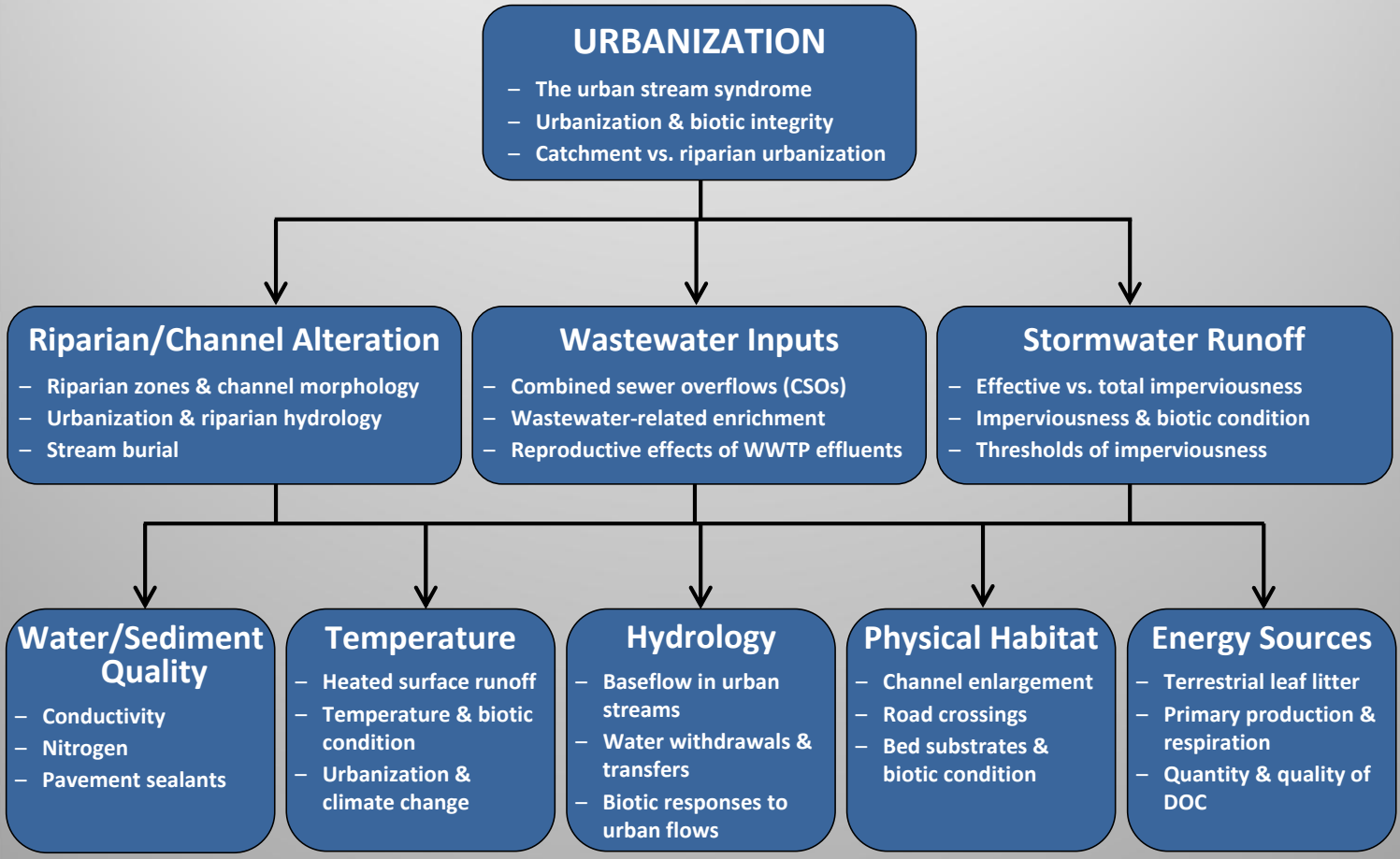
The CADDIS Urbanization Module

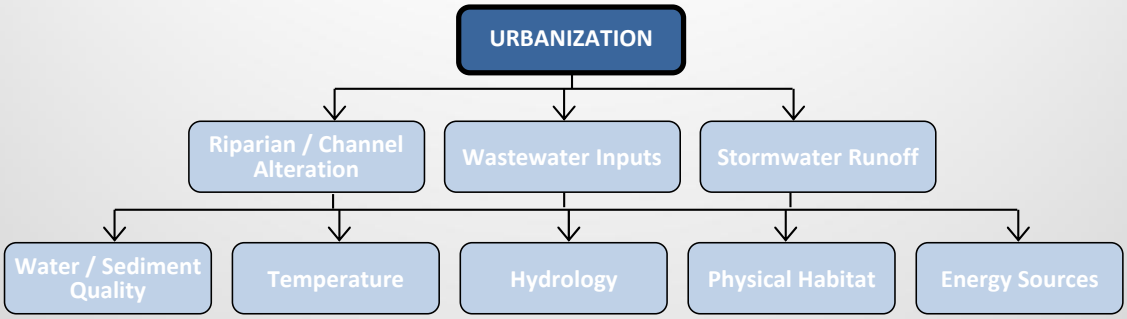
(PDF version)



Urbanization is an increasingly pervasive land cover transformation that significantly alters the physical, chemical and biological environment within surface waters.

The diagram above provides a simple schematic illustrating pathways through which urbanization may affect stream ecosystems. **Riparian/channel alteration**, **wastewater inputs,** and **stormwater runoff** associated with urbanization can lead to changes in five general stressor categories: **water/sediment quality**, water **temperature**, **hydrology**, **physical habitat** within the channel, and basic **energy sources** for the stream food web.

This module is organized along these pathways (the nine shapes above), with subheadings for specific topics covered in greater detail. For an interactive version of this module, visit the CADDIS website (http://www.epa.gov/caddis).



What is urbanization?

Urbanization refers to the concentration of human populations into discrete areas, leading to transformation of land for **residential, commercial, industrial and transportation purposes**. It can include densely populated centers, as well as their adjacent periurban or suburban fringes (Fig 1), and can be quantified in many different ways (Table 1). Example definitions used to classify areas as "urban" or "developed" include:

- Core areas with **population density ≥ 1,000 people per square mile**, plus surrounding areas with population density ≥ 500 people per square mile (U.S. Census Bureau, for 2000 Census)
- Areas characterized by **≥ 30% constructed materials**, such as asphalt, concrete, and buildings (USGS National Land Cover Dataset)

Why does it matter?

- Urban development has **increased dramatically** in recent decades, and this increase is **projected to continue**. For example, in the US developed land is projected to increase from 5.2% to 9.2% of the total land base in the next 25 years (Alig et al. 2004).
- On a national scale urbanization affects relatively little land cover, but it has a **significant ecological footprint**—meaning that even small amounts of urban development can have large effects on stream ecosystems.

Key pathways by which urbanization alters streams

- **Riparian/channel alteration** – Removal of riparian vegetation reduces stream cover and organic matter inputs; direct modification of channel alters hydrology and physical habitat.
- **Wastewater inputs** – Human, industrial and other wastewaters enter streams via point (e.g., wastewater treatment plant effluents) and non-point (e.g., leaky infrastructure) discharges.
- **Impervious surfaces** – Impervious cover increases surface runoff, resulting in increased delivery of stormwater and associated contaminants into streams.

Click below for more detailed information on specific topics

The urban stream syndrome | **Urbanization & biotic integrity** | **Catchment vs. riparian urbanization**

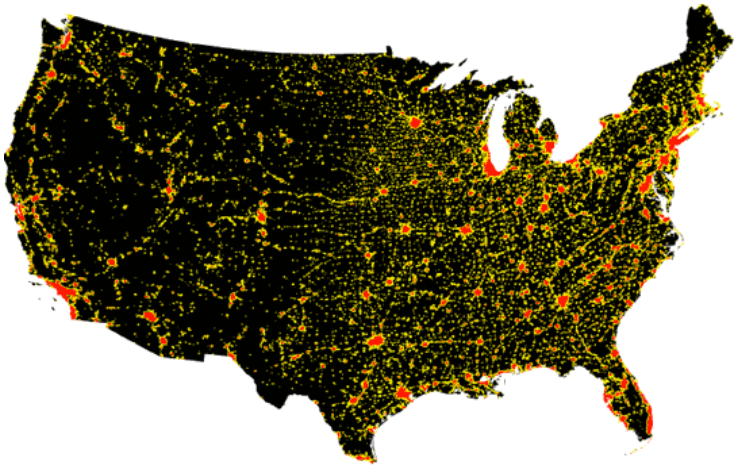
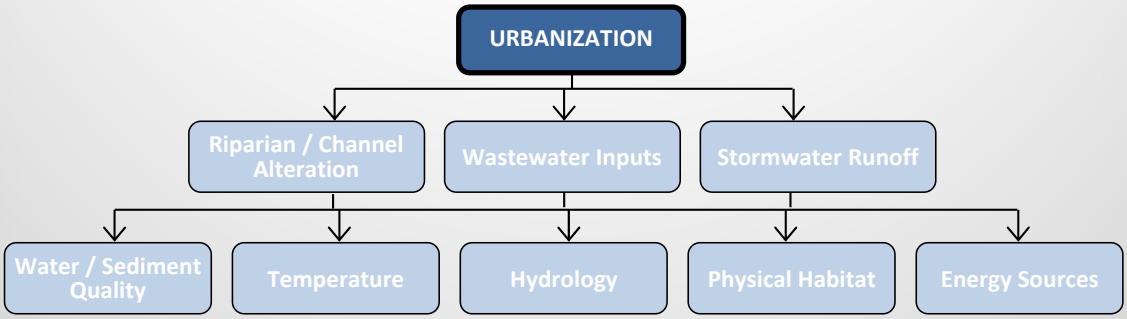


Figure 1. Urbanization map of the United States derived from city lights data. Urban areas are colored red, while peri-urban areas are colored yellow.

Image created by Flashback Imaging Corporation, under contract with NOAA and NASA [accessed 7.16.09].

Table 1. Common ways of quantifying urbanization

MEASURE	DESCRIPTION
% Total urban area	Area in all urban land uses
% High intensity urban	Area above some higher development threshold
% Low intensity urban	Area above some lower development threshold
% Residential	Area in residential-related uses
% Commercial / industrial	Area in commercial- or industrial-related uses
% Transportation	Area in transportation-related uses
% Total impervious area	Area of impervious surfaces such as roads, parking lots and roofs; also called impervious surface cover
% Effective impervious area	Impervious area directly connected to streams via pipes; also called % drainage connection
Road density	Road length per area
Road crossing density	# Road-stream crossings per area
Population density	# People per area
Household density	# Houses per area
Urban intensity indices	Multimetric indices combining a suite of development-related measures into one index value [e.g., the USGS national urban intensity index (NUII), based on housing density, % developed land in basin, and road density]



The urban stream syndrome

Common effects of urbanization on stream ecosystems have been referred to as the "**urban stream syndrome**" (Walsh et al. 2005a). Table 2 lists symptoms typically associated with the urban stream syndrome. Symptoms preceded by an arrow have been observed to consistently increase (↑) or decrease (↓) in response to urbanization, while symptoms preceded by a delta (Δ) have been observed to increase, decrease, or remain unchanged with urbanization.

As the urban stream syndrome illustrates, these streams are **simultaneously affected by multiple sources, resulting in multiple, co-occurring and interacting stressors**. As a result, identifying specific causes of biological impairment in urban streams, or the specific stressors that should be managed to improve condition, is difficult. Some communities are approaching this challenge by managing overall urbanization, rather than the specific stressors associated with it—for example, by establishing **total maximum daily loads (TMDLs) for impervious surfaces**, rather than individual pollutants.

Many characteristics of urban development affect how the urban stream syndrome is expressed within a given system. These characteristics include (but are not limited to):

- **Location and distribution of development**
  - catchment vs. riparian
  - upstream vs. downstream
  - sprawling vs. compact
- **Density of development**
- **Type of development and infrastructure**
  - residential vs. commercial/transportation
  - stormwater systems
  - wastewater treatment systems
- **Age of development and infrastructure**

Table 2. Symptoms generally associated with the urban stream syndrome

STRESSOR CATEGORY	SYMPTOM
Water / sediment quality	↑ nutrients ↑ toxics Δ suspended sediment
Temperature	↑ temperature
Hydrology	↑ overland flow frequency ↑ erosive flow frequency ↑ stormflow magnitude ↑ flashiness ↓ lag time to peak flow Δ baseflow magnitude
Physical habitat	↑ direct channel modification (e.g., channel hardening) ↑ channel width (in non-hardened channels) ↑ pool depth ↑ scour ↓ channel complexity Δ bedded sediment
Energy sources	↓ organic matter retention Δ organic matter inputs and standing stocks Δ algal biomass

Modified from *Walsh CJ et al. 2005a. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society 24(3):706-723.*

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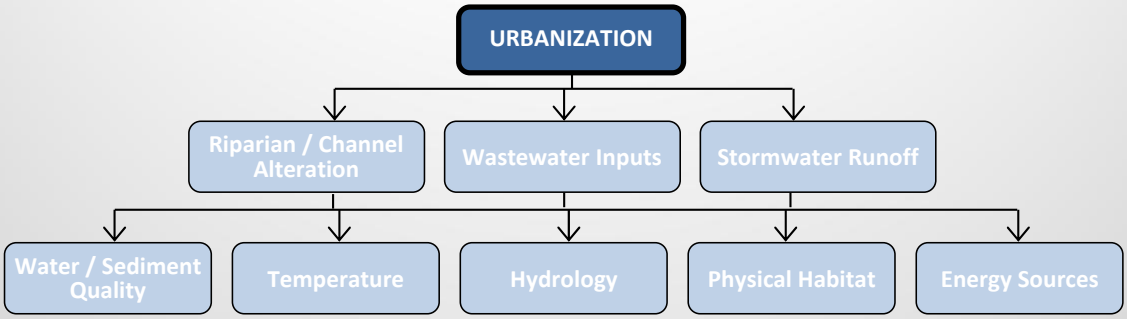
The urban stream syndrome | **Urbanization & biotic integrity** | **Catchment vs. riparian urbanization**



Urbanization & biotic integrity

Numerous studies have examined relationships between land use variables and stream biota, and shown that urban-related land uses can significantly alter stream assemblages.

Land use variables considered include % urban land (in the watershed and in riparian areas), % impervious surface area (total and effective), road density, and other measures of urbanization.

Biotic responses associated with these land use variables include (but are not limited to):

ALGAE

- ↑ abundance or biomass
  [Roy et al. 2003a, Taylor et al. 2004, Busse et al. 2006]
- other changes in assemblage structure (e.g., changes in diatom composition)
  [Winter & Duthie 2000, Sonneman et al. 2001, Newall & Walsh 2005]

BENTHIC MACROINVERTEBRATES

- ↓ total abundance, richness or diversity
  [Morley & Karr 2002, Moore & Palmer 2005, Walsh et al. 2007]
- ↓ EPT (Ephemeroptera, Plecoptera, Trichoptera) abundance, richness or diversity
  [Morley & Karr 2002, Roy et al. 2003a, Riley et al. 2005, Walsh 2006]
- ↑ abundance of tolerant taxa
  [Jones & Clark 1987, Walsh et al. 2007]
- other changes in assemblage structure (e.g., changes in functional feeding groups)
  [Stepenuck et al. 2002, Smith & Lamp 2008]
- ↓ quality of biotic index scores
  [Kennen 1999, Morley & Karr 2002, DeGasperi et al. 2009]

FISHES

- ↓ abundance, biomass, richness or diversity
  [Wang et al. 2003a, Bilby & Mollot 2008, Stranko et al. 2008]
- other changes in assemblage structure (e.g., changes in reproductive guilds)
  [Stepenuck et al. 2002, Roy et al. 2007, Helms et al. 2009]
- ↓ quality of biotic index scores
  [Snyder et al. 2003, Miltner et al. 2004, Morgan & Cushman 2005]
- ↑ biotic homogenization (replacement of more endemic, specialist fishes with more broadly distributed, generalist fishes)
  [Scott 2006 (Fig 2), Walters et al. 2009]

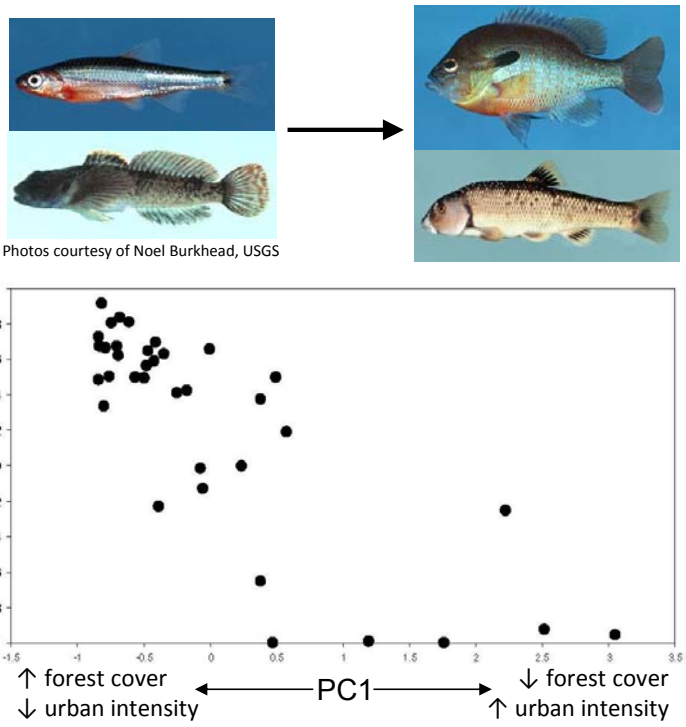


Figure 2. Plot of a measure of biotic homogenization [relative abundance of Appalachian highland endemic fishes – relative abundance of cosmopolitan fishes] on the first axis of a principal components analysis of three catchment land use variables [1993 forest cover, forest cover change from 1970s-1990s, and urbanization intensity (normalized catchment building + road density)]. Sites with higher forest cover and lower urban intensity had more endemic taxa (e.g., fishes such as the Tennessee shiner and the mottled sculpin, above left), while sites with lower forest cover and higher urban intensity had more broadly distributed, generalist taxa (e.g., fishes such as the redbreast sunfish and central stoneroller, above right).

From *Scott MC. 2006. Winners and losers among stream fishes in relation to land use legacies and urban development in the southeastern US. Biological Conservation 127:301-309.* Reprinted with permission from Elsevier.

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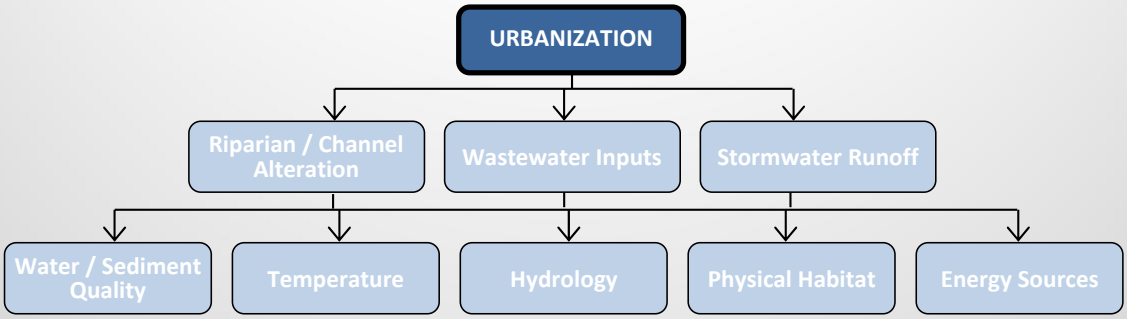
The urban stream syndrome | **Urbanization & biotic integrity** | Catchment vs. riparian urbanization



Catchment vs. riparian urbanization

Where urbanization occurs in the watershed can affect its influence on stream ecosystems. Studies examining land use variables and stream characteristics typically consider land use at one (or more) of three general spatial scales:

- Catchment – the entire catchment above the site
- Riparian – the entire riparian area above the site
- Reach – the riparian area for a relatively short distance above the site

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King et al. (2005) examined whether macroinvertebrate assemblages in Coastal Plain, Maryland streams responded differently to development in the watershed versus development in areas closer to the focal site (Fig 3). They found that ***where* development occurs** can significantly influence its effects on benthic biota:

- For % developed land in the watershed (Fig 3A), there was an apparent threshold between 21-32% where the probability of assemblage alterations increased rapidly; once >32% of the watershed was developed, all macroinvertebrate assemblages were affected.
- When % developed land in the 250-m buffer was considered (Fig 3B), this threshold shifted left and all macroinvertebrate assemblages were affected once >22% of land in the 250-m buffer was developed.
- A similar pattern was seen when developed land in the watershed was inverse-distance weighted (i.e., development closer to the focal site was weighted more than development farther away; Fig 3C), with the threshold for macroinvertebrate effects occurring between 18-23%.

