The importance of ecosystem valuation in multi-functional infrastructure asset management

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Provocative Questions:

- Is it "***asset management***" if it does not consider impacts on ecosystems, along with impacts on other infrastructure classes, and traditional performance metrics?
- Is it "***asset management***" if it does not recognize its role in redistributing natural resources over time, and between human and biological populations?

Provocative Answers:

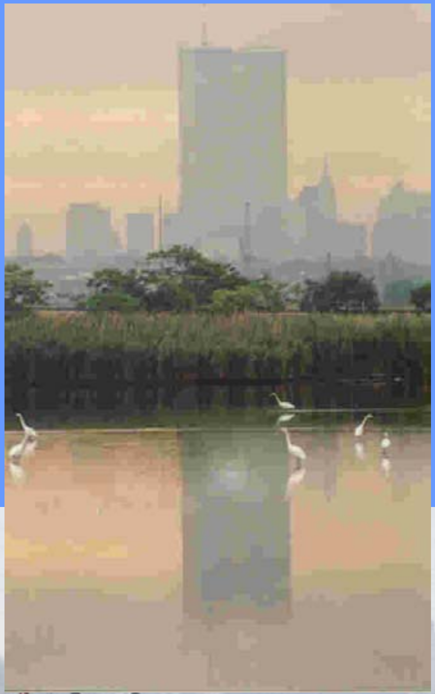
- Is it really "***asset management***" if it does not consider impacts on ecosystems, along with impacts on other infrastructure classes, and traditional performance metrics?

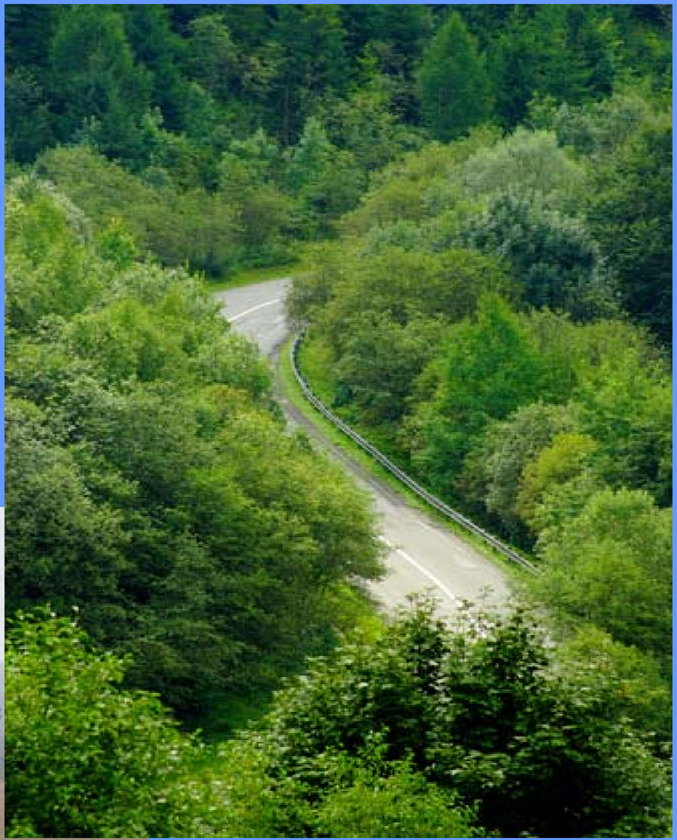
  NO…

- Is it "***asset management***" if it does not recognize its role in redistributing natural resources over time, and between human and biological populations?

  NO…

Every infrastructure system is situated in an ecosystem.





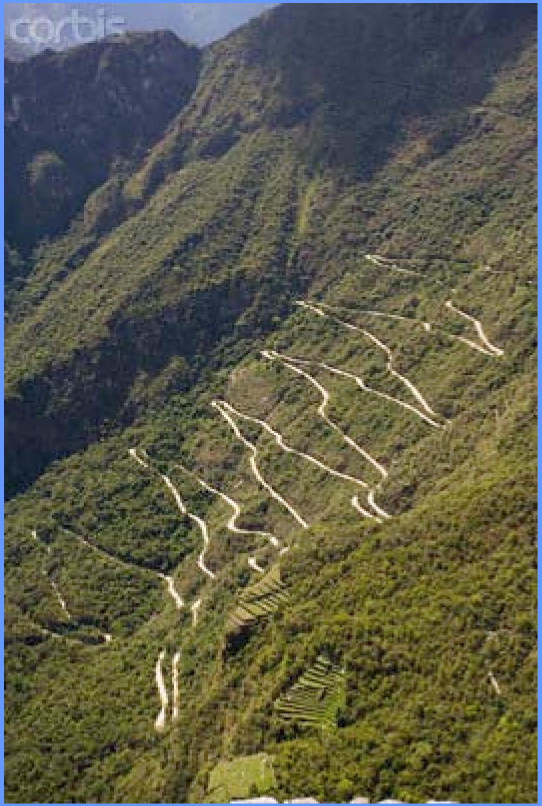
Before infrastructure…rural populations depended exclusively on ecosystems for survival:

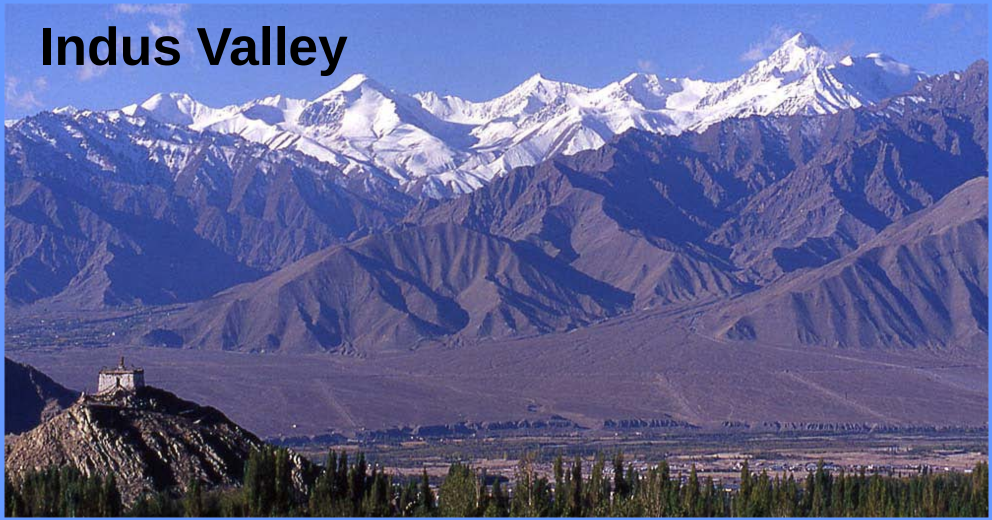
- Ecosystem Services: the benefits that human and other biological populations derive, directly or indirectly from ecosystem functions
- Ecosystem Functions: a wide range of biological, ecological, physical, or chemical processes that occur in natural ecosystems
- Ecosystem Goods: the generally tangible, material products that result from ecosystem functions

The richest ecosystems became the sites of earliest urbanization

Earliest urbanization occurred in mid-latitude river valleys rich in water supply and other ecosystem goods, functions and services (Sjoberg 1965)

Andes




Indus Valley

The evolving need for engineered infrastructure

Urbanization → Ecosystem impacts → Service gaps → The need for engineered infrastructure

Effects of urbanization on ecosystems:

- Local **demand** for goods and services **exceeds** ability of local ecosystems to naturally supply them
- **Ability** of local ecosystem to yield goods and services is **reduced** by urban impacts

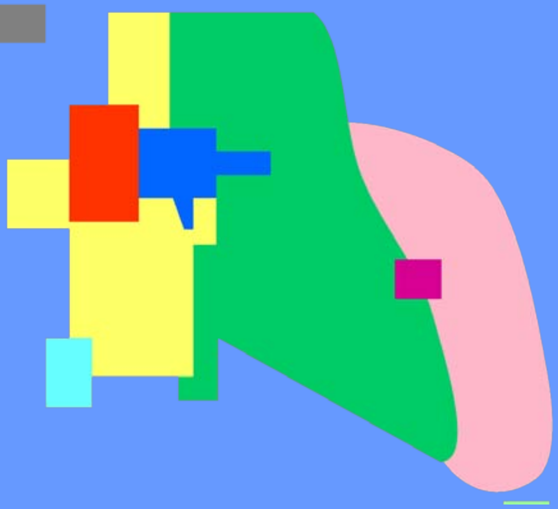
Service gaps

- formed and were filled with engineered systems and structures (aka: **infrastructure**) for example to provide flood control, drinking water, waste assimilation, etc.
- Expands "resource footprint"

Impacts of infrastructure inside and outside of urban areas

Cities:

"…***focal points in the occupation and utilization of the earth by man. Both a product of and an influence on surrounding regions, they develop in definite patterns in response to economic and social needs*** " (Harris and Ullman The Nature of Cities 1945)



Regional effects:

"***Agriculture is not even tolerably productive unless it incorporates many goods and services produced in cities or transplanted from cities***." (Jane Jacobs The Economy of Cities 1968)

Evolution of infrastructure management

- Urbanization paralleled the emergence of groups who were able to exact tributes, impose taxes, and control labor power, usually through some form of religious persuasion or military coercion. (Know et al 1998)
- In so doing, these groups controlled the supply of goods and services to urban populations… **i.e. they managed infrastructure.**

