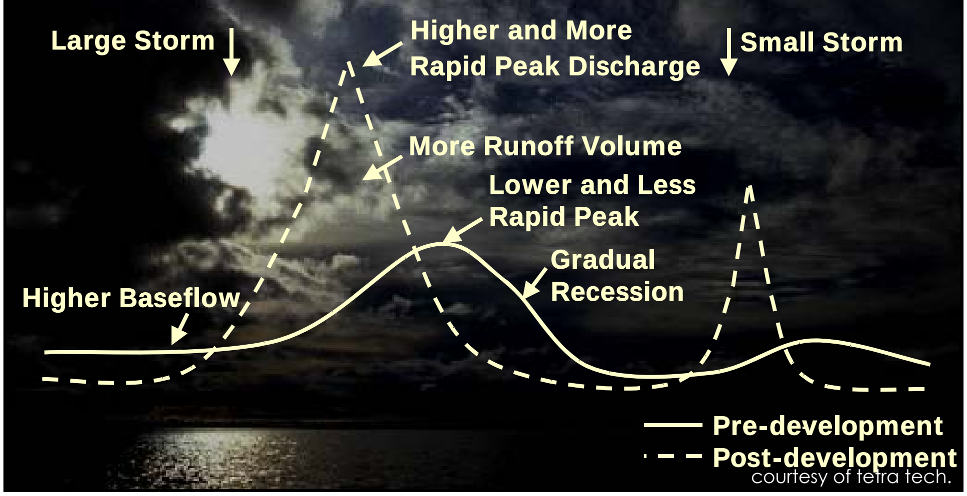
green infrastructure design

San Antonio, Texas
February 17-18, 2009
Chris Kloss
Low Impact Development Center
www.lowimpactdevelopment.org

consequences of development on urban streams



courtesy of tetra tech.

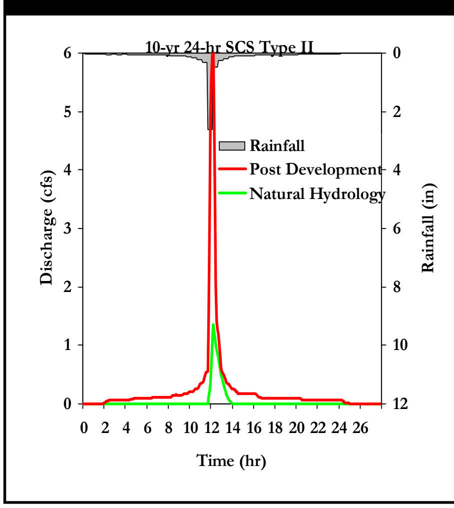
consider a typical development example

- area = 2.98 ac
  - building footprint = 20.9%
  - parking/sidewalk = 36.5%
  - turf grass = 42.6%
- B/C soil
- flat
- EPA-SWMM V5 model

courtesy of tetra tech.

no stormwater controls

- traditional development with no stormwater controls

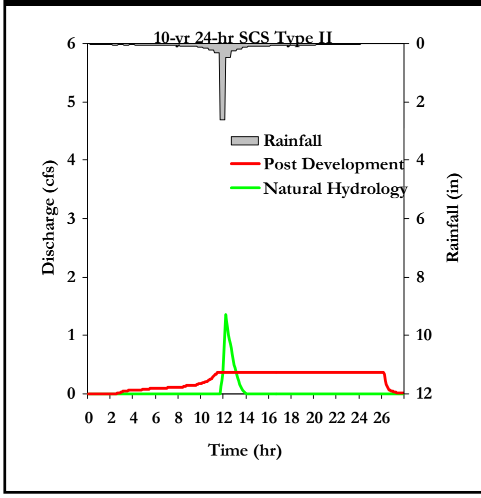


Average Annual (from 50-years)	Natural Hydrology	Post Development
Evaporation	10%	19%
Infiltration	90%	38%
Surface Runoff	**<1%**	**43%**

courtesy of tetra tech.

traditional detention

- detention sized with 0.15 cfs/acre maximum release rate
- no change in average annual surface runoff