The relative importance of development at different scales varies across studies (e.g., Sponseller et al. 2001, Wang et al. 2001, Morley & Karr 2002, Roy et al. 2007, Snyder et al. 2003, Schiff & Benoit 2007), and likely depends, at least in part, on the stressors considered (Allan 2004). For example, some stressors associated with urbanization (e.g., changes in flow) are highly dependent on catchment-scale processes, while other stressors (e.g., changes in basal energy sources) are more affected by reach-scale processes.

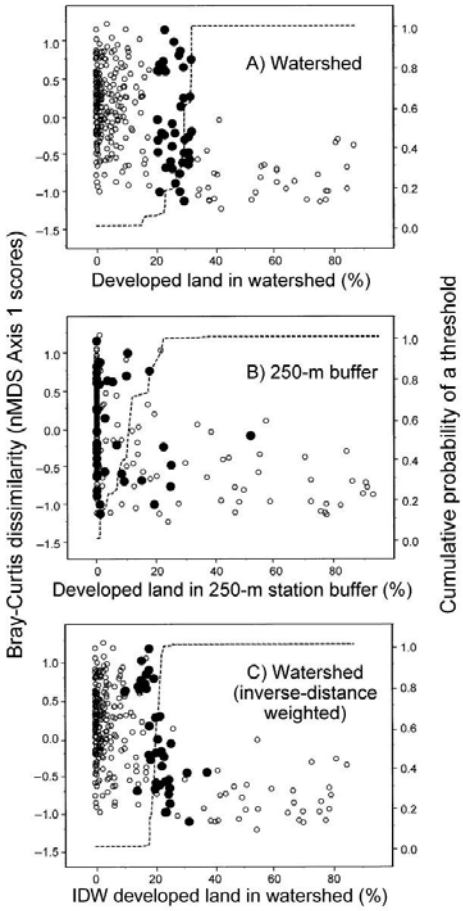

Figure 3. Scatterplots of the threshold effect of developed land on macroinvertebrate assemblage composition (Bray-Curtis dissimilarity expressed as nonmetric multidimensional scale [nMDS] Axis 1 scores), for (A) % developed land in watershed, (B) % developed land within 250-m radius buffer of site, (C) % developed land in watershed weighted by its inverse distance (IDW) to site. Dotted lines indicate the cumulative probability of an ecological response to increasing % developed land. Sites within the watershed-scale threshold zone of 21-32% developed land in (A) are highlighted in black in all panels.

From *King RS et al. 2005. Spatial considerations for linking watershed land cover to ecological indicators in streams. Ecological Applications 15(1):137-153.* Reprinted with permission.

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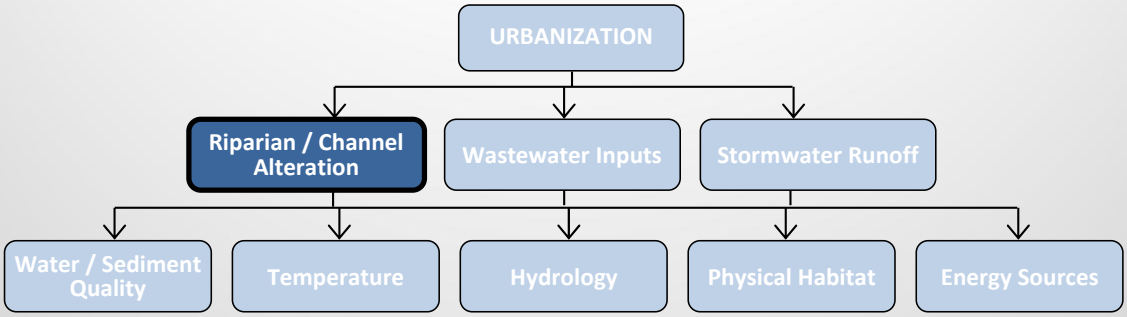
The urban stream syndrome | Urbanization & biotic integrity | Catchment vs. riparian urbanization



Riparian / channel alteration

Intact riparian zones, or vegetated areas adjacent to stream channels, can serve several functions (Allan 1995), including:

- Provide organic matter for stream food webs
- Provide habitat (e.g., woody debris, bank vegetation)
- Reduce bank and channel erosion
- Moderate stream temperatures
- Intercept and process groundwater nutrients and pollutants

Urbanization typically reduces the extent and quality of riparian areas, via the removal of native vegetation and the development of near-stream areas (Fig 4). These alterations can contribute to multiple instream stressors, including:

- **Water / sediment quality** – ↓ nutrient uptake and retention, ↑ erosion of bank sediments (and associated contaminants)
- **Temperature** – ↓ shading and thermal buffering
- **Hydrology** – ↓ woody debris inputs, ↓ interception of surface and groundwater flows
- **Physical habitat** – ↑ erosion of bank sediments, ↓ woody debris inputs
- **Energy sources** – ↓ leaf inputs, ↑ algal biomass (due to ↓ shading), ↑ dissolved organic carbon

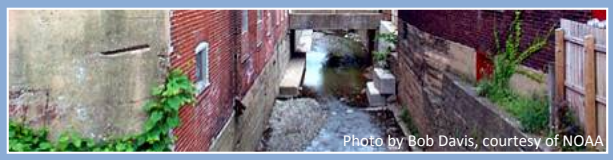


Photo by Bob Davis, courtesy of NOAA

Direct modification of stream channels is common in urban systems, and these direct alterations of channel morphology often are the most damaging changes urban streams experience (see the Physical Habitat module, as well as the Physical Habitat section of this module).

Typical channel alterations in urban streams include:

- Channelization (i.e., channel straightening)
- Channel hardening or armoring (e.g., lining channels and banks with concrete and riprap)
- Creation of dams and impoundments
- Stream piping and burial

Removal of riparian vegetation and channel hardening in an urban stream


Courtesy of USEPA

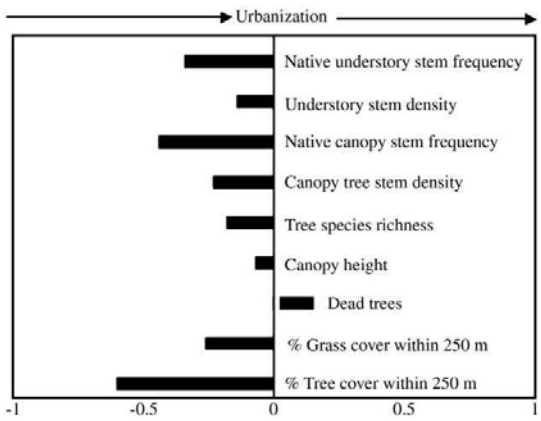


Figure 4. Spearman's rank correlations between riparian urbanization (building area within 250 m radius of stream site) and riparian vegetation characteristics, at 71 sites near Cincinnati, Ohio. Many of these characteristics (e.g., riparian tree density and cover) showed negative relationships with urbanization.

From ***Pennington DN et al. 2008. The conservation value of urban riparian areas for landbirds during spring migration: land cover, scale, and vegetation effects. Biological Conservation 141:1235-1248.*** **Reprinted with permission from Elsevier.**

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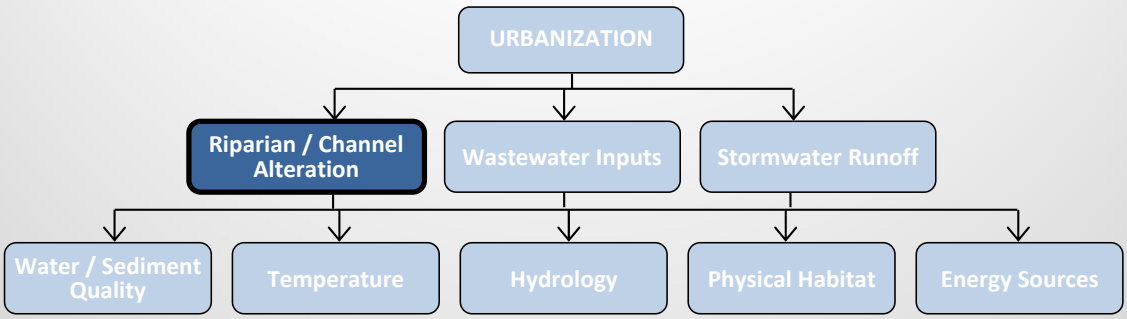
Riparian zones & channel morphology | **Urbanization & riparian hydrology** | **Stream burial**



Riparian zones & channel morphology

Forested riparian zones play a key role in determining stream channel morphology. Their root structures can help stabilize streambanks, and the woody debris they contribute to streams can protect banks by absorbing flow energy.

Because urbanization often results in riparian alteration, it is difficult to separate the effects of general watershed urbanization (e.g., increased stormflows) on channel morphology from those of riparian alteration. Hession et al. (2003) tackled this issue, using a paired design that considered forested and nonforested riparian reaches on both urban and nonurban streams. They examined the effects of urbanization and riparian vegetation on channel morphology in 26 unchannelized mid-Atlantic streams (Fig 5), and found that:

- **Urban streams were generally wider** than nonurban streams, especially for smaller streams.
- **Forested urban streams were generally wider** than nonforested (i.e., grassed) urban streams.
- Differences between forested and nonforested reaches (i.e., the vertical arrows in Fig 5) were generally similar for urban and nonurban streams—illustrating that **even in urban systems, riparian vegetation influences channel morphology**.

In extrapolating these results to other sites, however, keep in mind that relationships between riparian alteration and channel morphology in urban streams **depend upon numerous other factors**, including stream size, stream gradient, surrounding geology, and riparian vegetation type.

Stream with reduced riparian tree cover and an eroded bank

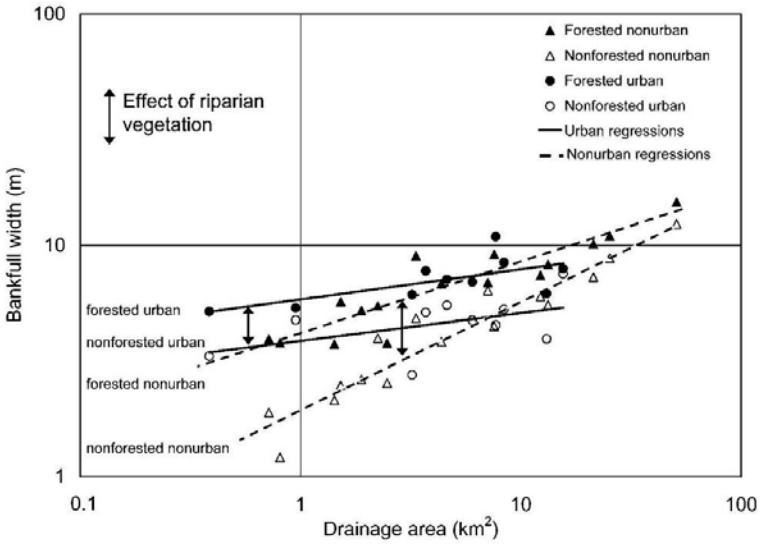


Figure 5. Bankfull width in urban and nonurban streams, with forested and nonforested riparian reaches, as a function of drainage basin area. Vertical arrows indicate the effect of riparian vegetation on bankfull width in urban and nonurban streams.

From *Hession WC et al. 2003. Influence of bank vegetation on channel morphology in rural and urban watersheds. Geology 31(2):147-150.* Reprinted with permission.

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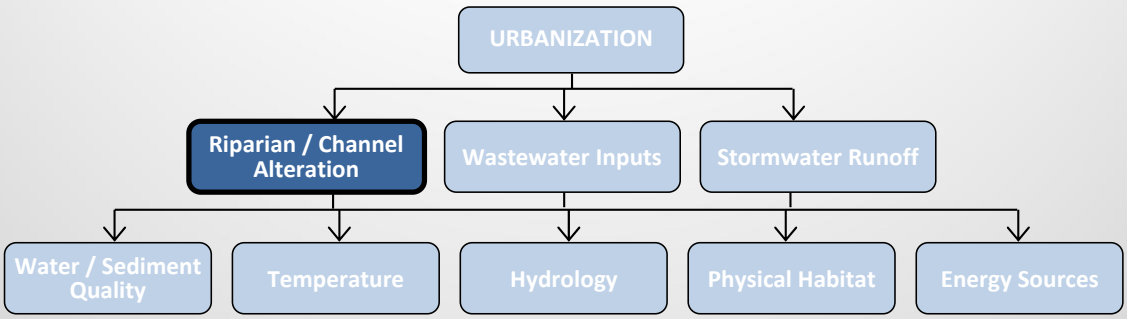
Riparian zones & channel morphology | **Urbanization & riparian hydrology** | **Stream burial**



Urbanization & riparian hydrology

Increased stormwater flows associated with urban development can scour stream channels and increase channel incision, especially in systems with limited sediment inputs (e.g., highly impervious watersheds, which often occur in older urban areas).

Channel incision and reduced infiltration (again, due to impervious surfaces) act to lower riparian water tables (Fig 6), thereby altering riparian hydrology. For example, Hardison et al. (2009) examined six Coastal Plain streams in North Carolina, ranging from 3.8-36.7% catchment impervious area. They found that:

- **Channel incision** increased with total impervious area (TIA).
- The **duration of shallow riparian groundwater** throughout the year decreased as TIA increased.
- Sites with higher TIA had greater **depths to riparian groundwater** (Fig 7).

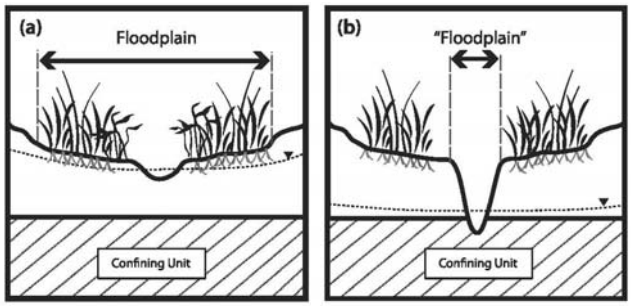


Figure 6. Cross-sectional view of typical groundwater tables (dotted lines) in (a) rural and (b) urban streams underlain by a shallow confining unit.

This "**urban riparian drought**" can have significant repercussions for the structure and function of riparian areas (Groffman et al. 2002, 2003; Hardison et al. 2009), including:

- **Shifts in riparian vegetation** from wetland to upland species, or from diverse to limited size distributions
- **Changes in nitrogen uptake and cycling**, such that urban riparian areas may be sources of, rather than sinks for, nitrate

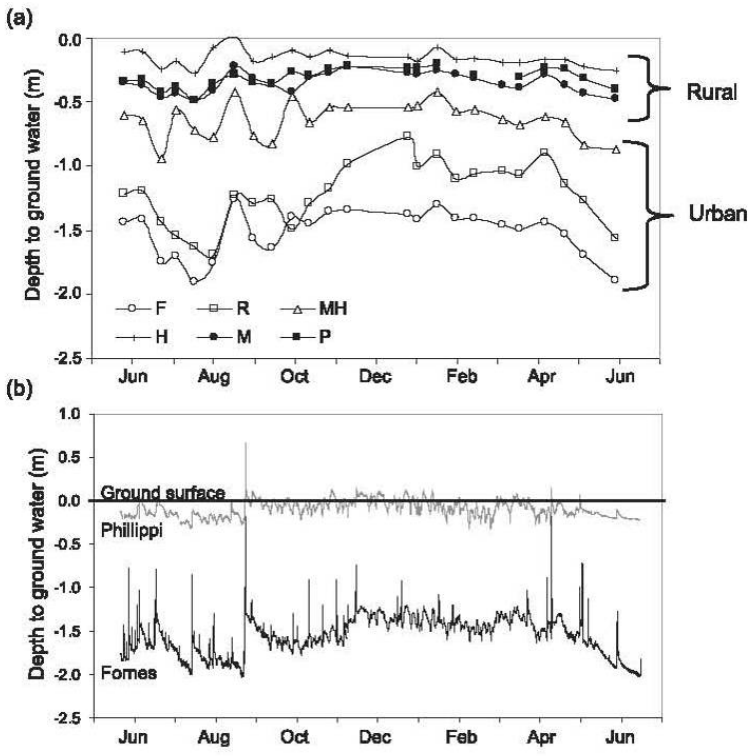


Figure 7. (a) Mean riparian zone groundwater depths, June 2006-June 2007, for six sites varying in catchment impervious area (rural = 3.8-12.4% total impervious area, urban = 22.1-36.7%). (b) Half-hourly riparian zone groundwater depths, over the same period, at the most rural (Phillippi) and most urban (Fornes) sites.

Figures 6 and 7 from *Hardison EC et al. 2009. Urban land use, channel incision, and water table decline along Coastal Plain streams, North Carolina. Journal of the American Water Resources Association 45(4):1032-1046.* Reprinted with permission.

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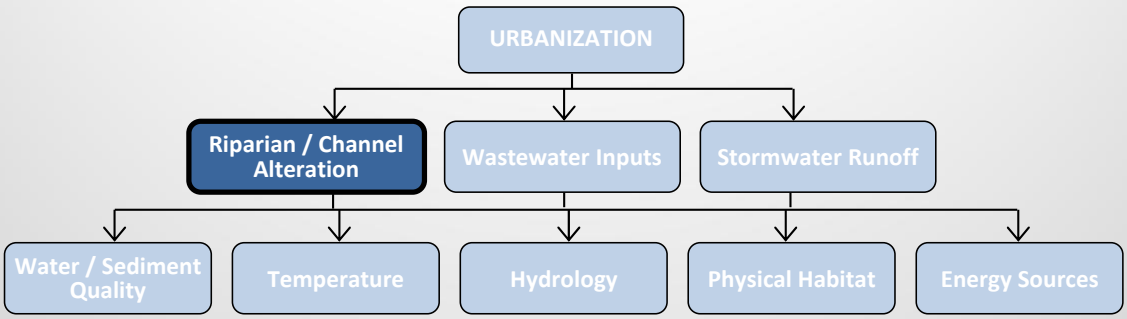
Riparian zones & channel morphology | Urbanization & riparian hydrology | Stream burial



Stream burial

Headwater streams are key habitats in terms of aquatic ecosystem structure and function, and they comprise a significant portion of total stream miles. In urban watersheds, however, these small streams often are filled in or incorporated into storm sewer systems (i.e., piped), altering hydrologic connectivity and physical habitat within the buried streams, as well as urban drainage networks. For example:

- **Drainage density of natural channels was approximately ⅓ less in urban and suburban vs. forested catchments** in Atlanta, GA (Meyer & Wallace 2001).
- **Approximately ⅔ of all streams were buried** in Baltimore City, MD (Elmore & Kaushal 2008).
- **93% of ephemeral channel length and 46% of intermittent channel length were lost to burial and piping** associated with urbanization in Hamilton County, OH (Roy et al. 2009, Figs 8 and 9). As a result, drainage areas for remaining ephemeral and intermittent channels were larger in urban areas.

Interestingly, Roy et al. (2009) found that **perennial channel length actually increased with urbanization** (Fig 8), although **approximately 40% of perennial channels originated from pipes**. This increase in perennial channel length was due at least in part to increased baseflow stemming from reductions in forest cover and evapotranspiration.

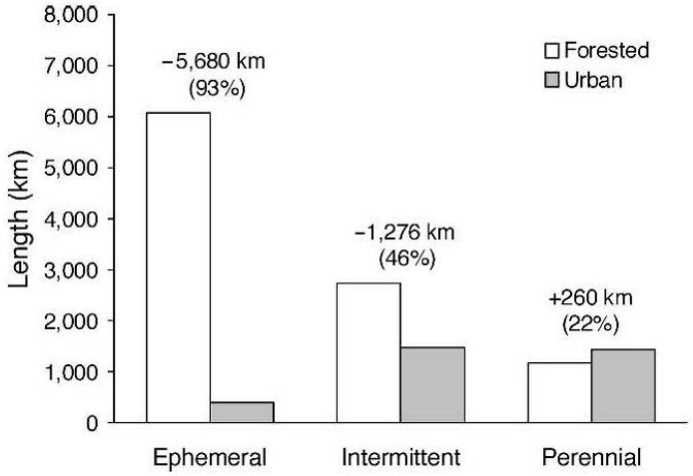


Figure 8. Total ephemeral, intermittent and perennial channel length within Hamilton County, OH for forested vs. urban catchments. Ephemeral streams are channels with distinct stream beds and banks that carry water briefly during and after storms; intermittent streams are channels that carry water during the wet season; perennial streams are channels that carry flow all year. Numbers above bars indicate absolute and % different in channel length between forested and urban catchments.

