THE URBAN STREAM CONTINUUM: THE EFFECTS OF UPLAND RIPARIAN ZONES AND ENGINEERED "URBAN KARST" ON ORGANIC MATTER, CONTAMINANT FLUXES AND LOTIC ECOLOGY

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National Water Monitoring Conference
Monitoring: Key to Understanding Our Waters

Atlantic city, NJ, May 19, 2008

Very Much A Multidisciplinary, Cooperative Effort…

US Forest Service
UMBC Geography & Environmental Systems
UMCES Appalachian & Chesapeake Biological Labs
City of Baltimore DPW
Center for Urban Environmental Research and Education
Baltimore Ecosystem Study/Cary Institute of Ecosystem Studies
US Geological Survey

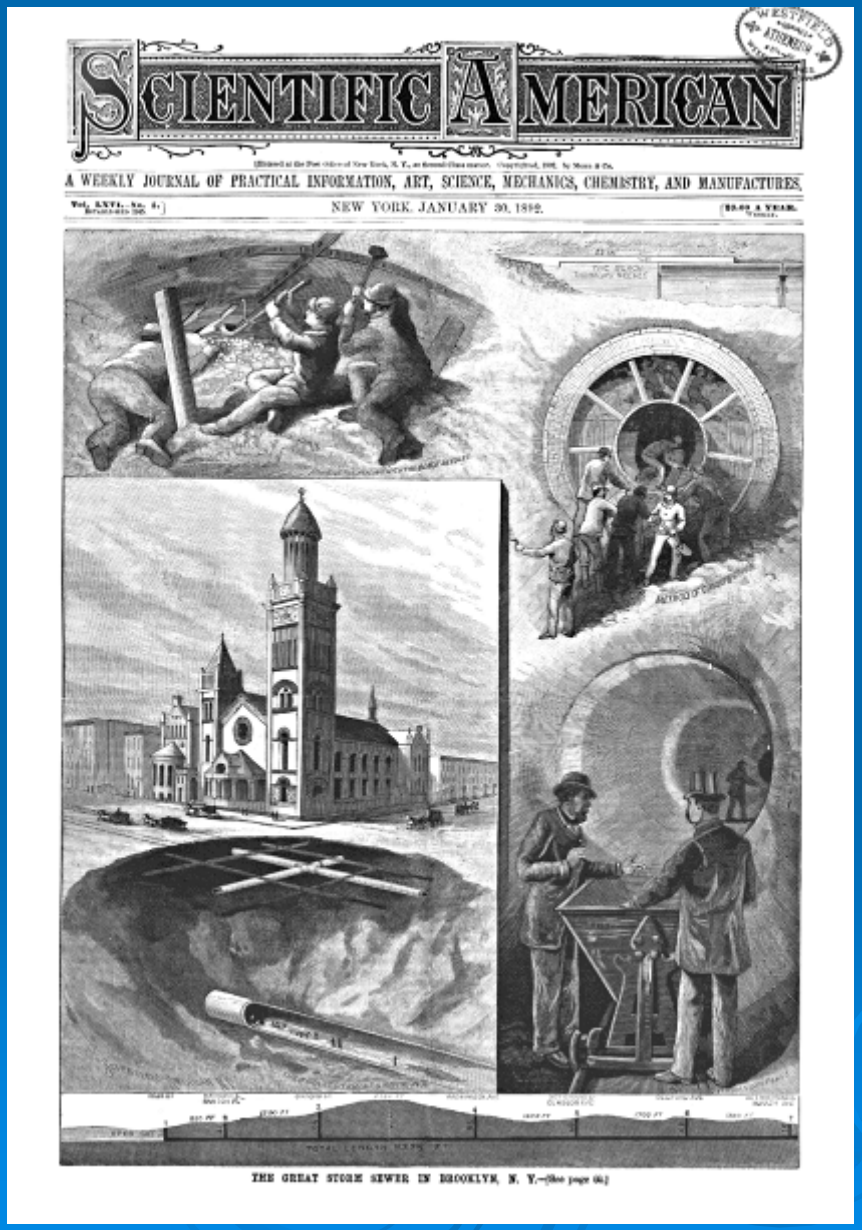
…and still more partners

Outline

1. Conceptual Framework
2. Urban Stream Continuum
3. The Gutter Subsidy
4. Stream DOC & FPOM
5. Urban “Karst”

1. Conceptual Framework

Sewers…. Major Advance of the Day



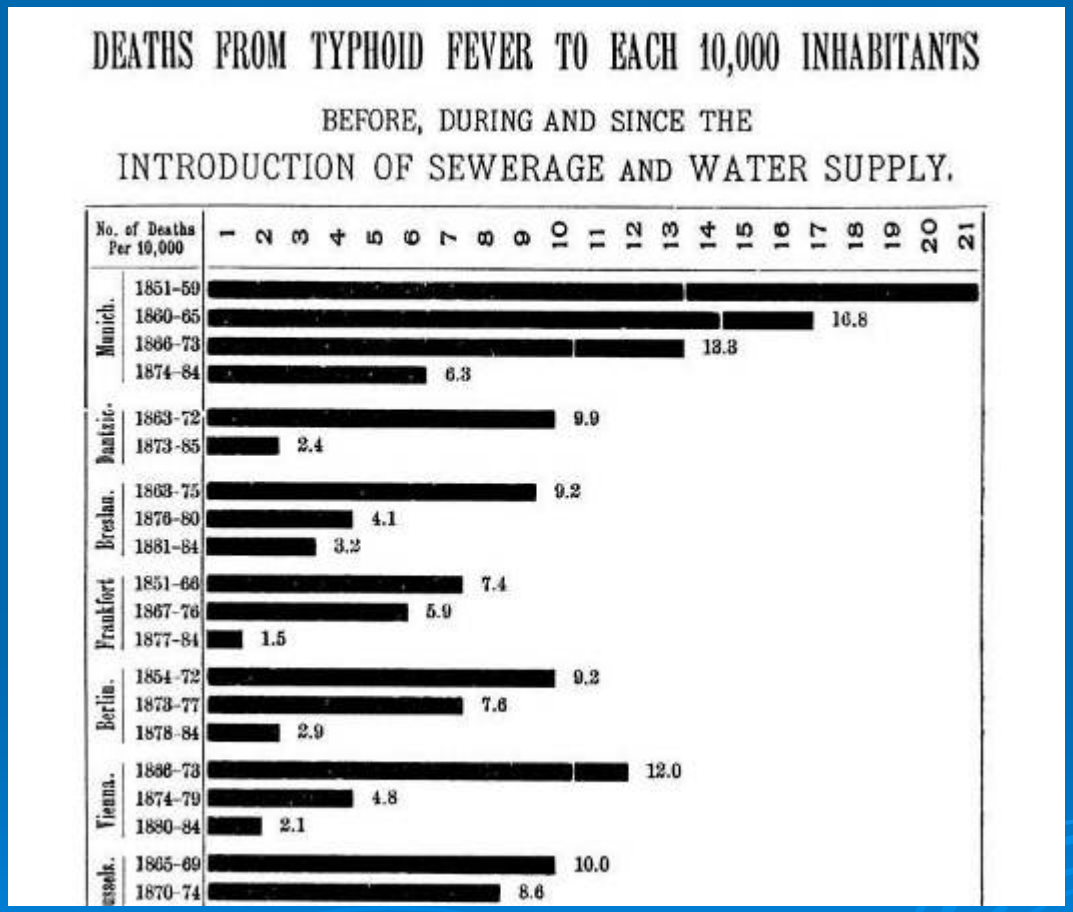
SCIENTIFIC AMERICAN

A WEEKLY JOURNAL OF PRACTICAL INFORMATION, ART, SCIENCE, MECHANICS, CHEMISTRY, AND MANUFACTURES.

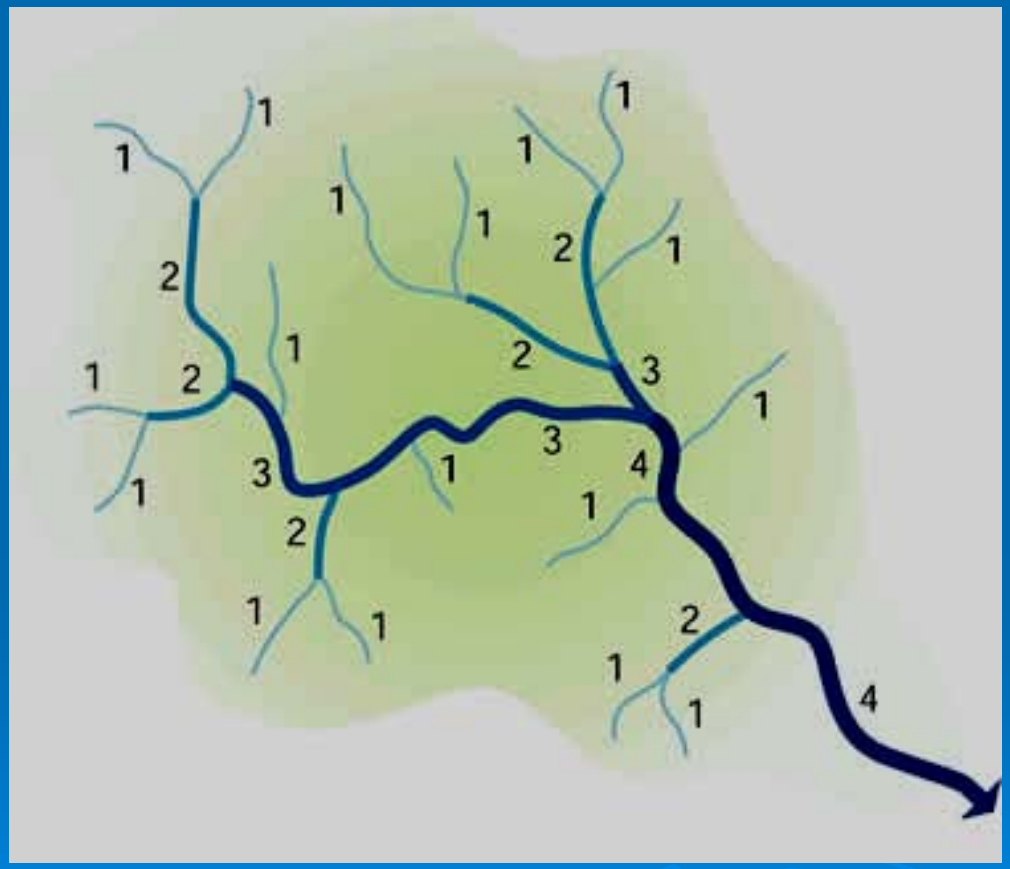
NEW YORK, JANUARY 30, 1892.

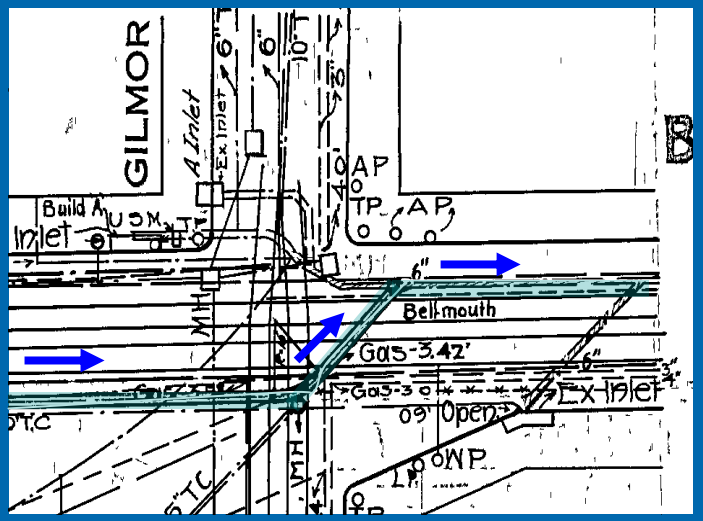
THE GREAT STORM SEWER IN BROOKLYN, N. Y.

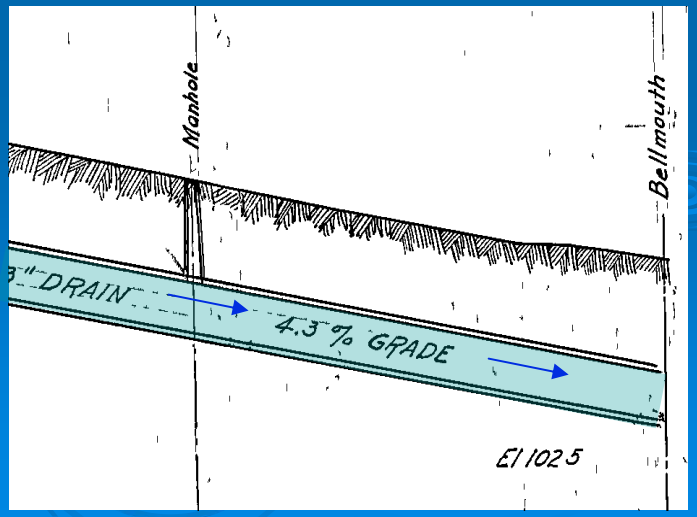
Sanitary Sewers…. Public Health Motivations



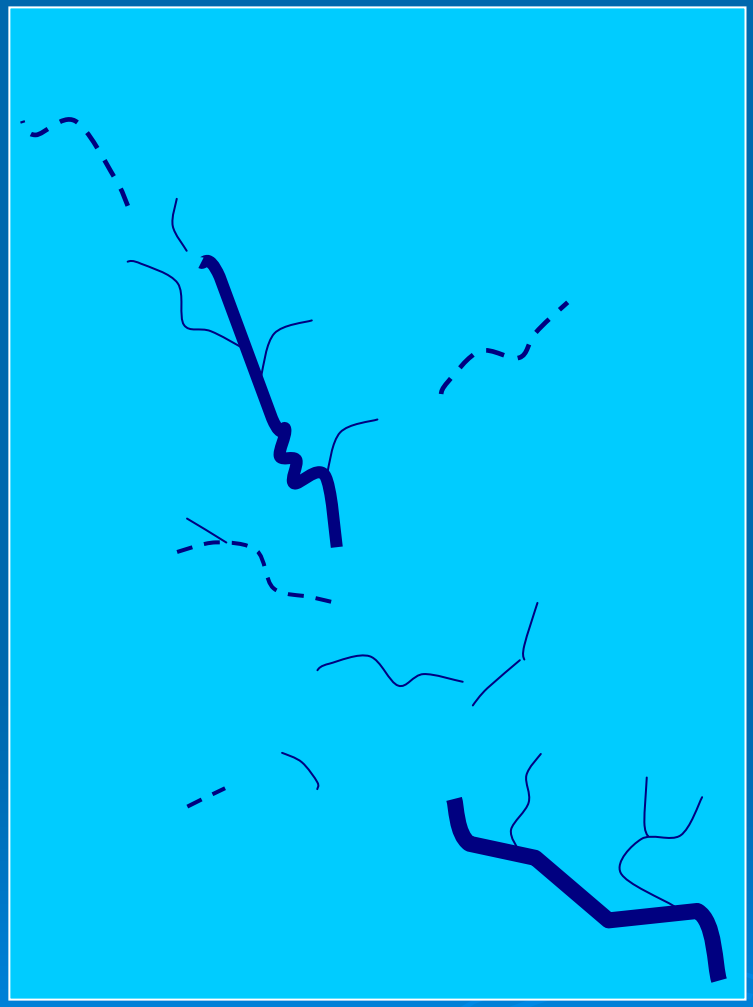
Storm Drainage Networks…Natural & Unnatural