Unlimited growth exceeds ecosystem limits, causing crises and collapse

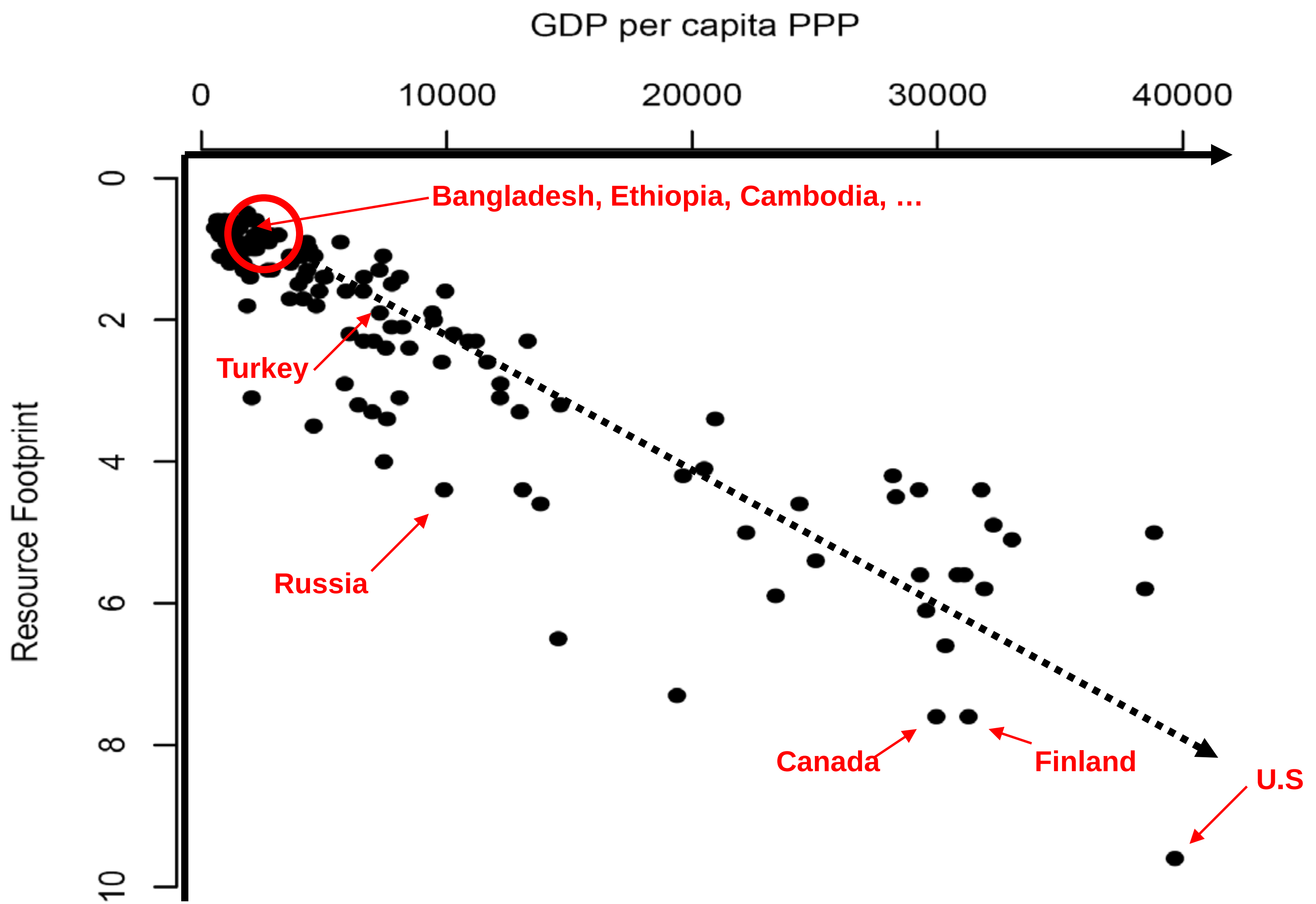
Lewis Mumford (1951) <u>The Conduct of Life</u>

“As Rome grew, it began to overtax its environs. At this point, the relationship became parasitic, and Rome was only able to maintain further growth by engaging in a systematic military exploitation of other regions. Rome was not original in this respect; other cities and empires before and after have done much the same“

Urban development today

- Global Population Growth
- Urbanization
- Coastal Development

As nations develop economically, they also tend to expand their natural resource footprint



Montalto, Russell, Greene (unpublished 2007)

Contemporary development impacts

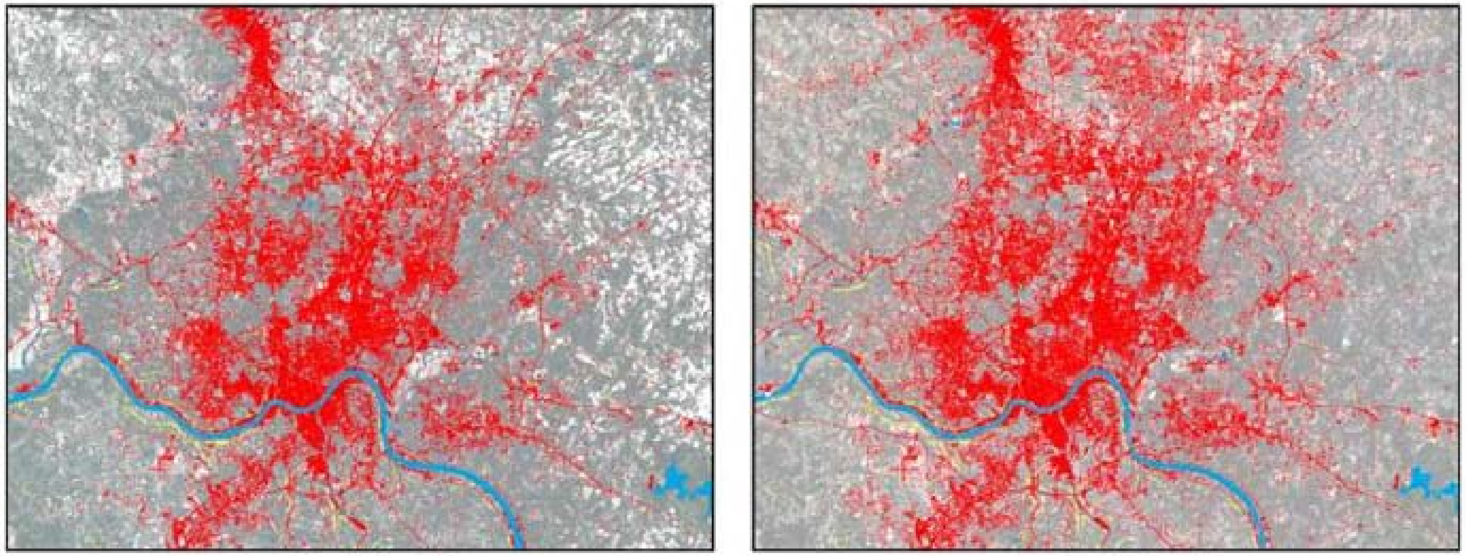
Cause

- Increases in built up area
- Reductions in urban density

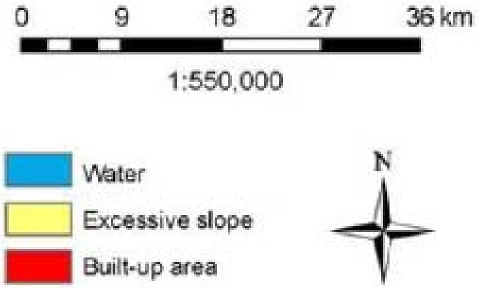
Effect

- Destruction of ecosystems and reduction in the quantity of goods and services they provide (increasing the service gap)
- Expansion of infrastructure service areas
- Expansion of “resource footprints”

Cincinnati, United States



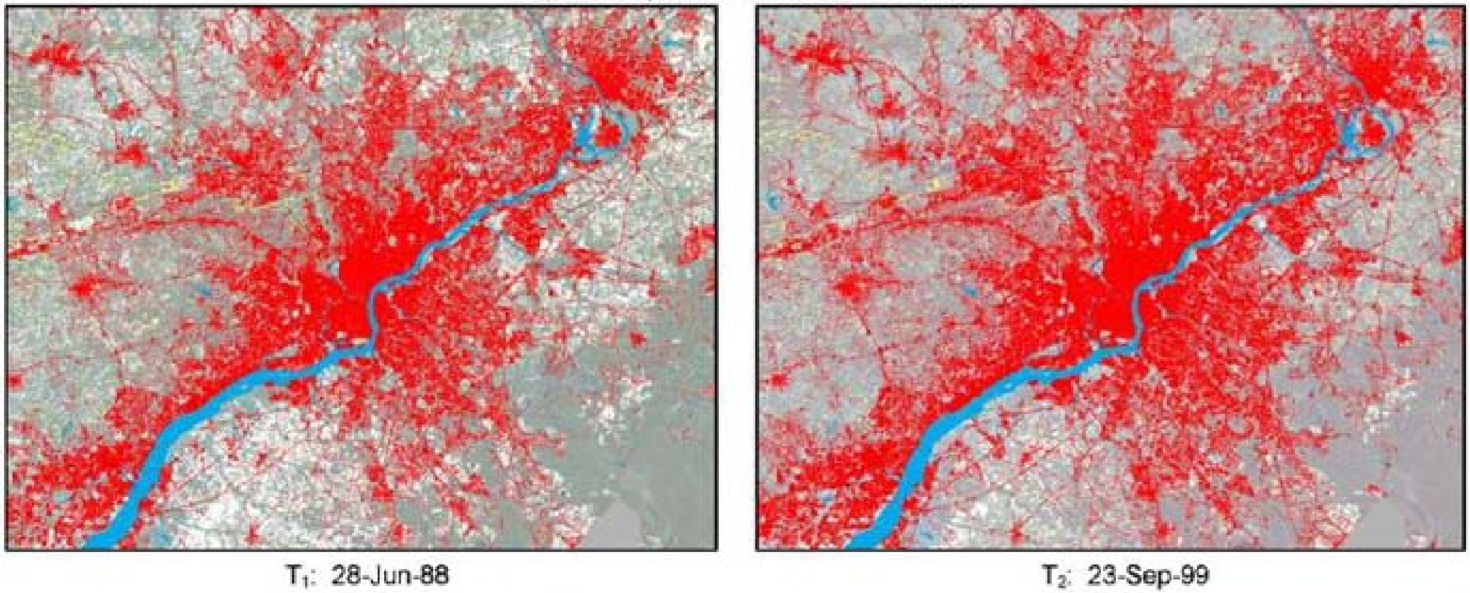
T₁: 6-Jun-88 T₂: 16-Aug-99

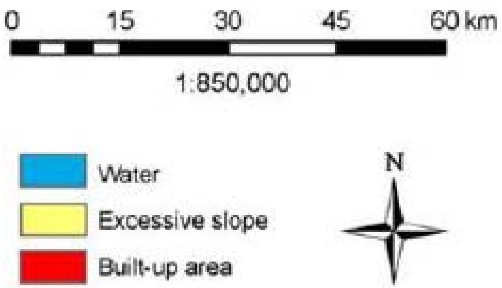


Measure	T_1	T_2	Annual % Change
Population	1,441,806	1,517,141	0.64%
Built-Up Area (sq km)	594.48	774.10	3.36%
Average Density (persons / sq km)	2,425.34	1,959.89	-2.63%
Built-Up Area per Person (sq m)	412.31	510.23	2.70%
Average Slope of Built-Up Area (%)	4.52	4.43	-0.28%
Maximum Slope of Built-Up Area (%)	29.00	28.00	-0.44%
The Buildable Perimeter (%)	0.94	0.94	0.05%
The Contiguity Index	0.71	0.76	0.80%
The Compactness Index	0.24	0.31	2.99%
Per Capita Gross Domestic Product	$27,243.74	$31,414.84	1.80%

The Dynamics of Global Urban Expansion (World Bank 2005)