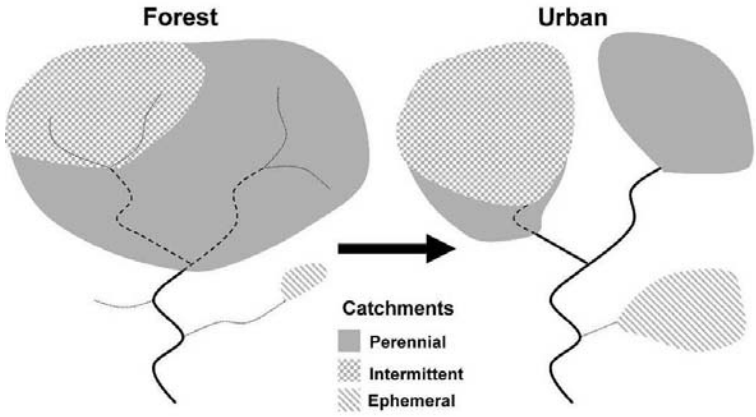


Figure 9. Conceptual representation of how urbanization affects headwater streams in Hamilton County, OH. Dotted lines indicate ephemeral streams, dashed lines indicate intermittent streams, solid lines indicate perennial streams; shading indicates drainage area for each stream type.

Figures 8 and 9 from *Roy AH et al. 2009. Urbanization affects the extent and hydrologic permanence of headwater streams in a midwestern US metropolitan area. Journal of the North American Benthological Society 28(4):911-928.* Reprinted with permission.

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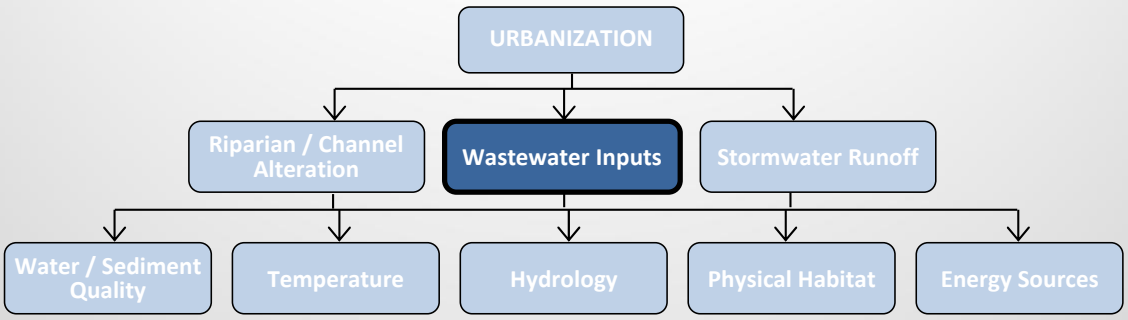
Riparian zones & channel morphology | Urbanization & riparian hydrology | Stream burial



What are wastewater inputs?

Urbanization often involves the input of wastewaters into streams and rivers. Common wastewater sources in urban streams include:

- **Wastewater treatment plant (WWTP) effluents** – permitted municipal sewage discharges (Fig 10), treated to varying degrees (Table 3)
- **Industrial effluents** – permitted discharges from industrial facilities
- **Accidental or unpermitted discharges**
- **Sanitary sewer overflows** – wet weather overflows resulting in direct discharge of domestic and other wastewaters into streams and rivers
- **Combined sewer overflows (CSOs)** – wet weather overflows resulting in direct discharge of surface runoff and domestic and other wastewaters into streams and rivers
- **Sewer pipes** – leakage from broken, blocked or aging infrastructure
- **Septic systems** – leachate from septic tanks (usually in less densely developed areas)

Stressors associated with wastewater inputs

Numerous stressors may be associated with wastewater inputs, including:

- ↑ nutrients
  [Gücker et al. 2006, Carey & Migliaccio 2009]
- ↓ dissolved oxygen (↑ biological oxygen demand)
  [Ortiz & Puig 2007]
- ↑ pathogens
  [Gibson et al. 1998, Frenzel & Couvillion 2002]
- ↑ metals (e.g., copper, mercury, cadmium, lead, iron)
  [Nedeau et al. 2003]
- ↑ pharmaceuticals and personal care products
  [Kolpin et al. 2002, Watkinson et al. 2009]
- ↑ toxics (e.g., PAHs, alkylphenols, pesticides)
  [Kolpin et al. 2002, Phillips & Chalmers 2009]
- ↑ dissolved solids (e.g., chloride, sulfate, specific conductance)
  [Hur et al. 2007, Rose 2007]
- ↑ stream discharge
  [Nedeau et al. 2003, Barber et al. 2006, Carey & Migliaccio 2009]
- ↑ temperature
  [Nedeau et al. 2003, Kinouchi 2007]

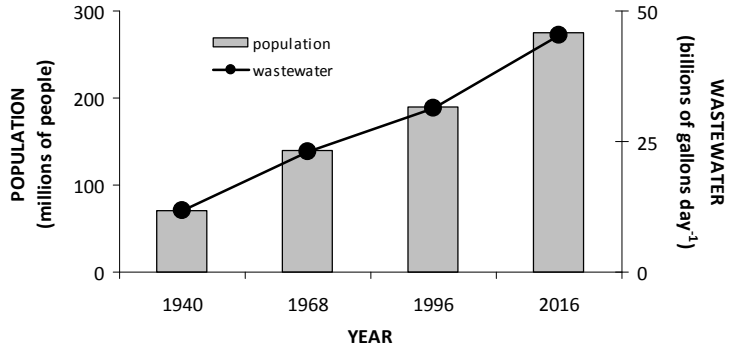


Figure 10. Historical and projected US resident population served by publically-owned wastewater treatment facilities, and volume of wastewater flows produced.

Adapted from *USEPA. 2000. Progress in Water Quality: An Evaluation of the National Investment in Municipal Wastewater Treatment. US Environmental Protection Agency, Office of Water, Washington DC. EPA-832-R-00-008.*

WWTP discharge on Fourmile Creek, IA

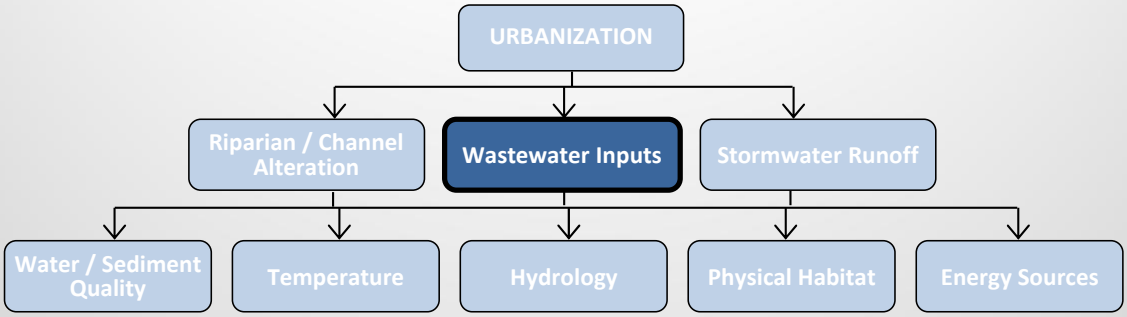
Table 3. Typical treatment efficiencies of municipal sewage treatment for specific pollutants

POLLUTANT	TYPICAL TREATMENT EFFICIENCIES (% inflow concentrations)		
	Sewage ponds	Secondary treatment	Advanced treatment
Biological oxygen demand	50-95	95	95
Nitrogen	43-80	50	87
Phosphorus	50	51	85
Suspended solids	85	95	95
Metals	Variable	Variable	Variable

Modified from *Baker LA. 2009. New concepts for managing urban pollution. Pp. 69-91 in: Baker, LA (ed). The Water Environment of Cities. Springer Science+Business Media, LLC.*

Click below for more detailed information on specific topics

Combined sewer overflows (CSOs) | **Wastewater-related enrichment** | **Reproductive effects of WWTP effluents**



What is a CSO?

A **combined sewer system** (CSS) is a wastewater collection system that collects and transports sanitary wastewater (domestic sewage, commercial and industrial wastewater) and stormwater to a treatment plant in one pipe. During wet weather, when capacity of the system is exceeded, it discharges untreated wastes directly to surface waters—resulting in a **combined sewer overflow** (CSO; Fig 11).

Because CSOs release untreated wastewater, they can contribute pathogens, nutrients, organic carbon, toxic substances and other pollutants to surface waters (Fig 12).

How prevalent are CSOs in the US (USEPA 2004)?

- CSSs serve approximately 40 million people, in 772 communities (Fig 13).
- 828 NPDES permits authorize discharges from 9,350 CSO outfalls.
- USEPA estimates that CSOs release approximately 850 billion gallons of untreated wastewater and stormwater each year.

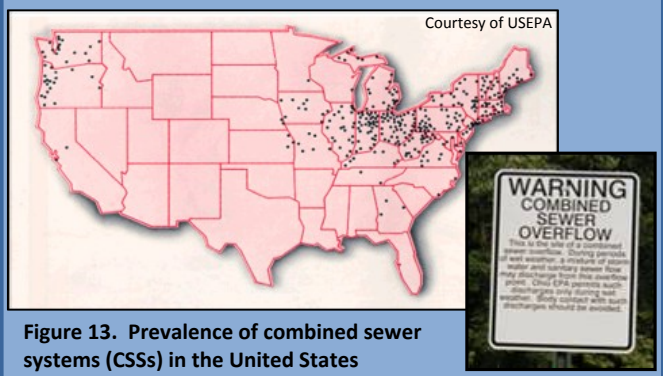


Figure 13. Prevalence of combined sewer systems (CSSs) in the United States

CSSs generally have not been constructed since the mid-20th century, and efforts are underway to reduce CSOs in many existing systems (e.g., by separating wastewater and stormwater sewer systems).

Click below for more detailed information on specific topics

Combined sewer overflows (CSOs) | Wastewater-related enrichment | Reproductive effects of WWTP effluents

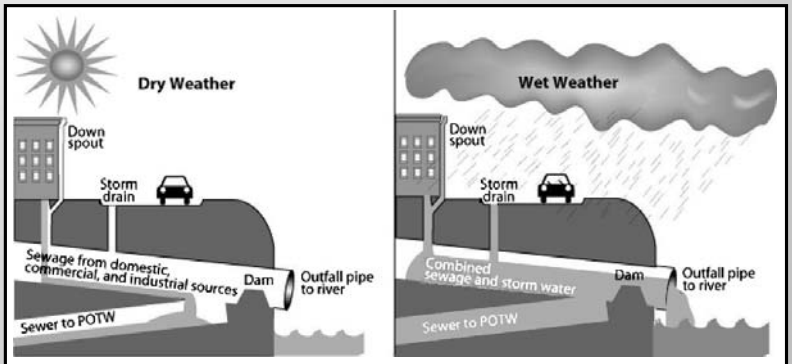


Figure 11. Schematic of a typical combined sewer system that discharges directly to surface waters during wet weather.

From *USEPA. 2004. Report to Congress: Impacts and Control of CSOs and SSOs. U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA 833-R-04-001.*

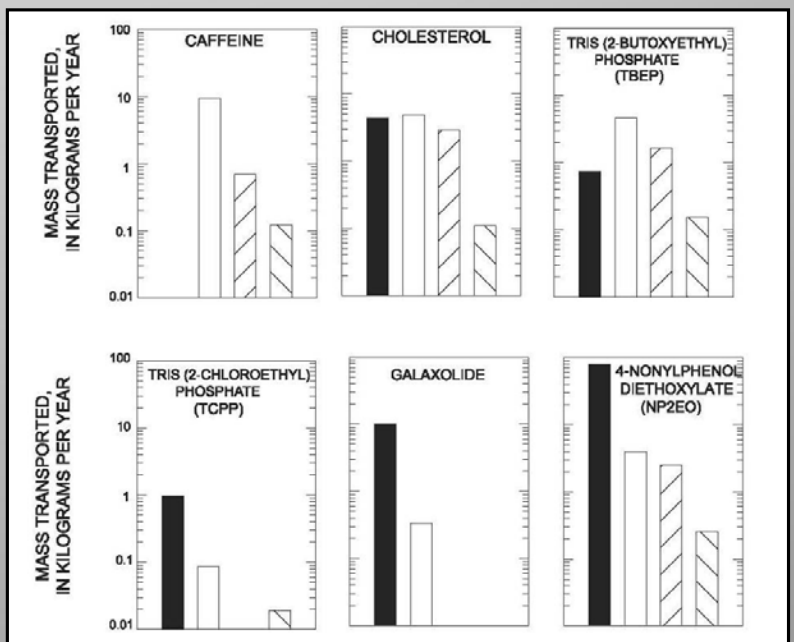
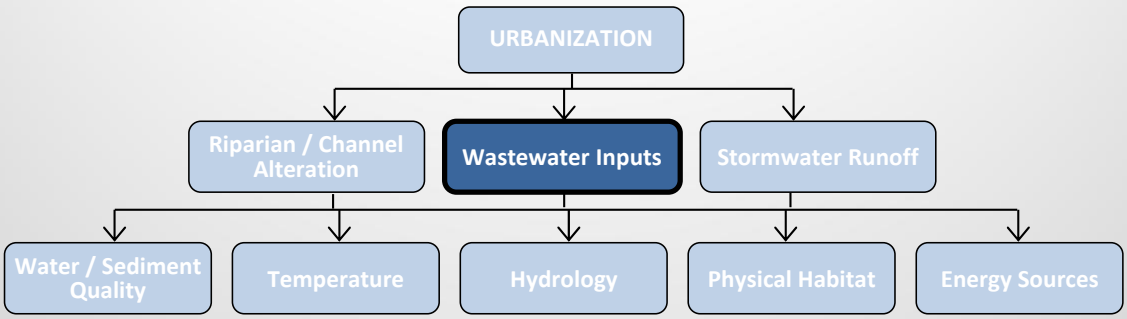


Figure 12. 2006 annual mass loads for six organic wastewater compounds (OWCs) for the Burlington (VT) Main Wastewater Treatment Plant (filled bar), combined sewer overflow (open bar), and two streams below CSO and WWTP outfalls (striped bars). OWCs on top are highly removed during normal wastewater treatment, while those on bottom are poorly removed.

From *Phillips P & Chalmers A. 2009. Wastewater effluent, combined sewer overflows, and other sources of organic compounds to Lake Champlain. Journal of the American Water Resources Association 45(1):45-57.* Reprinted with permission.



Wastewater-related enrichment of streams

WWTP effluents and other sources of domestic wastes (e.g., septic tanks) can subsidize stream ecosystems by increasing nutrient and organic matter inputs to streams (Gücker et al. 2006, Singer & Battin 2007). The amount of enrichment that occurs depends upon the volume of waste discharged, as well as the level of treatment that waste receives.


Courtesy of USEPA

For example, Singer & Battin (2007) estimated that **sewage-derived particulate organic matter (SDPOM)** inputs contributed **mean annual input fluxes of 108.3 g carbon (C), 21.7 g nitrogen (N) and 5.9 g phosphorus (P) per day**. On average, these inputs represented a 34% increase in seston-bound C and a 29% increase in seston-bound P (although these values were highly variable). Resources in the wastewater-subsidized reach also had higher nutritional quality: **% C, % N and % P content were many times greater in SDPOM** than in natural seston and benthic fine particulate organic matter (Table 4).

These subsidies were incorporated into higher trophic levels, as **macroinvertebrate secondary production increased** in the wastewater-influenced reach; this enrichment effect was largely due to the response of gatherers and grazer/gatherers (Fig 14). However, **macroinvertebrate diversity and evenness declined** in the subsidized reach, indicating enrichment also negatively affected community structure.

Click below for more detailed information on specific topics

Combined sewer overflows (CSOs) | **Wastewater-related enrichment** | Reproductive effects of WWTP effluents

Table 4. Carbon, nitrogen and phosphorus contents of resources in reference (top value) and wastewater-subsidized (bottom value) reaches of a third-order Austrian stream.

RESOURCE	% C	% N	% P
Periphyton	5.9 ± 3.7 8.0 ± 5.0	0.8 ± 0.5 1.1 ± 0.6	0.15 ± 0.14 0.26 ± 0.15
Seston	0.6 ± 0.2 1.0 ± 0.3	0.1 ± 0.04 0.1 ± 0.05	0.021 ± 0.01 0.035 ± 0.02
Benthic fine particulate organic matter	0.2 ± 0.1 0.2 ± 0.1	0.02 ± 0.01 0.02 ± 0.01	0.01 ± 0.004 0.009 ± 0.004
Sewage-derived particulate organic matter	- 2.1 ± 0.8	- 0.4 ± 0.2	- 0.09 ± 0.03

Modified from *Singer GA & Battin TJ. 2007. Anthropogenic subsidies alter stream consumer-resource stoichiometry, biodiversity, and food chains. Ecological Applications 17(2): 376-389.*

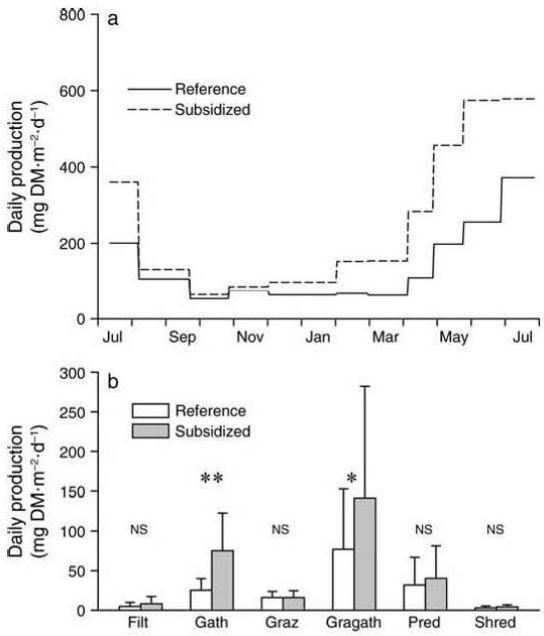
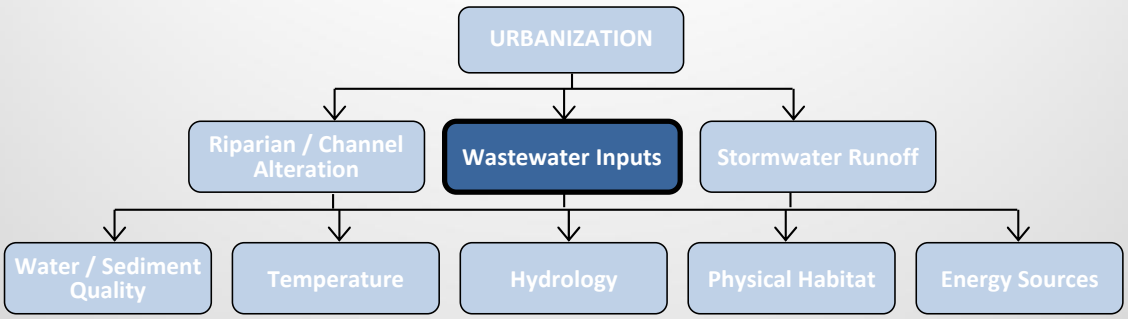


Figure 14. Daily macroinvertebrate secondary production in reference and wastewater-subsidized reaches of a third-order Austrian stream, by (a) month and (b) functional feeding group.

From *Singer GA & Battin TJ. 2007. Anthropogenic subsidies alter stream consumer-resource stoichiometry, biodiversity, and food chains. Ecological Applications 17(2):376-389.* Reprinted with permission.



Reproductive effects of WWTP effluents

Municipal effluents often contain **endocrine disrupting chemicals (EDCs)**, which can mimic or interfere with normal hormone signaling in aquatic animals and result in adverse reproductive effects (Jobling & Tyler 2003). Standard wastewater treatment practices typically are not effective at removing these chemicals.

Examples of known or suspected EDCs found in WWTP effluents include:

- **Natural hormones** (e.g., 17β-estradiol)
- **Synthetic hormones and other pharmaceuticals** (e.g., 17α-ethynlestradiol)
- **Pesticides** (e.g., diazinon, lindane, atrazine)
- **Phthalates**
- **Toxic metals** (e.g., copper, mercury, cadmium)
- **Alkylphenols**
- **Bisphenol A**

Vajda et al. (2008) examined the estrogenic effects of WWTP effluent on white suckers in Boulder Creek, CO. They found that intersex fish—fish containing both ovarian and testicular tissue—comprised 18-22% of the population downstream of the WWTP outfall, but were not found upstream. Fish downstream of the outfall also had altered sex ratios, reduced sperm production, increased vitellogenin levels (a protein associated with egg development in females), and reduced gonad size (Fig 15).