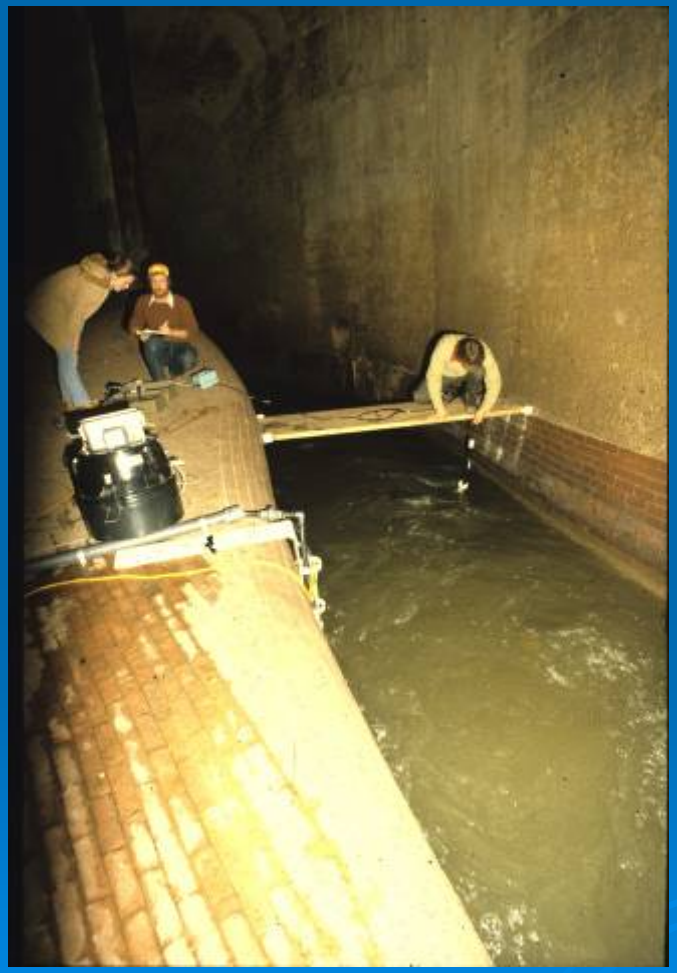


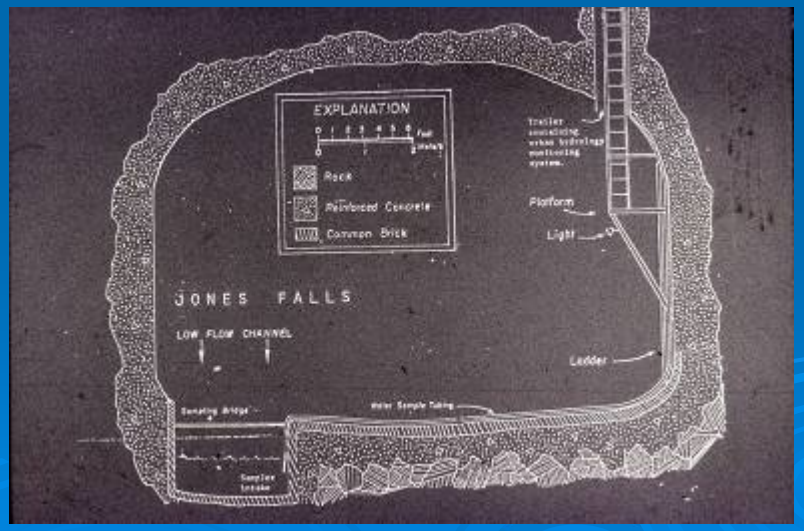


Buried (“missing”) Urban Streams

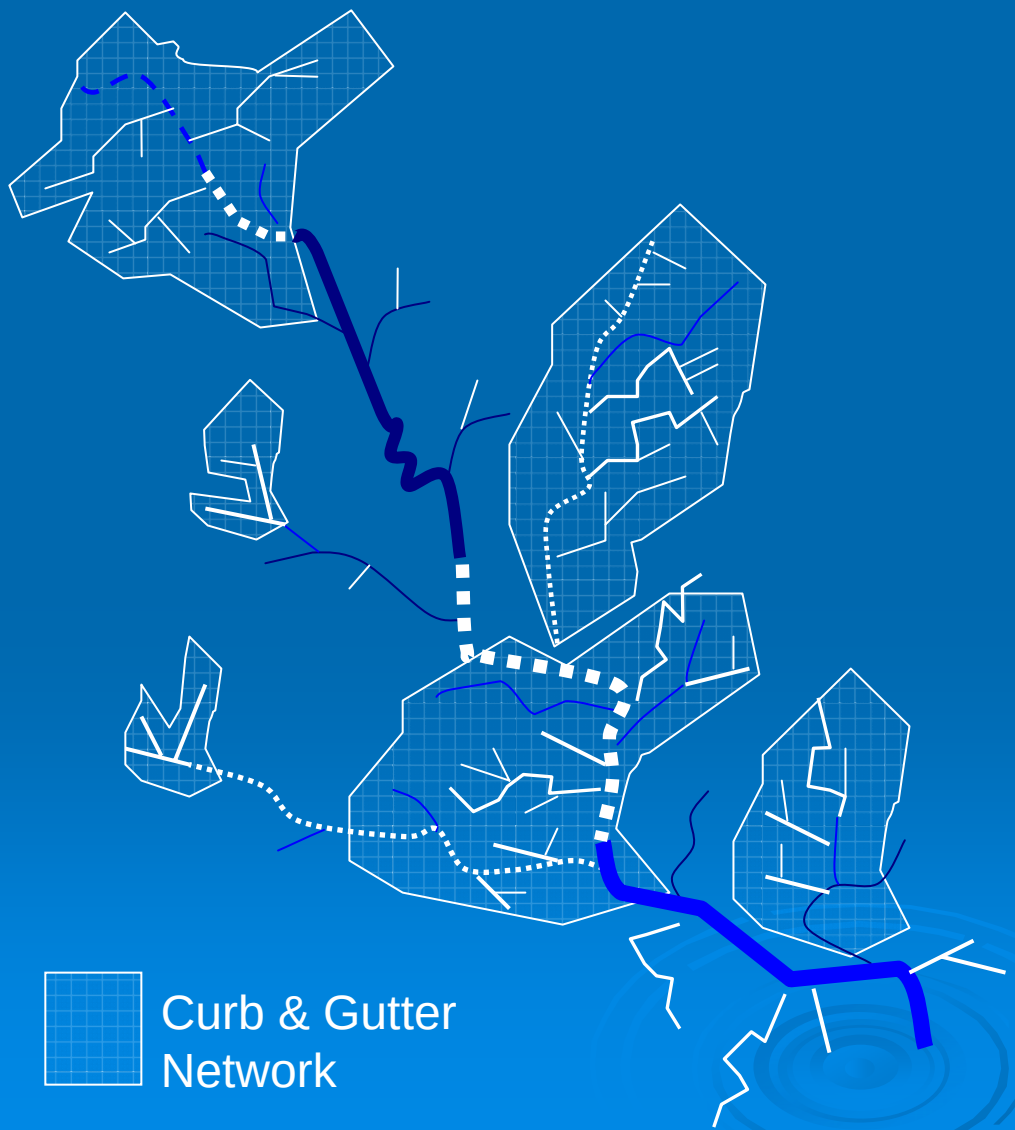


The Long Buried Jones Falls (Downtown Baltimore)



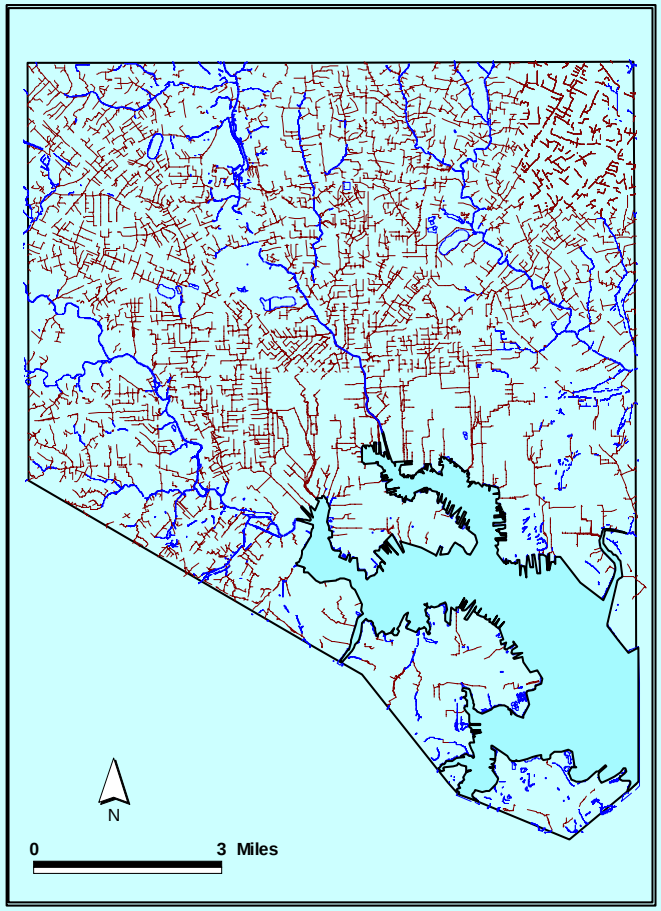


The Other Transformation: Increased Drainage Density



Regional Drainage Density Increases

Storm Drains GE 36” and Streams in Baltimore City



Baltimore City DPW

Urban Runoff…. A function of impervious surfaces & storm drainage systems

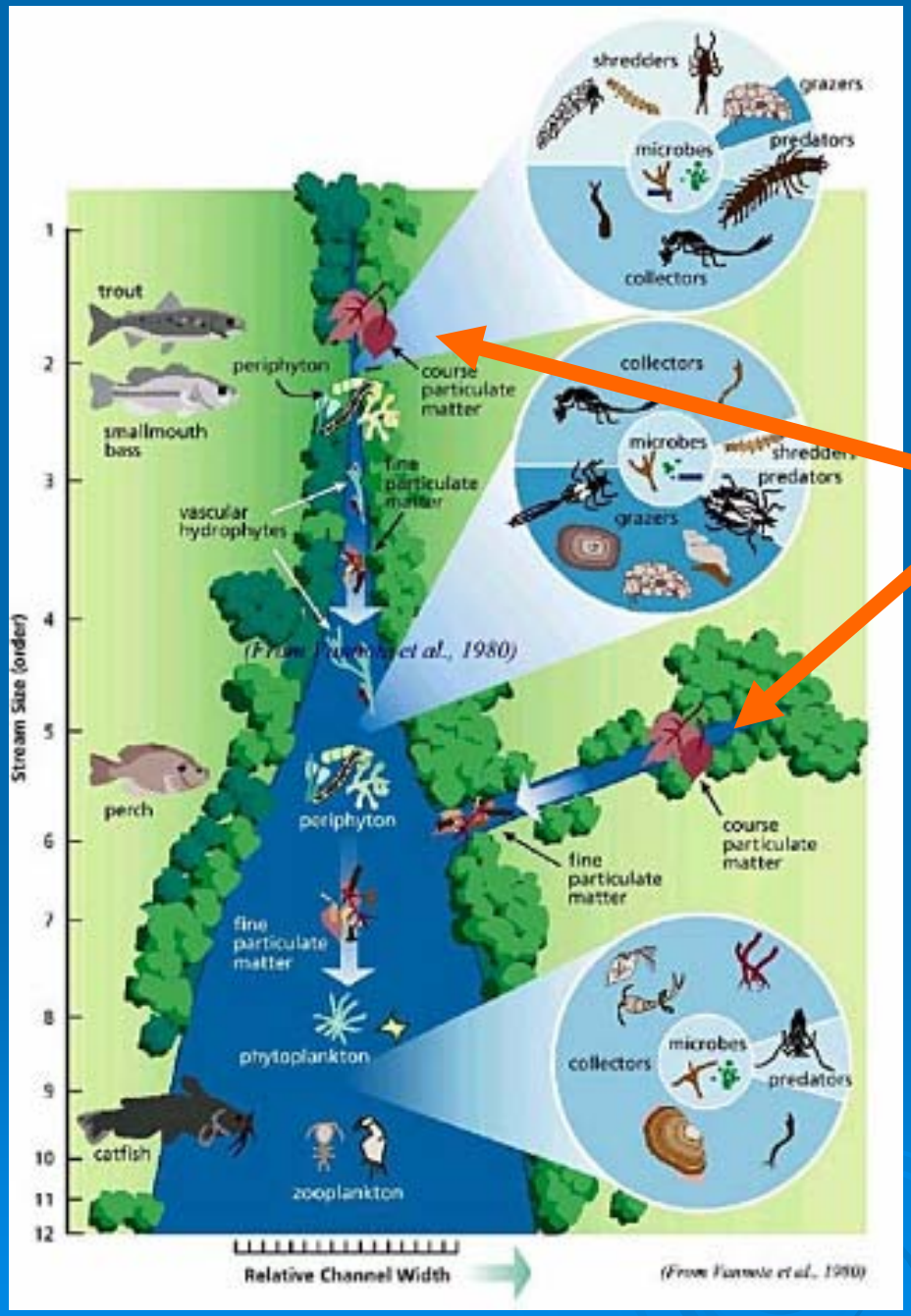
The Urban Stream Syndrome…
poor water quality & biota, floods,
channel damage, etc.

Urban Runoff Networks….
effects on ecological structure and function?

Organic matter transport & transformations, food webs…

2. The Urban Stream Continuum (USC)

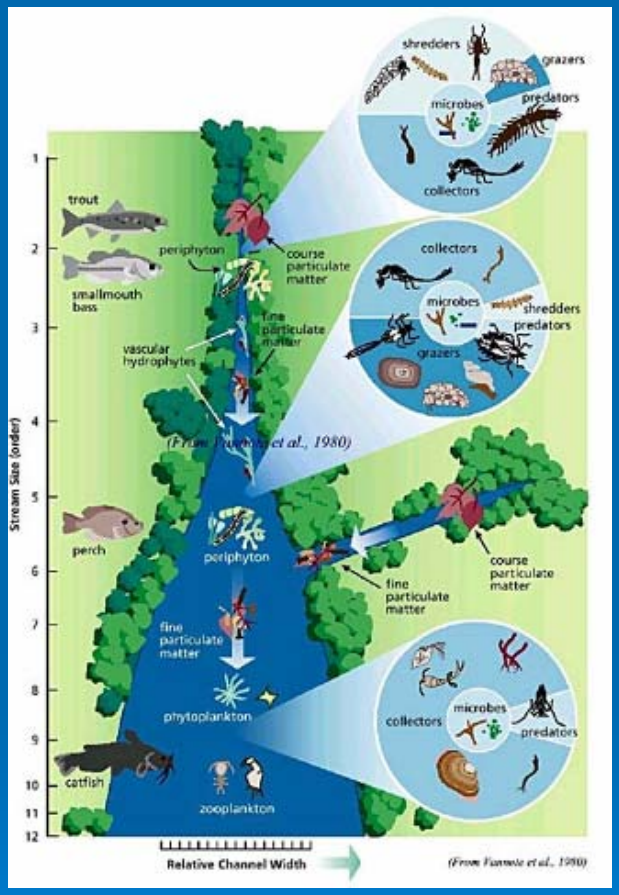
Aquatic Ecology's River Continuum Concept



Leaf Litter inputs at headwater streams…

OM Transformations downstream…

Commensurate changes in biotic communities downstream



Is there an URBAN River Continuum Concept ?

The River Continuum… Upstream OM (Leaf) Inputs, with Changes in OM and Biota downstream

… starts in the headwaters

Zero Order Streams

1st Order Stream

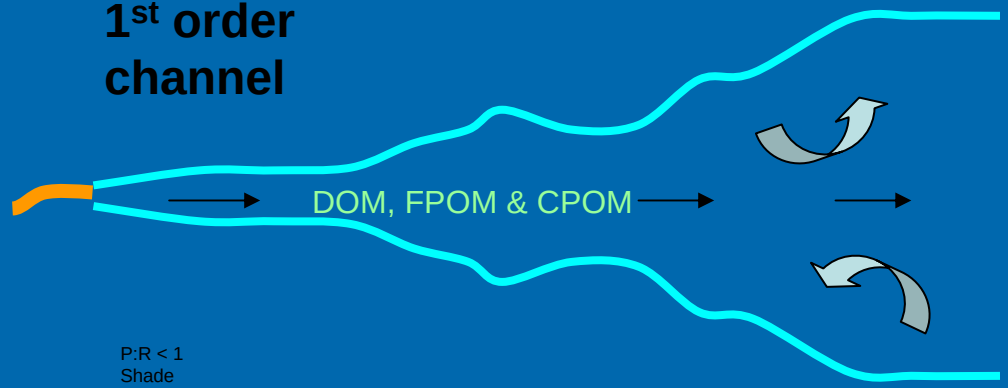
The Natural Stream Continuum

1st order channel

2nd order channel

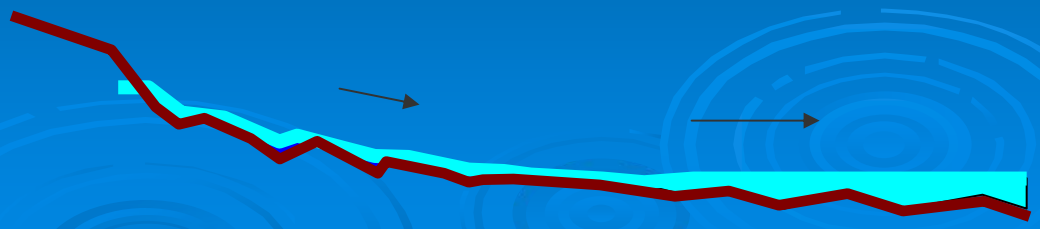
3rd order channel

Zero Order Channel
(Some RO, OM Inputs)



P:R < 1
Shade
CPOM variable
CPOM:FPOM lower
High FPOM
FFG: Filterers
Periphyton biomass low-moderate

P:R = 1 (but variable)
Open Canopy
CPOM more prevalent
CPOM:FPOM lower
High FPOM
FFG: Filterers, Shredders
Collector Gatherers
Periphyton Biomass high



