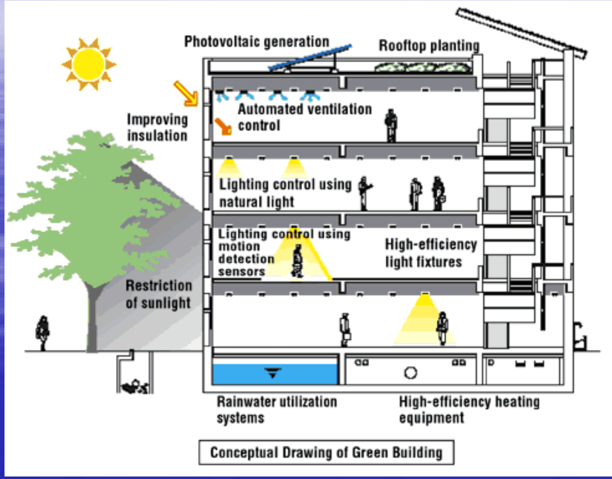
Solar energy



Concentrated heat

Photovoltaics

30 % from Renewable Energy



Passive energy sources

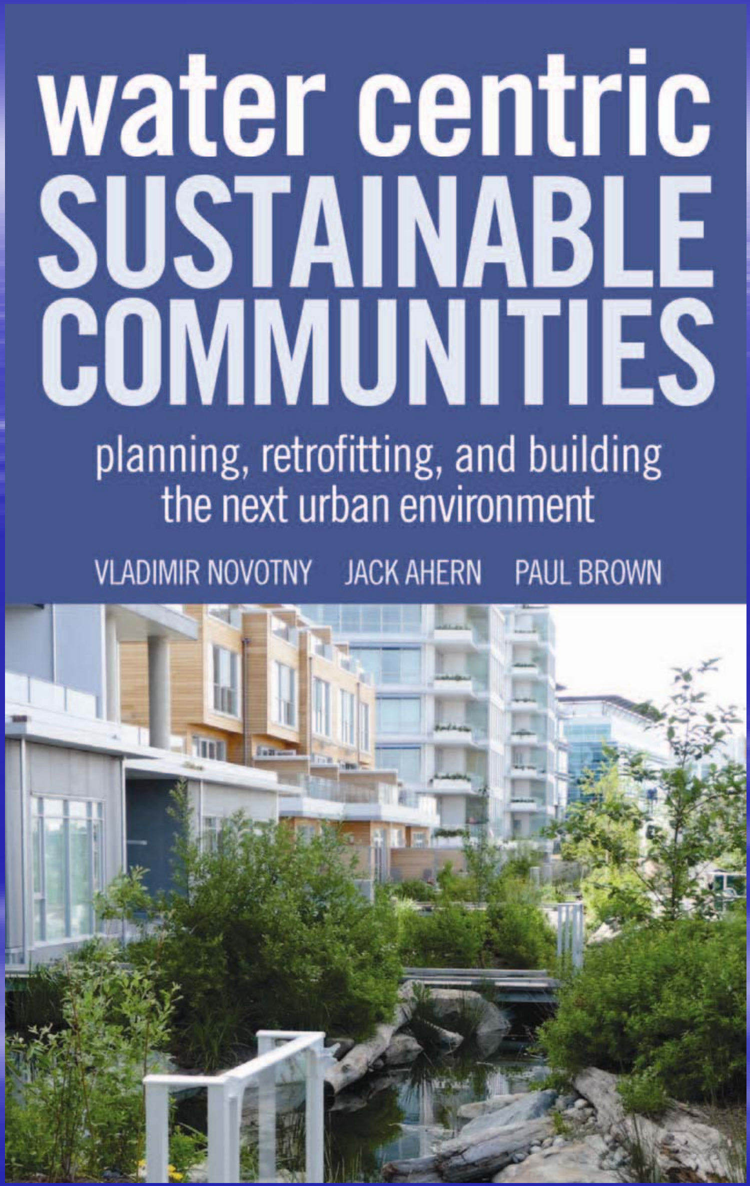
Household voltaics

1.4. MW Voltaics array in Sonoma Valley

Wind turbines in Dongtan

CONCLUSIONS ON ECOCITIES

- Ecocities are emerging and will be tested
- A complete change of the paradigm
    - Closed hydrologic cycle (reuse, recycle), surface drainage
    - Ecologic flow
- Zero or minimal carbon imprint
    - Energy recovery from wastewater
    - Distributed resource recovery, minimum sewers
    - Alternate energy sources
    - Carbon sequestering
- Terrific public transportation, walking and biking
- Alternate energy sources
- Stream restoration and protection of ecosystems
- Leisure and recreation
- Huge new infrastructure business potential



http://www.wiley.com/WileyCDA/WileyTitle/productCd-0470476087.html