Philadelphia, United States

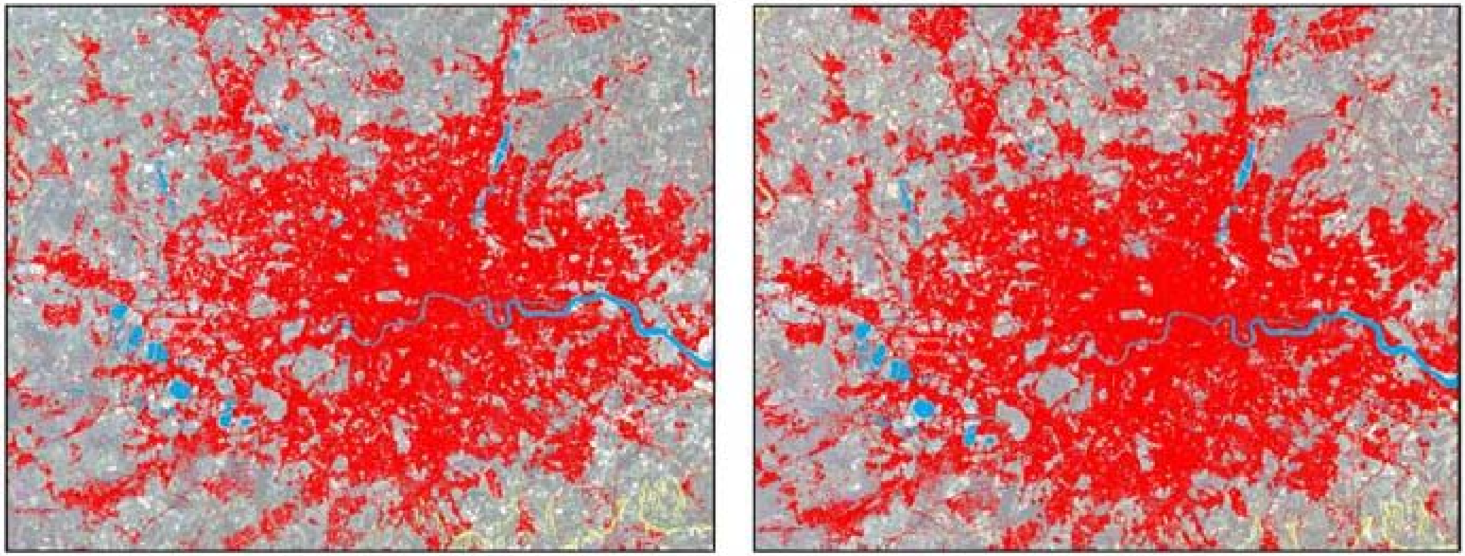




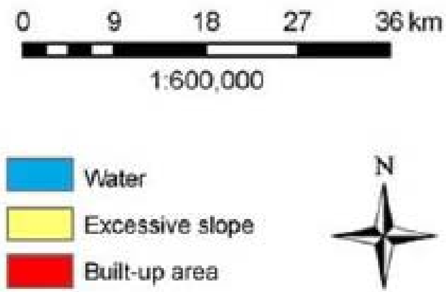
Measure	T_1	T_2	Annual % Change
Population	5,177,790	5,273,732	0.16%
Built-Up Area (sq km)	1,889.95	2,328.87	1.88%
Average Density (persons / sq km)	2,719.42	2,243.24	-1.70%
Built-Up Area per Person (sq m)	367.73	445.78	1.73%
Average Slope of Built-Up Area (%)	3.31	4.02	1.74%
Maximum Slope of Built-Up Area (%)	17.77	19.00	0.60%
The Buildable Perimeter (%)	0.92	0.92	-0.02%
The Contiguity Index	0.55	0.84	3.82%
The Compactness Index	0.21	0.28	2.40%
Per Capita Gross Domestic Product	$25,342.26	$30,959.91	1.80%

The Dynamics of Global Urban Expansion (World Bank 2005)

London, United Kingdom



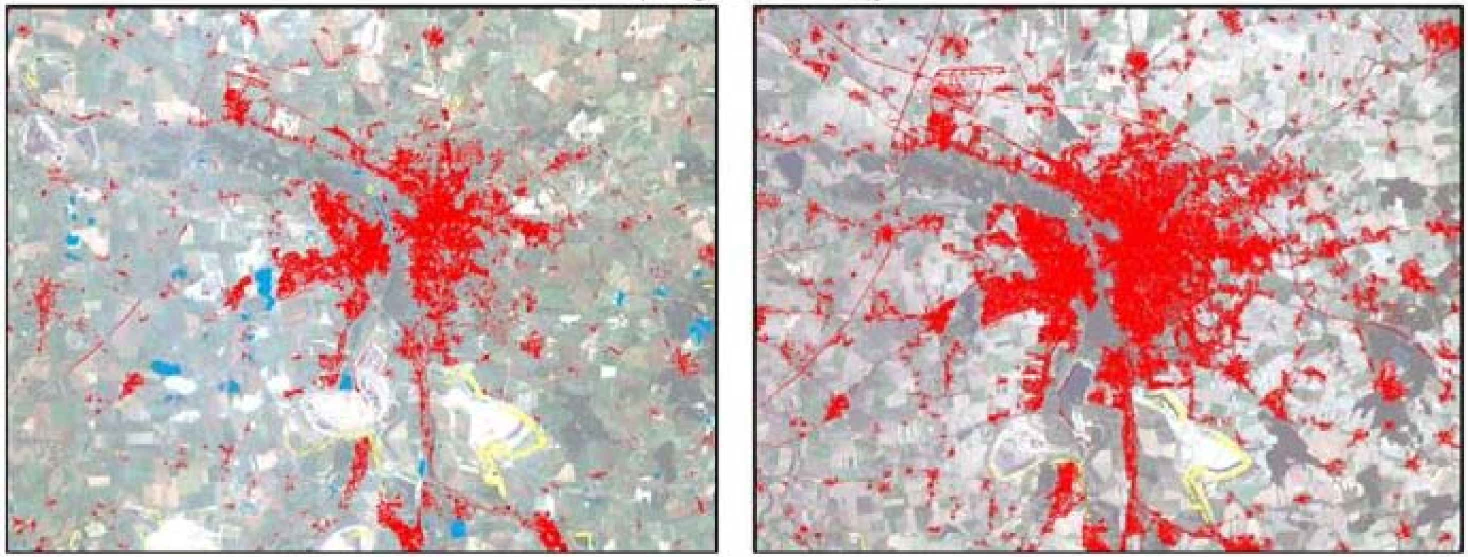
T₁: 28-May-89 — T₂: 19-Jun-00



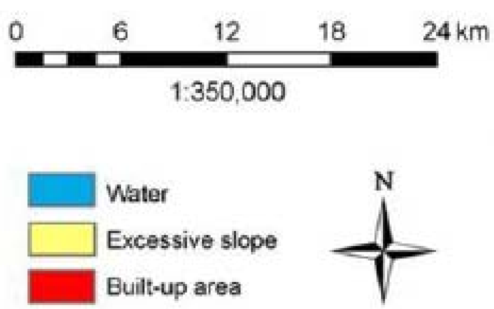
Measure	T_1	T_2	Annual % Change
Population	9,932,047	10,028,978	0.09%
Built-Up Area (sq km)	1,573.12	1,855.38	1.50%
Average Density (persons / sq km)	6,313.59	5,405.34	-1.39%
Built-Up Area per Person (sq m)	158.39	185.00	1.41%
Average Slope of Built-Up Area (%)	3.19	3.26	0.19%
Maximum Slope of Built-Up Area (%)	17.38	17.54	0.08%
The Buildable Perimeter (%)	0.94	0.93	-0.06%
The Contiguity Index	0.71	0.69	-0.28%
The Compactness Index	0.33	0.38	1.28%
Per Capita Gross Domestic Product	$18,442.58	$22,676.81	1.89%

The Dynamics of Global Urban Expansion (World Bank 2005)

Leipzig, Germany

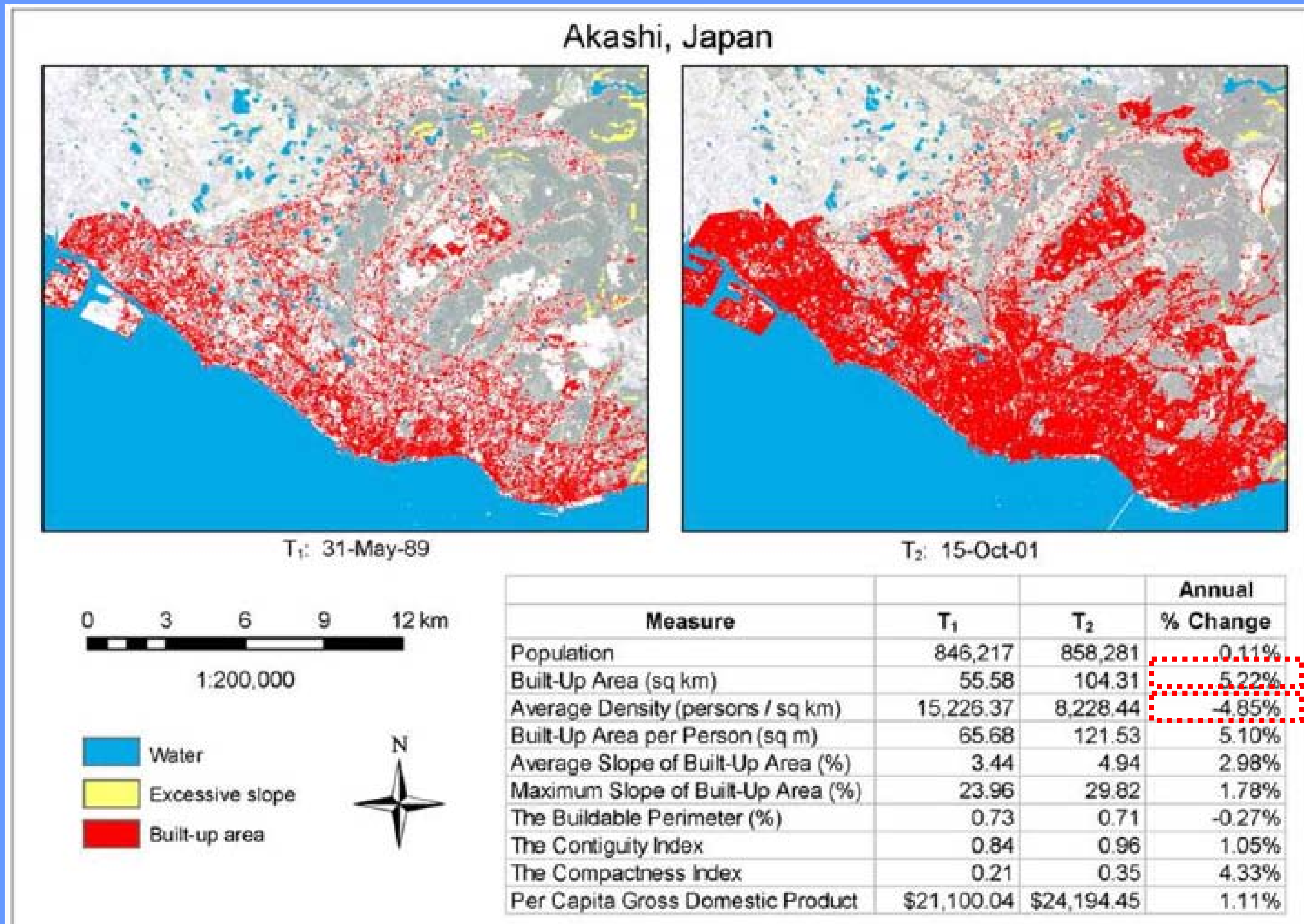


T_1: 7-Jul-89 | T_2: 13-Sep-99



Measure	T_1	T_2	Annual % Change
Population	1,278,052	1,198,715	-0.63%
Built-Up Area (sq km)	188.43	406.64	7.85%
Average Density (persons / sq km)	6,782.66	2,947.83	-7.86%
Built-Up Area per Person (sq m)	147.43	339.23	8.53%
Average Slope of Built-Up Area (%)	2.10	2.26	0.73%
Maximum Slope of Built-Up Area (%)	13.19	14.16	0.70%
The Buildable Perimeter (%)	0.94	0.95	0.06%
The Contiguity Index	0.41	0.38	-0.92%
The Compactness Index	0.29	0.24	-1.82%
Per Capita Gross Domestic Product	$19,829.21	$23,622.87	1.73%