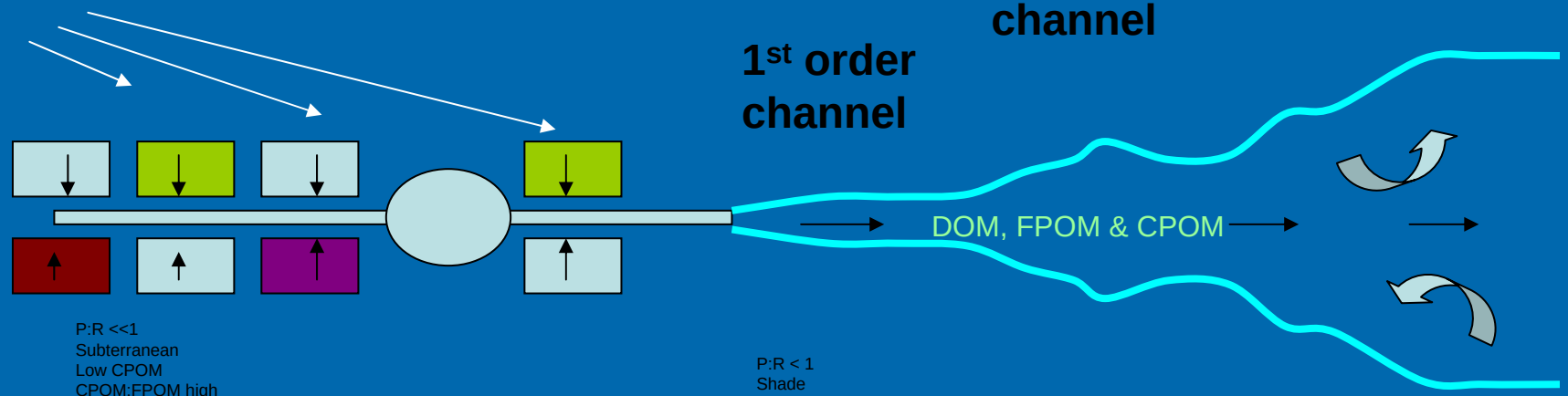
The Urban Stream Continuum

Extensive New "Zero Order" and New 1st Order (buried) streams

1st order channel

2nd order channel

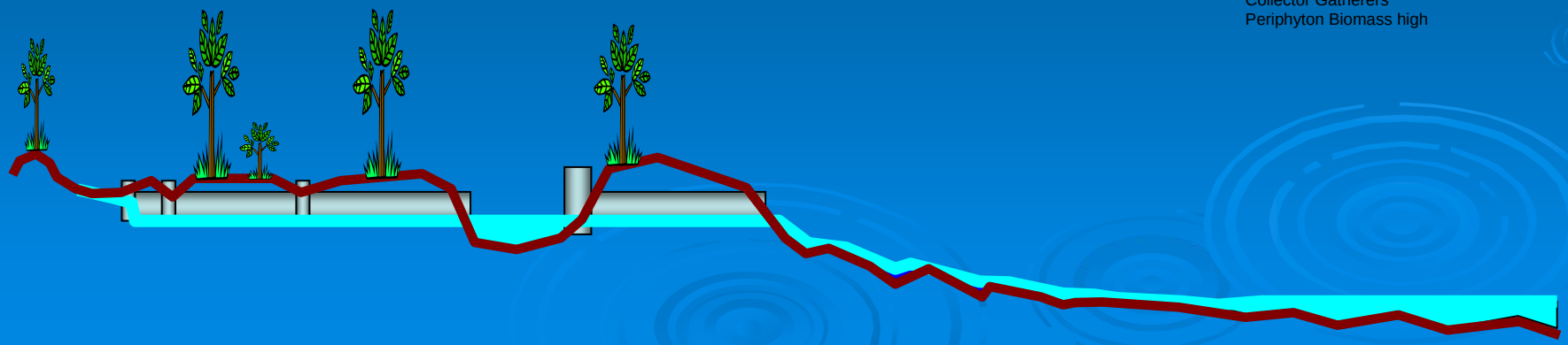
3rd order channel



P:R <<1
Subterranean
Low CPOM
CPOM:FPOM high
No FFG

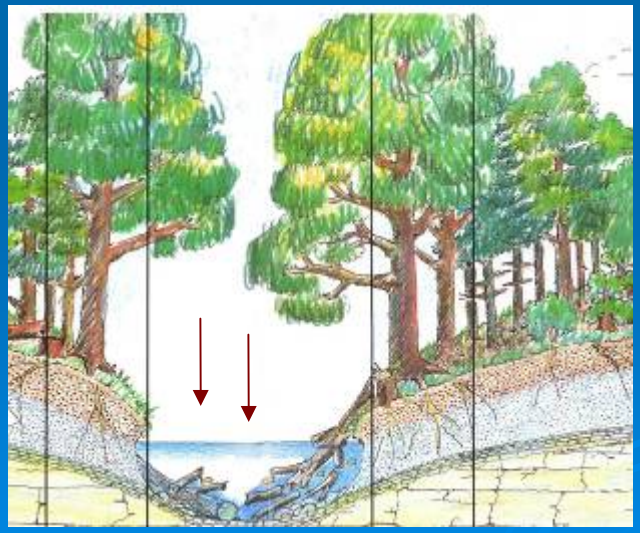
P:R < 1
Shade
CPOM variable
CPOM:FPOM lower
High FPOM
FFG: Filterers
Periphyton biomass low-moderate

P:R = 1 (but variable)
Open Canopy
CPOM more prevalent
CPOM:FPOM lower
High FPOM
FFG: Filterers, Shredders
Collector Gatherers
Periphyton Biomass high



Urban Headwater Streams….
a range of types

Key Issue: Gutters & Storm Drainage… Unnatural Sources of OM & Other Constituents

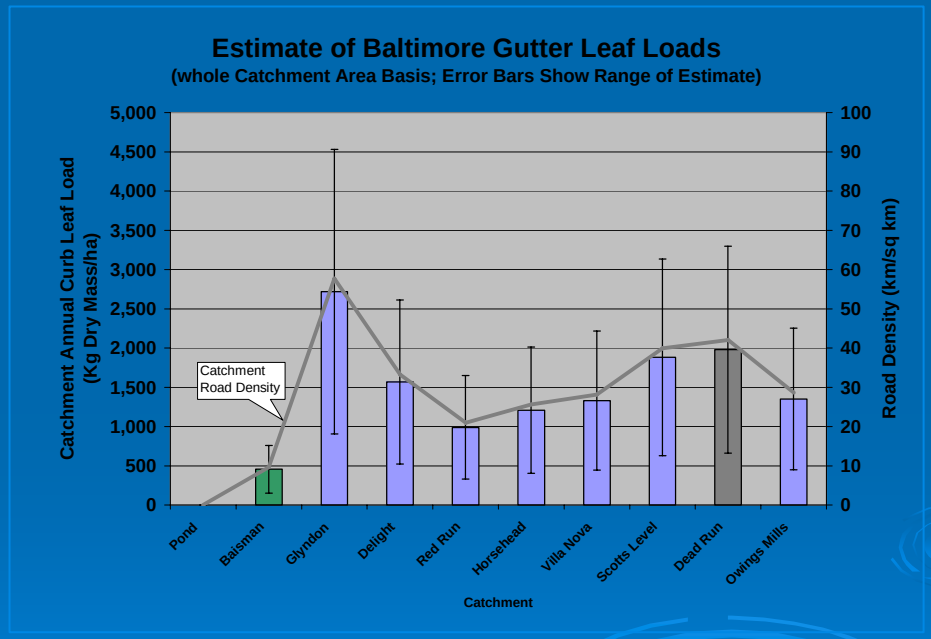


Gutters & storm drainage systems are effectively zero order streams….

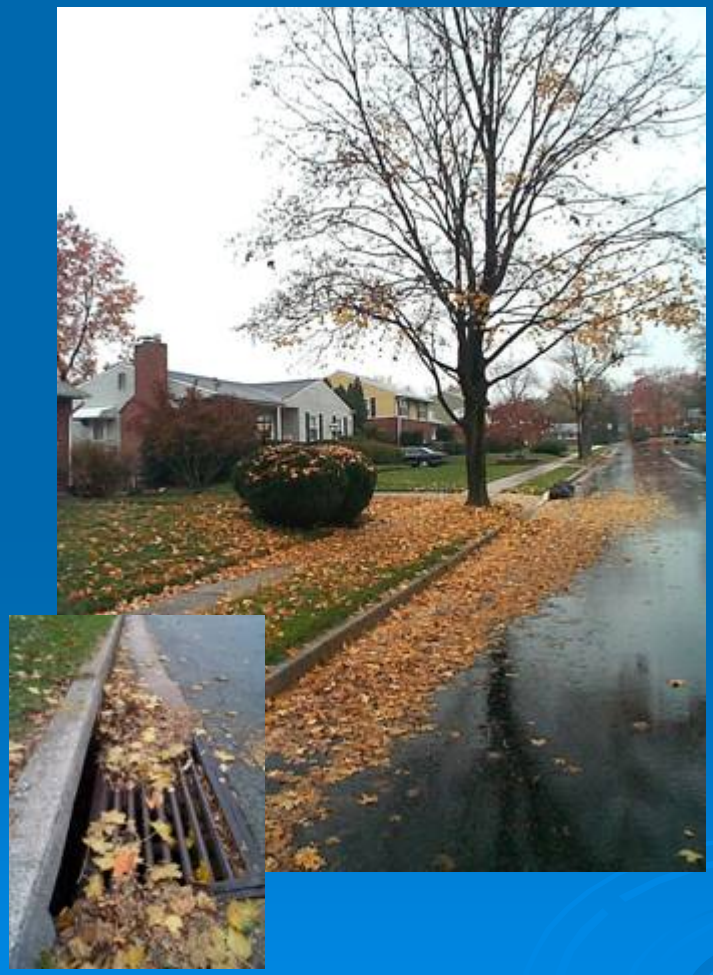
Able to move materials & dissolved constituents not of “riparian” origin

3. The Gutter Subsidy

So…. Urban Landscapes Should be “Big Time” OM Exporters… and Processors



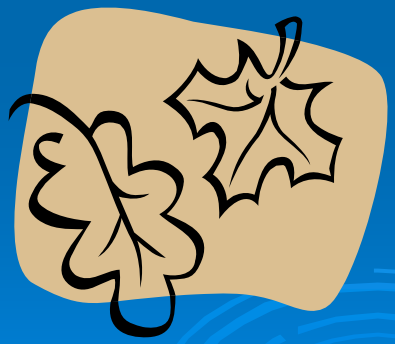
Types of Organic Matter in Streams



DOC- dissolved OM

FPOM- fine particulate OM

CPOM- coarse particulate OM



Why is Urban OM transport Important ?

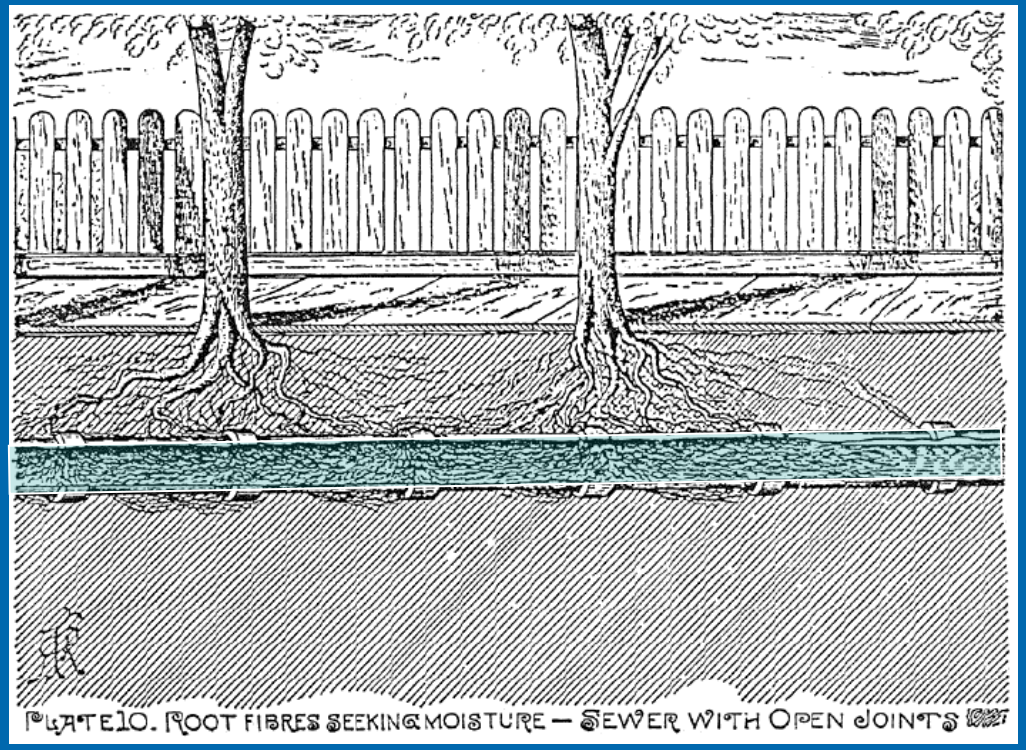
- Leaves in streams: **energy** (food source) and **habitat**
- Important in a variety of **BGC reactions and pathways**
- Important in **DBPs and drinking water treatment?**
- "Vectors" for **pathogens** and **pollutant loads?**

Diptera:
Tipula sp.

“Upland Riparian” Zero Order Streams… URZO’s

Alleyways, Roof Gutters…

Urban Canopy… intimately connected to drainage



CPOM-FPOM-DOC… lots of procesing

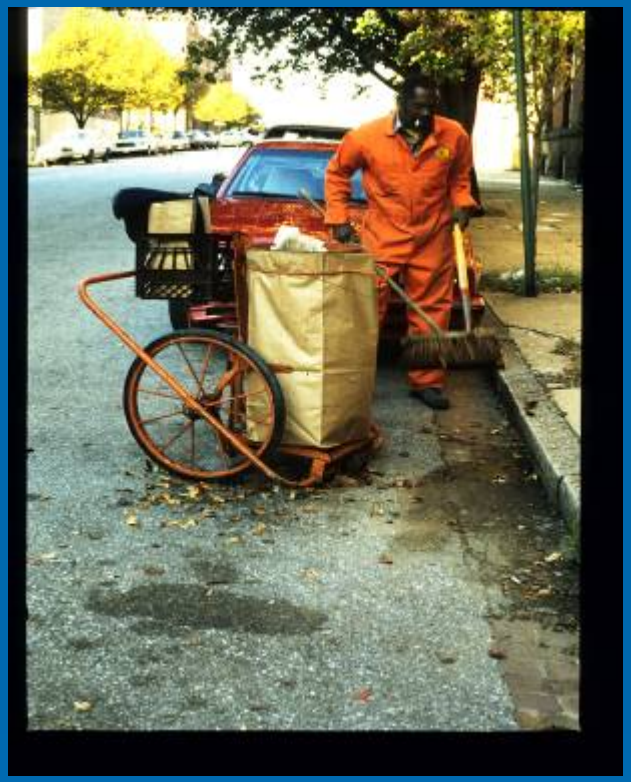
Storage in the Pipe

Catchbasins… urban “debris dams” ?