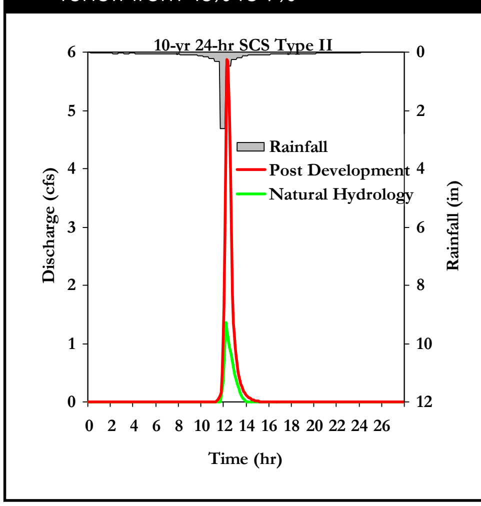


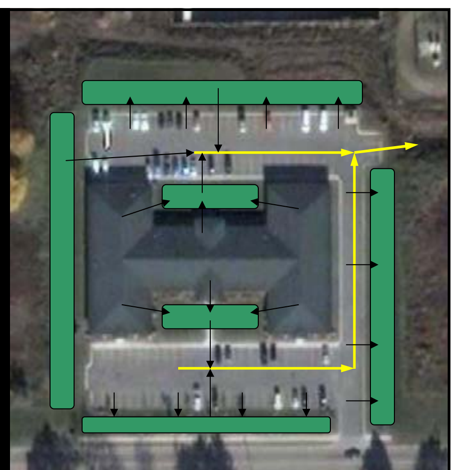
Average Annual (from 50-years)	Natural Hydrology	Post Development
Evaporation	10%	19%
Infiltration	90%	38%
Surface Runoff	**<1%**	**43%**

courtesy of tetra tech.

impervious → pervious

- impervious surfaces discharge to green areas
- green areas discharge to drainage system
- decreased average annual surface runoff from 43% to 9%



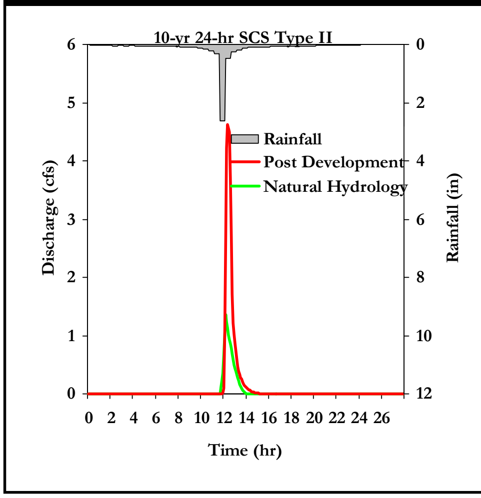


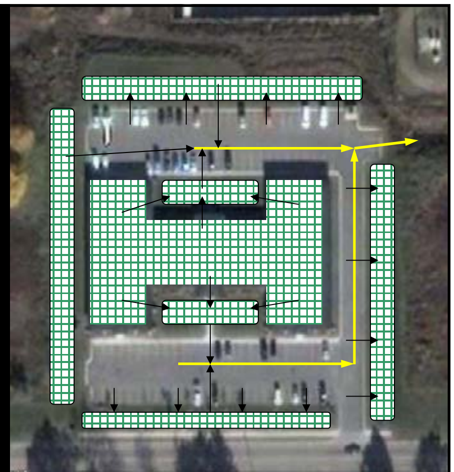
Average Annual (from 50-years)	Natural Hydrology	Post Development
Evaporation	10%	20%
Infiltration	90%	72%
Surface Runoff	**<1%**	**9%**

courtesy of tetra tech.

added storage

- impervious → pervious
- 1-inch roof storage (or equiv)
- 1-inch storage on pervious areas