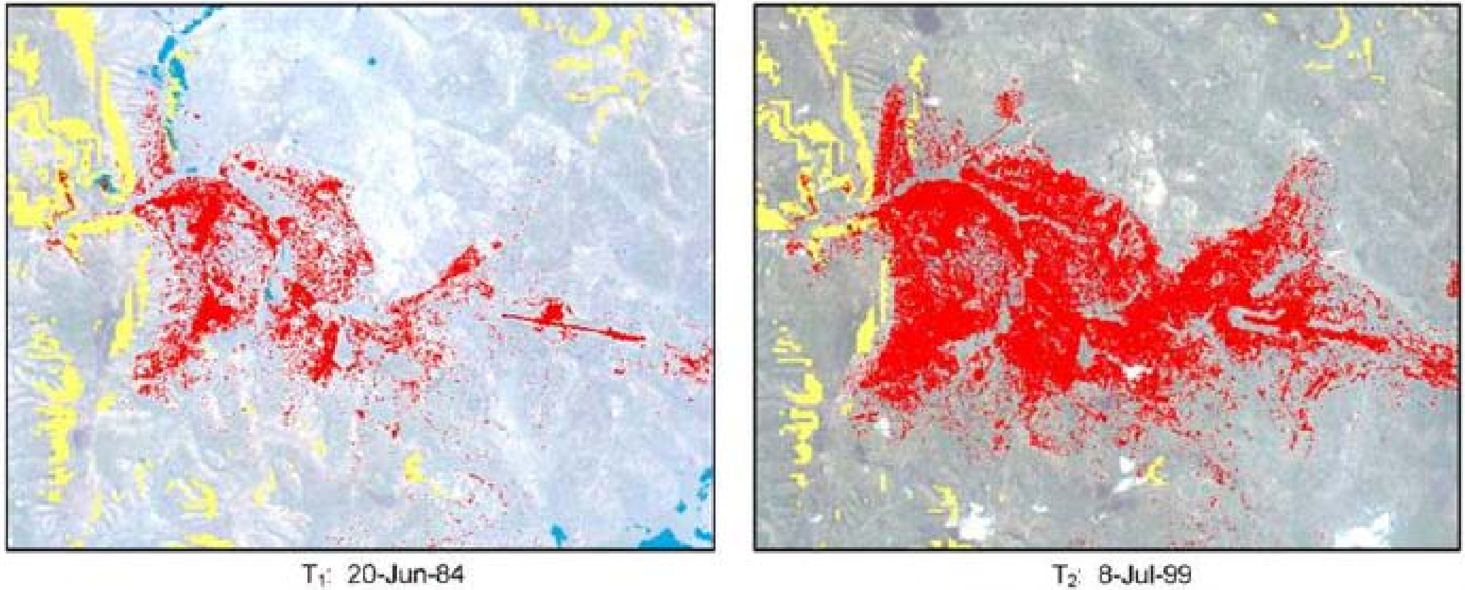
The Dynamics of Global Urban Expansion (World Bank 2005)

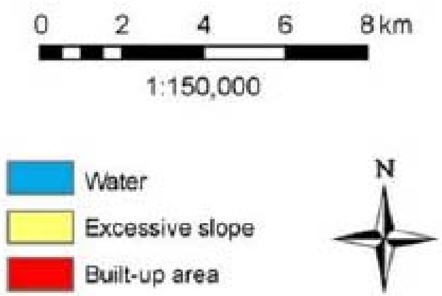


Measure	T_1	T_2	Annual % Change
Population	846,217	858,281	0.11%
Built-Up Area (sq km)	55.58	104.31	5.22%
Average Density (persons / sq km)	15,226.37	8,228.44	-4.85%
Built-Up Area per Person (sq m)	65.68	121.53	5.10%
Average Slope of Built-Up Area (%)	3.44	4.94	2.98%
Maximum Slope of Built-Up Area (%)	23.96	29.82	1.78%
The Buildable Perimeter (%)	0.73	0.71	-0.27%
The Contiguity Index	0.84	0.96	1.05%
The Compactness Index	0.21	0.35	4.33%
Per Capita Gross Domestic Product	$21,100.04	$24,194.45	1.11%

The Dynamics of Global Urban Expansion (World Bank 2005)

Kigali, Rwanda

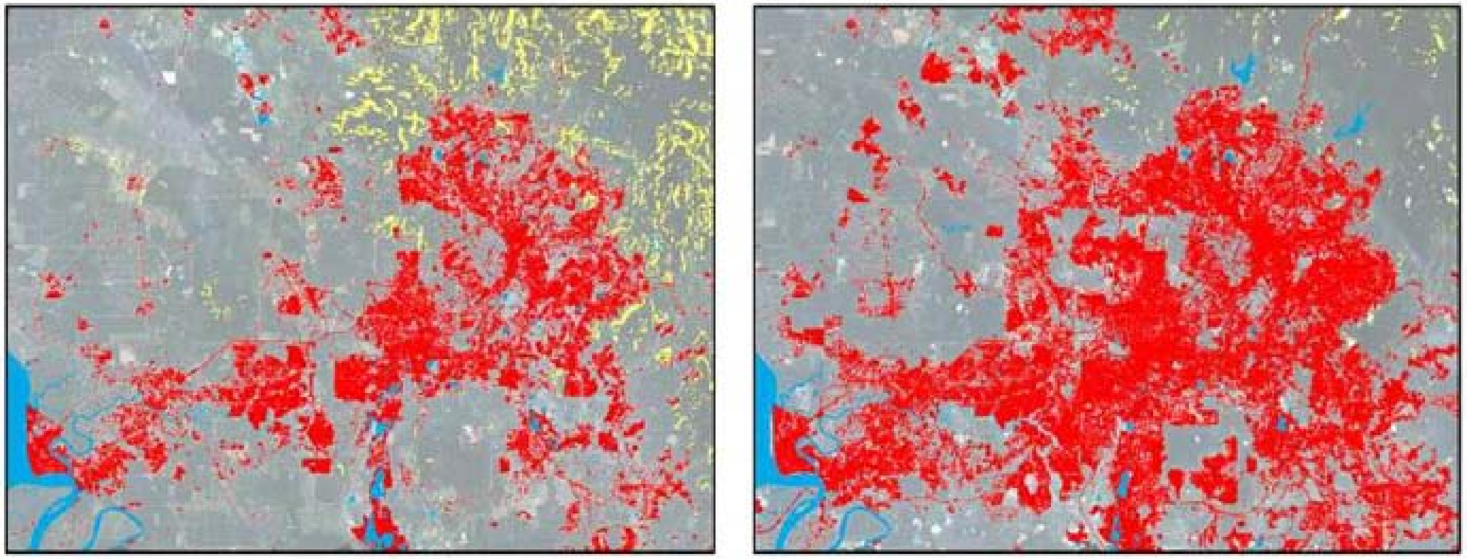




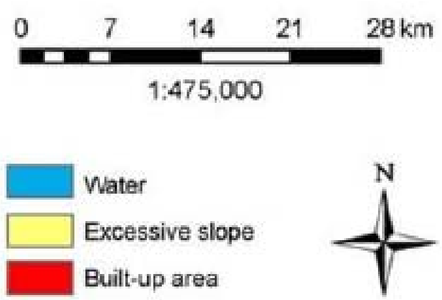
Measure	T_1	T_2	Annual % Change
Population	296,879	354,273	1.18%
Built-Up Area (sq km)	15.19	45.13	7.51%
Average Density (persons / sq km)	19,549.74	7,849.33	-5.88%
Built-Up Area per Person (sq m)	51.15	127.40	6.25%
Average Slope of Built-Up Area (%)	7.14	10.24	2.42%
Maximum Slope of Built-Up Area (%)	36.3	40.77	0.77%
The Buildable Perimeter (%)	0.91	0.93	0.12%
The Contiguity Index	0.71	0.94	1.91%
The Compactness Index	0.35	0.30	-0.89%
Per Capita Gross Domestic Product	$1,147.52	$1,010.36	-0.84%

The Dynamics of Global Urban Expansion (World Bank 2005)

Kuala Lumpur, Malaysia



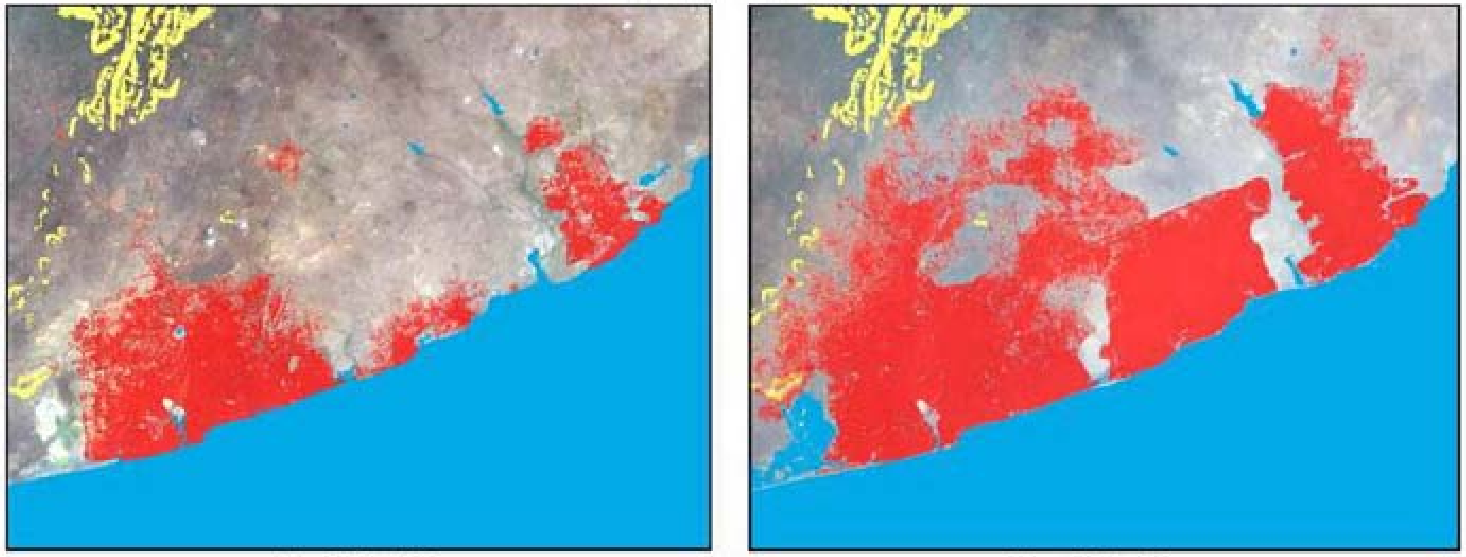
T_1: 15-Jun-89 T_2: 20-Sep-01



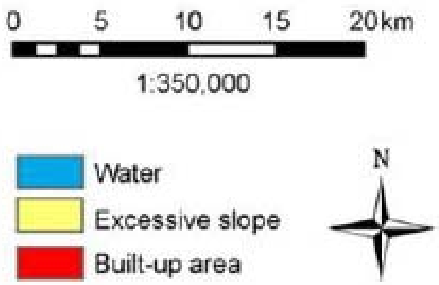
Measure	T_1	T_2	Annual % Change
Population	2,733,393	4,959,393	4.98%
Built-Up Area (sq km)	383.13	805.41	6.24%
Average Density (persons / sq km)	7,134.38	6,157.60	-1.19%
Built-Up Area per Person (sq m)	140.17	162.40	1.21%
Average Slope of Built-Up Area (%)	5.67	9.06	3.89%
Maximum Slope of Built-Up Area (%)	34.00	51.00	3.36%
The Buildable Perimeter (%)	0.89	0.92	0.27%
The Contiguity Index	0.58	0.83	2.97%
The Compactness Index	0.41	0.32	-2.00%
Per Capita Gross Domestic Product	$4,849.18	$8,752.33	4.93%