Street Sweeping in Rognel Heights

Rognel Heights Storm Composite

Catchbasins… receive large volumes of BOD



4. DOC & FPOM in Urban Streams

BES Stream Sites

Pond Branch
32.3 ha
0 % ISC

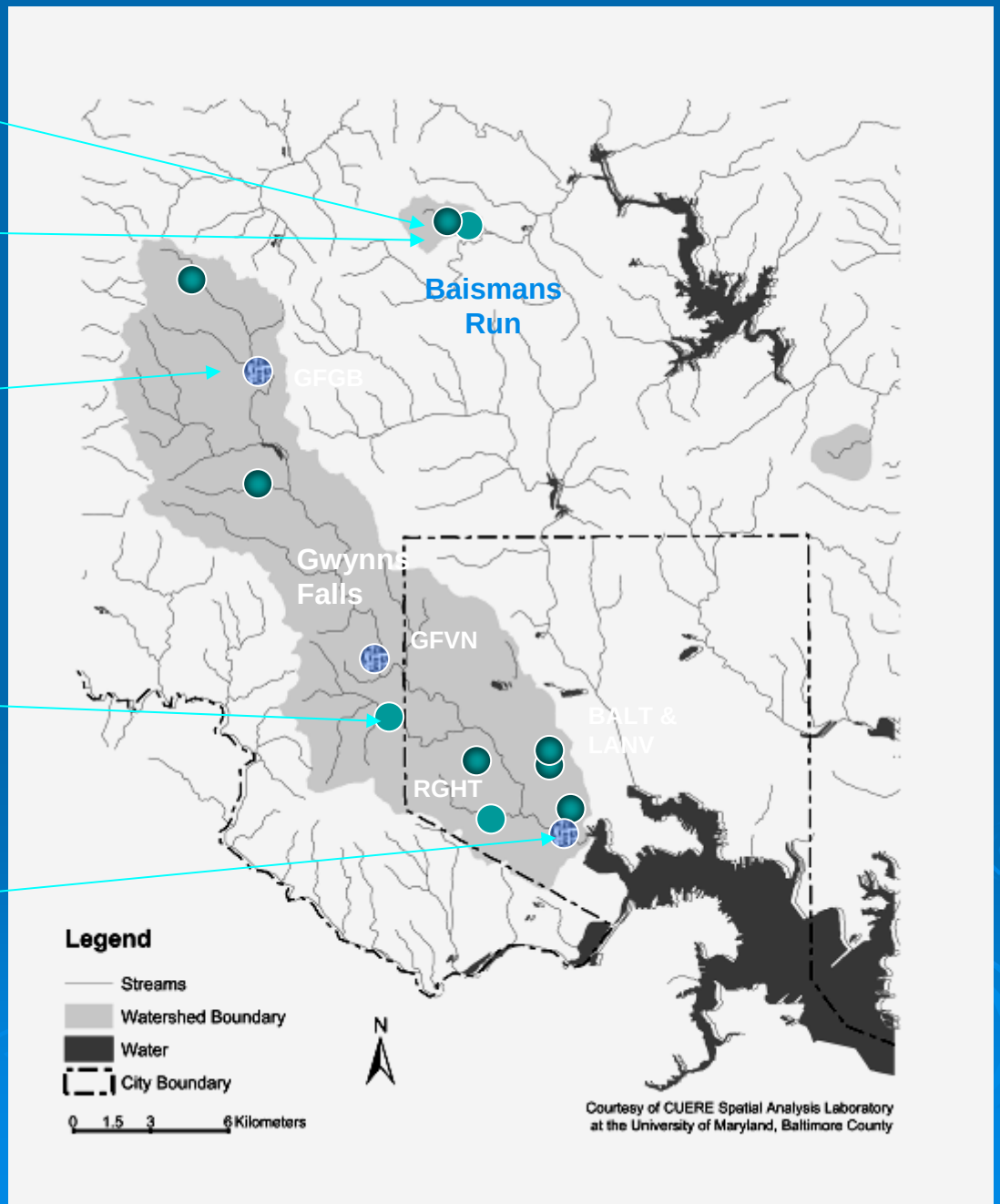
Baisman Run

381 ha
1 % ISC

Gwynns Falls
At Gwynnbrook
1066 ha
17 % ISC

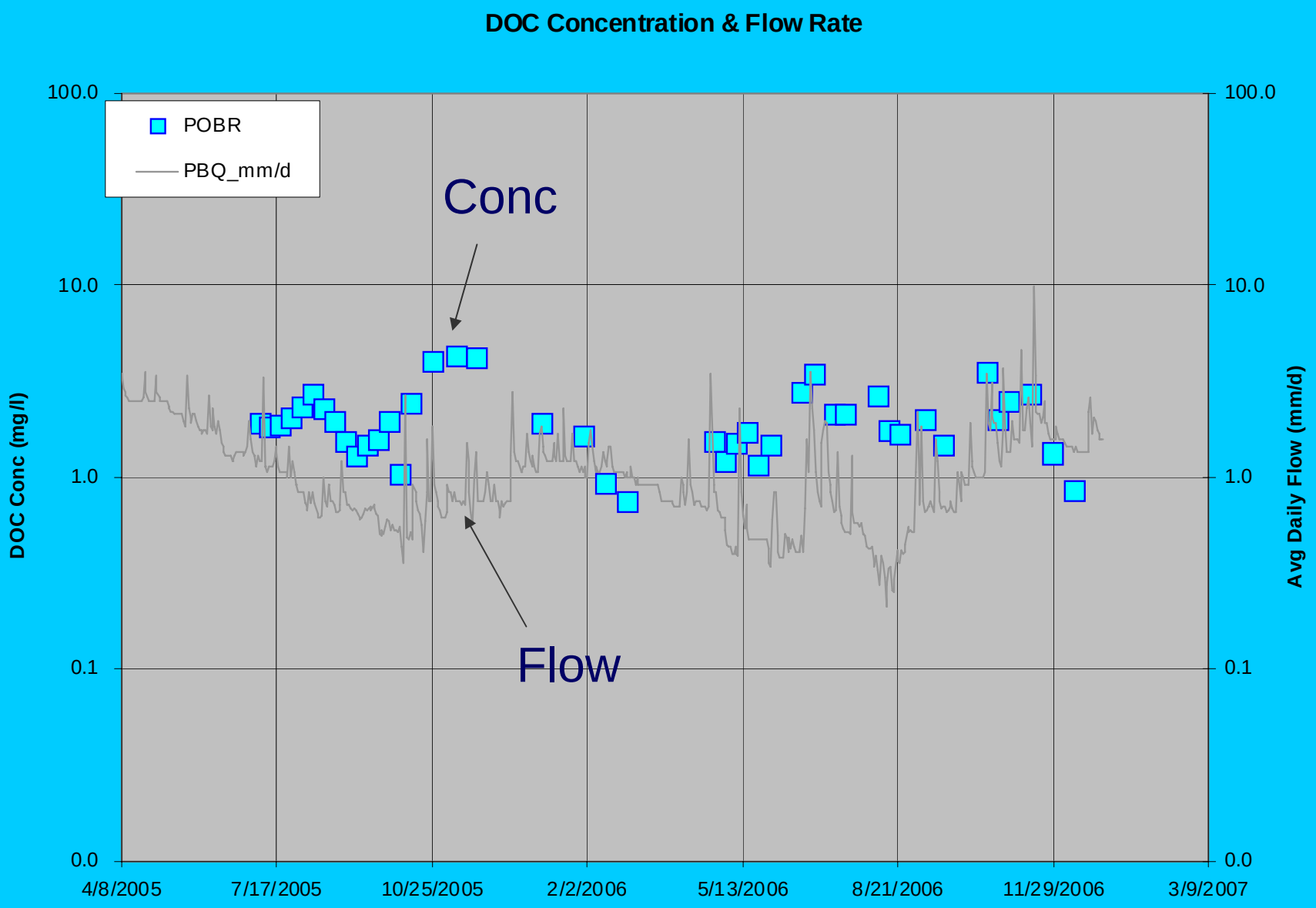
Dead Run
1414 ha
41% ISC

Carroll Park
16278
27 % ISC

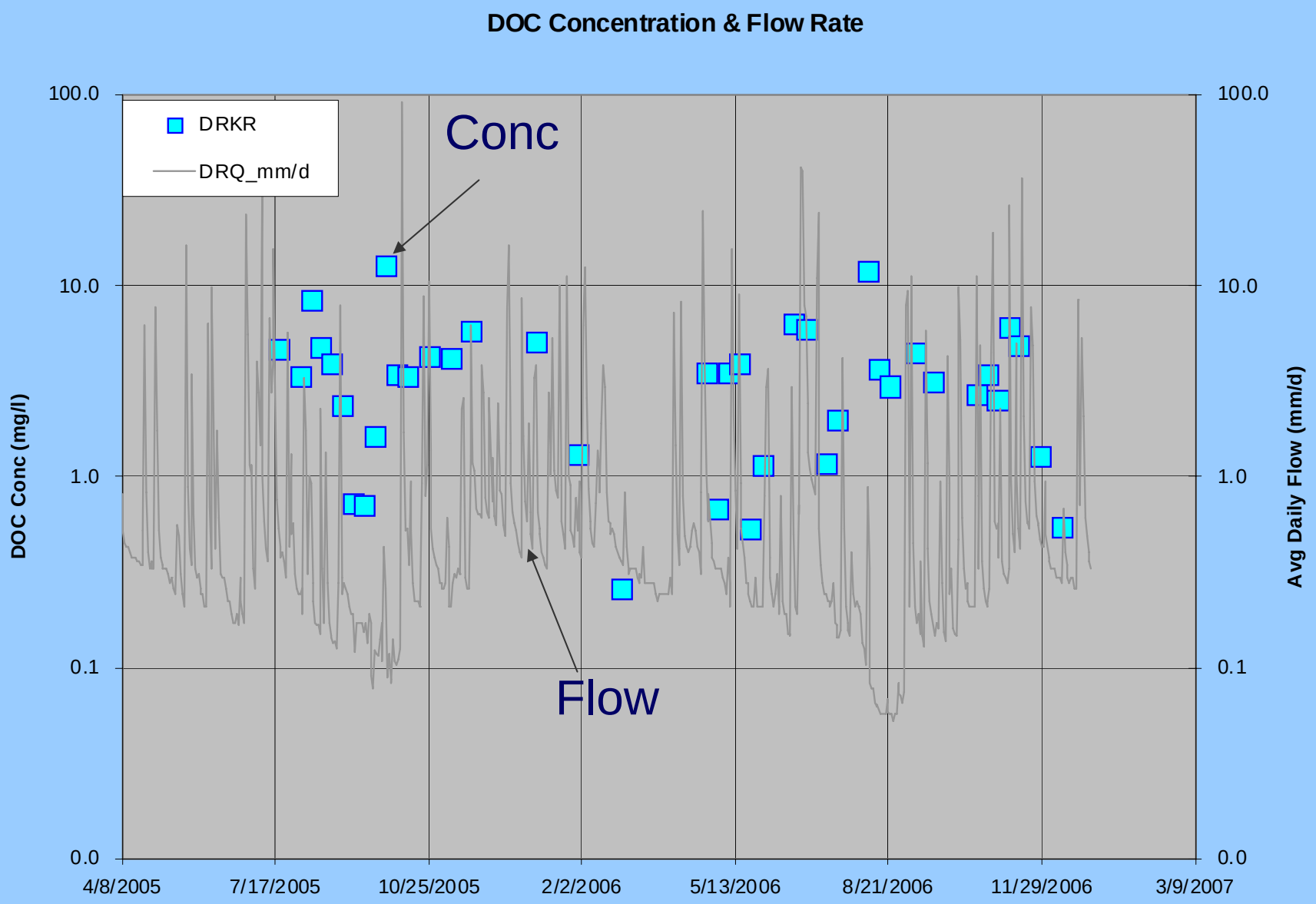


USGS- Ratings & Continuous Record of Flows

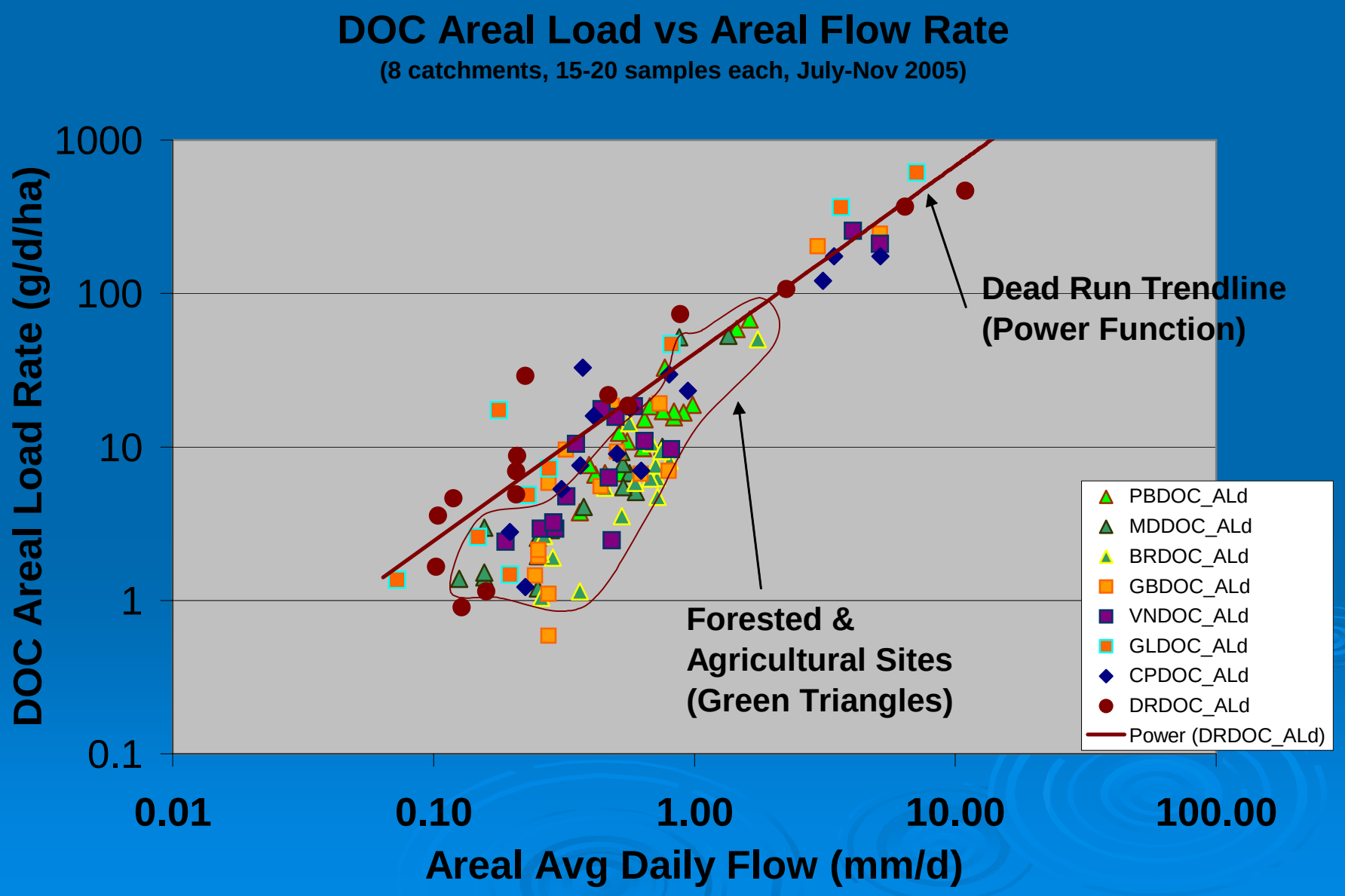
DOC Concentration & Flow… Forested



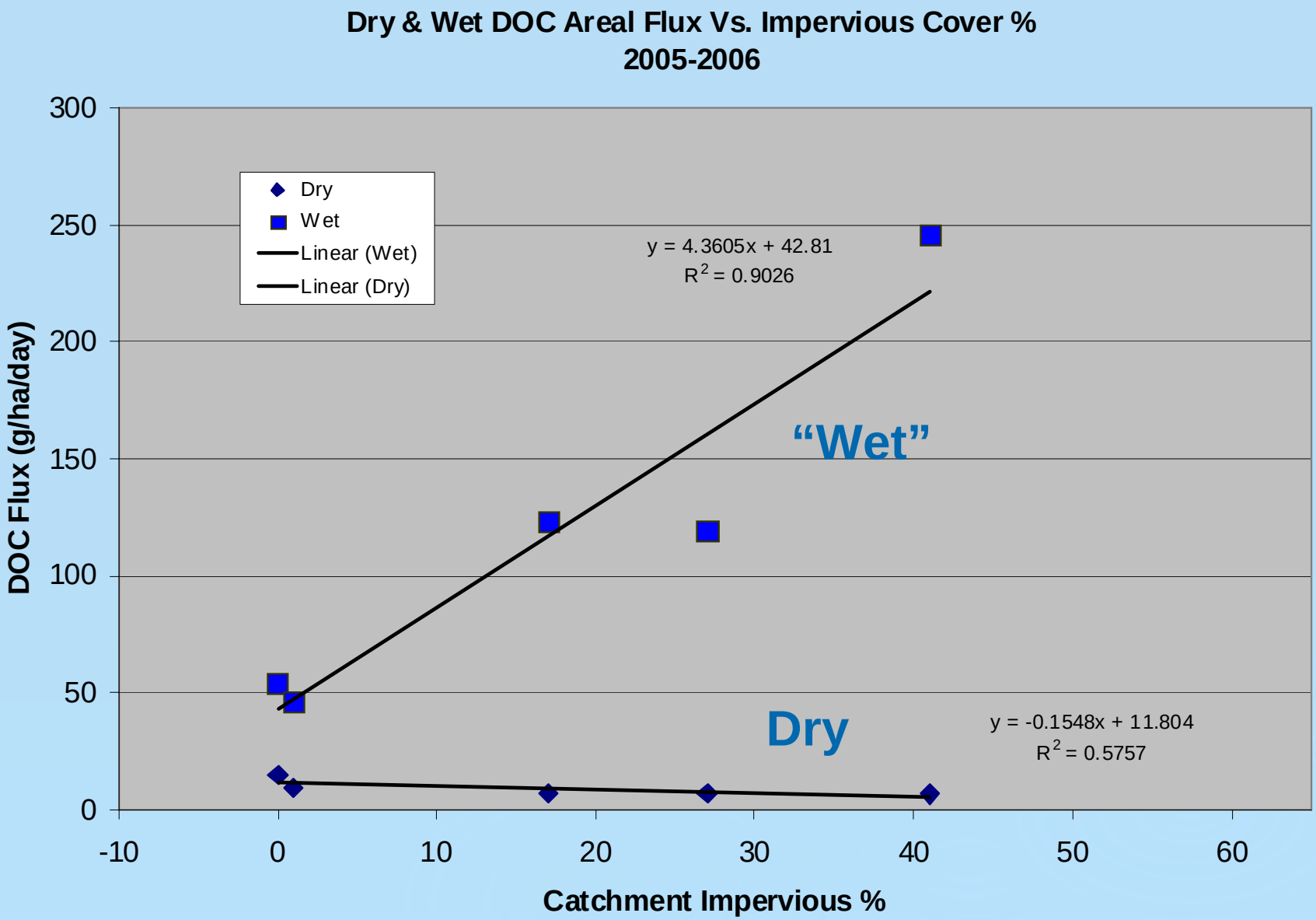
DOC Concentration & Flow… Urban



Urban: Higher DOC… and Greater Fluxes

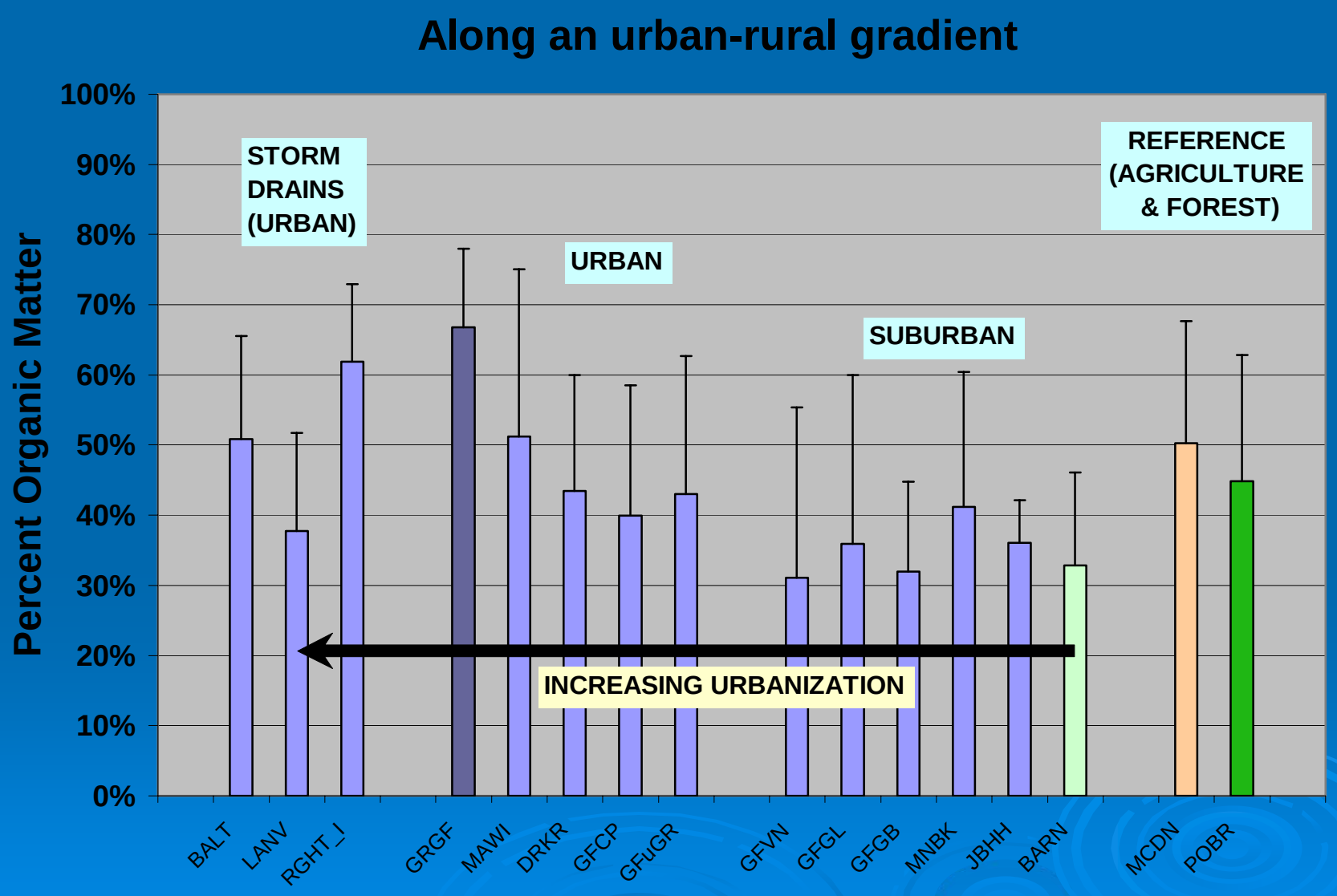


DOC Flux vs. ISC… the gutter subsidy?