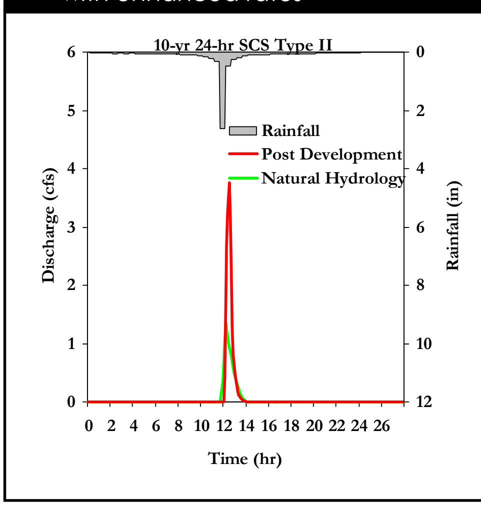


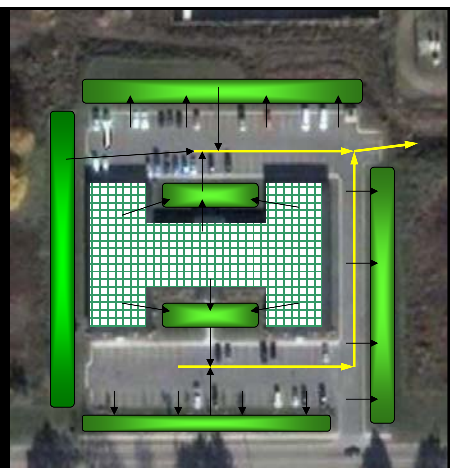
Average Annual (from 50-years)	Natural Hydrology	Post Development
Evaporation	10%	32%
Infiltration	90%	66%
Surface Runoff	**<1%**	**3%**

courtesy of tetra tech.

enhanced infiltration and evapotranspiration

- impervious → pervious
- 1-inch roof storage (or equivalent)
- 1-inch storage on pervious areas with enhanced rates





Average Annual (from 50-years)	Natural Hydrology	Post Development
Evaporation	10%	32%
Infiltration	90%	67%
Surface Runoff	**<1%**	**1%**

courtesy of tetra tech.

re-creating natural hydrology

- protect natural features
- mimic natural functions
  - let pervious be pervious (increased infiltration and plant growth)
  - minimize impervious and direct water to pervious areas
  - promote vigorous plant growth (increased infiltration and evapotranspiration)
  - slow the water down (increase time of concentration to promote infiltration and evapotranspiration and decrease erosion)
- design for stormwater as an asset and amenity

courtesy of tetra tech.

plants


R. Domm

role

- water uptake
- stabilization
- impeding flow
- filtration
- infiltration
- nutrient uptake
- toxin uptake
- pollutant breakdown

example applications

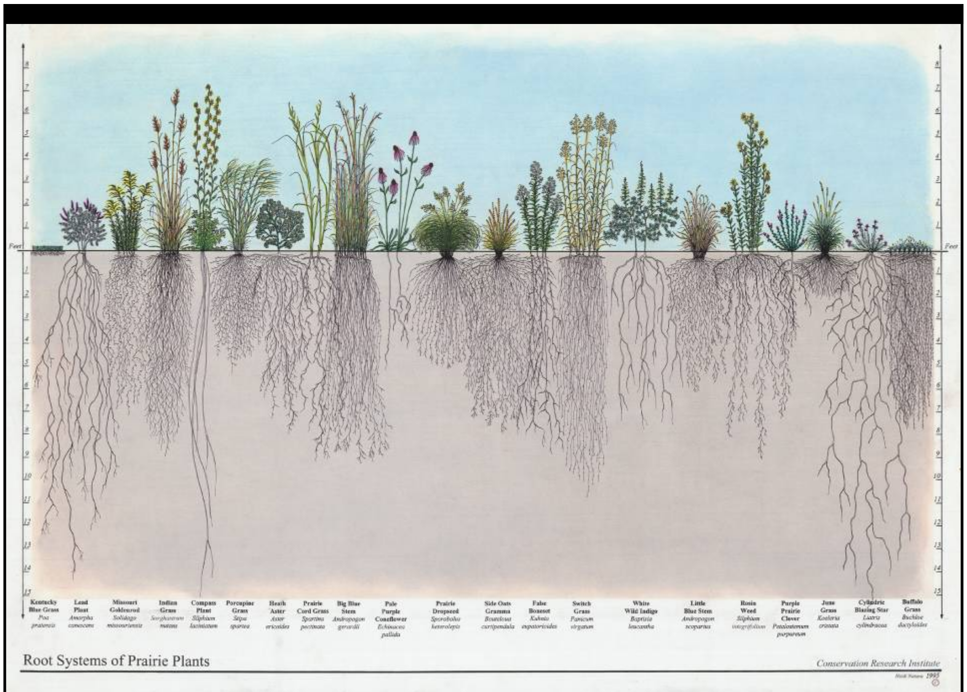
- nurse crop/cover crop
- buffer strips
- vegetated trenches
- biofiltration/rain gardens
- vegetated swales and ditches
- stormwater ponds/wetlands
- green roofs
- native plant reconstruction