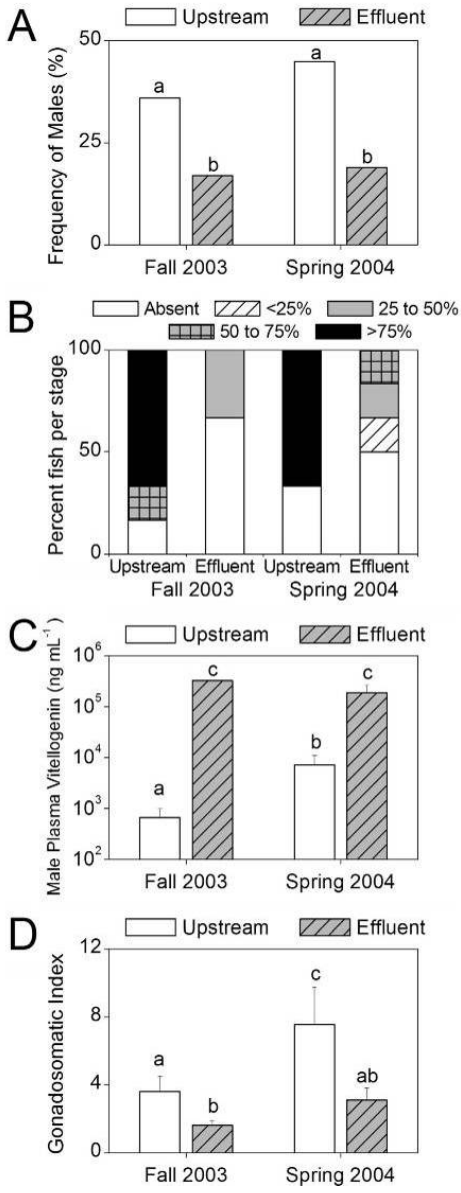


Figure 15. Evidence of reproductive impairment in white suckers collected from sites upstream (upstream) and downstream (effluent) of the Boulder WWTP on Boulder Creek, in terms of (A) % males, (B) sperm abundance in males, (C) plasma vitellogenin concentrations in males, and (D) gonadosomatic index in females.

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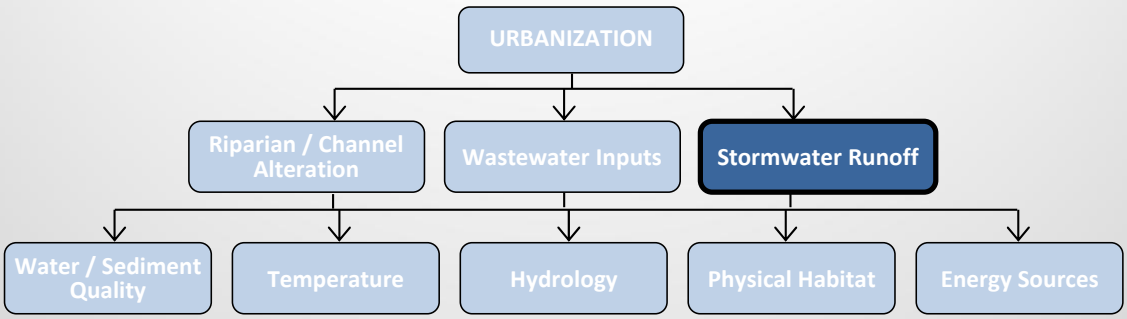
Combined sewer overflows (CSOs) | Wastewater-related enrichment | **Reproductive effects of WWTP effluents**



Stormwater runoff & impervious surfaces

Perhaps the most **defining characteristic of urban streams** is the **increase in the amount and rapidity of stormwater or surface runoff** to those systems. Impervious surfaces associated with urbanization **reduce infiltration and increase surface runoff** (Fig 16), altering the pathways by which water (and any associated contaminants) reach urban streams.

Common **impervious surfaces** include:

- Roads
- Parking lots
- Rooftops
- Driveways and sidewalks
- Compacted soils

How does stormwater runoff affect streams?

- It alters natural hydrology, generally leading to **more frequent, larger magnitude, and shorter duration peak flows**.
- It **alters channel morphology**, generally leading to changes such as increased channel width, increased downcutting, and reduced bank stability.
- It **alters in-stream hydraulics**, affecting biologically important parameters such as water velocity and shear stress.
- It disrupts the balance between sediment supply and transport, generally leading to **increased sediment transport capacity and channel erosion**.
- It **increases stream temperatures**, due to the transfer of heat from impervious surfaces to stormwater runoff.
- It increases **delivery of pollutants** from the landscape to the stream. Pollutants commonly found in stormwater runoff include:
  - sediment
  - nutrients
  - pesticides
  - wear metals
  - organic pollutants
  - oil and grease

Three common types of impervious surfaces in urban watersheds: roads, roofs and parking lots

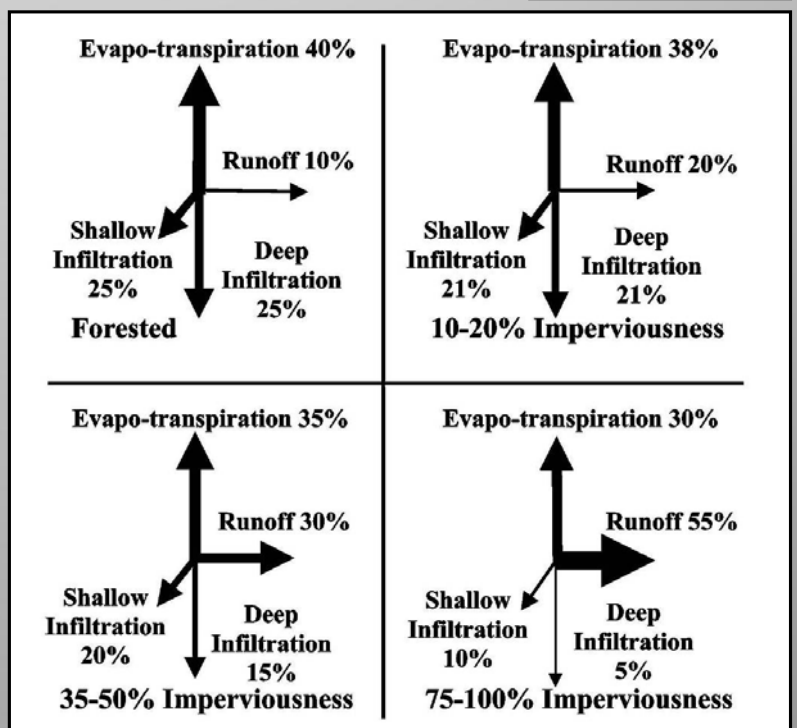
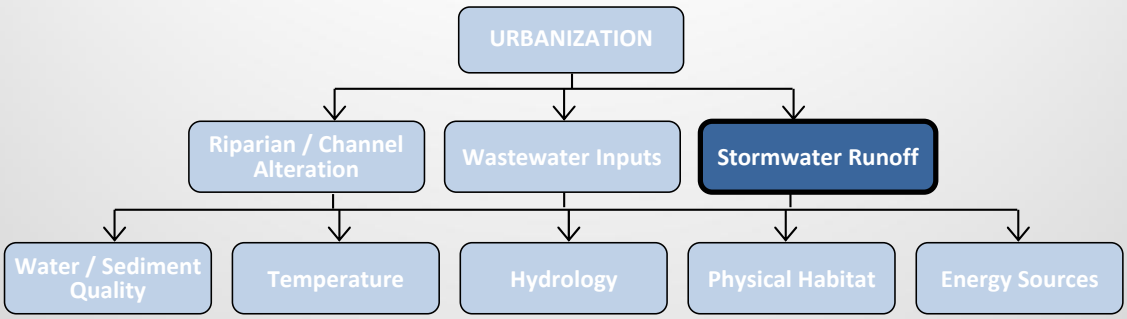


Figure 16. The shift in relative hydrologic flow in increasingly impervious watersheds. Note the large increase in stormwater runoff as imperviousness increases, at the expense of infiltration.

From *Paul MJ & Meyer JL. 2001. The ecology of urban streams. Annual Review of Ecology & Systematics 32:333-365.* © 2001 by Annual Reviews. Reprinted with permission.

Click below for more detailed information on specific topics

Effective vs. total imperviousness | Imperviousness & biotic condition | Thresholds of imperviousness



Effective vs. total imperviousness

The effects of urbanization on stream ecosystems are largely driven by impervious cover. There are two general ways to quantify impervious cover:

- **Total impervious area** (TIA) = all impervious area in catchment
- **Effective impervious area** (EIA) = impervious area in catchment that is directly connected to stream channels (i.e., precipitation falling on that area is effectively transported to the stream)

Several methods can be used to determine EIA, with varying levels of accuracy (Roy & Shuster 2009). They include:

- Geographic information system data combined with overlays of stormwater infrastructure
- Published empirical relationships between TIA and EIA (Alley & Veenhuis 1983, Wenger et al. 2008)
- Field assessments

Courtesy of USEPA

Many studies have found that EIA (also known as **drainage connection** or **directly connected impervious area**) is a **better predictor of ecosystem alteration** in urban streams. For example, Hatt et al. (2004) showed that % connection was more strongly related to water chemistry variables (e.g., conductivity, total phosphorus) than % total imperviousness, during both baseflows and stormflows (Fig 17).

The strength of EIA relationships suggests that **stormwater management techniques aimed at disconnecting impervious areas** from stream channels can improve urban water quality (Walsh et al. 2005b).

Click below for more detailed information on specific topics

Effective vs. total imperviousness | Imperviousness & biotic condition | Thresholds of imperviousness

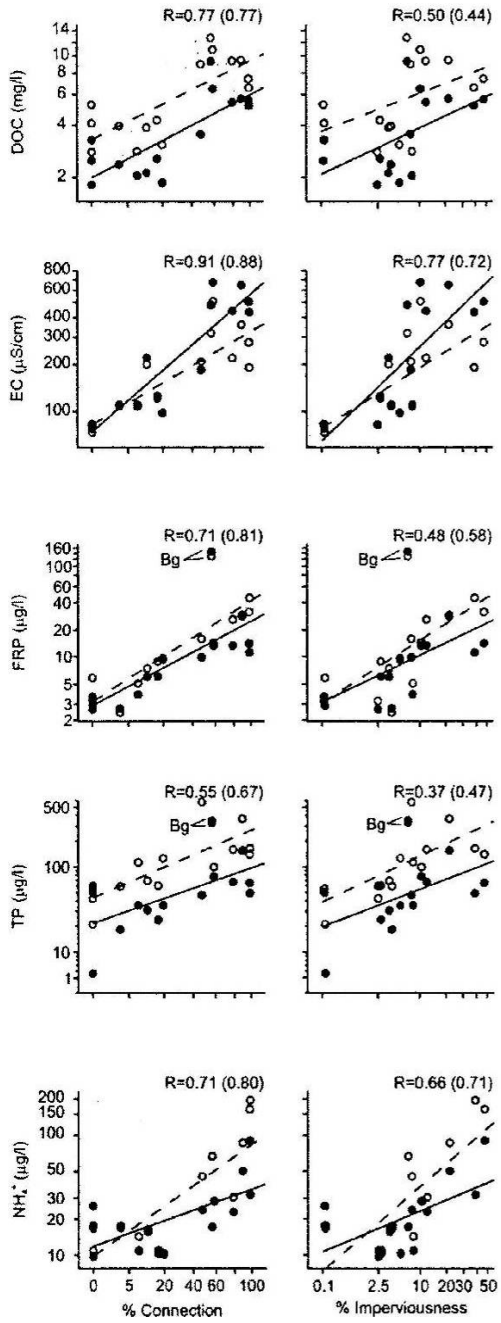
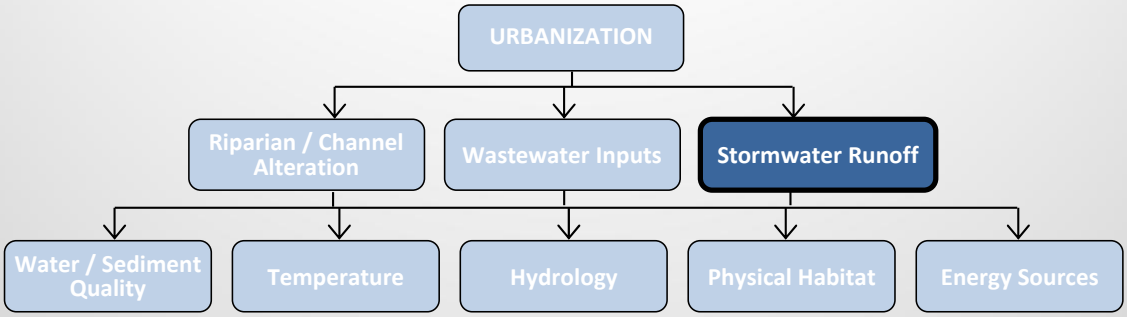


Figure 17. Relationships between geometric means of baseflow (close circles, solid regression lines) and storm event (open circles, dashed regression lines) concentrations and two impervious cover variables: % drainage connection and % total imperviousness. R values provided as baseflow concentrations (storm event concentrations). DOC = dissolved organic carbon; EC = electrical conductivity; FRP = filterable reactive phosphorus; TP = total phosphorus; NH_4^+ = ammonium.

From *Hatt BE et al. 2004. The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams. Environmental Management 34(1):112-124.* Reprinted with permission from Springer Science+Business Media.



Imperviousness & biotic condition

Total or effective impervious cover has been linked to numerous **changes in stream biotic assemblages**. These changes include (but are not limited to):

ALGAE

- ↑ abundance or biomass
  [Walsh et al. 2005b, Busse et al. 2006]
- other changes in assemblage structure
  [Walsh et al. 2005b]

BENTHIC MACROINVERTEBRATES

- ↓ total abundance, richness or diversity
  [Walsh 2004, Moore & Palmer 2005, Utz et al. 2009]
- ↓ EPT abundance, richness or diversity
  [Walsh 2004, Walsh et al. 2005b, Schiff & Benoit 2007]
- other changes in assemblage structure (e.g., changes in functional feeding groups)
  [Stepenuck et al. 2002, Wang & Kanehl 2003]
- ↓ quality of biotic index scores
  [Morley & Karr 2002, Walsh et al. 2005b, Schiff & Benoit 2007]

FISHES

- ↓ abundance, biomass, richness or diversity
  [Wang et al. 2001, Wang et al. 2003, Stranko et al. 2008]
- other changes in assemblage structure (e.g., loss of individual species, changes in reproductive guilds)
  [Wenger et al. 2008 (Fig 18), Helms et al. 2009]
- ↓ quality of biotic index scores
  [Wang et al. 2001, Wang et al. 2003]

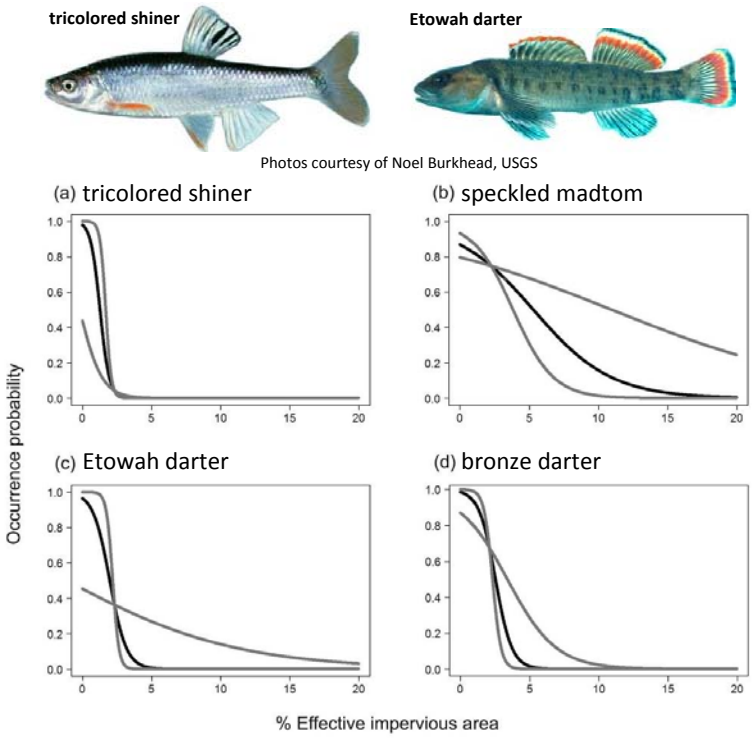
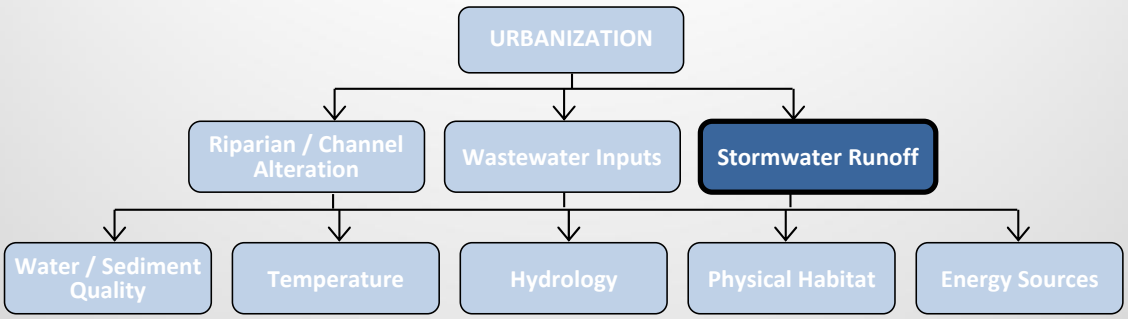


Figure 18. Occurrence probability of 4 fish species vs. impervious cover. Black line represents response curve based on mean parameter estimate for effective impervious area (EIA); gray lines represent response curves based on 5% and 95% values for parameter estimate for EIA. For three of the four species (all but speckled madtom), occurrence probability was predicted to approach zero at approximately 2-4% effective impervious cover.

Click below for more detailed information on specific topics

Effective vs. total imperviousness | Imperviousness & biotic condition | Thresholds of imperviousness



Thresholds of imperviousness

Relationships between impervious cover and measures of stream condition, defined by either physical, chemical, or biological parameters, can take several forms (Fig 19). When the relationship is linear, any increase in imperviousness results in a decrease in condition (Fig 19, yellow and Fig 20); in other cases, there may be **threshold values of impervious cover** above which condition either decreases rapidly (Fig 19, green) or remains consistently low (Fig 19, blue and Fig 21).

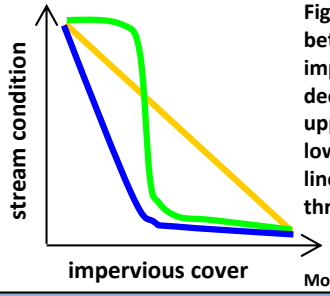


Figure 19. Example relationships between stream condition and impervious cover: a linear decline in condition (yellow); an upper threshold switching to a lower threshold (green); a linear decline to a lower threshold (blue).