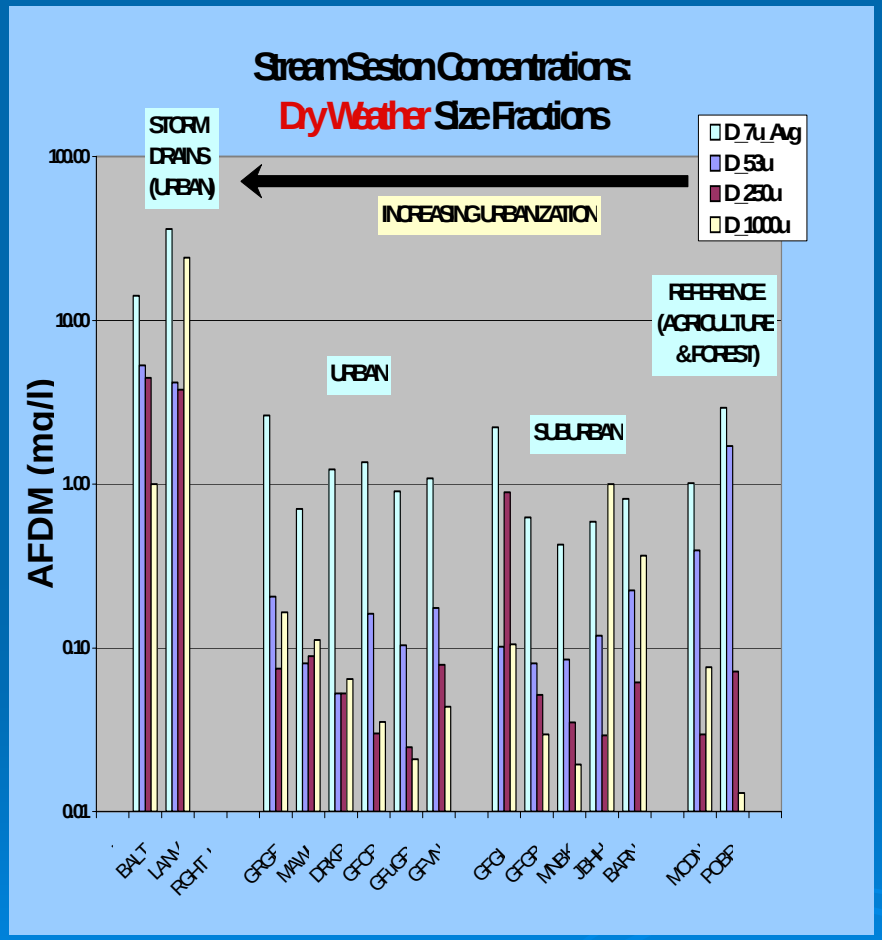


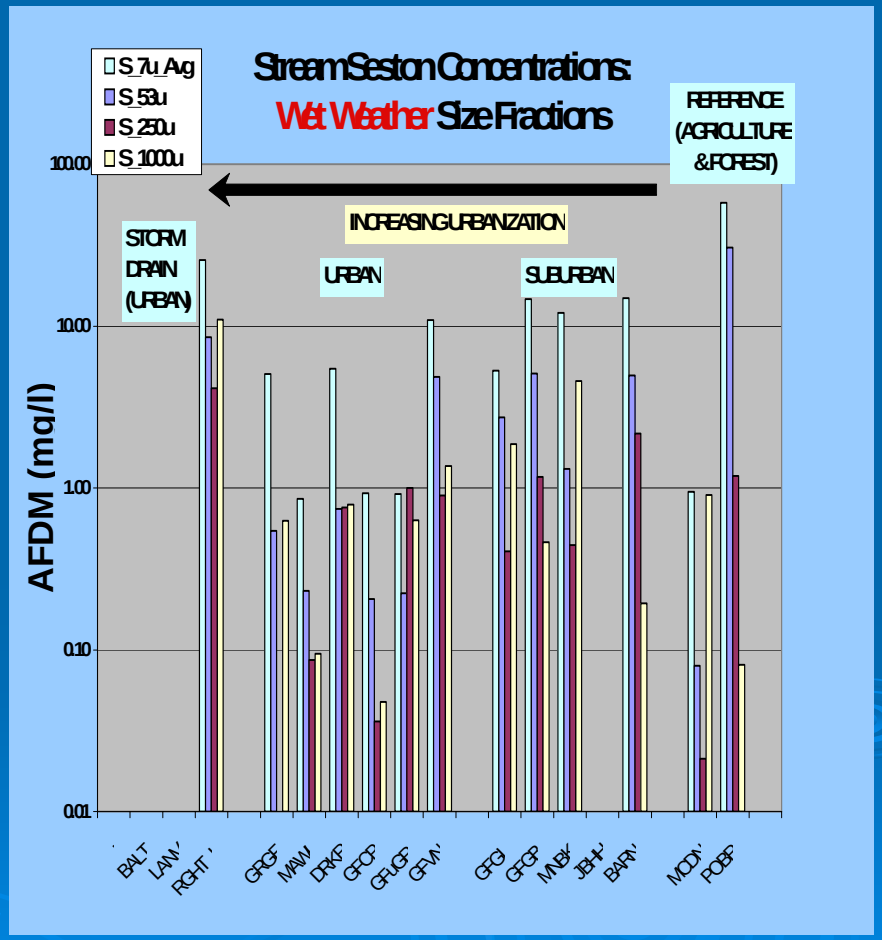
FPOM- Fine Particulate Organic Matter (VSS)

% OM (of TSS)… Higher in Urban Streams

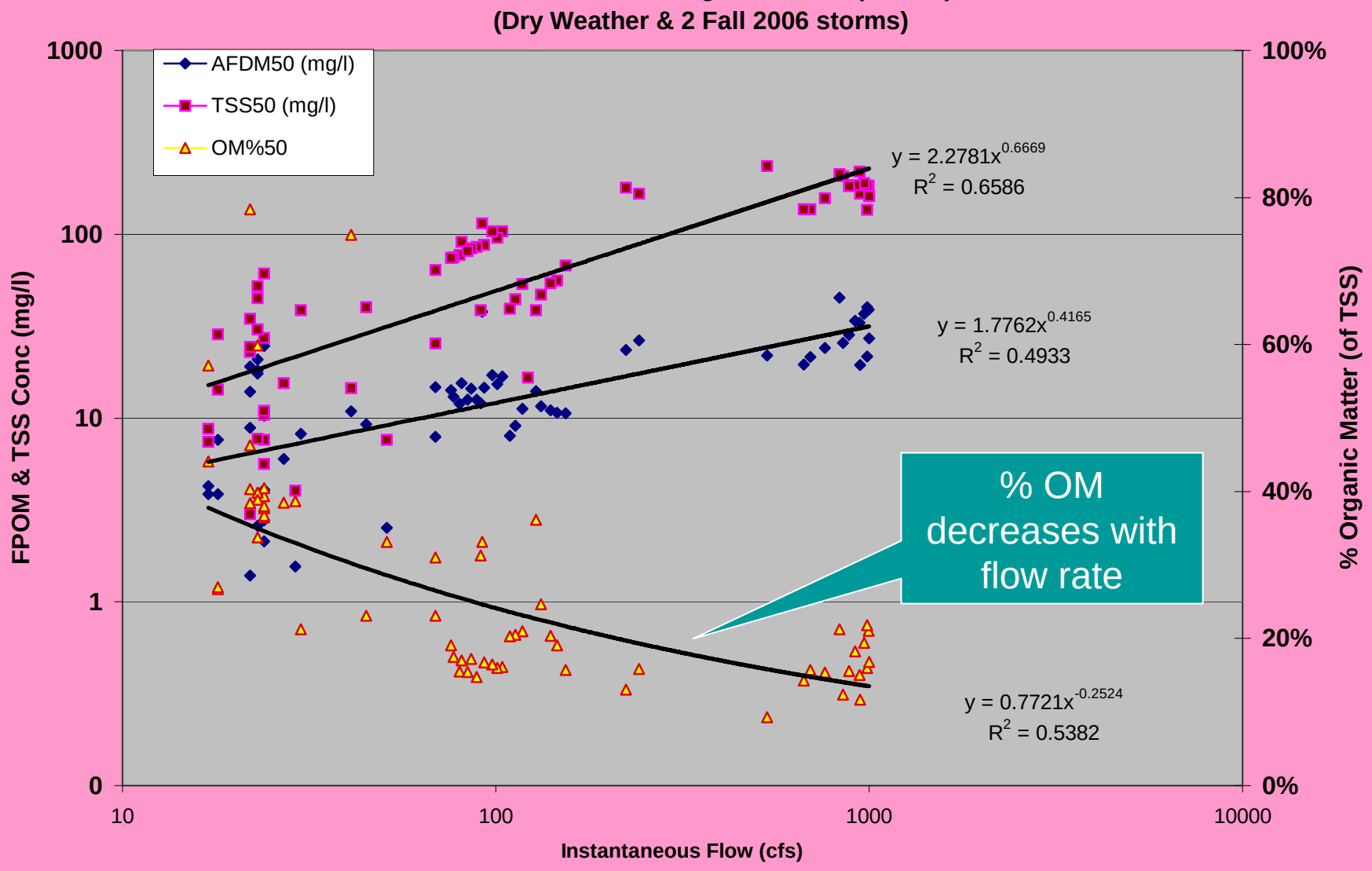


FPOM: Size Fractions…. Post Storm Sampling



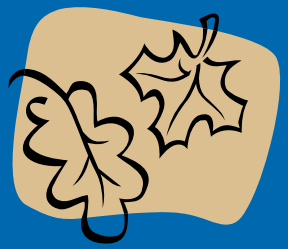


Villa Nova: Seston Conc vs. Storm Flow Rates



Urban catchments produce large DOC/POC fluxes

These loads may in large part be related to urban drainage infrastructure



Delivered to urban streams: immense quantities of particulate & dissolved OM…

<u>implications</u>:

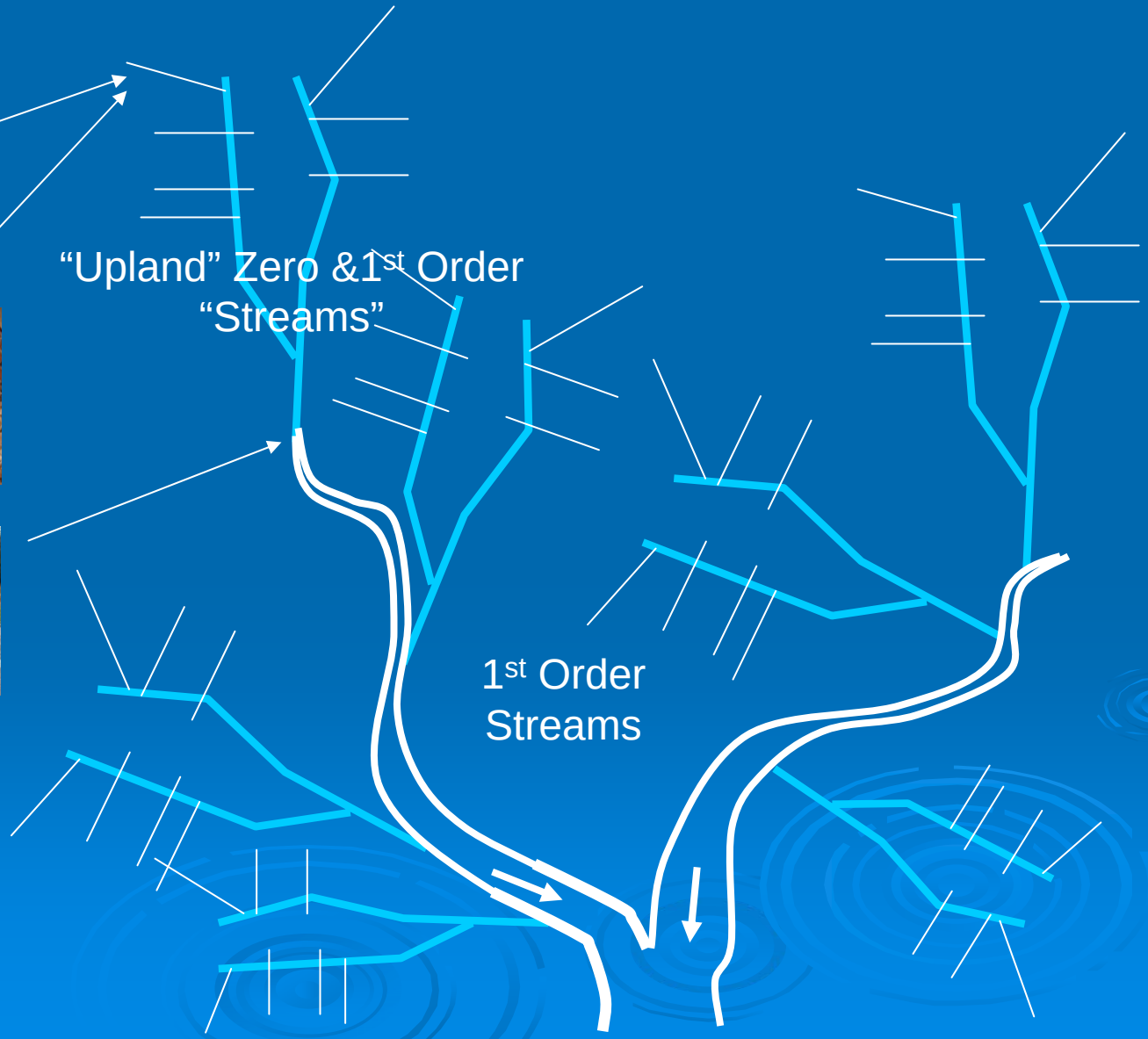
Aquatic Ecology (Food Webs)?

Public health (DBPs) ?

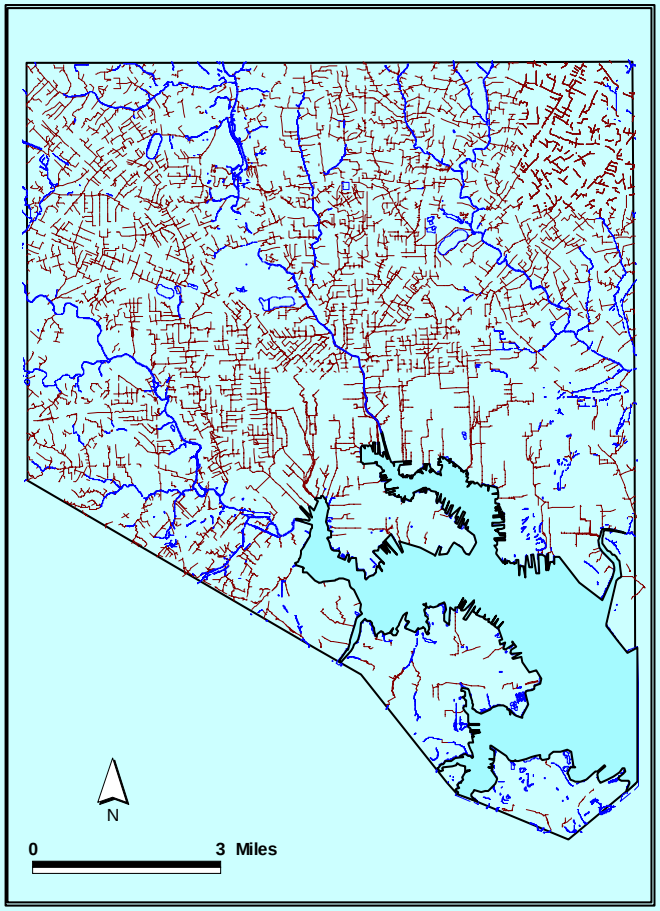
Watershed Mgt (Missing L)?