The Dynamics of Global Urban Expansion (World Bank 2005)

Accra, Ghana



T1: 6-Mar-85 | T2: 4-Feb-00



Measure	T_1	T_2	Annual % Change
Population	1,882,990	2,789,380	2.67%
Built-Up Area (sq km)	133.35	344.26	6.56%
Average Density (persons / sq km)	14,120.39	8,102.64	-3.66%
Built-Up Area per Person (sq m)	70.82	123.42	3.79%
Average Slope of Built-Up Area (%)	3.11	3.11	0.01%
Maximum Slope of Built-Up Area (%)	12.28	12.28	0.00%
The Buildable Perimeter (%)	0.71	0.73	0.15%
The Contiguity Index	0.69	0.80	1.01%
The Compactness Index	0.68	0.61	-0.75%
Per Capita Gross Domestic Product	$1,325.50	$1,836.23	2.21%

The Dynamics of Global Urban Expansion (World Bank 2005)

Ecosystems Services: Free, But Valuable

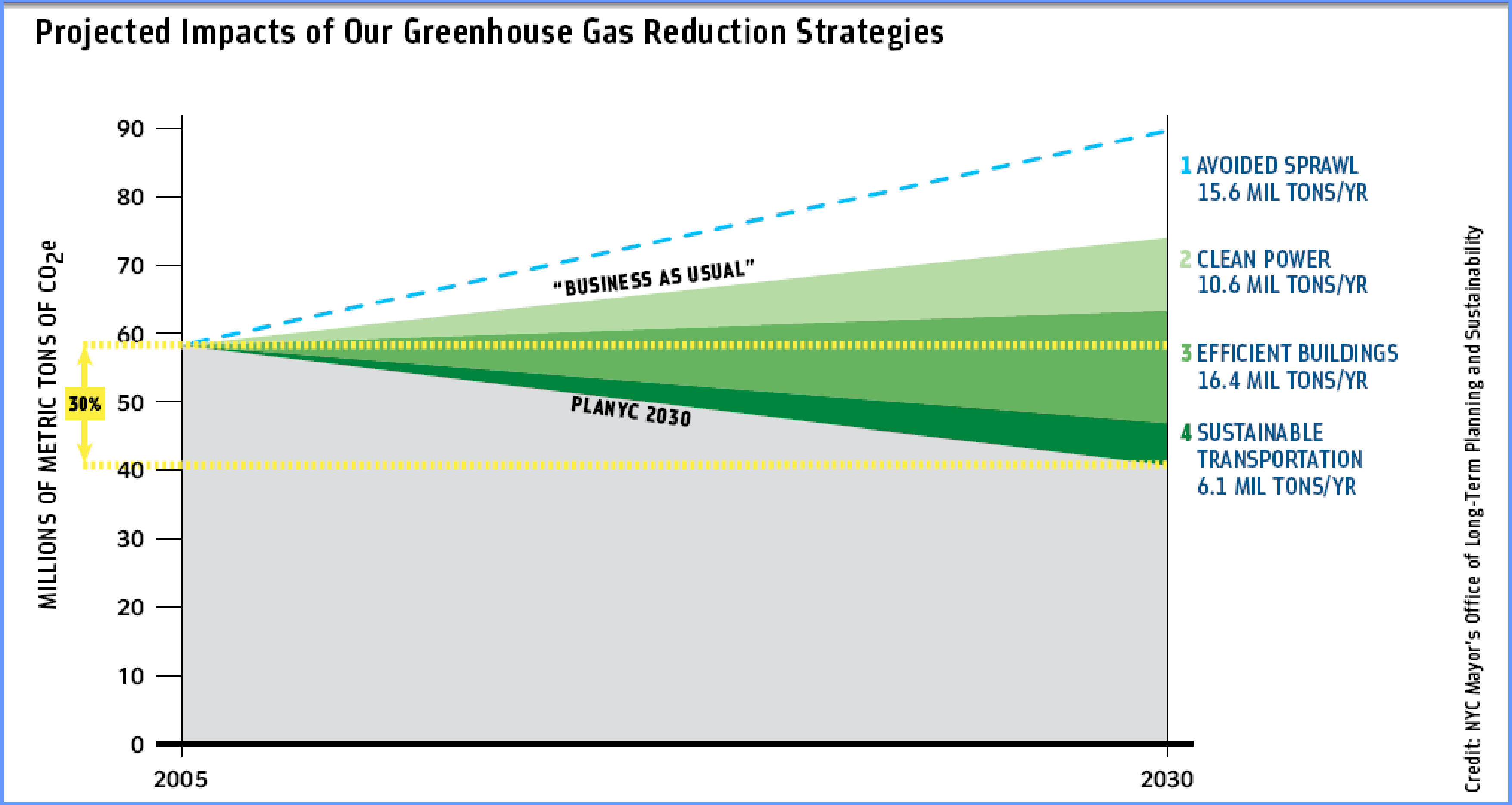
Figure 2: Estimates of Various Ecosystem Services, 1997

ECOSYSTEM SERVICES	VALUE (TRILLION $US)
Soil formation	17.1
Recreation	3.0
Nutrient cycling	2.3
Water regulation and supply	2.3
Climate regulation (temperature and precipitation)	1.8
Habitat	1.4
Flood and storm protection	1.1
Food and raw materials	0.8
Genetic resources	0.8
Atmospheric gas balance	0.7
Pollination	0.4
All other services	1.6
Total value of ecosystem services	**33.3**

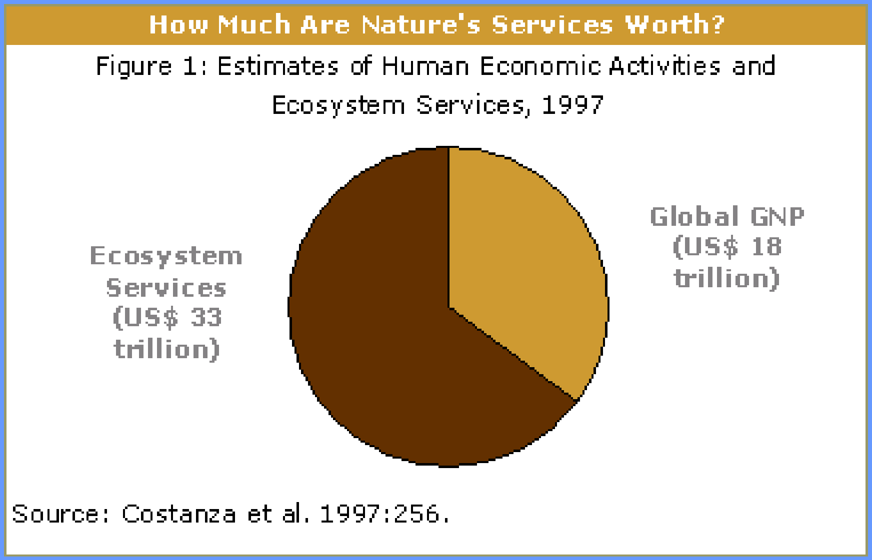
Source: Costanza et al. 1997:256

The ecosystems that we are expanding into and extracting resources from are extremely valuable.

Infrastructure Impacts on Climate



Infrastructure Decisions (among other factors) cause climate change



"Cost" of human-induced climate change: 5-20% of global domestic product annually "now and forever" (Stern Review of the Economics of Climate Change 2006)

Ecosystem valuation and consequences of omission

"Until the economic value of ecosystem goods and services is acknowledged in environmental decision-making, they will implicitly be assigned a value of zero in cost benefit analyses, and policy choices will be biased against conservation" - NRC (2004)

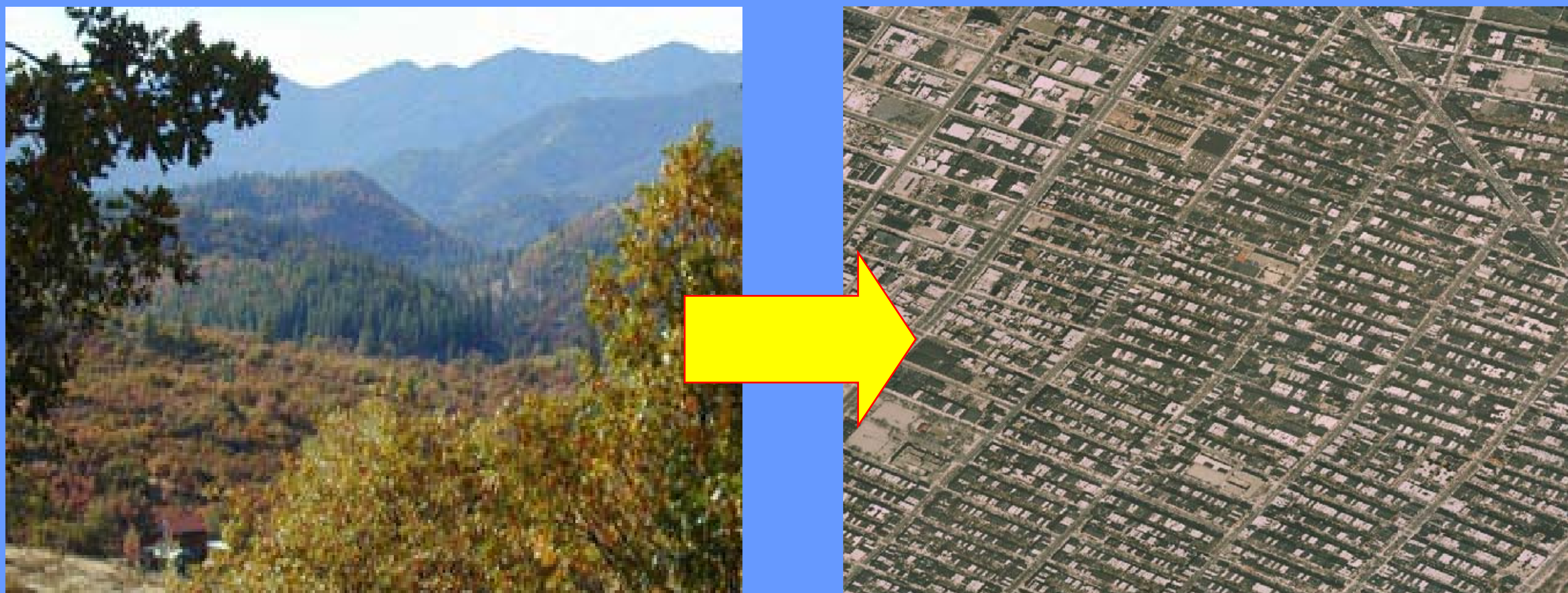
Ecosystem destruction → Reduced ecosystem goods and services →