Modified from *Walsh et al. (2005a).*

Example thresholds or critical levels of imperviousness reported in the literature include:

PHYSICAL & CHEMICAL PARAMETERS

- Consistent channel instability when **EIA > 10%** [Booth & Jackson 1997]
- Different geomorphic response patterns (e.g., in terms of depth diversity, maximum pool depth) across sites with **< 13% vs. > 24% TIA** [Cianfrani et al. 2006]
- Consistently higher conductivity, dissolved organic carbon, and filterable reactive phosphorus when **EIA > 5%, 4%, and 1%**, respectively [Walsh et al. 2005b]
- Uniformly low summer baseflow when **TIA > 40%** [Finkenbine et al. 2000]

BIOLOGICAL PARAMETERS

- Consistently high algal biomass when **EIA > 5%**, low diatom index value when **EIA > 2%** [Walsh et al. 2005b]
- Sharp declines in macroinvertebrate diversity and richness when **TIA between 8-12%** [Stepenuck et al. 2002]
- Invertebrate taxa sensitive to impervious cover lost when **TIA between 2.5-15%** in Piedmont streams and **between 4-23%** in Coastal Plain streams [Utz et al. 2009]
- Brook trout absent when **TIA > 4%** [Stranko et al. 2008]
- Occurrence probability of three sensitive fish species approaches zero when **EIA between 2-4%** [Wenger et al. 2008]
- Sharp declines in fish IBI score and trout abundance when **EIA between 6-11%**, consistently low values when **EIA > 11%** [Wang et al. 2003]

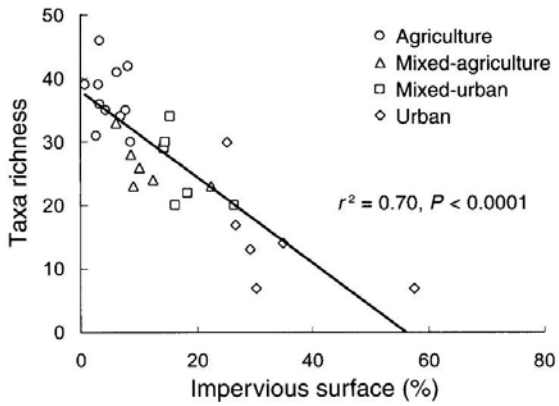


Figure 20. Relationship between total macroinvertebrate richness and % impervious surface cover in 29 headwater Maryland streams sampled in 2001. Taxa richness declined linearly with increasing impervious cover.

From ***Moore AA & Palmer MA. 2005. Invertebrate biodiversity in agricultural and urban headwater streams: implications for conservation and management. Ecological Applications 15(4):1169-1177.*** Reprinted with permission.

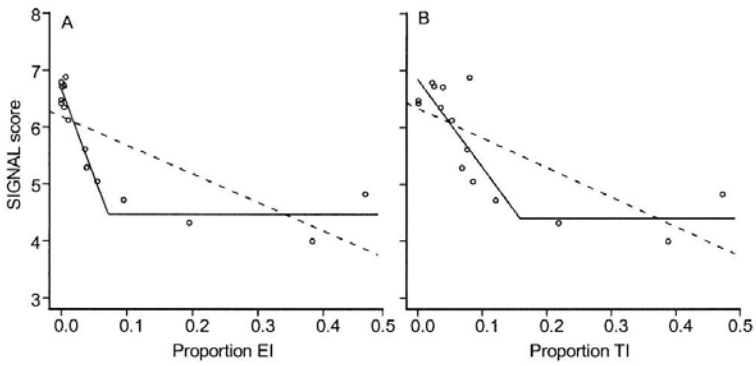


Figure 21. SIGNAL scores (a biotic index) for macroinvertebrates in edge habitats vs. (A) effective imperviousness (EI) and (B) total imperviousness (TI). Solid lines are piecewise regressions, dashed lines are linear regressions; the piecewise regression for EI provided the best fit. Note that the threshold value was 0.07 for EI, approximately half the threshold value for TI.

From ***Walsh CJ et al. 2005b. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. Journal of the North American Benthological Society 24(3):690-705.*** Reprinted with permission.

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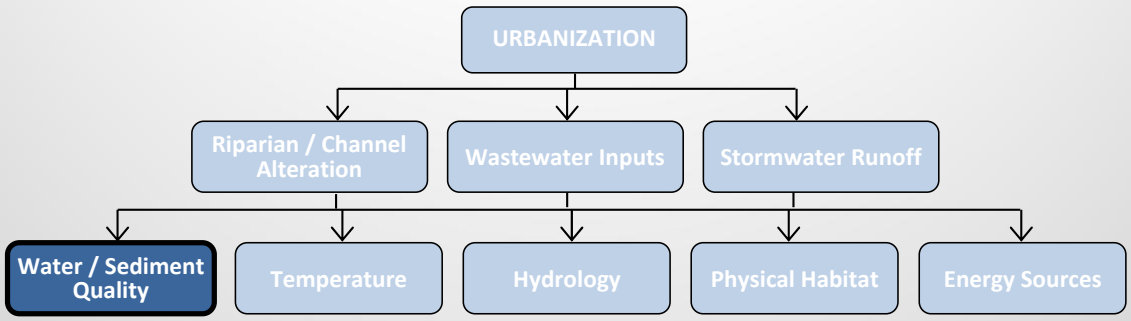
Effective vs. total imperviousness | Imperviousness & biotic condition | Thresholds of imperviousness



Water & sediment quality in urban streams

Urbanization has been associated with **numerous impairments of water and sediment quality**, including:

- ↑ dissolved solutes and conductivity (Table 5)
- ↑ suspended solids or turbidity
- ↑ fecal bacteria
- ↑ nitrogen and phosphorus (Table 5)
- ↓ dissolved oxygen
- ↑ toxics (Table 5, Fig 22)
  - metals (e.g., Cd, Cr, Cu, Hg, Ni, Pb, Zn)
  - polycyclic aromatic hydrocarbons (PAHs)
  - polychlorinated biphenyls (PCBs)
  - pesticides (e.g., chlordane, chlorpyrifos, diazinon)
  - pharmaceuticals (e.g., antibiotics, hormones, anti-depressants, ibuprofen)
  - other organic pollutants (e.g., caffeine, triclosan, detergents, fragrances)

Exposure of aquatic organisms to these pollutants can result in toxic effects, specific to each pollutant's mode of action. The following pages focus on a few urban-specific water and sediment quality issues in greater depth; in addition, more detailed information on many of these parameters can be found in CADDIS' individual stressor modules.

Click below for more detailed information on specific topics

Urbanization & conductivity | **Nitrogen in urban streams** | **Pavement sealants**

Table 5. Example water (Malibu Creek, Etowah River) and sediment (Charles River and Stillwater River) quality differences between urban and non-urban stream sites [DIN = dissolved inorganic nitrogen; SRP = soluble reactive phosphorus].

LOCATION [Reference]	PARAMETER	LEAST URBAN SITE	MOST URBAN SITE
Malibu Creek, CA [Busse et al. 2006]	% Impervious	2	55
	Conductivity (µS cm^{-1})	670	3060
	SRP (µg L^{-1})	43	75
	DIN (µg L^{-1})	30	521
Etowah River, GA [Roy et al. 2003]	% Urban	5	61
	Conductivity (µS cm^{-1})	21	172
	SRP (µg L^{-1})	8	135
	NH_4-N (µg L^{-1})	0.6	2.0
Charles River and Stillwater River, MA [Chalmers et al. 2007]	% Urban	2	97
	PAHs (mg kg^{-1})	1.2	32.5
	PCBs (mg kg^{-1})	<0.1	0.3
	Cr (µg g^{-1})	36	92
	Pb (µg g^{-1})	73	250

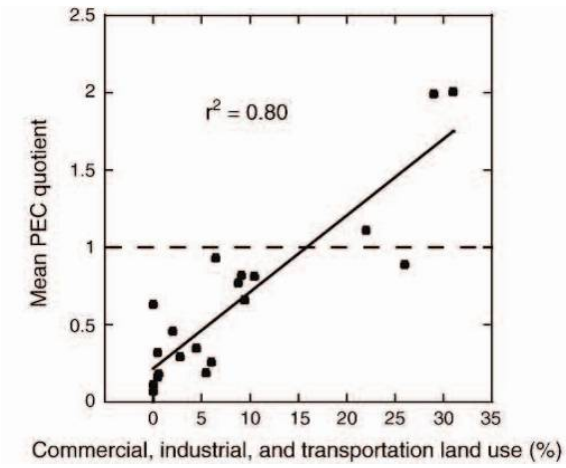
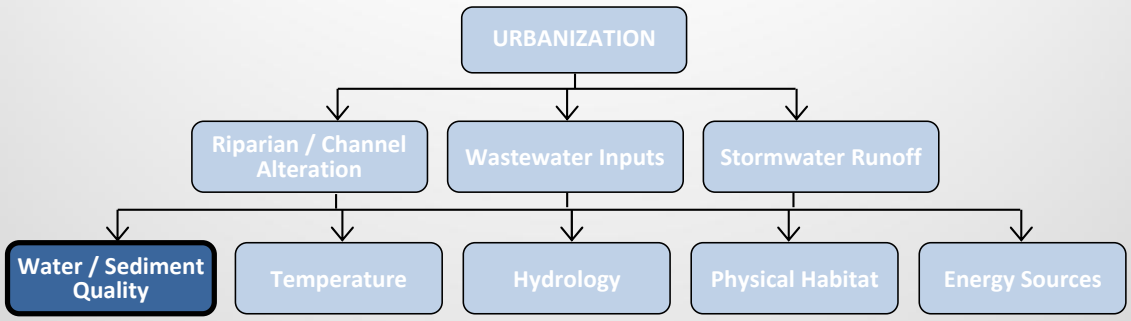


Figure 22. Overall sediment quality, as indicated by mean probable effect concentration (PEC) quotient, vs. commercial, industrial and transportation land use. PEC quotient = contaminant concentration/PEC for that contaminant; at each site, PEC quotients for metals, chlorinated hydrocarbons, and PAHs were averaged to determine mean PEC quotients.

From ***Chalmers AT et al. 2007. The chemical response of particle-associated contaminants in aquatic sediments to urbanization in New England, U.S.A. Journal of Contaminant Hydrology 91:4-25.*** **Reprinted with permission from Elsevier.**



Urbanization & conductivity

Increases in conductivity or similar measures of ionic strength (see the Ionic Strength module for further discussion of different measurements) are among the most consistently documented water quality changes associated with urbanization. For example, Kaushal et al. (2005) examined salinization of suburban and urban streams in Maryland. They found that **chloride concentrations exceeded thresholds for sensitive freshwater taxa at sites with greater than 40% impervious cover** (Fig 23). In winter, chloride concentrations reached peaks of **nearly 25% the concentration of seawater**, and concentrations remained up to 100 times higher than at forested and agricultural non-impervious sites throughout the year.

This increase in dissolved solutes in urban streams has been attributed to several sources, including:

- Road salt and other deicing agents (in northern regions)
- Point source discharges (e.g., WWTP and industrial effluents)
- Leaky sewer and septic systems
- Concrete weathering

Some studies have shown that urbanization-associated changes in conductivity are related to shifts in biotic assemblages. For example:

- Roy et al. (2003) found that **specific conductance was a significant predictor of invertebrate responses to urbanization**, negatively related to total invertebrate richness, EPT richness, total invertebrate density, and several benthic invertebrate indices.
- Helms et al. (2009) found that **streams with high concentrations of total dissolved solids were dominated by sunfish-based fish assemblages**.

However, in many cases it is believed that conductivity is a general indicator of overall urban impact, rather than a direct cause of observed biotic effects.

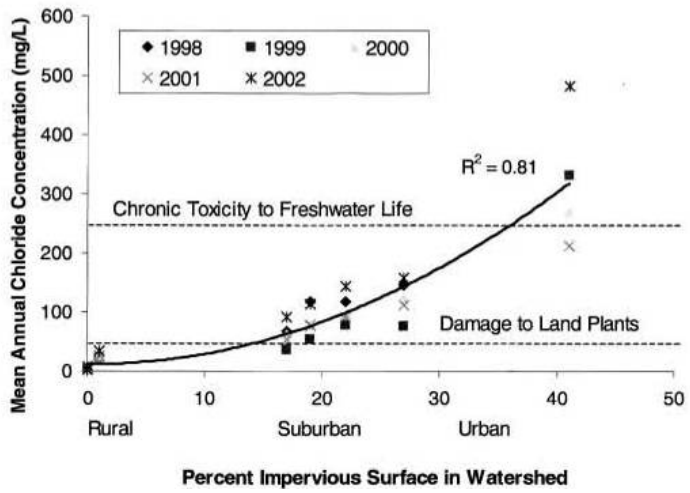


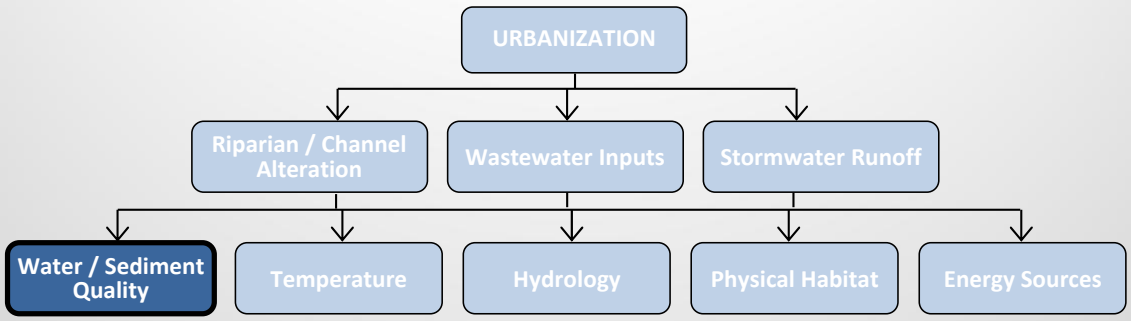
Figure 23. Relationship between impervious surface and mean annual chloride concentration in Baltimore Long Term Ecological Research (LTER) streams, 1998-2002. Dashed lines indicate thresholds for damage to certain land plants and for chronic toxicity to sensitive freshwater taxa (U.S. EPA 1988).

Courtesy of USEPA

Road salt and other deicers can contribute to elevated stream conductivity in northern urban catchments.

Click below for more detailed information on specific topics

Urbanization & conductivity | **Nitrogen in urban streams** | **Pavement sealants**



Nitrogen in urban streams

One common water quality change associated with urban development is an increase in nutrient concentrations, especially nitrogen (Fig 24, Table 6). **Wastewater inputs** and **stormwater runoff** both contribute to **increased nitrogen loading** in urban catchments. Specific sources of nitrogen in urban systems include:

- **Human wastes**
  - wastewater treatment plant effluents
  - leaky sewer and septic systems
- **Atmospheric deposition**
  - vehicle exhaust
  - other forms of fossil fuel combustion
- **Fertilizers** applied to lawns and golf courses
- **Pet wastes**
- **Landfill leachates**
- **Legacy sources** (e.g., development of agricultural land)

In addition, **riparian alteration** can affect **nitrogen uptake and cycling,** and turn urban riparian areas into nitrogen sources (Groffman et al. 2002, 2003).


Courtesy of USEPA

Although nitrogen loading to and export from urban streams typically are elevated, many studies also have found relatively **high nitrogen retention** [Groffman et al. 2004, Wollheim et al. 2005 (Table 6)] in these systems. Pervious surfaces such as lawns may act as **nitrogen sinks** in urban areas (Raciti et al. 2008), and help to mitigate at least some nitrogen loading increases. However, this mitigation may be limited as fertilizers often are over-applied in urban systems.

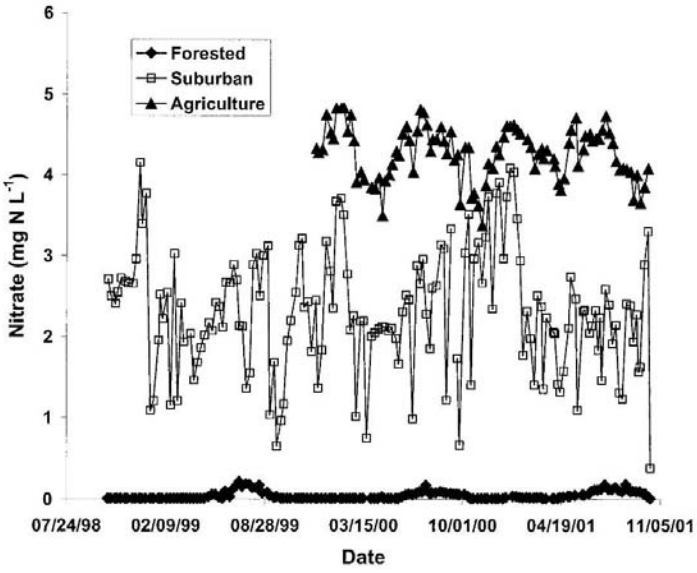


Figure 24. Nitrate concentrations in three streams draining completely forested, suburban, and agricultural watersheds in Baltimore County, MD, October 1998–October 2001.

From *Groffman PM et al. 2004. Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems 7:393-403.* Reprinted with permission from Springer Science+Business Media.

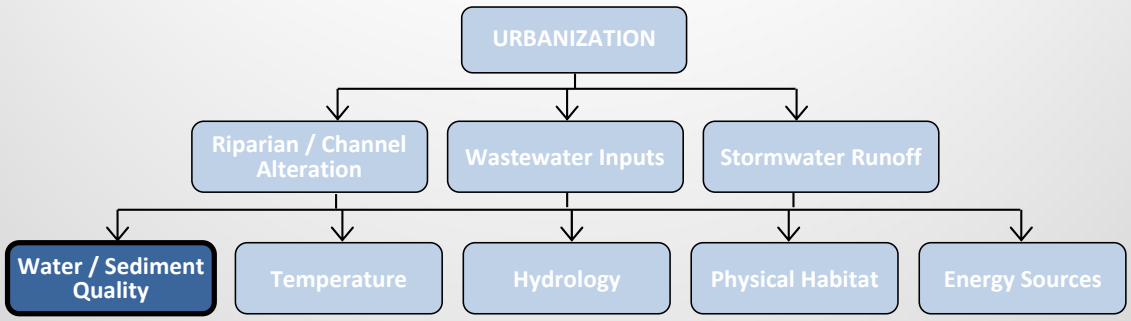
Table 6. Nitrogen budgets for an urban and a forested headwater stream in Massachusetts, 2001-2002 water year.

PARAMETER		URBAN	FOREST
Total N loading ($kg\ km^{-2}\ y^{-1}$)	Wet deposition (DIN)	494	496
	Dry deposition (DIN)	290	290
	Net waste N	350	586
	Fertilizer N	1443	395
	SUM	*2578*	*1767*
River N exports ($kg\ km^{-2}\ y^{-1}$)	DIN (NO_3 + NH_4)	333	7.5
	DON	51.5	51.6
	SUM	*384.5*	*59.1*
N retention (%)		85	97

After Wollheim WM et al. 2005. N retention in urbanizing headwater catchments. Ecosystems 8:871-884.

Click below for more detailed information on specific topics

Urbanization & conductivity | Nitrogen in urban streams | Pavement sealants



Pavement sealants & PAHs

Polycyclic aromatic hydrocarbons (PAHs) are common pollutants in urban streams, resulting from numerous transportation-related sources including **oil leakage, vehicle exhaust, tire and brake wear, and pavement erosion**. Many studies have shown that these compounds can **adversely affect stream biota** (e.g., Maltby et al. 1995, Pinkney et al. 2004).

Pavement sealants are routinely applied to parking lots and driveways to protect the underlying surfaces, and these sealants can be significant sources of PAHs. For example:

- PAH concentrations were **65 times higher** in runoff from coal-tar seal-coated parking lots versus unsealed parking lots (Mahler et al. 2005).
- PAH concentrations in stream sediments were **3.9 to 32 mg kg^{-1} higher** downstream of coal-tar seal-coated parking lots versus upstream reference sites (Scoggins et al. 2007).

Scoggins et al. (2007) examined the effect of these sealcoats on benthic macroinvertebrate assemblages. They found that:

- Average **macroinvertebrate densities were 2 times higher** at sites upstream of seal-coated parking lots.
- **Chironomid density decreased** at sites downstream of seal-coated parking lots, whereas **oligochaete density usually increased**.
- **Increases in pool habitat PAH sediment toxicity units** between sites upstream and downstream of seal-coated parking lots explained **decreases in macroinvertebrate richness and density** (Fig 25).

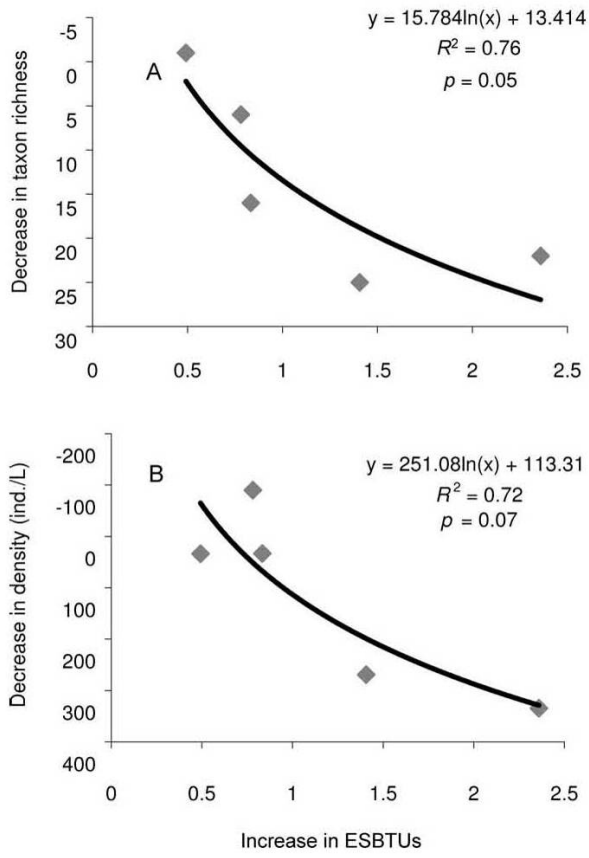


Figure 25. Regression plot of the decrease in (A) macroinvertebrate richness and (B) density between sites upstream and downstream of seal-coated parking lots, as a function of the increase in PAH equilibrium partitioning sediment benchmark toxicity units (ESBTUs) in pool sediments between those sites. ESBTUs were based on 16 EPA priority PAH pollutants; values > 1 suggest toxicity.