5. More Inter-connectedness… Urban “Karst”

Urban Headwater Streams… additional upstream sources



The Urban “Spaghetti” does not end with stormwater…



Baltimore City DPW

Dense Pipe Networks: Baltimore City

Stormwater:
1,000 miles of storm drains
33,000 storm inlets

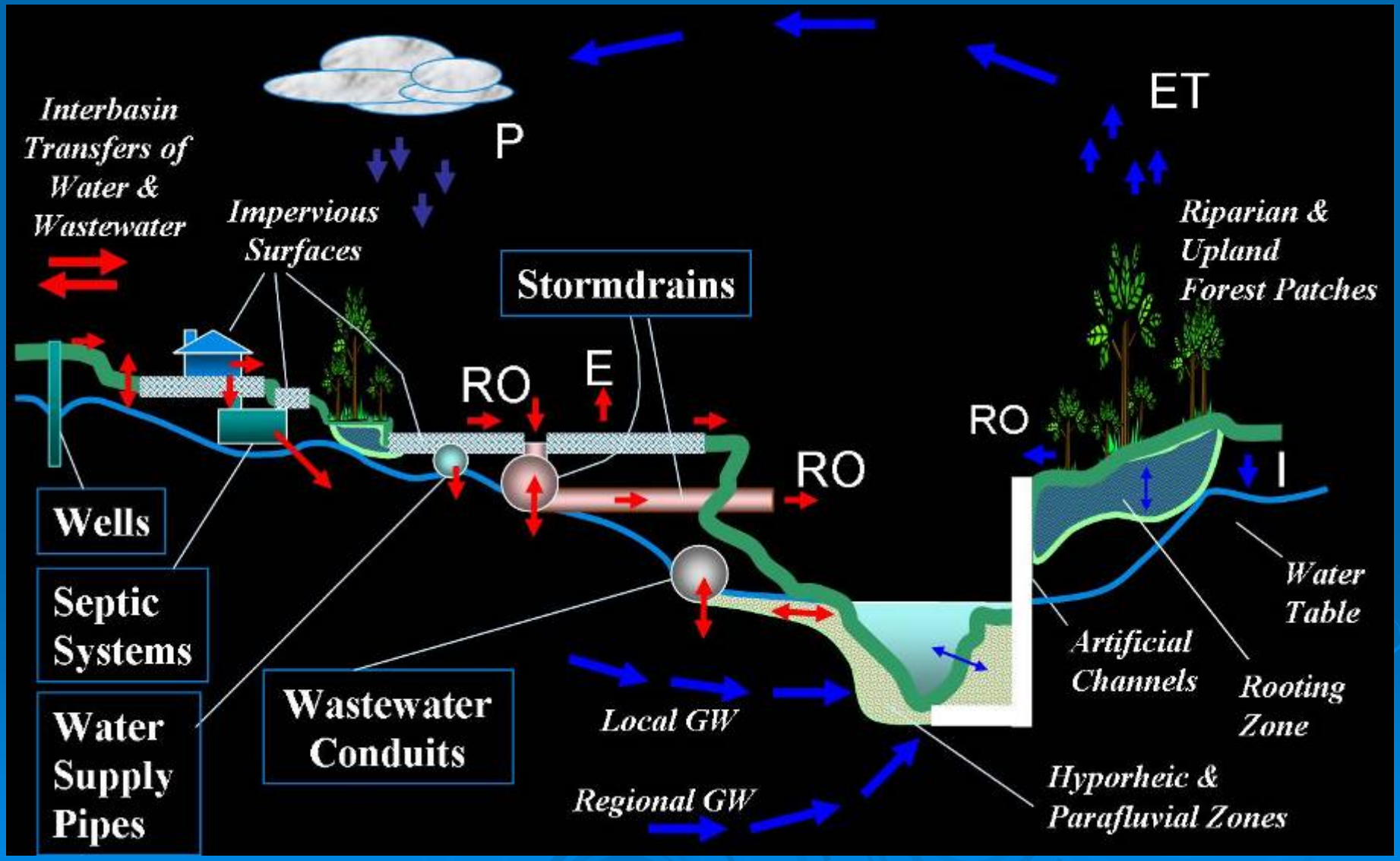
Potable Water:
3,400 miles water mains
265 mgd
19,100 fire hydrants

Wastewater:
3,100 miles sanitary mains, etc
250 mgd
Ca. 1000 joints per mile of pipe