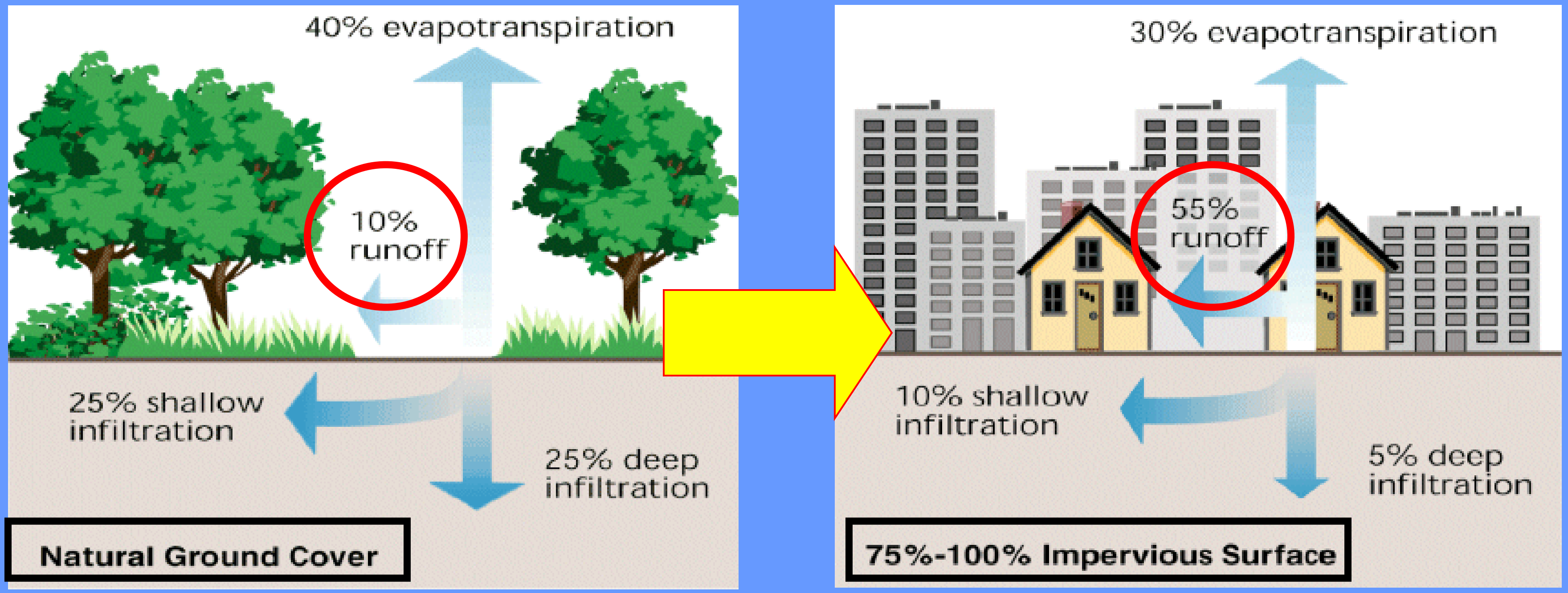
1) Increased liabilities for managers of other infrastructure classes
2) Expanded infrastructure asset portfolios
3) Greater need for infrastructure asset management

Example: Water Infrastructure

- Drainage
- Drinking water provision
- Drinking water treatment
- Wastewater disposal
- Wastewater treatment
- Nonpoint source pollution control
- Water body water quality/TMDLs
- Ecological restoration

Evolution of water utility infrastructure responsibilities





Images adapted from USEPA graphics

Mono-functional infrastructure solution to runoff problem

Rapid Collection, Conveyance,
& Disposal of Runoff with drainage infrastructure

Mono-functional infrastructure solution results

PRO'S

- Effectively removes "waste" runoff away from developed sites

CON'S

- Private development costs
- Environmental costs
- Public infrastructure costs




Private development costs

- EPA (2007) “Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices”
  - Total capital cost savings: 15-80%

Table 2. Summary of Cost Comparisons Between Conventional and LID Approaches[a]

Project	Conventional Development Cost	LID Cost	Cost Difference[b]	Percent Difference[b]
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington Estates	$765,700	$1,502,900	–$737,200	-96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[c]	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

SEA Street, Seattle monitoring results for three years:

99%

reduction in total runoff volume

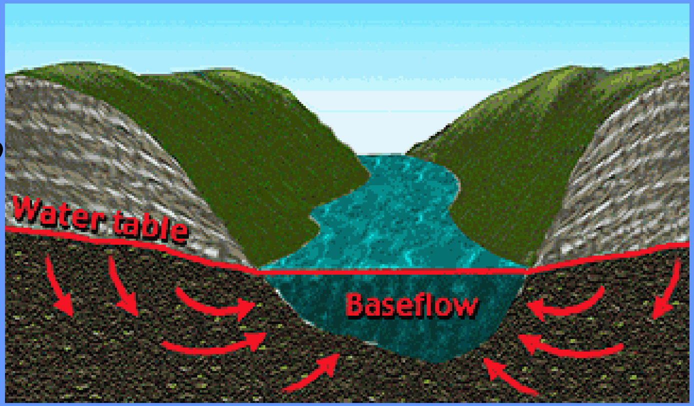
Table 3. Cost Comparison for 2nd Avenue SEA Street [15]

Item	Conventional Development Cost	SEA Street Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$65,084	$88,173	–$23,089	–35%	–11%
Stormwater management	$372,988	$264,212	$108,776	29%	50%
Site paving and sidewalks	$287,646	$147,368	$140,278	49%	65%
Landscaping	$78,729	$113,034	–$34,305	–44%	–16%
Misc. (mobilization, etc.)	$64,356	$38,761	$25,595	40%	12%
Total	**$868,803**	**$651,548**	**$217,255**	---	---

* Negative values denote increased cost for the LID design over conventional development costs.

Environmental Costs
Highly altered flows in the watershed

Reduced infiltration & GW; undermined foundations; flashy streams

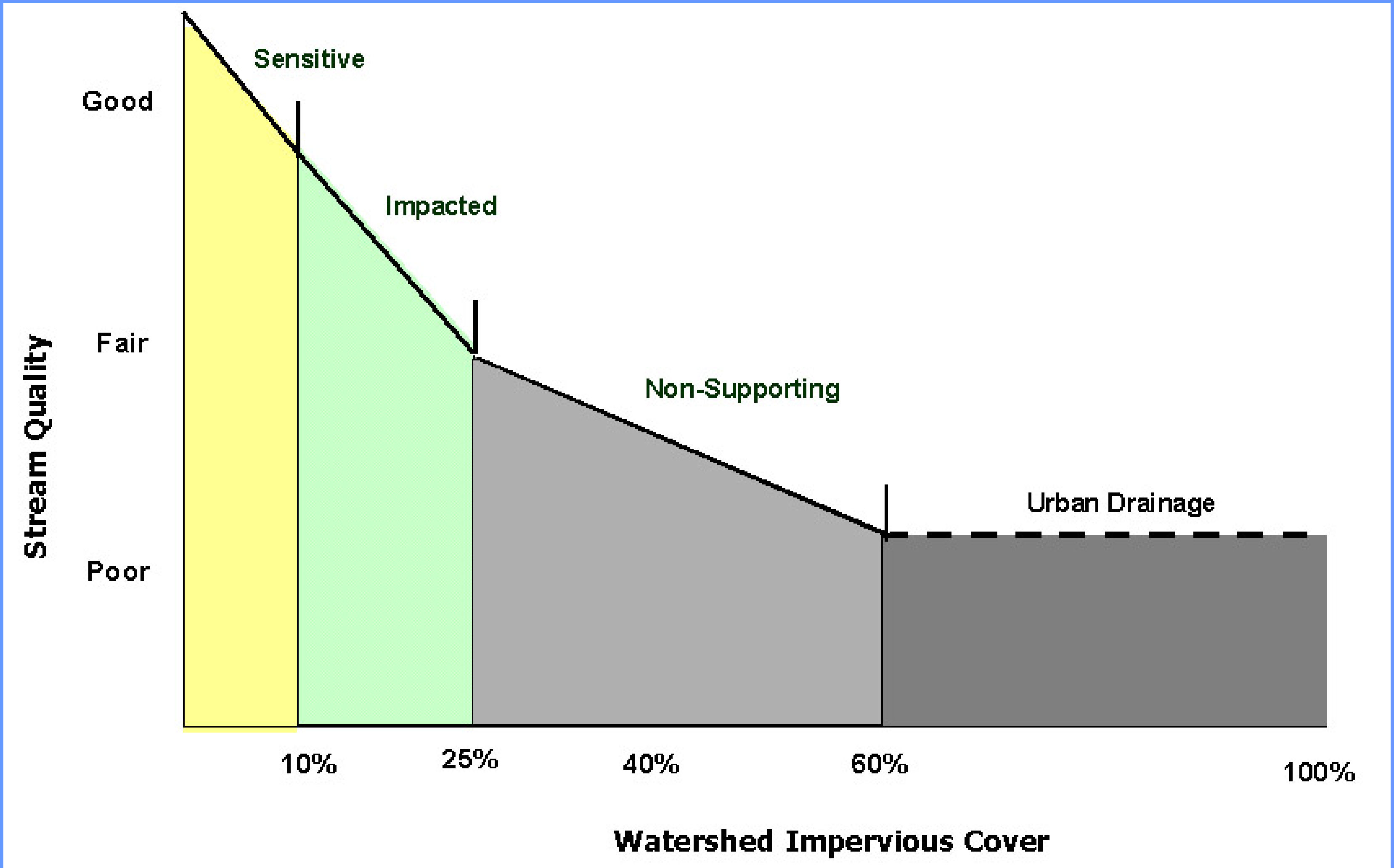


Flooding of downstream communities

Topsoil and bank erosion & impacts to civil infrastructures

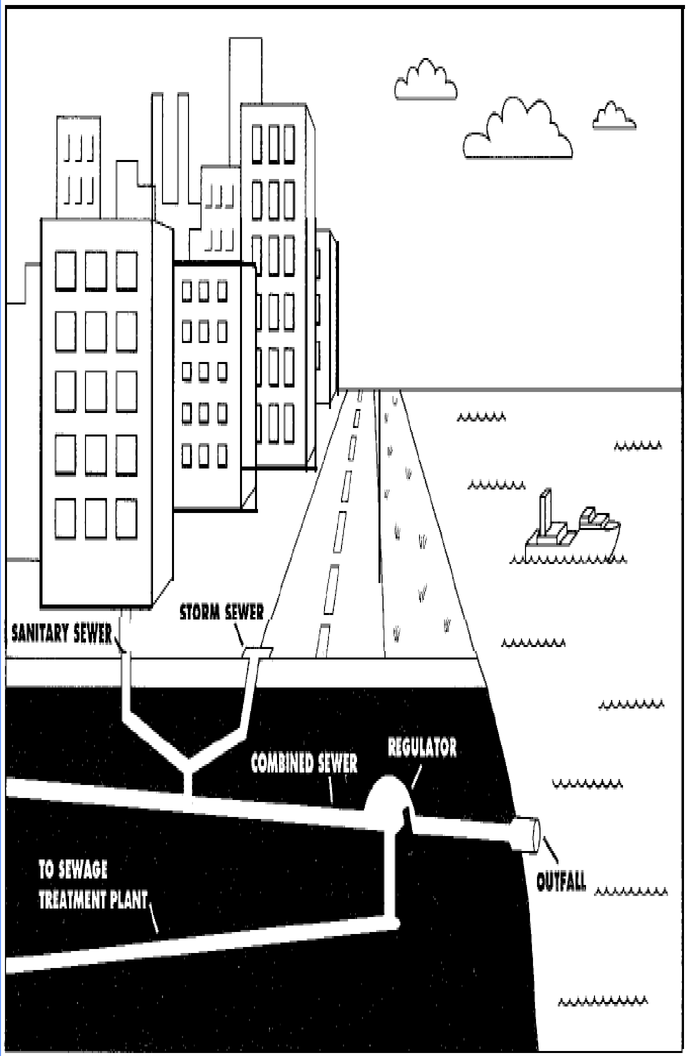
Heat Island effects

Environmental Costs
Negative water quality impacts



From Center for Watershed Protection (2003) Impacts of Impervious Cover on Aquatic Systems