From ***Scoggins M et al. 2007. Occurrence of polycyclic aromatic hydrocarbons below coal-tar-sealed parking lots and effects on stream benthic macroinvertebrate communities. Journal of the North American Benthological Society 26(4):694-707.*** **Reprinted with permission.**

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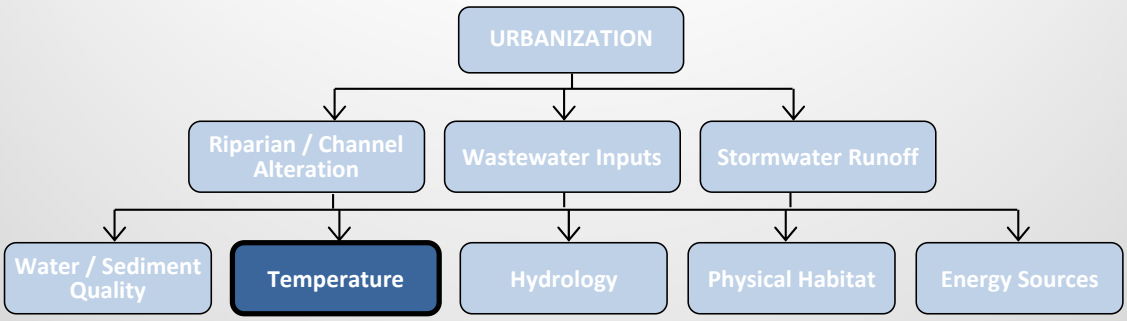
Urbanization & conductivity | Nitrogen in urban streams | Pavement sealants



Urbanization & stream temperature

Urbanization often results in increased stream temperatures (e.g., increased daily maximum temperature, increased number of temperature exceedances), especially in summer. This is due in part to the formation of **urban heat islands**, or localized areas of heat storage (and warmer air temperatures) near urban centers. Many other aspects of urbanization also can contribute to stream warming:

- **Riparian alteration** can reduce canopy cover and shading, increasing solar radiation reaching the water surface.
- **Wastewater inputs** can lead to the direct discharge of warmer effluents into stream and rivers (Figs 26 and 27).
- **Stormwater runoff** from warm impervious surfaces can contribute heated surface runoff to surface waters, and reduce cooler groundwater inputs via decreased infiltration.
- **Lower baseflows** can lead to shallower water and standing pools, which warm quickly.
- **Physical habitat** changes such as channel widening can increase channel width:depth ratios, further reducing riparian shading and increasing surface area for heat exchange.
- Certain **best management practices (BMPs) for urban streams**, such as stormwater retention ponds, can increase water retention time and warming, particularly in unshaded systems.

Increases in water temperature also can affect other urban-associated stressors, including:

- **Water / sediment quality** – via decreased dissolved oxygen saturation, increased ammonia toxicity, and increased biotic uptake of toxic substances
- **Energy sources** – via increased microbial respiration and primary production

---

Elevated water temperatures can be stressful to aquatic organisms, and may result in numerous lethal and sublethal effects (e.g., death, increased disease susceptibility, and decreased growth and reproduction). See the Temperature module for further discussion of temperature as a cause of stream impairment.

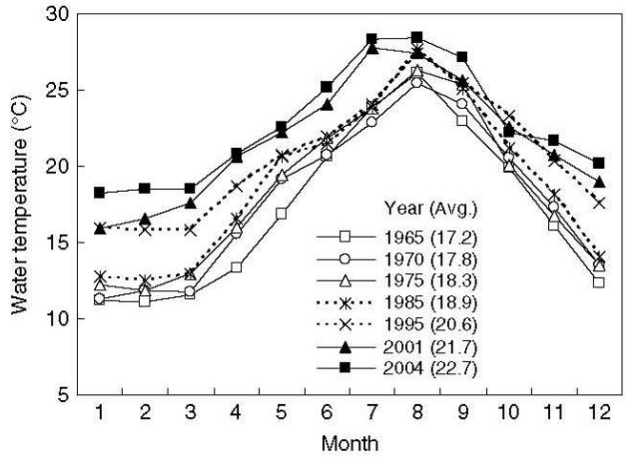


Figure 26. Monthly mean (plot) and yearly mean (legend) temperatures of wastewater effluents from all treatment plants located in the central Tokyo area, 1965-2004. Increases in effluent temperatures stem largely from increased residential use of heated water.

From *Kinouchi T. 2007. Impact of long-term water and energy consumption in Tokyo on wastewater effluent: implications for the thermal degradation of urban streams. Hydrological Processes 21:1207-1216.* Reprinted with permission.

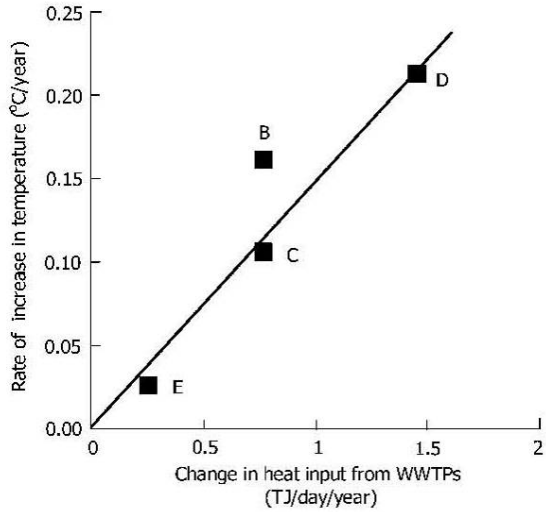
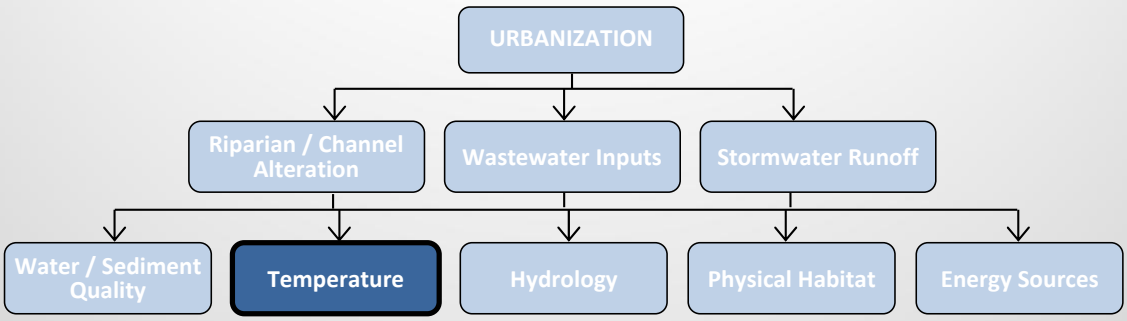


Figure 27. Change in wastewater heat effluent from wastewater treatment plants vs. the rate of temperature increase in four stream segments (B-E) in the Ara River system, central Tokyo. Kinouchi et al. (2007) contend that increased wastewater effluent temperatures contribute to the thermal degradation of effluent-receiving streams.

From *Kinouchi T et al. 2007. Increase in stream temperature related to anthropogenic heat input from urban wastewater. Journal of Hydrology 335:78-88.* Reprinted with permission from Elsevier.

Click below for more detailed information on specific topics

Heated surface runoff | Temperature & biotic condition | Urbanization & climate change



Heated surface runoff from impervious surfaces

Impervious surfaces absorb and store heat, which is then transmitted to surface runoff during rainfall events. Several studies have shown positive correlations between impervious surface area and stream temperature (Wang et al. 2003, Nelson & Palmer 2007, Imberger et al. 2008, Stranko et al. 2008).


Courtesy of USEPA

Thompson et al. (2008) compared runoff temperatures from asphalt and sod surfaces during 24 rainfall simulations (see Fig 28 for one of these simulations). They found that:

- **Asphalt surfaces were more than 20°C warmer** than sod surfaces prior to rainfall simulations.
- Initial **asphalt runoff temperatures were roughly 10°C warmer** than sod runoff temperatures (35.0 vs. 25.5°C).
- Asphalt runoff temperature decreased by an average of 4.1°C over the 1-hour rainfall simulation.

However, impervious surfaces do not always elevate stream temperatures. Many factors influence whether impervious surfaces generate heated surface runoff (Herb et al. 2008, Thompson et al. 2008b), including:

- Air temperature and humidity
- Type of impervious surface (e.g., reflectance)
- Solar radiation before and during rainfall
- Rainfall intensity
- Rainfall temperature

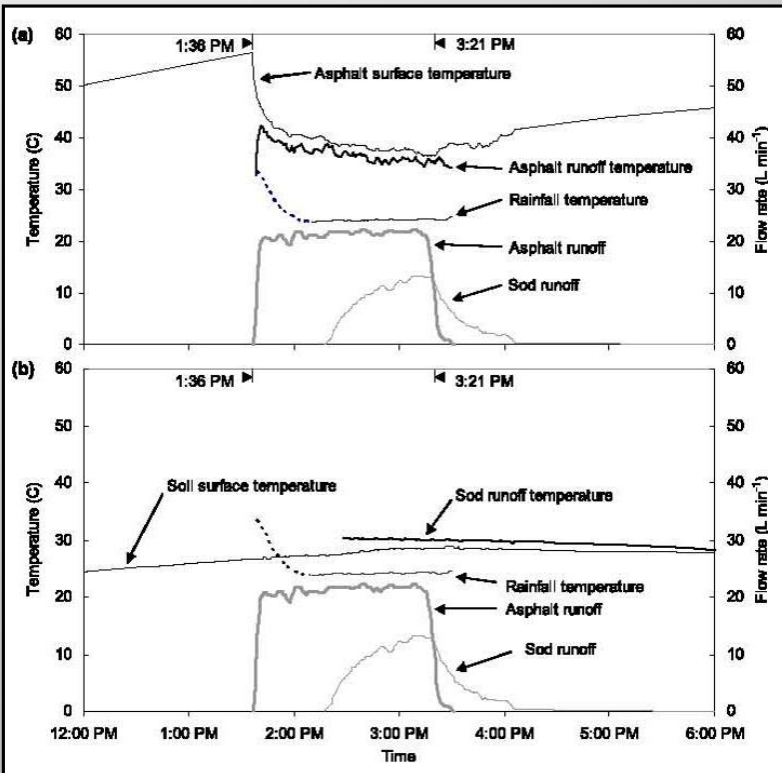
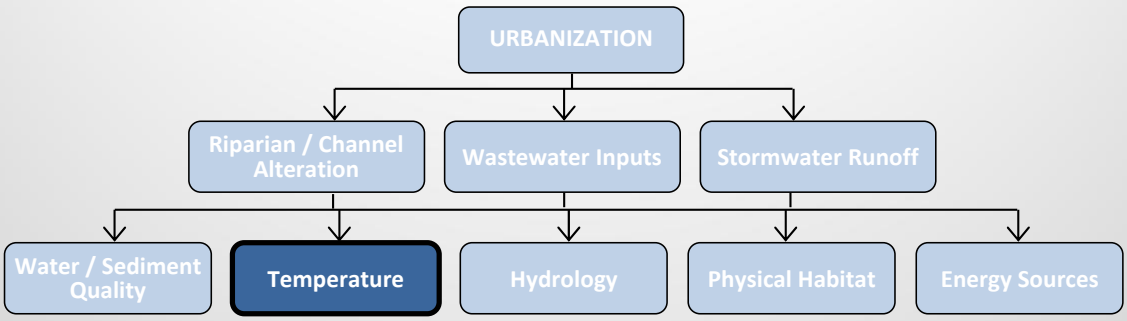


Figure 28. Temperature of (a) asphalt and (b) sod surface and runoff during July 15, 2005 rainfall simulation; asphalt and sod runoff and rainfall temperature are shown in both (a) and (b).

From *Thompson AM et al. 2008. Thermal characteristics of stormwater runoff from asphalt and sod surfaces. Journal of the American Water Resources Association 44(5):1325-1336.* Reprinted with permission.

Click below for more detailed information on specific topics

Heated surface runoff | **Temperature & biotic condition** | **Urbanization & climate change**



Temperature & biotic condition in urban streams

Biotic responses associated with increased temperatures in urban streams include (but are not limited to):

BENTHIC MACROINVERTEBRATES

- ↓ total abundance, richness or diversity
  [Sponseller et al. 2001]
- ↓ EPT abundance, richness or diversity
  [Sponseller et al. 2001, Wang & Kanehl 2003]
- ↓ quality of biotic index scores
  [Wang & Kanehl 2003, Walters et al. 2009]

FISHES

- ↓ abundance, biomass, richness or diversity
  [Wang et al. 2003 (Fig 29), Stranko et al. 2008, Helms et al. 2009]
- ↓ quality of biotic index scores
  [Wang et al. 2003]

Coldwater fishes such as salmonids are among the taxa most affected by temperature increases. For example, Runge et al. (2008) found that the survival of stocked rainbow trout in the Chattahoochee River, Georgia, was negatively related to the amount of time water temperatures exceeded 20°C (Fig 30), and that fish dispersed from warmer downstream reaches to cooler upstream reaches.

It should be noted, however, that other studies have found little or no relationship between water temperature and biota in urban streams (Kemp & Spotila 1997, Walters et al. 2009)—and as with all urbanization-associated stressors, it often is difficult to determine which of these often correlated stressors is driving biotic responses.

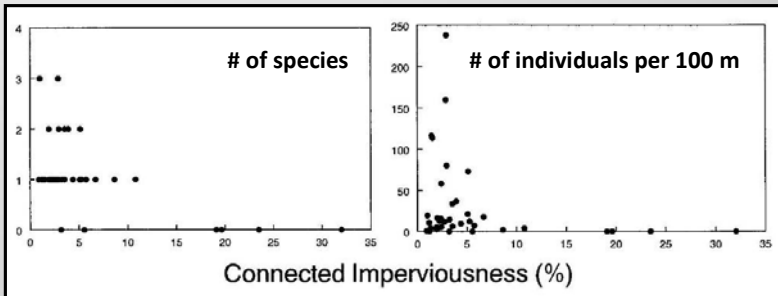


Figure 29. Relationship between % connected imperviousness and coldwater fish species richness and abundance in 33 Wisconsin and Minnesota trout streams.

From ***Wang L et al. 2003. Impacts of urban land cover on trout streams in Wisconsin and Minnesota. Transactions of the American Fisheries Society 132:825-839.*** **Reprinted with permission.**

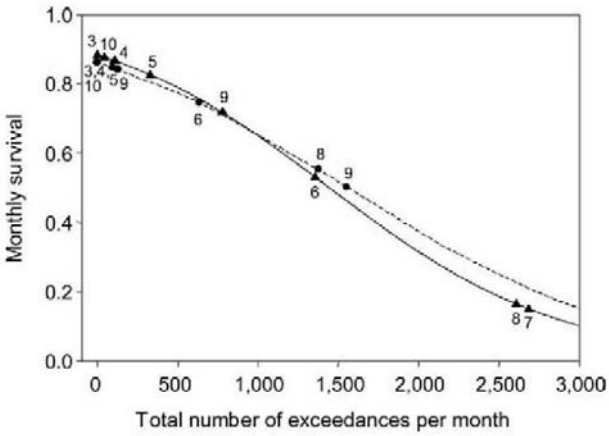
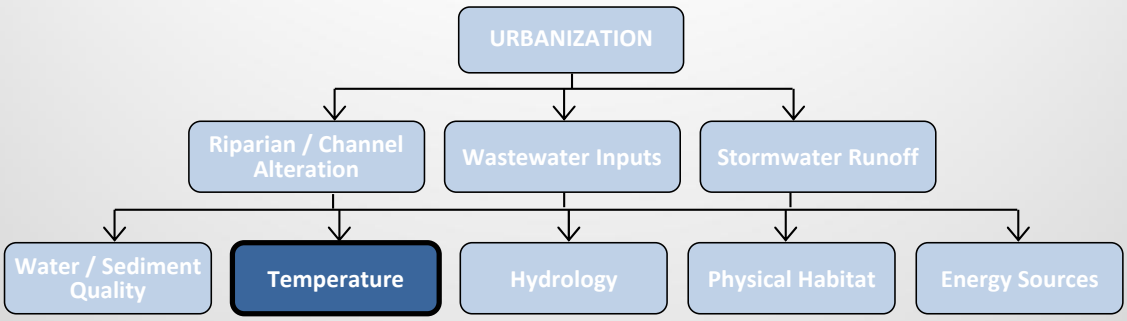


Figure 30. Estimates of monthly rainbow trout survival vs. number of temperature exceedances at upstream (circles, dashed line) and downstream (triangles, solid line) study reaches. An exceedance was defined as any 15-minute interval in which temperature exceeded 20°C; numbers represent months in which exceedances were recorded (e.g., 6=June).

From ***Runge JP et al. 2008. Survival and dispersal of hatchery-raised rainbow trout in a river basin undergoing urbanization. North American Journal of Fisheries Management 28:745-757.*** **Reprinted with permission.**

Click below for more detailed information on specific topics

Heated surface runoff | Temperature & biotic condition | Urbanization & climate change



Urbanization & climate change

An increasing number of studies are considering the **potentially interactive effects of urbanization and climate change** on stream ecosystems (Palmer et al. 2009). Some studies have focused on interactions between urbanization and climate change-associated changes in precipitation and runoff (Kaushal et al. 2008, Franczyk & Chang 2009, Han et al. 2009); others have examined **interacting effects on stream temperature**.

Nelson & Palmer (2007) and Nelson et al. (2009) developed models to predict the separate and combined effects of urbanization and climate change on small mid-Atlantic streams. They found that:

- Water temperatures were **highest under the scenario of increased urbanization plus a warming climate**, especially in midsummer when there was heated runoff from impervious surfaces (Fig 31).
- Water temperatures exceeded the "good growth" temperature maximum for coldwater fish species (28°C) on an average of **49 days per 10-year period under the urbanization plus climate change scenario, vs. 24 days per 10-year period in the urbanization alone scenario** (Fig 32).
- Water temperatures exceeded the "good growth" temperature maximum for coolwater fish species (32°C) only rarely, and **only in the urbanization plus climate change scenario**.

Click below for more detailed information on specific topics

Heated surface runoff | Temperature & biotic condition | Urbanization & climate change

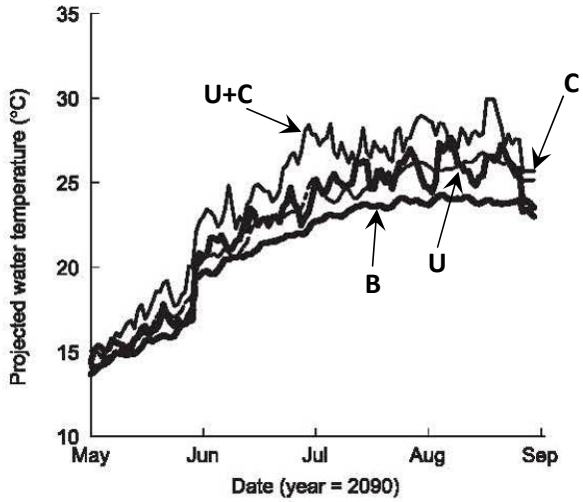


Figure 31. Projected maximum daily water temperatures for the year 2090 under four scenarios: baseline (B), urbanization (U), climate change (C), and urbanization plus climate change (U+C).