* From Baltimore City DPW Website

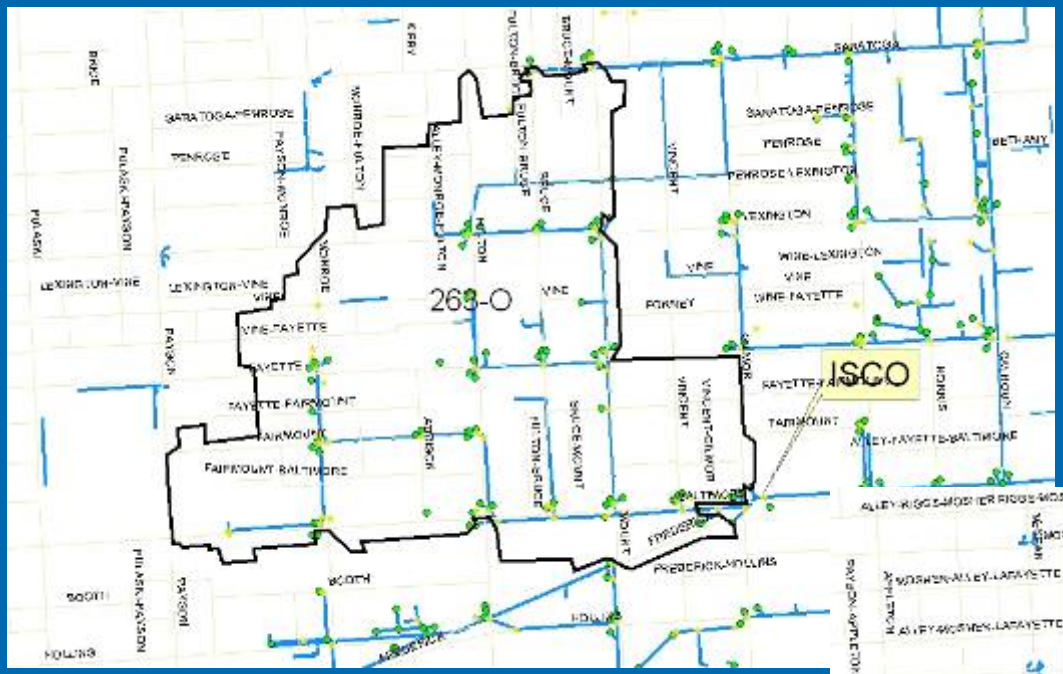
Three “water” pipes for every house…

The Urban Hydrologic System: infrastructure driven pathways



Sanitary Sewers….
Two Way Riparian Interchanges with stream water

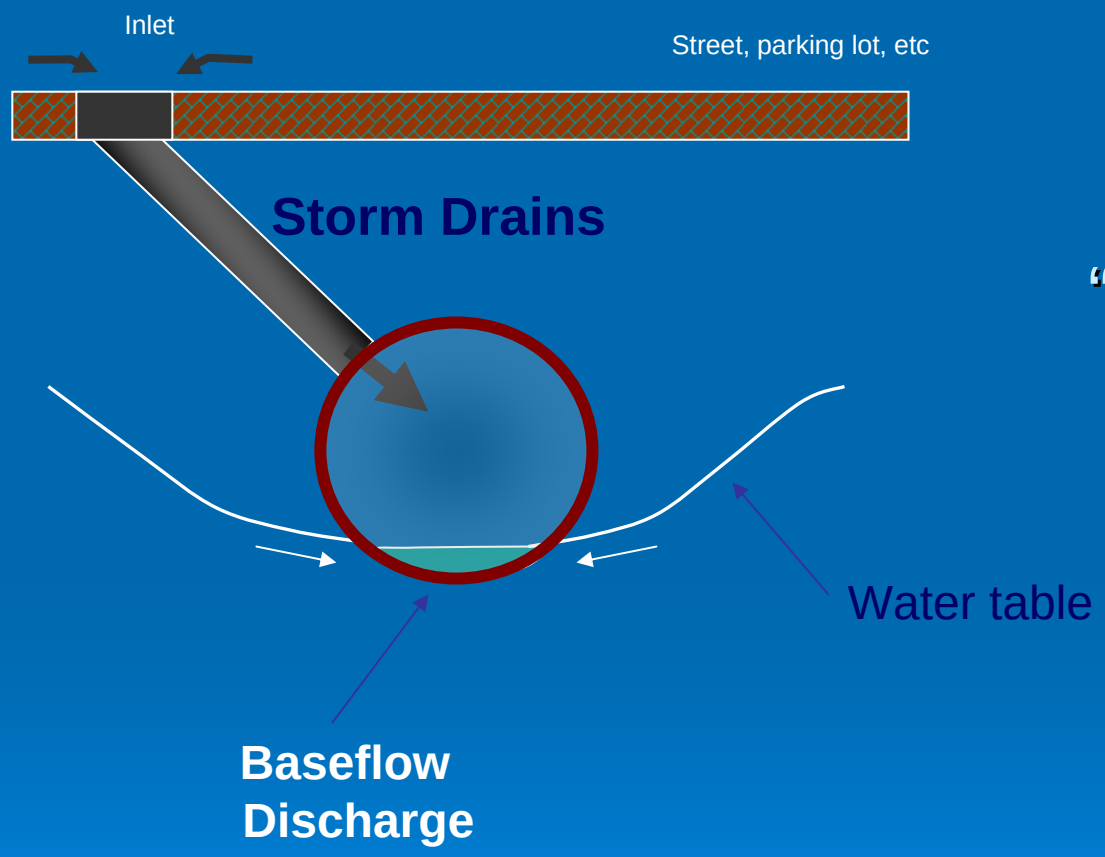
Stormwater…
Many Headwater Catchments



Baltimore St

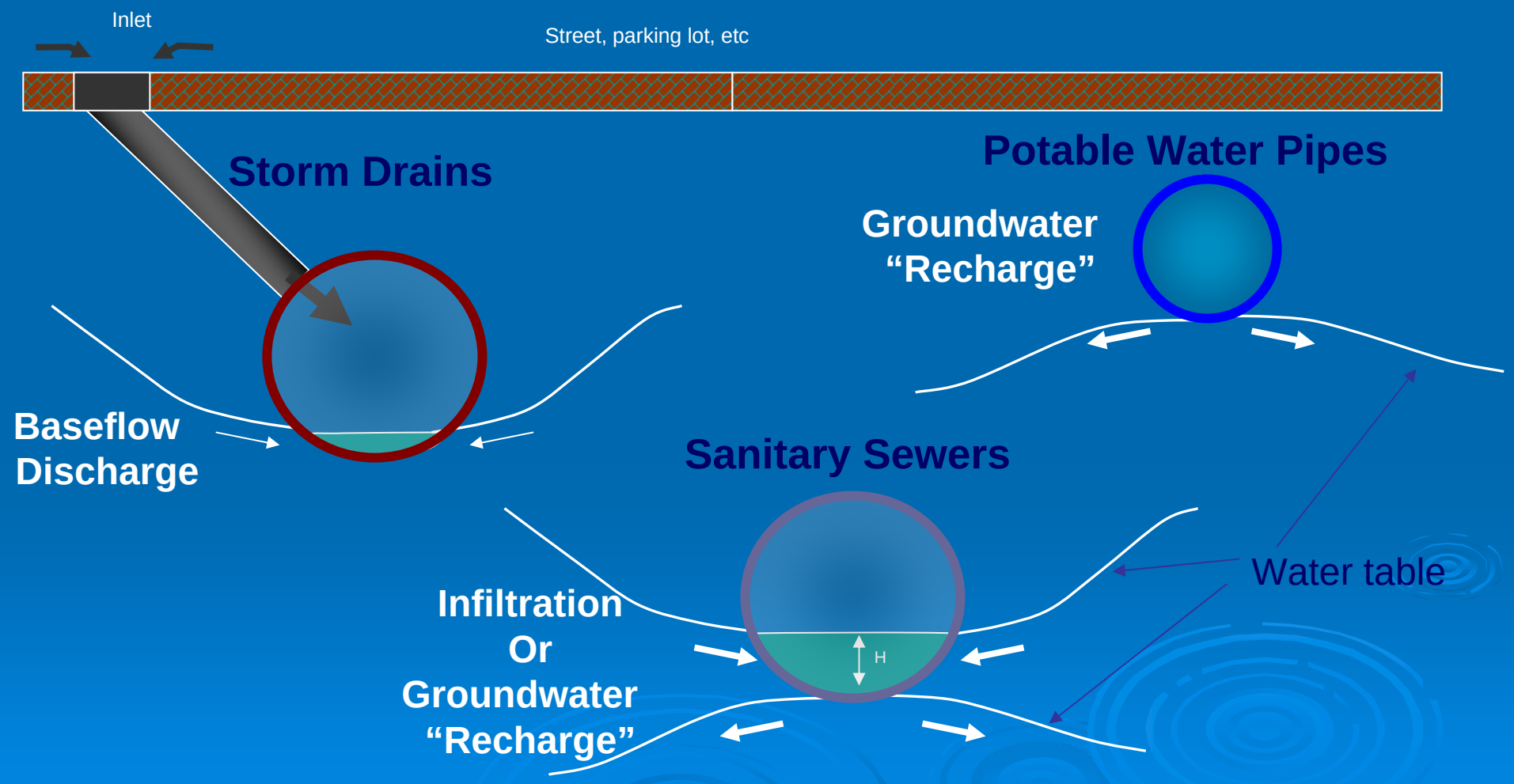
Lanvale St

“Headwater” Stormdrains Carrying Groundwater…

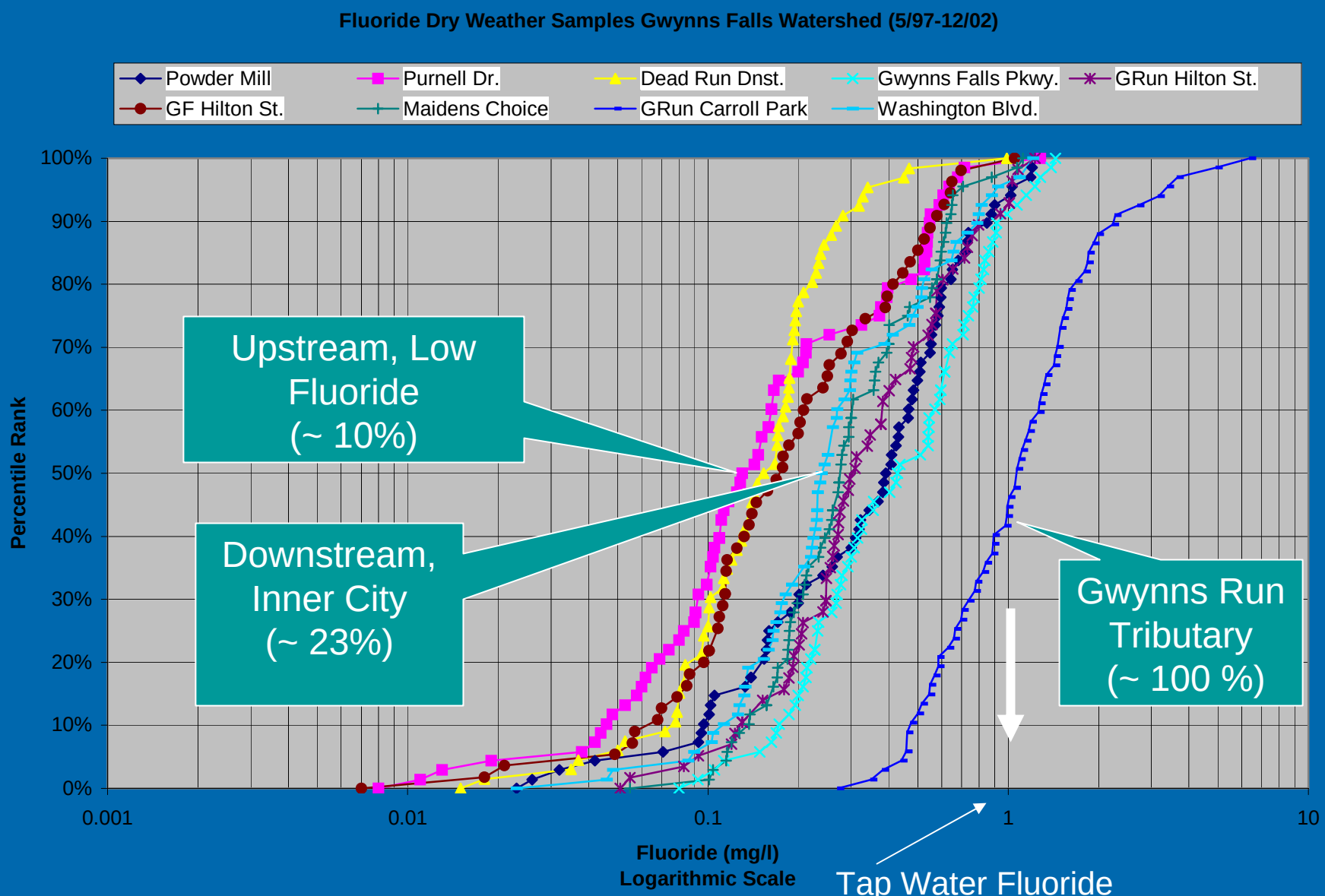


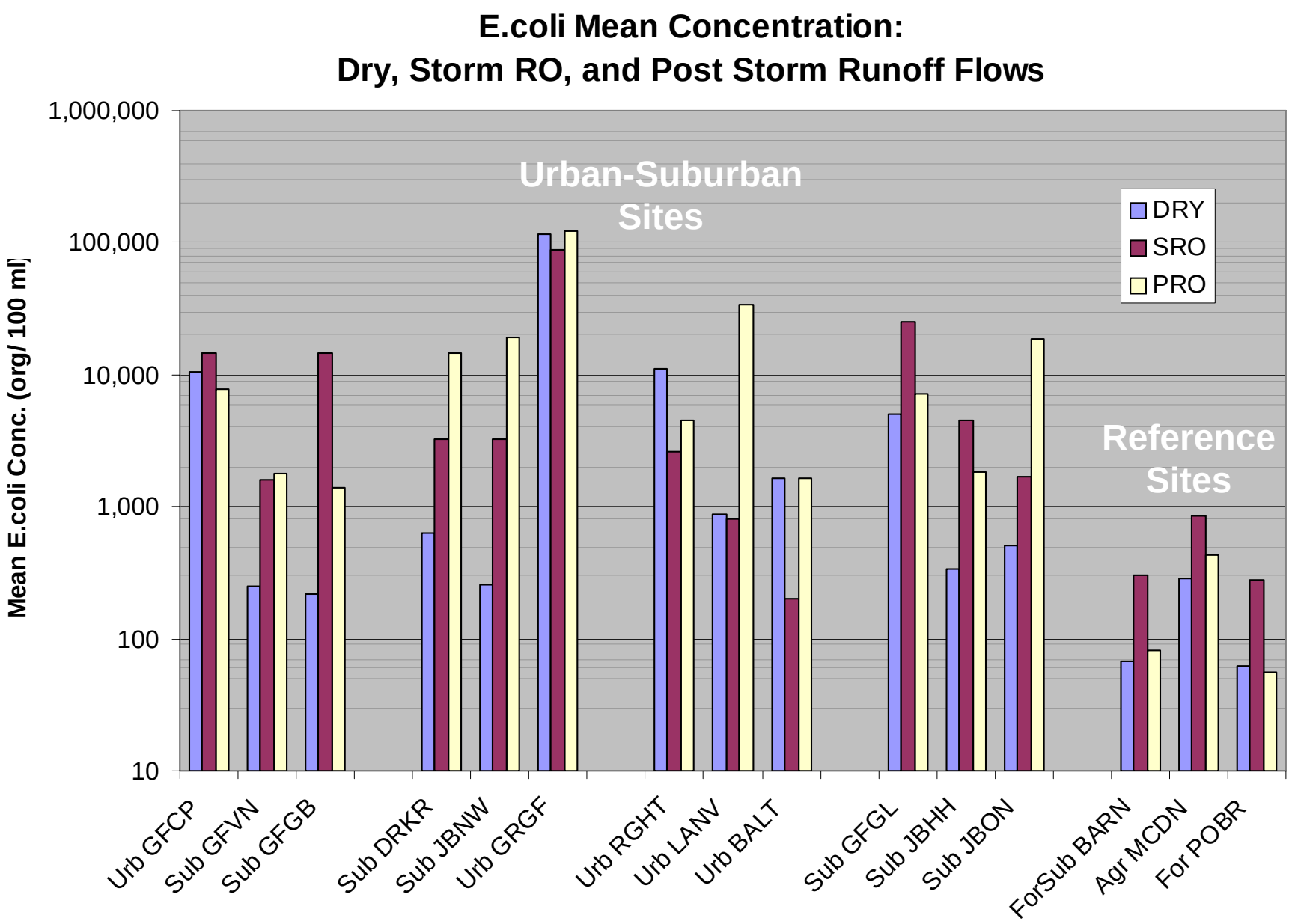
…become
“buried” streams

Dense, Landscape-wide systems of pipes… urban “Karst”

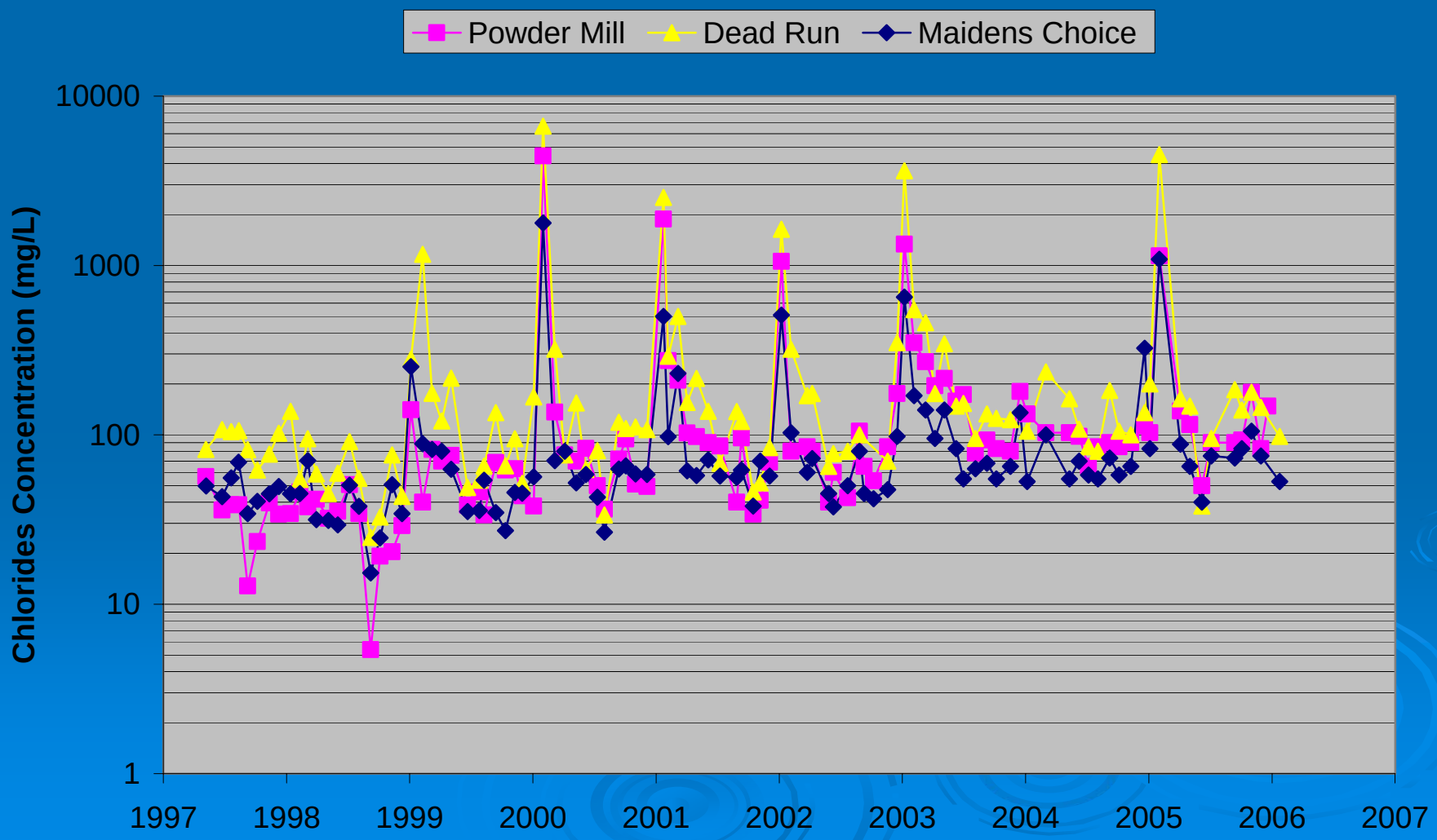


Fluoride in Gwynns Falls Streams

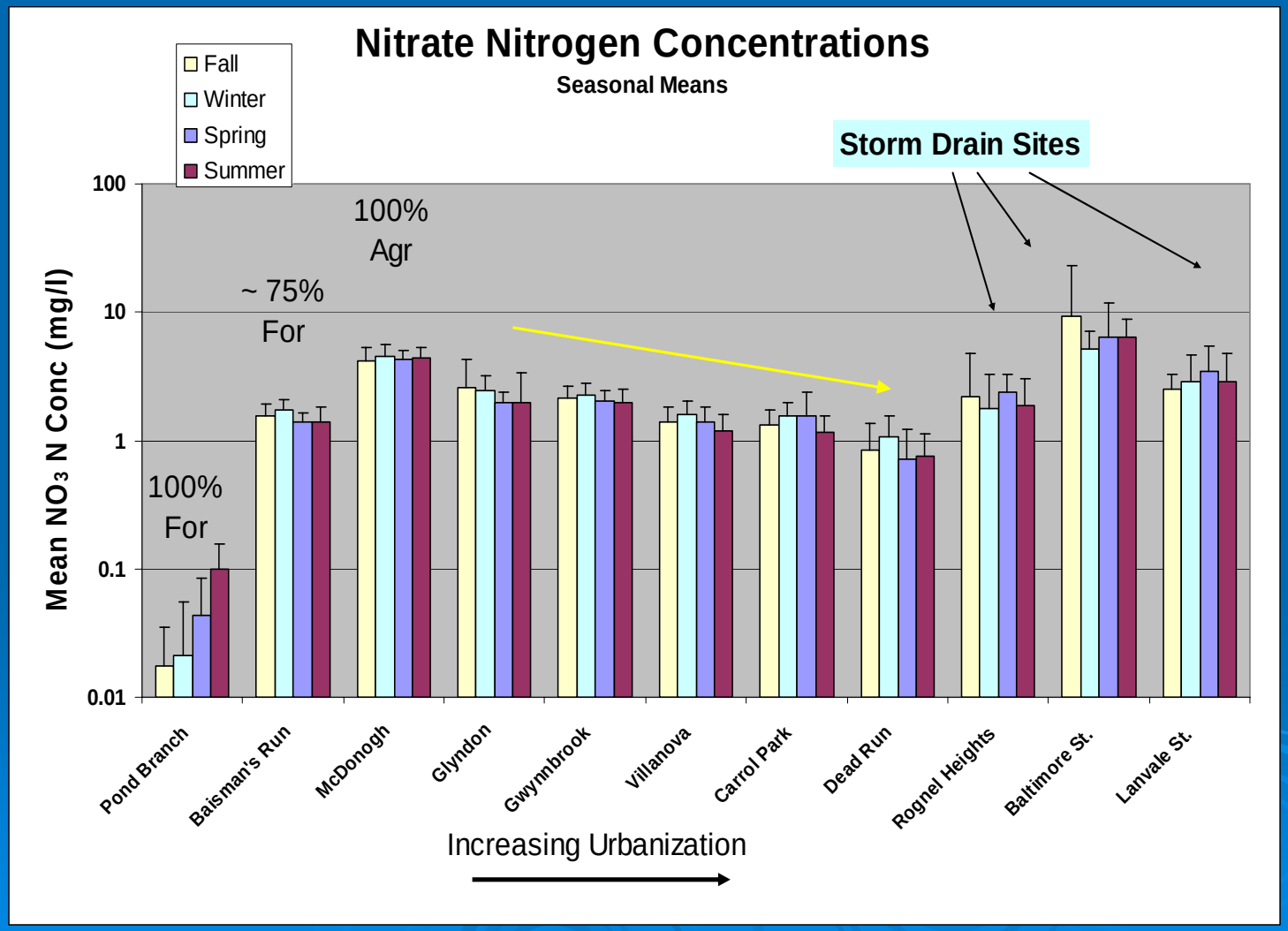



E.coli Mean Concentration:
Dry, Storm RO, and Post Storm Runoff Flows
Mean E.coli Conc. (org/ 100 ml)
1,000,000
100,000
10,000
1,000
100
10
Urban-Suburban Sites
Reference Sites
DRY
SRO
PRO
Urb GFCP
Sub GFVN
Sub GFGB
Sub DRKR
Sub JBNW
Urb GRGF
Urb RGHT
Urb LANV
Urb BALT
Sub GFGL
Sub JBHH
Sub JBON
ForSub BARN
Agr MCDN
For POBR

Deicers… High Chloride Year-around

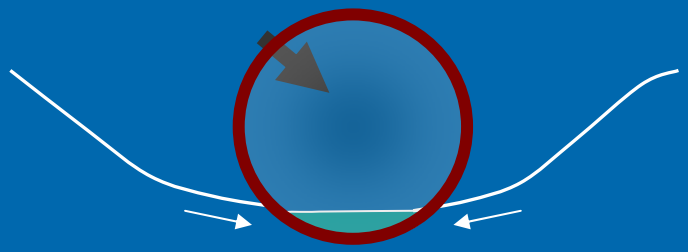


“Headwater” Stormdrain Catchments: Nitrate Dry Weather Flow Sources ?



Baltimore Street Sampling site… buried headwater stream

Multiple Systems… Intermingled Chemistry



Pervasive in urban streams:

Fluoride

E. Coli

Chloride

Nutrients

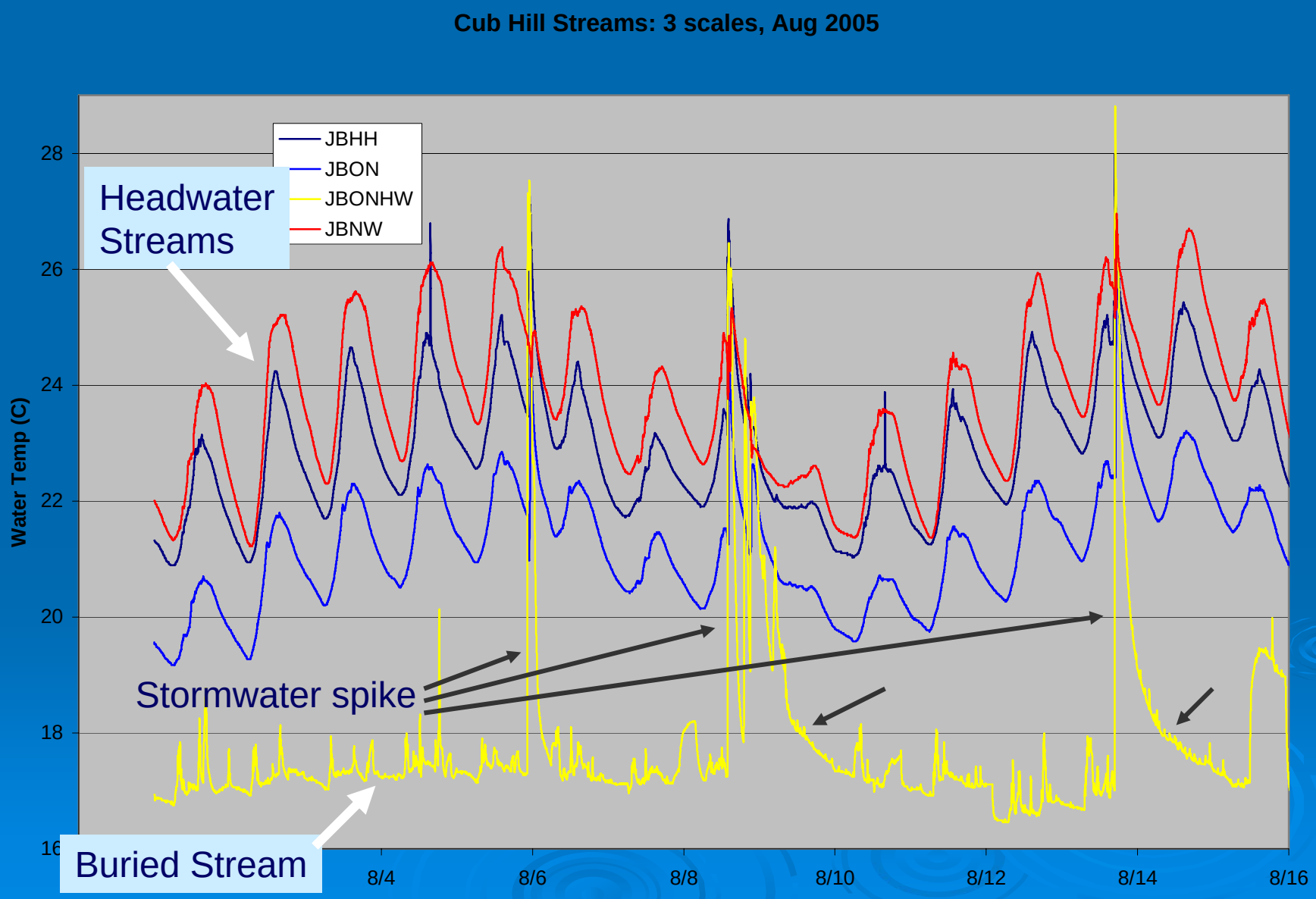
Thermal Loads

Headwater urban streams:

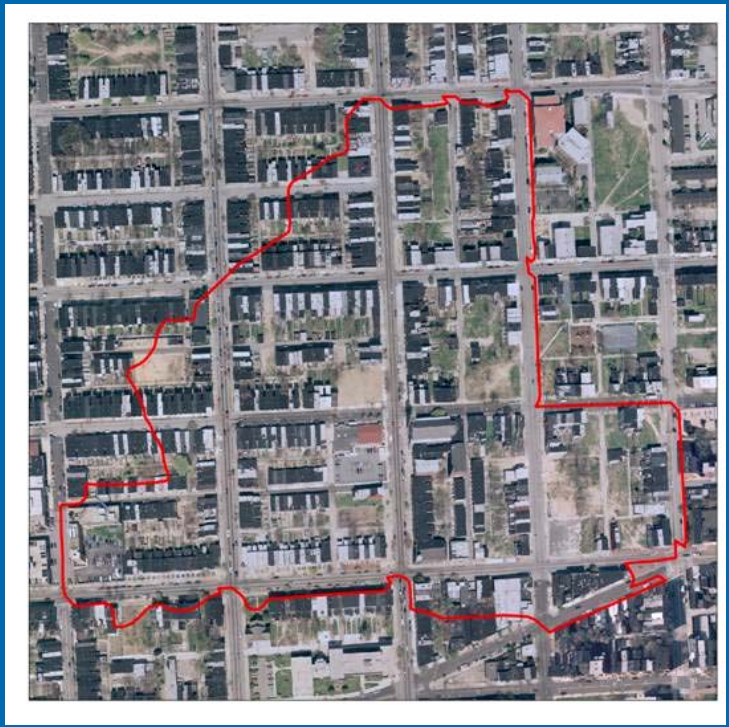
Urban Heat Island Effects

Storm RO spikes and extended thermal loads

Summer Stream Temps…. Stormwater Effects



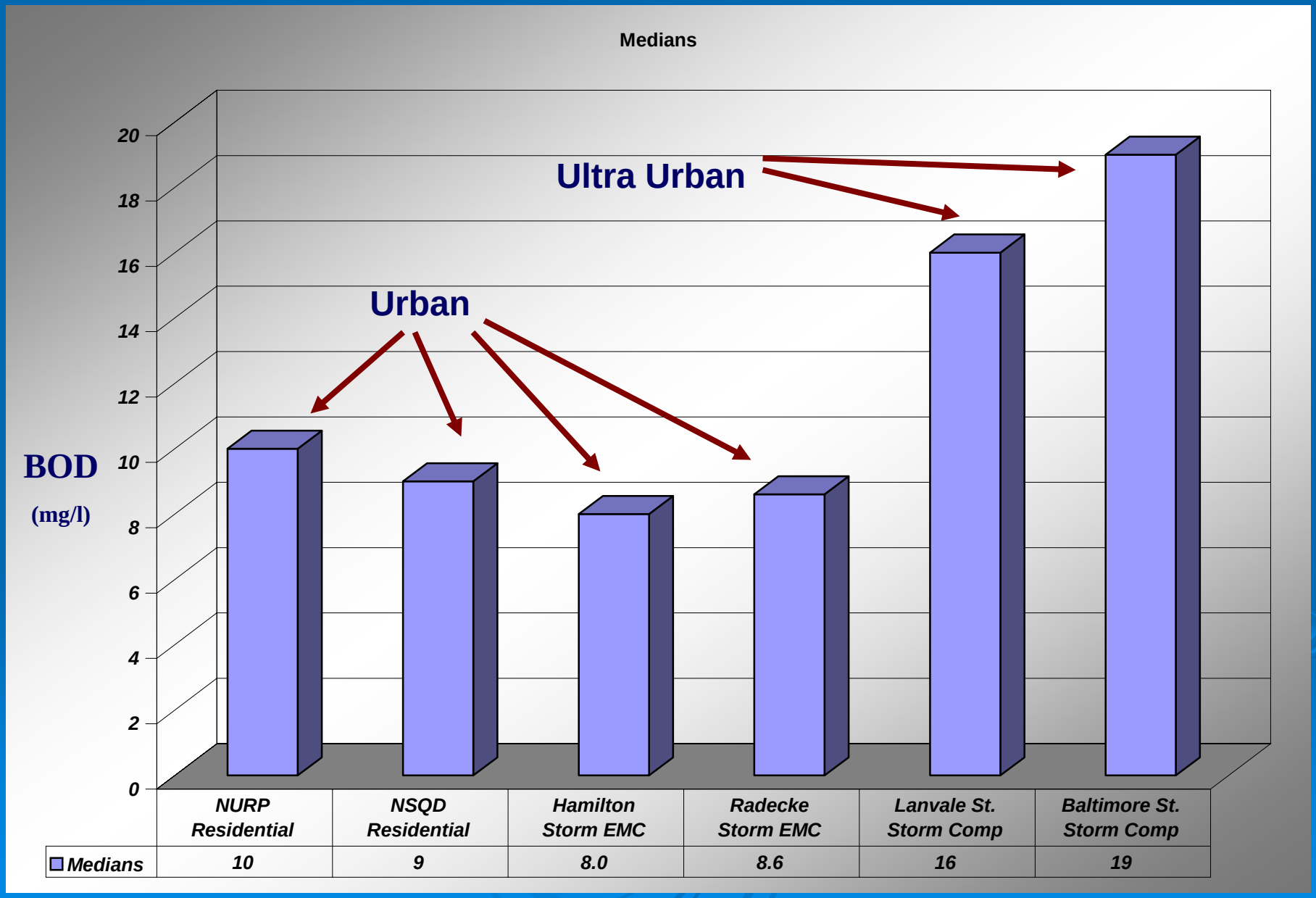
Ultra-Urban Hotspots ?



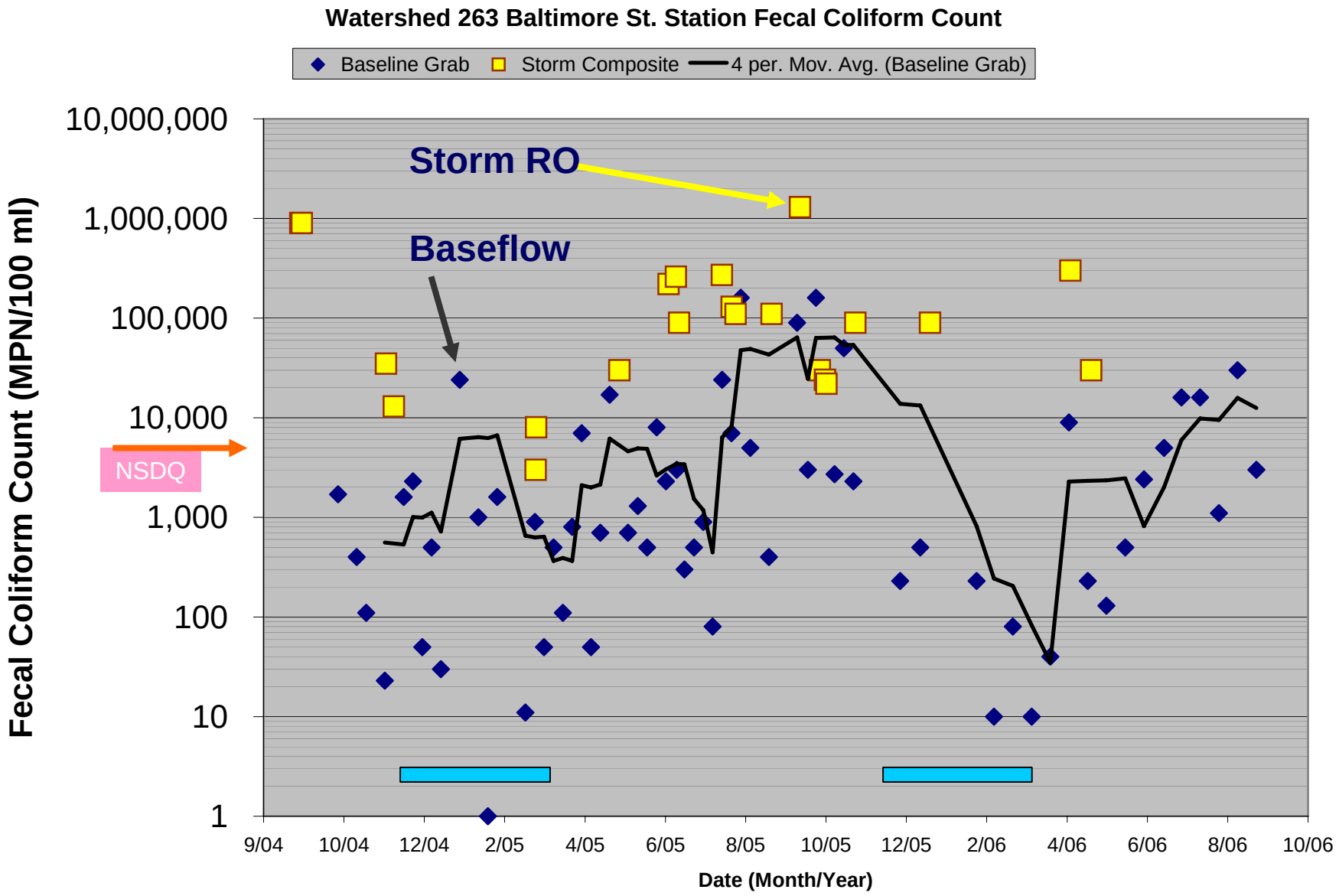
Baltimore St.

Are older “ultra”urban headwaters intrinsically different ?

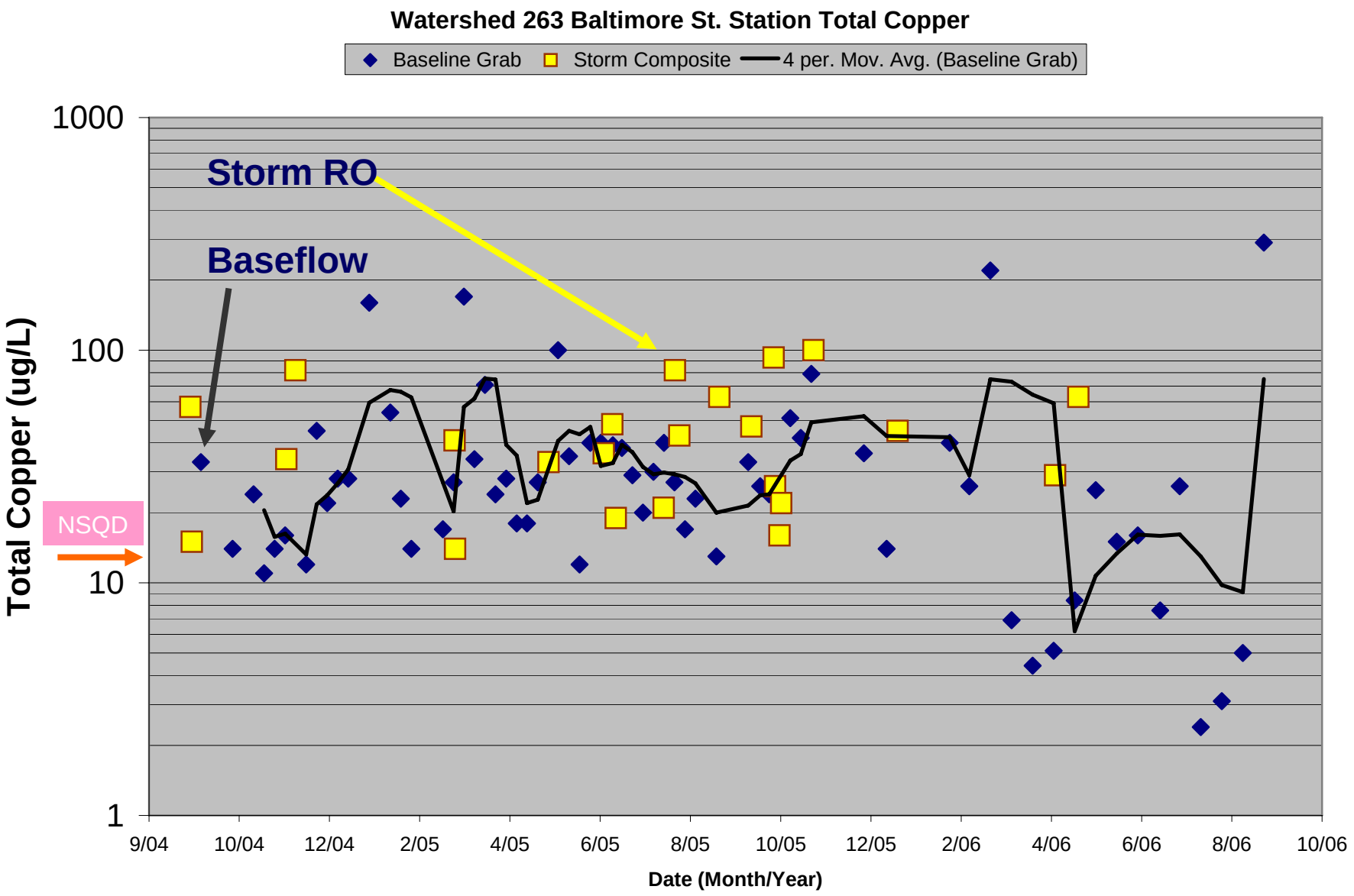
Urban Runoff: Biological Oxygen Demand



Ultra-Urban Buried Streams: E. coli Concentrations



Ultra-Urban Buried Stream: Total Copper Concentrations



Ultra-Urban Hotspots ?

Runoff Hotspots & Contaminated Groundwater

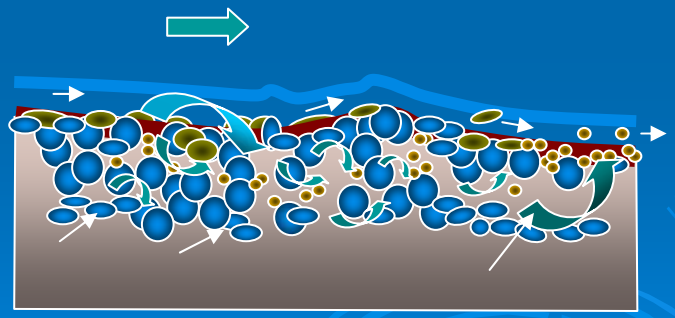
BOD, Nutrients, Metals…

Urban “Karst” Recapitulation

Urban Headwater Streams… additional upstream OM & contaminant sources, processing, etc.

Upland Riparian & Buried Streams: Function?

Urban Groundwater Conveyance ?
Implications for Urban BMPs ?
Ecology of Buried Streams ?
OM Processing & Contaminant Transformations ?
Pathogen Transmission & Sources ?
Downstream Energy & Contaminant Effects ?
Etc….



LTER Long Term Ecological Research

Baltimore Ecosystem Study

Support…

- USFS… most funding, technician support
- Rich Pouyat (USFS)…Guidance, encouragement, bag making…field work and FS technician help
- Phyl (my wife)…arthritic bag making sessions, field work…putting up with me.
- Sujay Kaushal (UMCES)…guidance, encouragement, DOC analyses
- Bill Stack (Baltimore DPW)… WS263 partner, colleague, City Stream data
- Chris Swan (UMBC GES)…guidance, encouragement, technician support
- Peter Groffman (IES)… sampling support, nutrient data, field crew support
- Claire Welty (CUERE)… facilities & lab support, autosamplers
- Brian O'Roark & Joel Baker… construction of storm shelters
- Chrissy Runyan, Tonya Watts, Istvan Turcsanyi, Bill Greenwood (FS/CUERE), Dan Jones & Michah O'Shaunessy (GES interns), Dan Dillon, Gio McClenan (BES techs)… and all those other technicians & colleagues…..

Abstract

Urban streams have long been known to have poor water quality due to stormwater runoff and sewer/illicit connections. However, understanding how these affect aquatic ecosystem structure and function requires a highly interdisciplinary, multi dimensional approach. Just as aquatic ecologists have come to realize the importance of hyporheic and watershed influences on stream ecology, it has become apparent that urban streams are even more complex, three dimensional, catchment-wide hydrologic ecosystems, and not simply runoff conveyance systems. Of great importance is the degree of connectivity between civil infrastructure and receiving streams, including the routing of stormflow, augmentation of baseflow by potable water networks, “upland riparian” sources and riparian interactions with sanitary sewers. Almost every hectare of the urban landscape can be underlain by this dense network of pipes which create a kind of “engineered karst” which not only affects hydrologic processes, but creates a previously under-appreciated “gutter subsidy” for organic matter and contaminants to urban streams. The exponential extension of the stream network density by stormwater drainage reaches almost every drainage feature in the landscape, essentially making every gutter and rooftop a zero order stream, with potentially important implications for stream ecosystems, watershed management and public health.

We present several years of water quality data for streams and storm drains of the BES LTER & Baltimore City stream networks. Storm and dry weather DOC, TSS, and FPOM revealed high temporal variance, with high flux levels and concentrations. Ultra urban small headwater residential catchments had very high organic matter, bacterial, nutrient, and metal concentrations, suggesting that these are hotspots in the urban hydrologic landscape deserving of more attention. Thermal inputs from urban headwaters were also significant, and may have implications for stream biota and biogeochemical processing. These results suggest that the altered drainage pathways and strong terrestrial-aquatic linkages of urban catchments may combine in a way such that both natural and urbanized headwaters are important locations for management of catchment pollutant loads, and are important for aquatic food webs and productivity. We discuss various aspects of these complexities with respect to how they create a new “urban stream continuum” and determine water quality and constrain aquatic communities.

KEYWORDS: Organic Matter, Urban Hydrology, Urban Stormwater, Leaf Litter, Drainage Networks