Public infrastructure: CSO abatement compliance costs using tanks & tunnels



Cross-section of a combined sewer system in an urban area

TUNNEL COSTS

NYC:	$7.7 billion (estimated)
Milwaukee:	>$1 billion
Chicago:	$3.4 billion
Portland:	$1.4 billion

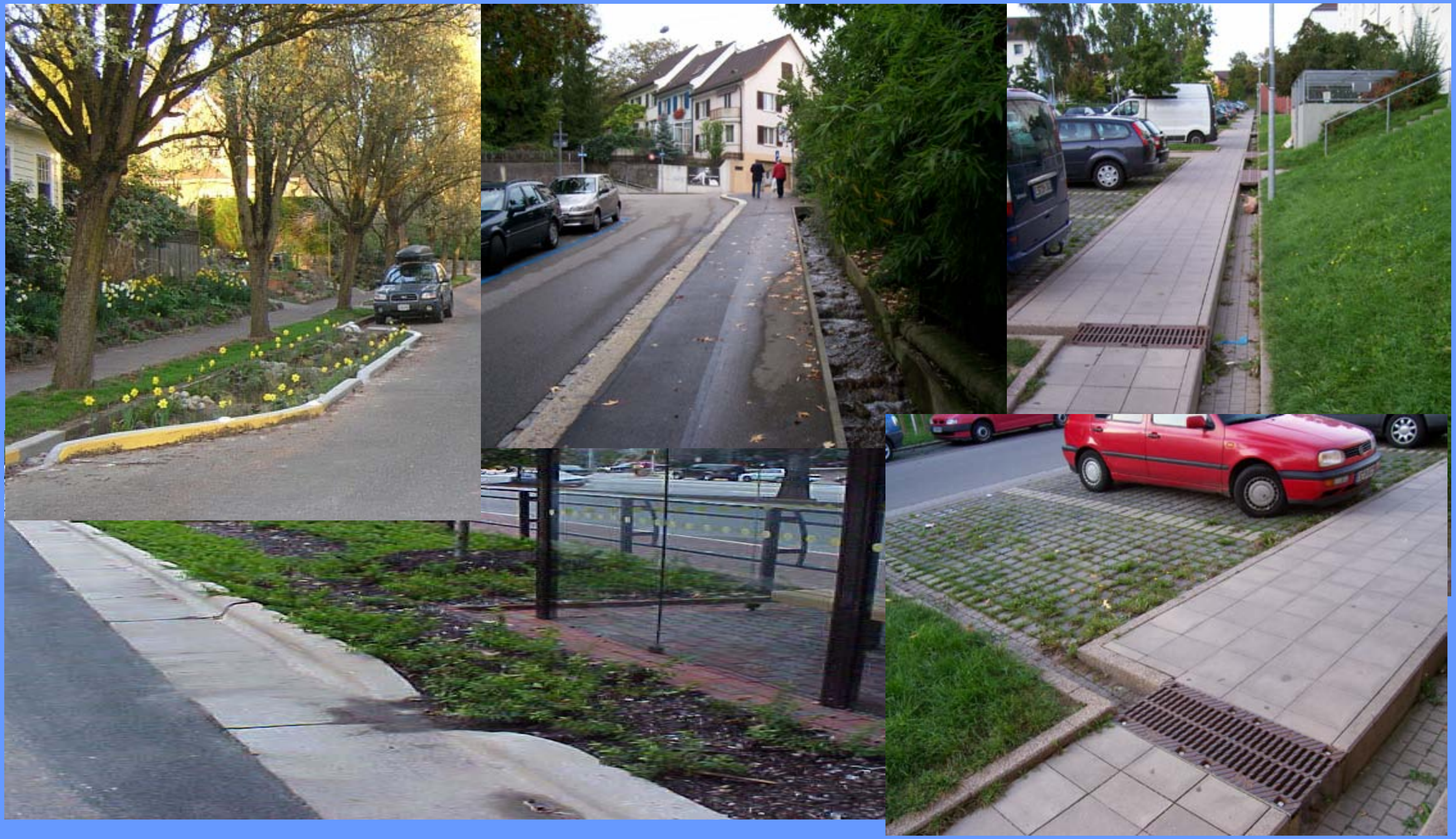
NYC CSO STORAGE TANK COSTS

Facility	Storage Volume (MG)	Cost ($ millions)
Flushing Bay	28.4	$ 300
Alley Pond Park	5	$ 93
Paerdegat Basin	30	$ 300

Source: NY Newsday, 2004

Multi-Functional infrastructure solution to runoff problem

Green Infrastructure/Low Impact Development



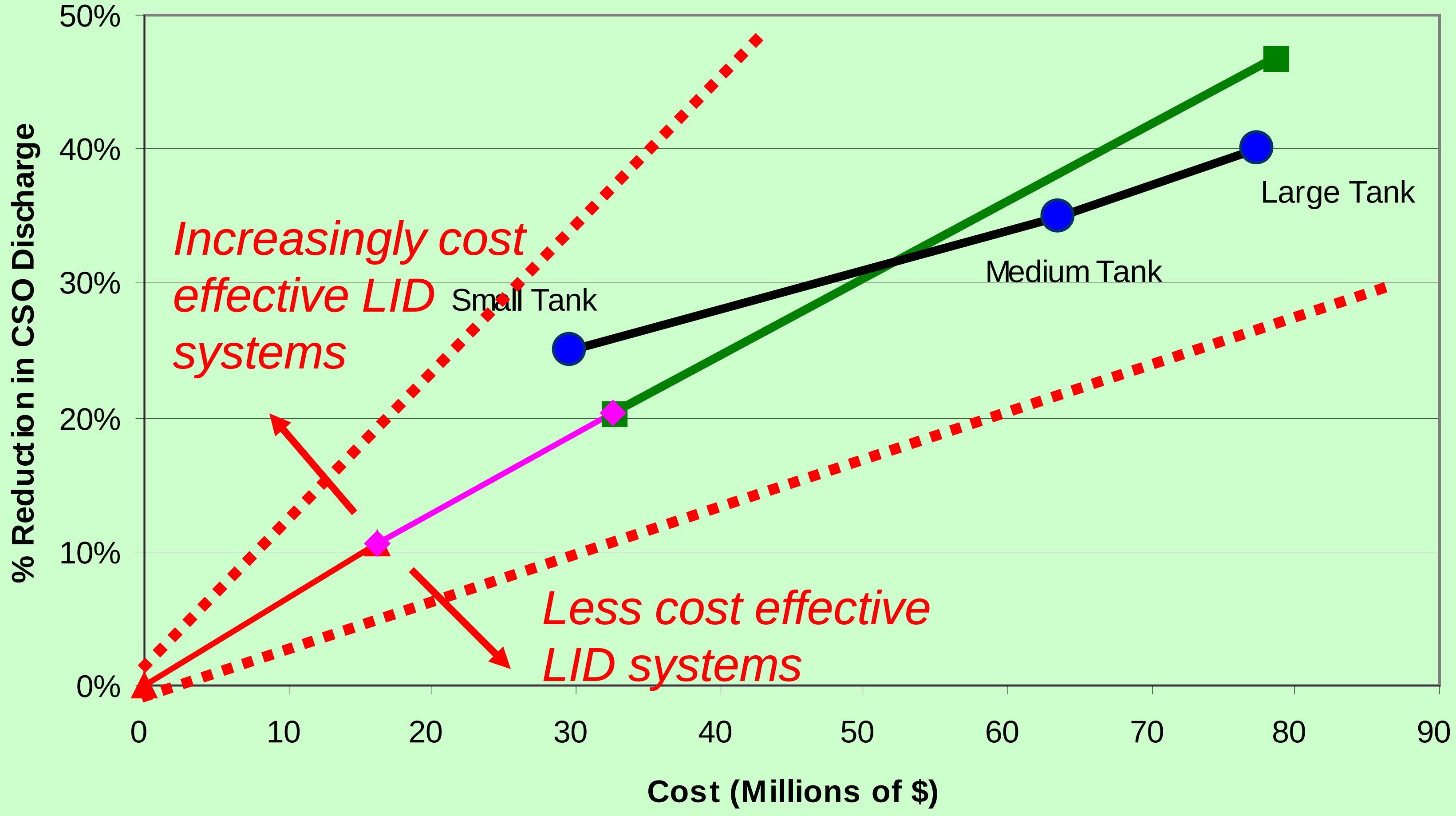
Multi-Functional infrastructure solution to runoff problem

Green Infrastructure/Low Impact Development

GOAL:

Seek to mimic pre-development hydrology in post-development condition

Comparison of LID vs. Conventional Approach to Reducing CSOs



Montalto et al (2007)

Communities using/analyzing GI/LID for CSO control

Already integrated into CSO plan*:

Portland Downspout Disconnection Program:

- Initiated in 1993
- Incentive programs ($53/disconnection) and sewer rate discounts lead to 49,000 disconnections = 1.2 billion gallon/yr reduction in stormwater load.
- Program included in city's LTCP.