From ***Nelson KC et al. 2009. Forecasting the combined effects of urbanization and climate change on stream ecosystems: from impacts to management options. Journal of Applied Ecology 46:154-163.*** **Reprinted with permission.**

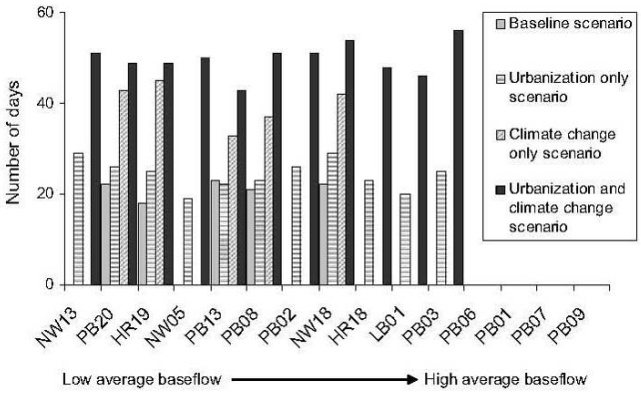
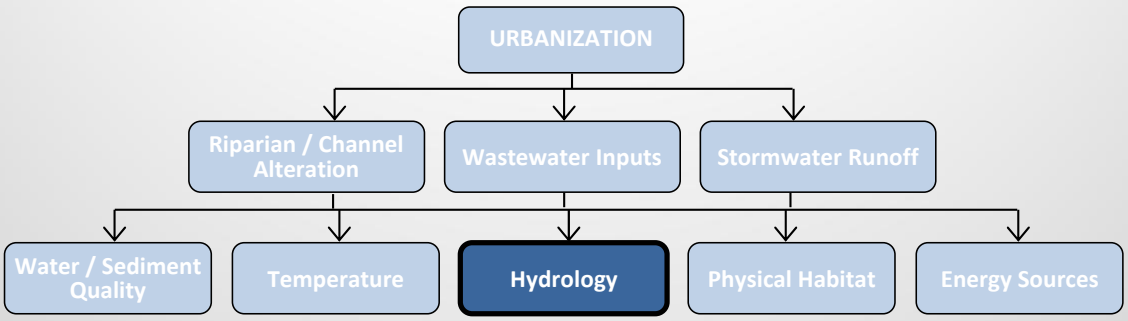


Figure 32. Predicted number of summer days with water temperatures > 28°C (summed over a 10-year period), at 15 sites ranging from low to high average baseflow, for four scenarios: baseline, urbanization, climate change, and urbanization plus climate change.

From ***Nelson KC & Palmer MA. 2007. Stream temperature surges under urbanization and climate change: data, models, and responses. Journal of the American Water Resources Association 43(2):440-452.*** **Reprinted with permission.**



Flow alteration in urban streams

Alteration of natural hydrologic regimes is a consistent and pervasive effect of urbanization on stream ecosystems, as discharge patterns—**the amount and timing of water flow through streams**—change with urban development. Key aspects of urbanization affecting hydrology may include:

- **↓ infiltration and ↑ surface runoff** of precipitation associated with impervious (and effectively impervious) surfaces
- **↑ speed and efficiency of runoff delivery** to streams, via stormwater drainage infrastructure
- **↓ evapotranspiration** due to vegetation removal
- **↑ direct water discharges,** via wastewater and industrial effluents
- **↑ infiltration** due to irrigation and leakage from water supply and wastewater infrastructure
- **↑ water withdrawals and interbasin transfers**

Commonly reported effects of urbanization on stream flow regimes include (but are not limited to):

STORMFLOW

- ↑ high flow frequency (Fig 33)
  [Roy et al. 2005, Schoonover et al. 2006, Brown et al. 2009]
- ↑ high flow magnitude (Figs 33 and 34)
  [Rose & Peters 2001, Burns et al. 2005, Schoonover et al. 2006]
- ↑ flashiness or rapidity of flow changes (Fig 33)
  [Roy et al. 2005, Schoonover et al. 2006, Chang 2007]
- ↓ high flow duration
  [Rose & Peters 2001, Poff et al. 2006, Chang 2007]
- ↓ lag time (Fig 34)
  [Arnold & Gibbons 1996, Changnon & Demissie 1996]

BASEFLOW

- ↓ low flow magnitude (Fig 34)
  [Finkenbine et al. 2000, Rose & Peters 2001, Kaufmann et al. 2009]
- ↑ low flow magnitude
  [Burns et al. 2005, Riley et al. 2005, Poff et al. 2006]
- ↑ low flow duration (Fig 34)
  [Roy et al. 2005, DeGasperi et al. 2009]

These hydrologic changes can reduce habitat quality in urban streams, and adversely affect stream biota. For example, high flows can scour organisms and substrate from streambeds, while low flows can reduce habitat area and volume. See the Flow Alteration and Physical Habitat modules for further details on biotic responses to these changes.

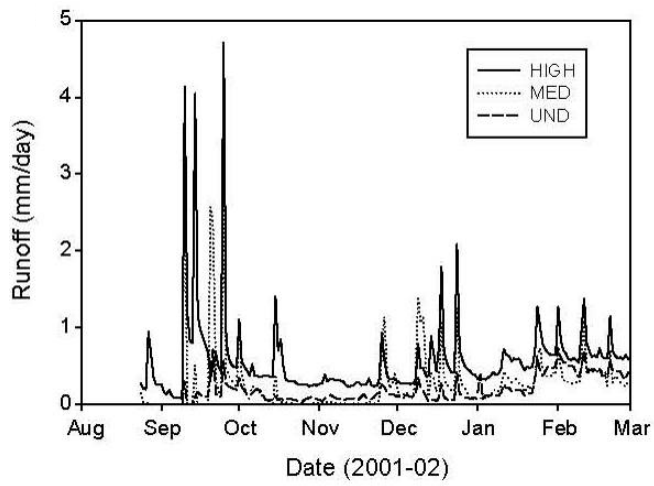


Figure 33. Stream runoff during a dry period (Aug 2001-Feb 2002) at three study catchments: UND = undeveloped, MED = medium density residential (1.6 houses ha^{-1}, 6% impervious), HIGH = high density residential (2.8 houses ha^{-1}, 11% impervious).

From ***Burns D et al. 2005. Effects of suburban development on runoff generation in the Croton River basin, New York, USA. Journal of Hydrology 311:266-281.*** **Reprinted with permission from Elsevier.**

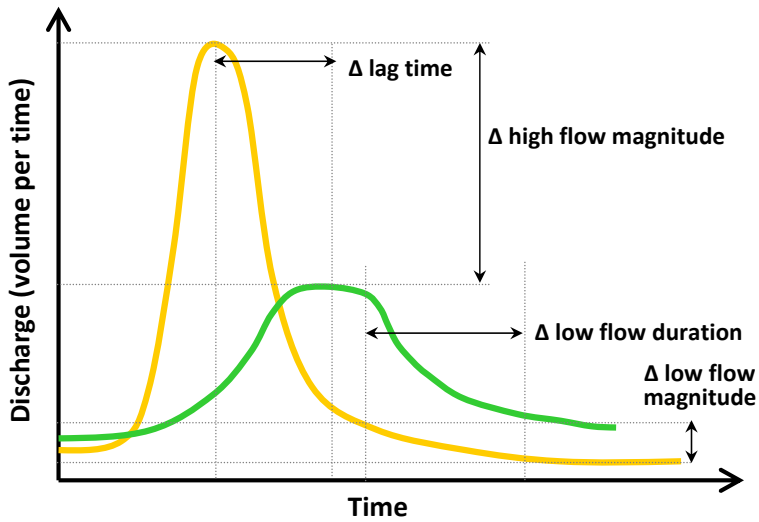
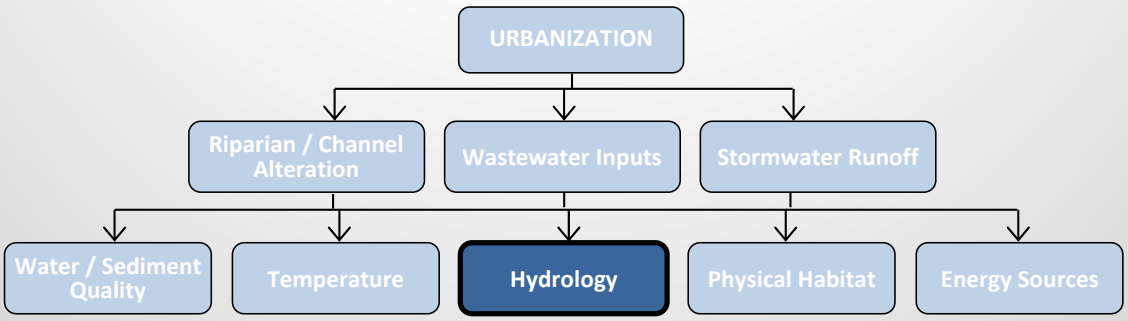


Figure 34. Hypothetical hydrographs for an urban stream (yellow) and a rural stream (green) after a storm, illustrating some common changes in stormflow and baseflow that occur with urban development. Other changes are listed at left.

Click below for more detailed information on specific topics

Baseflow in urban streams | **Water withdrawals & transfers** | **Biotic responses to urban flows**



Baseflow in urban streams

Urbanization generally results in increased magnitude and frequency of peak flows, but **baseflow effects typically are more variable**, with studies showing a range of responses in urban streams [Lerner 2002, Brandes et al. 2005, Meyer 2005, Roy et al. 2005 (Fig 35), Poff et al. 2006].

Decreases in baseflow may result from:

- ↓ infiltration due to ↑ impervious surfaces
- ↑ water withdrawals (surface or ground)

These decreases may be offset, however, by increases in baseflow resulting from:

- ↑ imported water supplies (i.e., interbasin transfers)
- ↑ leakage from sewers and septic systems
- ↑ leakage from water supply infrastructure
- ↑ irrigation (e.g., lawn watering)
- ↑ discharge of wastewater effluents
- ↑ infiltration due to water collection in recharge areas
- ↓ evapotranspiration due to ↓ vegetative cover

Urban-related increases in baseflow can be especially evident in **effluent-dominated** systems, or streams and rivers in which wastewater effluents comprise a significant portion of baseflow volumes. For example:

- Discharge from two wastewater treatment plants accounted for at least 70% of river flow in the Bush River, SC in Summer 2002 (Andersen et al. 2004).
- Average effluent flow in the South Platte River, CO is 41% total streamflow; during low flow conditions, this can increase to 90% (Woodling et al. 2006).

As a result, changes in baseflow in these streams likely affect water and sediment quality.

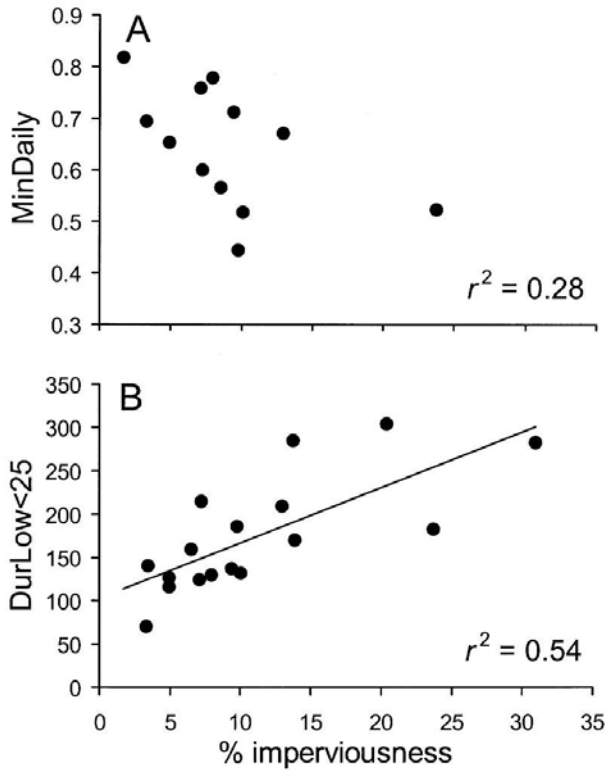
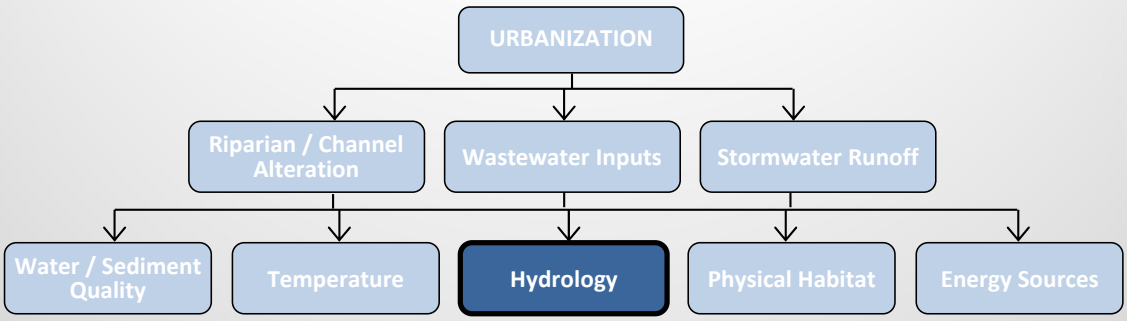


Figure 35. Linear regression models for baseflow variables showing highest correlations with subcatchment imperviousness: (A) minimum daily stage/mean daily stage during late spring; (B) maximum duration of low stage <25th percentile during autumn. Of the nine baseflow variables tested across five seasons, only these two variables showed relationships with $r^2 > 0.25$, and only in (B) was this relationship significant.

From ***Roy AH et al. 2005. Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams. Journal of the North American Benthological Society 24(3):656-678.*** **Reprinted with permission.**

Click below for more detailed information on specific topics

Baseflow in urban streams | **Water withdrawals & transfers** | **Biotic responses to urban flows**



Water withdrawals & transfers

Water withdrawals and transfers associated with meeting urban water demand can have significant repercussions for stream systems. Their effects depend upon many factors, including:

- **Where the water comes from**
  - Surface water vs. groundwater
  - Within catchment vs. imported from another catchment (i.e., water transfers)
  - Direct intake from channel vs. from water supply reservoir
  - Small vs. large streams
- **Where the water goes**
  - Within catchment vs. exported to another catchment (i.e., water transfers)
  - Small vs. large streams

Freeman & Marcinek (2006) examined how surface water withdrawals for municipal water supplies affected stream fish assemblages in the Georgia Piedmont, using a withdrawal index that represented the amount of water withdrawn on a monthly average basis, relative to the 7-day, 10-year recurrence low flow in those streams (7Q10). They found that:

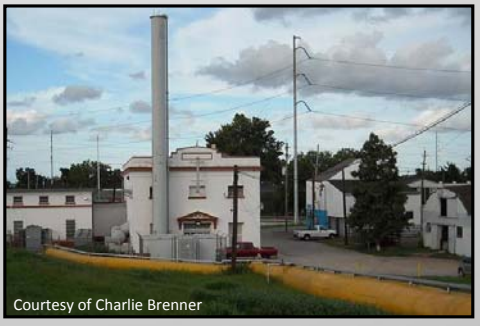
- Richness of **fluvial specialist fishes** (e.g., many minnows and darters) decreased as the amount of water withdrawn increased (Fig 36).
- This decrease generally occurred when permitted withdrawal rates exceeded approximately **0.5-1 7Q10-equivalent of water** (Fig 36).
- As water withdrawals increased, so did the **probability that sites would be classified as impaired** based on their Index of Biotic Integrity scores.
- The **type of water intake** also was important, as reservoir presence (along with withdrawal rate and drainage area) were significant predictors of fluvial specialist richness.

Click below for more detailed information on specific topics

Baseflow in urban streams | **Water withdrawals & transfers** | Biotic responses to urban flows

Water intake structure for a water supply plant on the Duck River, TN

A New Orleans pump station that withdraws water from the Mississippi River and transfers it to a nearby treatment facility



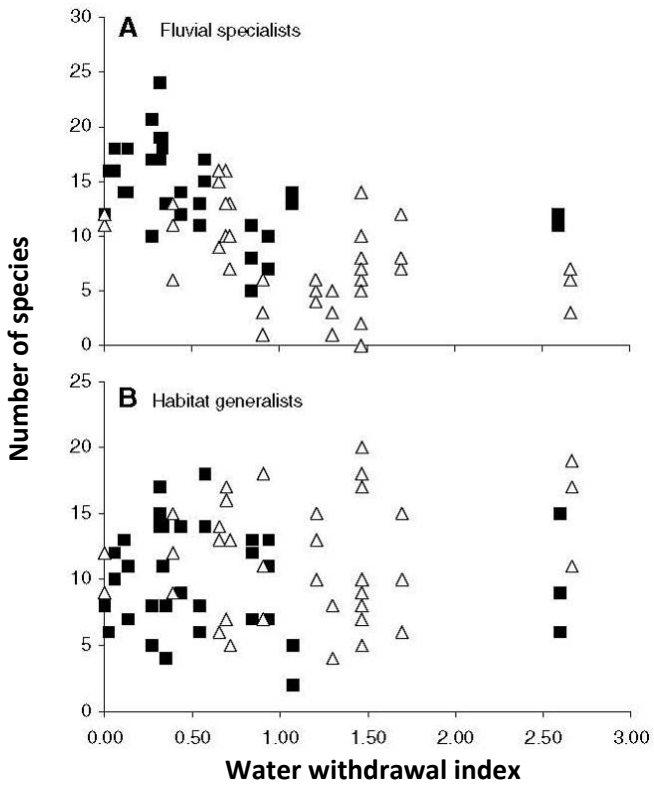
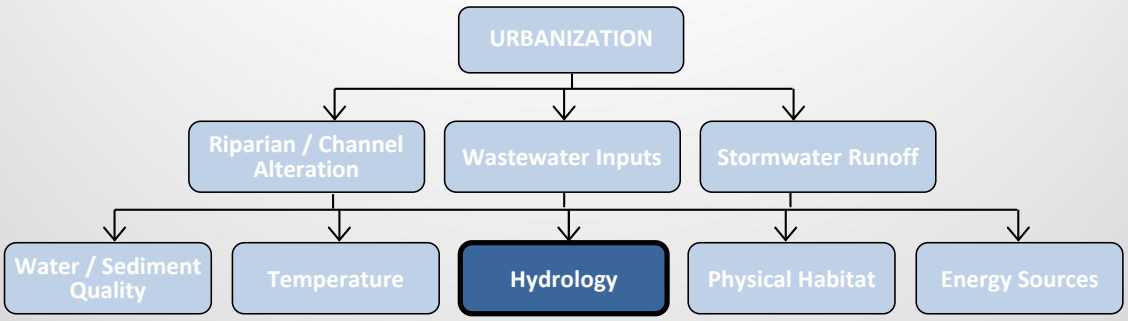


Figure 36. Richness estimates for (A) fluvial specialist and (B) habitat generalist fishes vs. water withdrawal index values [ln(permitted monthly average withdrawal / 7Q10)]. Squares indicate sites where water intake was directly from channel; triangles indicate sites directly downstream from water supply reservoirs. Data were collected in 28 Georgia streams used for municipal water supplies, 2001-2003.

From ***Freeman MC & Marcinek PA. 2006. Fish assemblage responses to water withdrawals and water supply reservoirs in Piedmont streams. Environmental Management 38(3):435-450.*** Reprinted with permission from Springer.



Biotic responses to urban flows

Hydrologic changes associated with urbanization can directly and indirectly affect stream biota in many ways. Effects may include:

- Direct scour and dislodgement from benthic surfaces due to increased peak flows
- Altered physical habitat
  - changes in in-stream hydraulic conditions (e.g., water velocity, wetted channel area and duration)
  - changes in channel geomorphology
- Life cycle disruption due to changes in timing of flows
- Other flow-associated alterations (e.g., increased sediment, nutrient and contaminant delivery; changes in food resources)


Courtesy of USEPA

For example, Booth et al. (2004) examined how benthic index of biological integrity (B-IBI) scores were related to two flow metrics associated with urbanization:

- T_{Qmean} = the fraction of a year that mean daily discharge exceeds annual mean discharge
- $T_{0.5\ yr}$ = the fraction of a multi-year period that a channel is exposed to flows greater than the 0.5-year flood

For both T_{Qmean} and $T_{0.5\ yr}$, low values indicate the prevalence high discharge peaks that both rise and dissipate sharply—that is, increased flashiness and flow variability.

Booth et al. (2004) found that:

- T_{Qmean} and $T_{0.5\ yr}$ decreased as % total impervious area increased, indicating that **urban streams experienced flashier hydrographs**.
- B-IBI scores increased as T_{Qmean} and $T_{0.5\ yr}$ increased, indicating that **macroinvertebrate biotic condition was reduced in flashier streams** (Fig 37a,b).
- Sites with ≥ 54% urban land cover fall below the main trendline, indicating that macroinvertebrate biotic condition was poorer than predicted by hydrologic conditions alone (Fig 37c).