courtesy of tetra tech.

transpiration rates of various plants

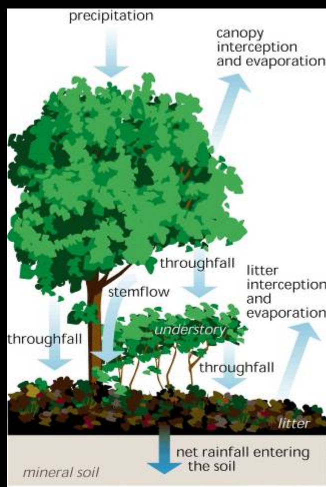
Plant Name	Plant Type	Transpiration Rate
Perennial rye	Lawn grass	0.27 in/day
Alfalfa	Agriculture crop	0.41 in/day
Common reed	Wetland species	0.44 in/day
Great bulrush	Wetland species	0.86 in/day
Sedge	Wetland/prairie species	1.9 in/day
Prairie cordgrass	Prairie species	0.48 in/day
Cottonwood	Tree (2 year old)	2-3.75 gpd/tree
Hybrid poplar	Tree (5 year old)	20-40 gpd/tree
Cottonwood	Tree (mature)	50-350 gpd/tree
Weeping Willow	Tree (mature)	200-800 gpd/tree

courtesy of tetra tech.



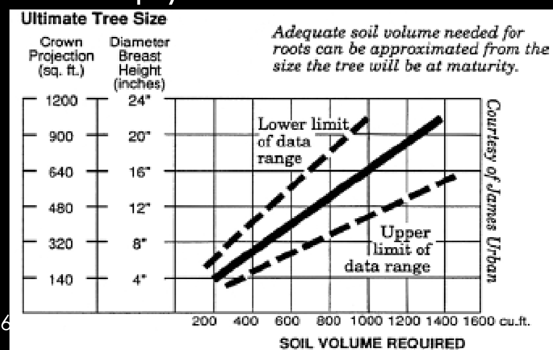
courtesy of tetra tech.

trees



source: FISRWG 2001

- enormous potential for stormwater management
- 2 cu. ft. of usable soil for every 1 sq. ft. of mature canopy



source: CWP 2006

courtesy of tetra tech.

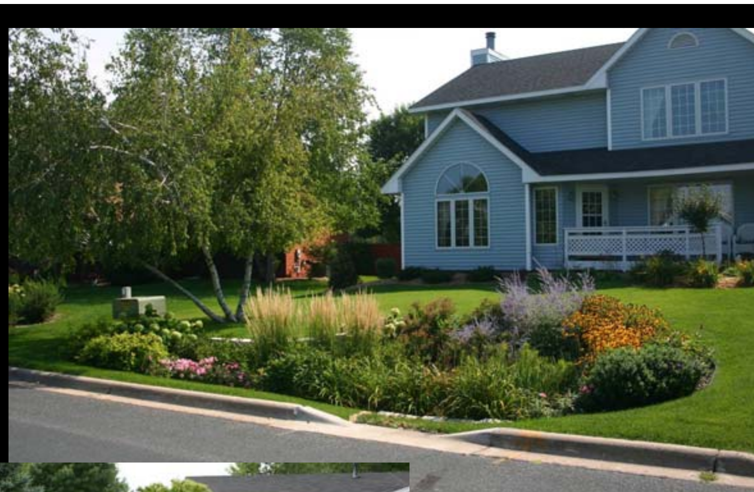
consider . . .