* See http://www.portlandonline.com/bes/index.cfm?c=34598

Communities using/analyzing GI/LID for CSO control

In Analysis Stage*:

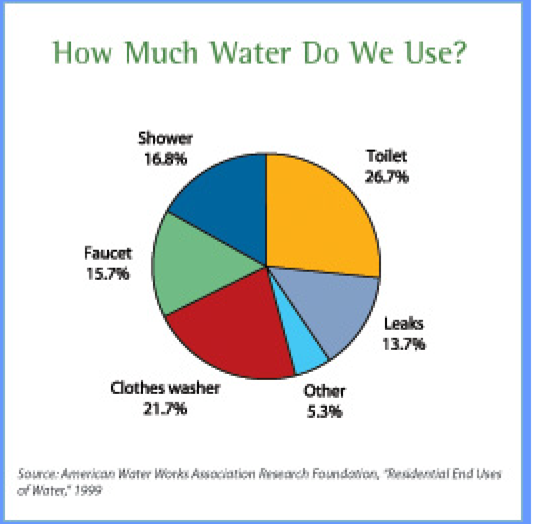
- Cincinnati (Hamilton Co.) – revising modeling efforts
- Kansas City, MO – beginning modeling studies
- Sanitation District #1 (30 communities across 3 counties in northern Kentucky)
- Louisville, KY – full analysis performed, now conducting screening analyses in each of 111 CSO-sheds

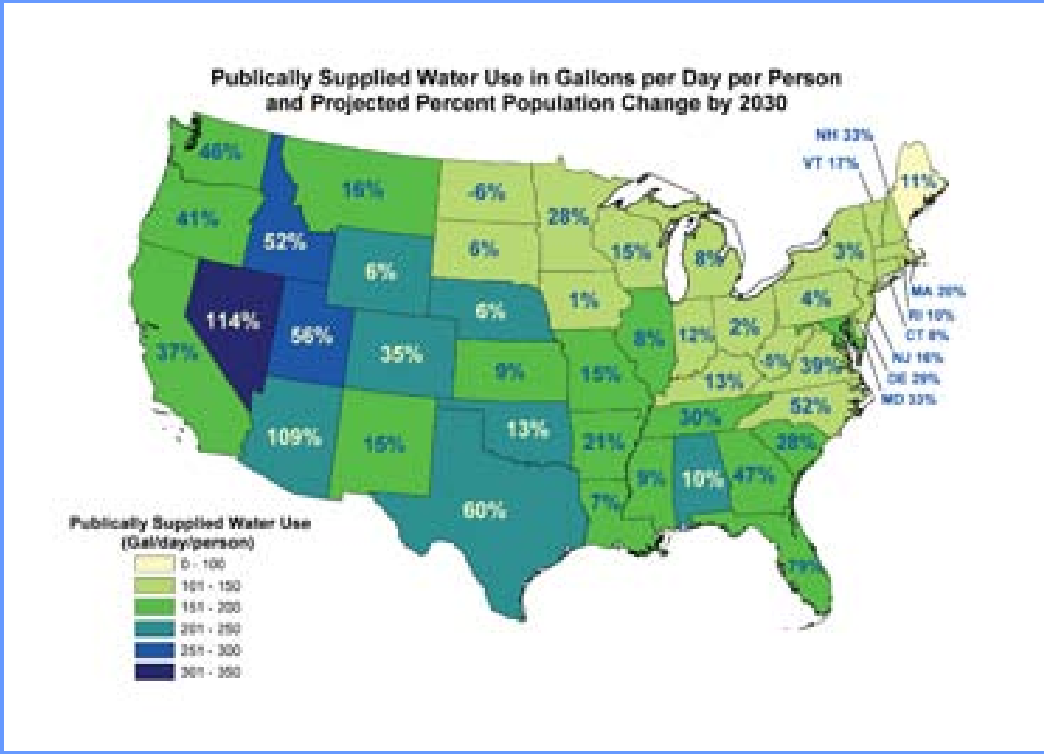
* Information courtesy of Jenny Molloy (USEPA); contacts available

Example: NYC street trees (cover only 24% of city), but

- Remove 2200 tons of criteria pollutants each year
  - Absorb sulfur dioxide, nitrogen dioxide, and carbon monoxide through their leaves
  - Filter particulates from the air
- Buffer against climate change
  - Shade buildings, reducing air conditioning costs (and fossil fuel consumption)
  - Assimilate 42,300 tons of carbon
- Can intercept as much as 5% of annual precipitation falling on a typical NYC street

Example: water conservation





Homes use more than half of publically supplied water in the United States, and almost 1/3 of that is used in toilet flushing

NYC water conservation efforts

Summary of Results for New York City

Water savings from leak detection program	30 to 50 mgd
Water savings from meter installation	200 mgd
Homeowner inspections	200,000
Water savings from homeowner inspections	4 mgd
Number of inefficient toilets replaced	1.3 million
Water savings from toilet replacement program	70 to 80 mgd

mgd = million gallons per day

EPA WaterSense

Example: Energy Infrastructure

- Increase capacity (build more power plants)
- Reduce demand (adopt conservation)
- Reduce environmental impacts of energy generation, distribution, and use (i.e. cooling water, heat islands, aesthetic/noise)

Evolution of water utility infrastructure responsibilities

Case Study

- Seattle City Light:
  - 1970s: projected doubling of energy demand every 10 years
  - Distributed, small-scale conservation measures prevented construction of new power plant for 20 years, at 20% of the cost of constructing new nuclear power plants that would have met that demand

Green Highways Partnership

Stewardship, Safety, & Sustainability

- Nearly 4 million miles of roads exist in the United States

Table 1-1. Ownership of U.S. highways, 2002.

	Miles			
Organization	**Rural**	**Urban**	**Total**	**% of Total**
State Highway Agency	662,855	110,434	773,289	19.5
County	1,628,510	144,615	1,773,125	44.7
Town or City	606,389	624,163	1,230,552	31.0
Other Jurisdictions	56,254	12,695	68,949	1.7
Federal Agency	117,751	2,819	120,570	3.0
Total	3,071,759	894,726	3,966,485	100.0
Percent of Total	77.4	22.6	100.0	

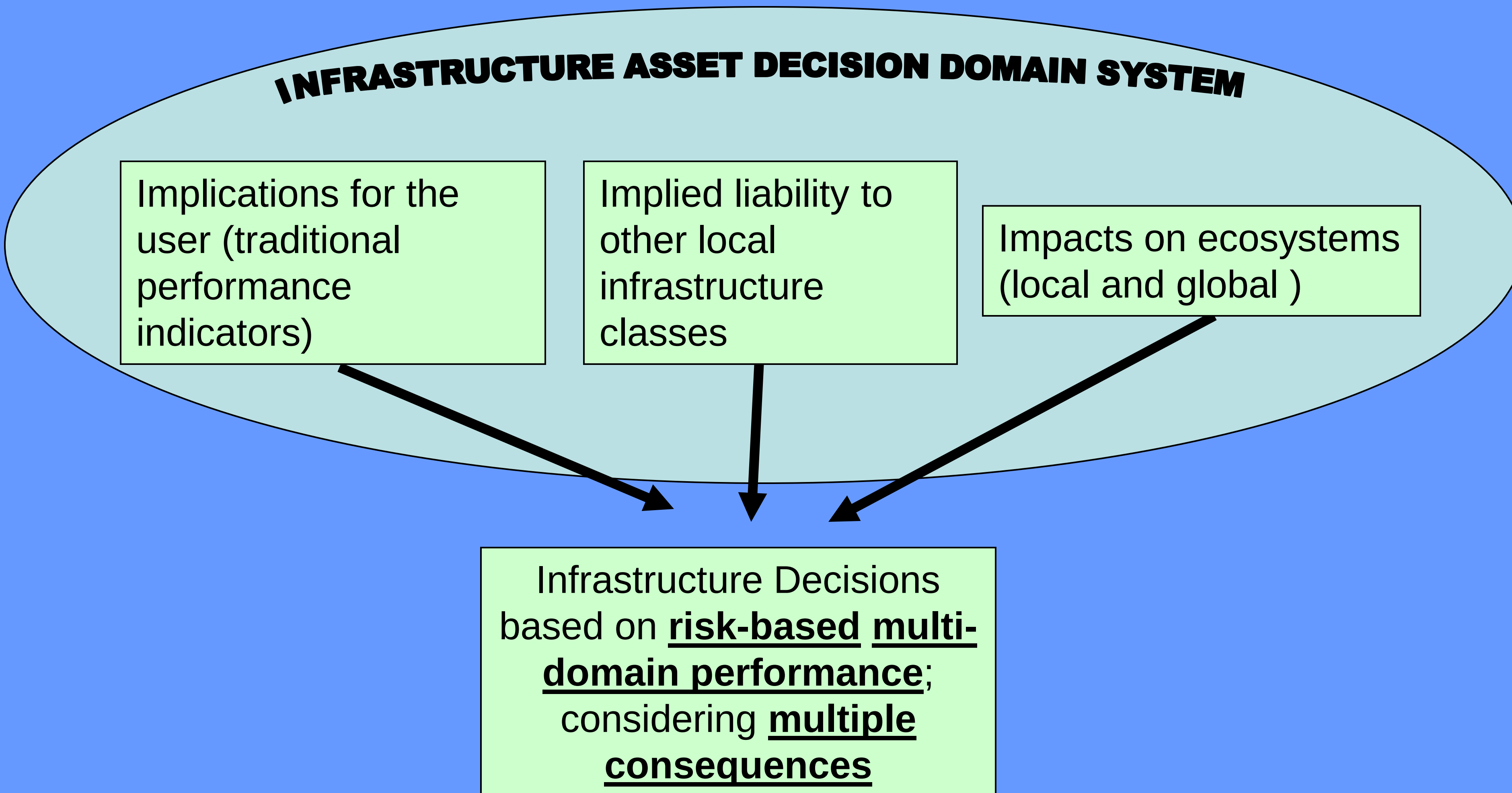
Source: Office of Highway Policy Information 2002.

This picture has been edited from its original format to illustrate Green Highways technologies. Original photograph taken by Tony Clevenger.

Green Highways Characteristics

- Provides net increase in environmental functions and values of the watershed
- Goes beyond minimum standards set forth by environmental laws and regulations
- Identifies and protects important historical and cultural landmarks
- Maps all resources in the area in order to identify, avoid, and protect critical resource areas
- Uses innovative, natural methods to reduce imperviousness, and cleanse all runoff within the project area
- Maximizes use of existing transportation infrastructure, provides multi-modal transportation opportunities, and promotes ride-sharing / public transportation
- Uses recycled materials to eliminate waste and reduce the energy required to build the highway
- Links regional transportation plans with local landuse through partnerships
- Controls populations of invasive species, and promotes the growth of native species
- Incorporates post project monitoring to ensure environmental results
- Protects the hydrology of wetlands and streams channels through restoration of natural drainage paths
- Results in a suite of targeted environmental outcomes based upon local environmental needs
- Reduces disruptions to ecological processes by promoting wildlife corridors and passages in areas identified through wildlife conservation plans
- Encourages smart growth by integrating and guiding future growth and capacity building with ecological constraints

Multi-functional infrastructure asset management



Stormwater management scenario	Cost data				Quantitative Performance						Qualitative Performance																	
											WATER RESOURCES RELATED															OTHER		
											Water quality processes involved								Volume control					Flow rate control				
	Installation costs	Maintenance costs	Operation al costs	Life cycle costs	Reduction in total annual runoff	Volumetric capture rate for different design storms	Reduction in annual water consumption	Reduction in annual domestic wastewater generation	Number of green jobs created	square feet of ecologically productive space created	Flotation	Filtration	Infiltration	Adsorption	Biological Uptake and conversion	Chemical treatment	Degradation	Hydrodynamic separation	Retention	Interception	Evaporation	Transpiration	Reuse	Peak discharge rate attenuation	Detention	Contributes to neighborhood beautification	Reduces building energy demand	Contributes to improving air quality
Do nothing case																												
BMP#1	Put in averages of NYCDEP, and other costs as provided here				Insert real numbers in here											Check all that apply here												
BMP#2																												
BMP#3																												
BMP#4																												
#1 and #2																												
#1, #3, #4																												

Thanks!