- consider a tree box sized for a 16" caliper tree, i.e. 1,000 cf of soil
- fine sandy loam soil with 25% unfilled void space (0.45 porosity – 0.2 field capacity)
- volume = 250 cf (1000 cf * 0.25)
- area of impervious surface needed to generate 250 cf of stormwater from a 1-inch storm = 3000 sf
- assuming drainage from ½ of a 66-ft ROW equates to one tree box every 180-ft, i.e. at the intersection corners and one mid-block

courtesy of tetra tech.

soil compaction

- decreased infiltration / decreased root growth / increased runoff



photos: Fred Rozumalski-Barr Engineering & City of Burnsville, MN

good design and aesthetics

- keep sediment out of planting area
- certify soils/materials
- inspect all plants prior to planting
- post construction stabilization critical

not good


proper restoration

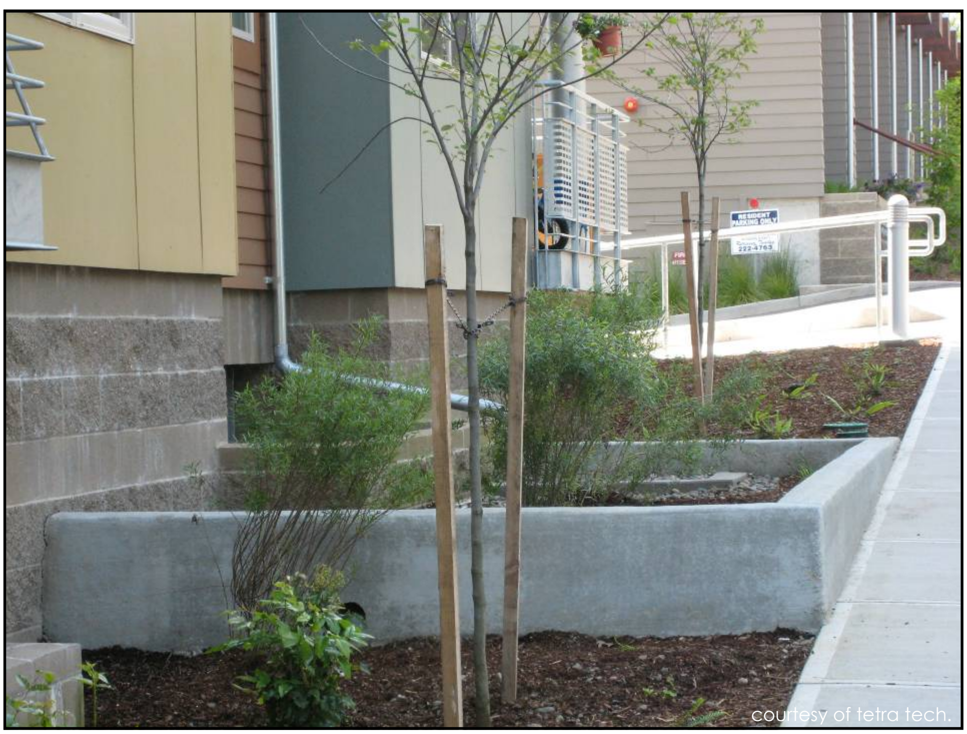
common construction errors

- unapproved material substitution

common construction errors

- unapproved material substitution

water storage - surface



bioretention designs to maximize infiltration

courtesy of tetra tech.

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water storage - rainwater harvesting

- collecting roof rainwater in rain barrels or cisterns for later reuse.
- residential and commercial applications.
- ideal for outdoor and non-potable indoor uses.
- can be used for potable uses with proper treatment.

Chicago Center for Green Technology.
Photo courtesy of Farr Associates.

U.S. water supply

- universal access to potable water supplies.
- world's highest per capita use – approximately twice that of Europe.
- cost of water is among the lowest in the world.
  - 0.07¢ - 0.4¢ per gallon ⇨ 70¢ - $4 per 1,000 gallons
  - Average cost nationally approximately $2 per 1,000 gallons

U.S. water supply (cont.)

- population growth & development increasing demand.
- sustained droughts in Southeast & Southwest.
- climate change may decrease snowpack and introduce drier climate.
- water managers in 36 states anticipate water shortages by 2020.

Prettyboy Reservoir, Maryland during 2002 drought.
Photo courtesy of National Weather Service.

domestic water use

Typical Domestic Daily per Capita Water Use.

Use	Gallons per Capita	% of Daily Total
Potable indoor uses		
▪ Showers	11.6	7.0%
▪ Dishwashers	1.0	0.6%
▪ Baths	1.2	0.8%
▪ Faucets	10.9	6.6%
▪ Other uses, leaks	11.1	6.7%
Subtotal	**35.8**	**21.7%**
Non-potable indoor uses		
▪ Clothes washers	15.0	9.1%
▪ Toilets	18.5	11.2%
Subtotal	**33.5**	**20.3%**
Outdoor uses	**95.7**	**58.0%**

American Waterworks Association Research Foundation (AWWARF), *Residential End Uses of Water*, Denver, CO, AWWARF, 1999.

commercial water use

Use	Office Buildings % of Daily Total	Hotels % of Daily Total
Potable indoor uses		
▪ Showers	---	27%
▪ Faucets	1%	1%
▪ Kitchen	3%	10%
▪ Other uses	10%	19%
Subtotal	**14%**	**57%**
Non-potable indoor uses		
▪ Toilets/urinals	25%	9%
▪ Laundry	---	14%
▪ Cooling	23%	10%
Subtotal	**48%**	**33%**
Outdoor uses	**38%**	**10%**

Typical Daily Water Use for Office Buildings and Hotels.

Pacific Institute, *Waste Not, Want Not: The Potential for Urban Water Conservation in California*, November 2003.

current conditions

- non-potable uses constitute a large percentage of demand.
- disparity between "high-quality" water supply and large percentage of "low-quality" demand.
- inefficiencies propagated by inadequate pricing and continuation of familiar practices.
- building and plumbing codes often necessitate potable water use throughout a building or residence.

water pricing

- inexpensive cost of water creates little incentive for conservation.
- GAO found insufficient funding in 29% of water utilities to cover cost of providing service.
- water demand is relatively inelastic – increased prices have limited effect on use but can encourage supply substitution.
- full cost pricing is one EPA's four pillars of sustainable infrastructure – ideally accounts for externalities in addition to capital and O&M costs.

rainwater harvesting benefits

- provides inexpensive supply of water.
- augments drinking water supplies.
- reduces stormwater runoff and pollution.
- reduces erosion in urban environments.
- provides water that needs little treatment for irrigation or non-potable indoor uses.
- helps reduce peak summer demands.
- helps introduce demand management for drinking water systems.

water supply & energy demand

Estimated Energy Consumption for Water Treatment and Distribution.

Activity	Energy Consumption kWh/MG		
	Northern CA	Southern CA	National Avg.
Supply and conveyance	150	8,900	---
Water Treatment	100	100	---
Distribution	1,200	1,200	---
Total	**1,450**	**10,200**	**250**

California Energy Commission, *California Water – Energy Issues*, Public Interest Energy Research Program, Presented at the Western Region Energy – Water Needs Assessment Workshop, Salt Lake City, Utah, January 10, 2006.

water supply & energy demand (cont.)

- reducing water demand 10% could save 293 billion kWh of electricity each year.
- energy costs account for 80% of typical water bill.
- energy accounts for 1/3 of utility operating costs.
- 7 to 8% of national energy consumption tied to treating and distributing water.

Michael Nicklas, *Rainwater*, High Performance Buildings, Summer 2008.

G. Tracy Mehan, *Energy, Climate Change, and Sustainable Water Management*, Environment Reporter, 2007.

water supply & CO_2 emissions

Carbon Dioxide Emissions from Electric Power Generation.

Fuel Type	CO_2 Output Rate Pounds CO_2/kWh	CO_2 Output per MG Water Delivered (x 1,450 kWh) Northern CA	CO_2 Output per MG Water Delivered (x 10,200 kWh) Southern CA	CO_2 Output per MG Water Delivered (x 250 kWh) National Avg.
Coal	2.117	3,070 lbs	21,600 lbs	530 lbs
Petroleum	1.915	2,775 lbs	19,500 lbs	480 lbs
Natural gas	1.314	1,905 lbs	13,400 lbs	330 lbs

U.S. Department of Energy and U.S. EPA, *Carbon Dioxide Emissions from the Generation of Electric Power in the United States*, July 2000.

los angeles water supply

- demand of 500 MGD.
- approximately 445 MGD supplied by Los Angeles, California, and Colorado River Aqueducts.
- 4.6 million kWh are used daily to deliver water via aqueducts.
- if natural gas is fuel for power plants – 3,000 tons of CO_2 emitted each day for water delivery.

king street center – seattle

rainwater harvesting

- Over 16,000 gallons of storage at 327,000 ft^2 King Street Center used for toilets and irrigation. Provides 60% (1.4 million gallons) of toilet flushing water annually.
- CO_2 reduction of 700 lbs.

king street center.

NRDC – santa monica, ca

- cisterns installed beneath planting beds.
- collected rainwater is added to graywater collection system and used for toilet flushing and irrigation.
- building uses duel-flush toilets, waterless urinals, and drought-tolerant plants.
- 60% reduction in potable water demand.

cisterns at NRDC santa monica office

rainwater harvesting considerations

- important to establish guidelines or codes – instances where rainwater governed by reclaimed water guidelines because of lack of adequate definitions.
- principles of rainwater harvesting apply equally to graywater reuse – concept of matching quality of supply to quality of demand.
- appropriate water pricing important to consider for adequate funding and resource valuation.

portland code

- defines rainwater harvesting uses for water closets, urinals, hose bibbs, and irrigation.
- establishes treatment and material requirements for collection and plumbing systems, including labeling and pipe color.
- defines inspection and maintenance requirements and responsibilities.

san francisco MOU

- entered into in June 2008.
- establishes responsibilities for SF Public Utilities Commission, Department of Building Inspection, and Department of Health.
- defines uses and treatment requirements for rain barrels and cisterns.

codes: know your audience

dc greenworks – green jobs

- dc Greenworks' Green Collar Jobs Training programs have placed over 80 participants into permanent jobs related to natural resource conservation and green communities since 2000.[1]
- information from the District suggests that for each 100,000 square feet of new green roofs installed, five (5) local jobs are created. Currently there are approximately 400,000 square feet of green roofs in DC supported by 20 local jobs.[2]
- jobs for 20 million sq. ft. of green roofs: 1,000

[1] Dawn Gifford, *Green Horticulture in Washington D.C.*, Race, Poverty & the Environment, Summer 2006.
[2] Sheila Hogan, *Testimony Before the Council of the District of Columbia Committee on Economic Development*, October 22, 2007.

washington, dc casey trees study (released in april 2007)

- green roofs of 103 million sq. ft., tree coverage of 57% of the city, and tree boxes of at least 6 X 20 ft. together would:
  - reduce discharges of untreated sewage and stormwater into DC waterways by 1.1 billion gallons (10%)
  - reduce CSO volume by 22% and frequency by 6.7%
  - reduce discharge volumes by up to 27% for most impervious sewer sheds

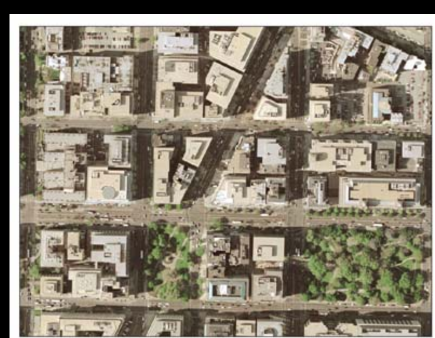

photo courtesy of casey trees, washington, dc

casey trees study job creation

Scenario		Total Investment *(in millions)*	Total Labor Requirements *(in person years)*	Average Number of Jobs per Working Year	Years of Work
Pessimistic	*Case 2*	$299.9	5,895	590	10
Conservative	*Case 3*	$599.8	11,791	1,179	10
Aggressive	*Case 4*	$899.6	17,686	1,769	10