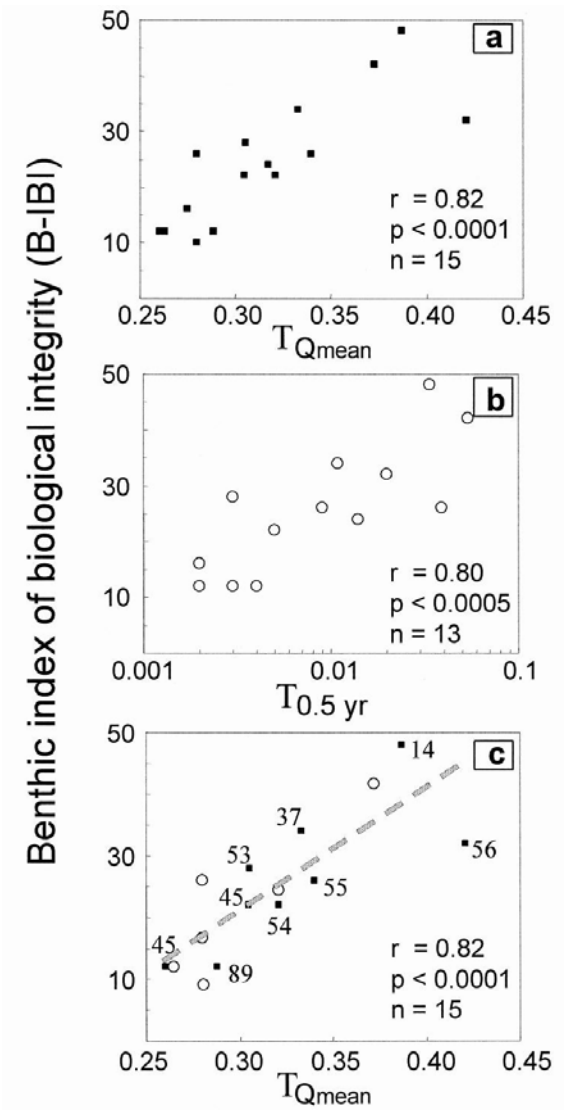


Figure 37. Relationship between benthic index of biological integrity for invertebrates and hydrologic variables T_{Qmean}(a, c) and $T_{0.5\ yr}$ (b). In (c), numbers indicate % urban land cover (sites plotted as circles lacked land cover data). Note that lower values for T_{Qmean} and $T_{0.5\ yr}$ indicate higher flow variablity and flashiness.

From *Booth DB et al. 2004. Reviving urban streams: land use, hydrology, biology, and human behavior. Journal of the American Water Resources Association 40(5):1351-1364.* Reprinted with permission.

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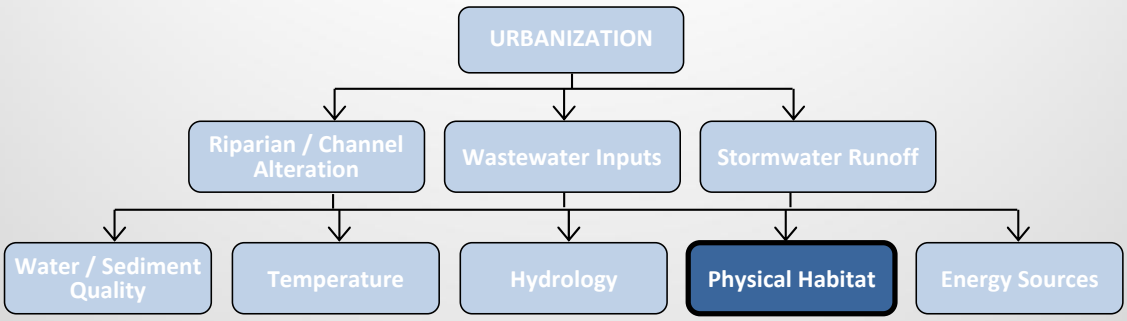
Baseflow in urban streams | Water withdrawals & transfers | Biotic responses to urban flows



Physical habitat in urban streams

Urbanization can alter the **geomorphologic and vegetative structural features of stream channels**—that is, their physical habitat.


Courtesy of USFWS

Studies have reported many physical habitat alterations associated with urbanization, including (but not limited to):

- ↑ direct channel modification (e.g., piping and burial) [Elmore & Kaushal 2008, Roy et al. 2009]
- ↑ channel enlargement [Booth & Jackson 1997, Trimble 1997, Hession et al. 2003, Chin 2006, Allmendinger et al. 2007]
- ↑ channel incision [Booth & Jackson 1997, Hardison et al. 2009]
- ↓ woody debris [Finkenbine et al. 2000, King et al. 2005, Horwitz et al. 2008]
- Δ geomorphologic units (Fig 38) [Gregory et al. 1994, Riley et al. 2005, Shoffner & Royall 2008]
- Δ streambed substrate composition (Fig 39) [Finkenbine et al. 2000, Pizzuto et al. 2000, Walters et al. 2003, Roy et al. 2005, Blakely et al. 2006]
- ↓ habitat complexity [Riley et al. 2005, Blakely et al. 2006, Gooseff et al. 2007]

See the Physical Habitat module for more general discussion of physical habitat in streams (i.e., not just urban streams).

Click below for more detailed information on specific topics

Channel enlargement | **Road crossings** | **Bed substrates & biotic condition**

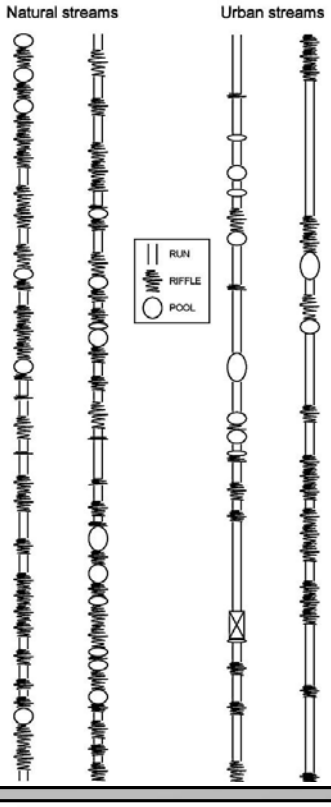


Figure 38. Schematic representation of the run, riffle and pool structure in two natural & two urban streams in southern California (the rectangle with an X in one of the urban streams represents a culvert). Urban streams had longer habitat segments, higher percentages of runs, & reduced habitat complexity.

From ***Riley SPD et al. 2005. Effects of urbanization on the distribution and abundance of amphibians and invasive species in southern California streams. Conservation Biology 19(6):1894-1907.*** **Reprinted with permission.**

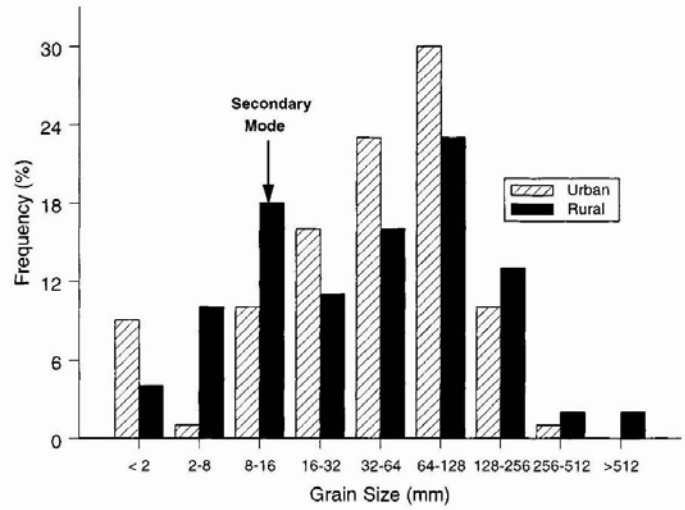
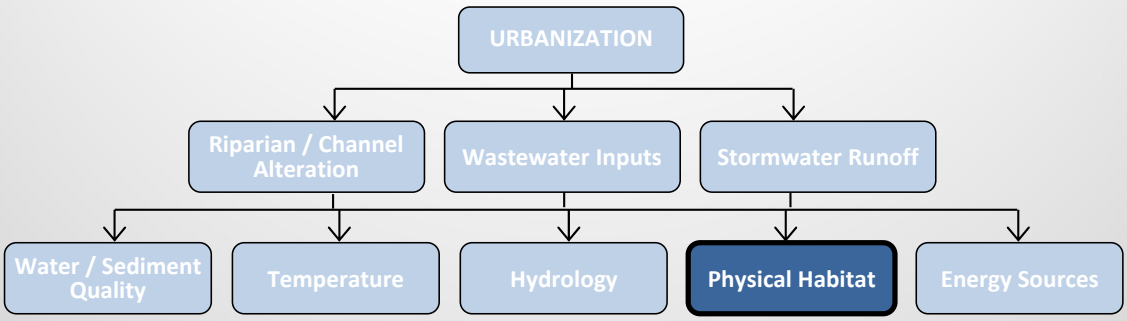


Figure 39. Typical grain-size histograms from urban and rural catchments. The frequency of < 2 mm particles more than doubled in urban streams. Rural streams had a secondary sediment size mode at 8-16 mm; this secondary mode was absent in urban channels, suggesting that these substrate sizes were selectively removed from urban streams.

From ***Pizzuto JE et al. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania. Geology 28(1):79-82.*** **Reprinted with permission.**



Channel enlargement with urbanization

Two key changes drive stream channel alterations in urban systems:

- **↑ sediment supply initially, followed by ↓ sediment supply over time**
- **↑ sediment transport capacity** (i.e., stream discharge)

Early in urban development, soil disturbance commonly increases sediment supply and leads to **channel aggradation** (Wolman 1967, Chin 2006). Once development is more established, imperviousness and stream discharge commonly increase and sediment supply decreases, leading to **channel degradation or incision** (Wolman 1967, Chin 2006). Thus, streams in urban catchments tend to widen and deepen. Trimble (1997) observed this process in Borrego Canyon Wash, CA (Fig 40), where **erosion rates downstream of an urbanizing area were 20 m^3 m^{-1} yr^{-1}**, versus 0.47 m^3 m^{-1} yr^{-1} at a less urbanized site. In lowland streams of western Washington, Booth & Jackson (1997) found that channels generally exhibited **stability thresholds** (below which there was little or no bed and bank erosion) **at 10% effective impervious area**, or at increased discharge such that 10-year discharge in a forested catchment equaled 2-year discharge under current catchment land use (Fig 41).

Channel enlargement is common but not universal in urban streams. Whether channel enlargement occurs can depend on several factors (Bledsoe & Watson 2001, Chin 2006, Colosimo & Wilcock 2007), including:

- Age and extent of urban development
- Riparian condition
- Connectedness of impervious areas and conveyance of stormwater to channel
- Degree of channel entrenchment
- Erodibility of bed and bank material

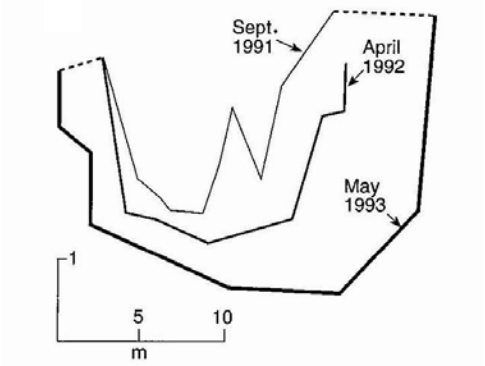


Figure 40. Surveyed stream channel cross-sections taken downstream of an urbanizing area on Borrego Canyon Wash, CA.

From ***Trimble SW. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. Science 278:1142-1144.*** **Reprinted with permission from AAAS.**

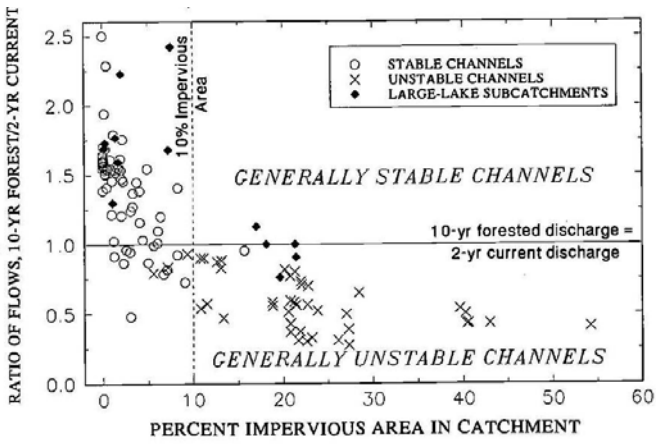
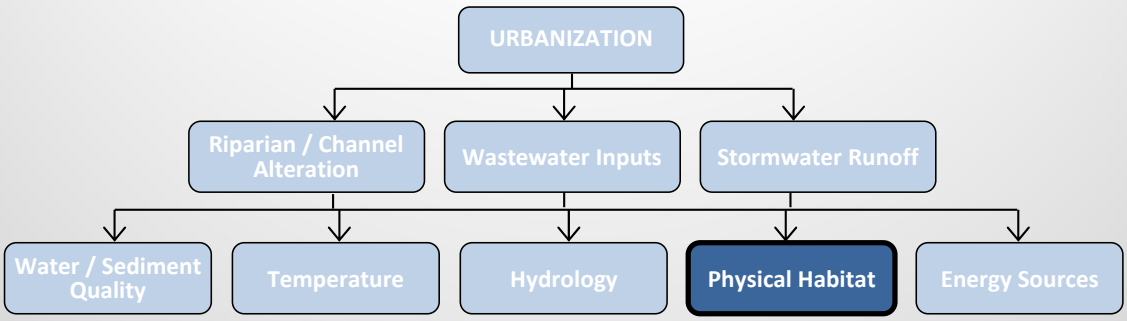


Figure 41. Observed stable and unstable channels, plotted by % effective impervious area in catchment and magnitude of simulated flow increases (ratio of modeled 10-year forested to 2-year current or urbanized discharges).

From ***Booth DB & Jackson CR. 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. Journal of the American Water Resources Association 33(5):1077-1090.***

Click below for more detailed information on specific topics

Channel enlargement | **Road crossings** | **Bed substrates & biotic condition**



Effects of road crossings

Roads can adversely affect stream ecosystems via multiple pathways. Indirect effects include:

- Altered stream discharge patterns due to increased imperviousness and stormwater runoff
- Increased contaminant loads due to accumulation on and runoff from road surfaces

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At road crossings, roads can directly impact stream ecosystems, for example by altering channel geomorphology, increasing sedimentation, and impeding fish and invertebrate movement. In addition, stormwater drains often run along roads, and road crossings frequently are points of stormwater discharge to streams. Thus, road crossing density can be a good predictor of stream biotic integrity, with **biotic condition decreasing as the number of road crossings increases** (Alberti et al. 2007, Carlisle et al. 2009).

However, not all road crossing types have the same effect. For example, Blakely et al. (2006) examined how different road crossing types affected movement of adult caddisflies in New Zealand streams. They found that **road culverts were barriers to caddisfly dispersal**: the number of adults caught immediately upstream of culvert crossings was much lower than the number caught at control sites downstream (Fig 42). Bridges, which provided more open spans over streams, did not inhibit movement. Fish movement has shown similar bridge vs. culvert patterns (Benton et al. 2008).

Example culvert (right) and bridge (below) road crossings.

Photos courtesy of Tetra Tech

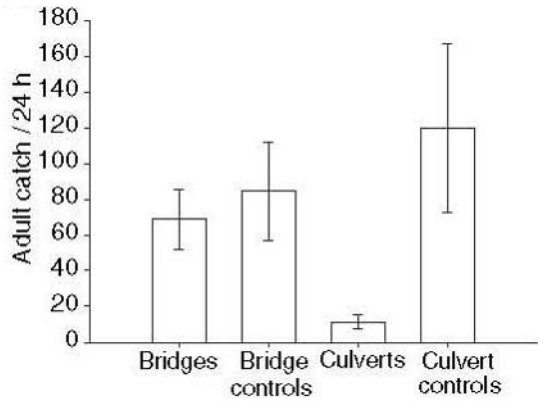
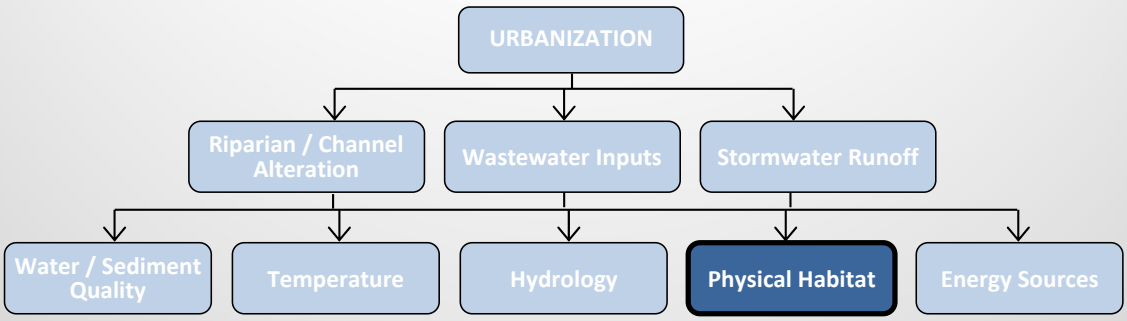


Figure 42. Number of adult caddisflies caught directly upstream of bridges and culverts (n = 8), vs. at control sites 50 m downstream.

From ***Blakely TJ et al. 2006. Barriers to the recovery of aquatic insect communities in urban streams. Freshwater Biology 51:1634-1645.*** **Reprinted with permission.**

Click below for more detailed information on specific topics

Channel enlargement | Road crossings | Bed substrates & biotic condition



Bed substrates & biotic condition

Urbanization typically affects both sediment supply and transport capacity in streams, resulting in **altered substrate composition and stability**—both of which are key factors influencing stream biotic communities (see Sediment module for further discussion of sediment as a stressor).

Many streambed substrate changes associated with urban development have been linked to changes in biotic condition, including:

- **↑ fine sediment**
  [Hogg & Norris 1991, Morley & Karr 2002, Roy et al. 2005, Taulbee et al. 2009, Walters et al. 2009]
- **↑ embeddedness and armoring**
  [Borchardt & Statzner 1990, Blakely et al. 2006, Chin 2006, Walters et al. 2009]
- **↓ substrate stability**
  [Pedersen & Perkins 1986]
- **↓ substrate complexity and heterogeneity**
  [Morley & Karr 2002, Blakely et al. 2006]

For example, Morley & Karr (2002) found that invertebrate biotic integrity (B-IBI) scores and taxa richness metrics **increased with substrate size and roughness**, but that these substrate parameters **decreased with urbanization** (Table 7).

However, fine sediments are not always higher in urban streams. Fines may be scoured from these systems as stream discharge increases with impervious cover, resulting in **coarser, more armored streambeds** (Chin 2006).

Sediment increases related to urbanization also can have indirect effects on stream biota, via **sediment-associated contaminants**. Urban sediments can contain high concentrations of metals, organics, & other toxics, & these compounds can adversely affect biotic condition (see Water & Sediment Quality).

Increased erosion and sediment runoff from disturbed soils.

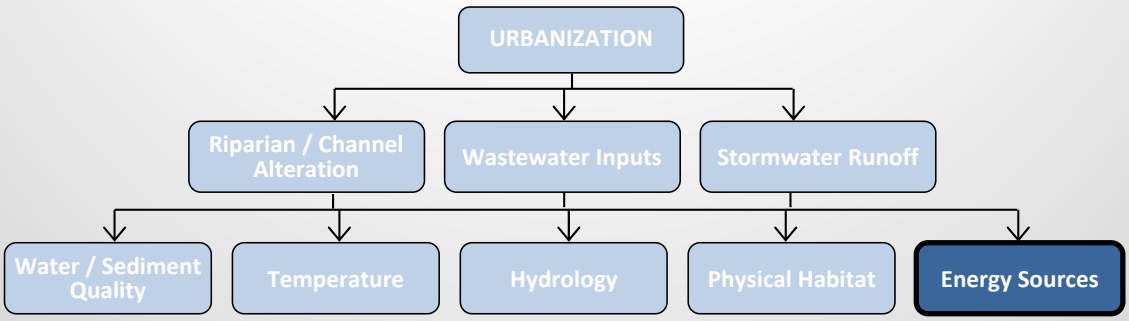
Table 7. Spearmen rank correlation coefficients for associations of urbanization and macroinvertebrate biotic condition parameters with substrate measures. D_{16} and D_{50} refer to the substrate diameter below which 16% and 50% of particles are smaller, respectively; roughness was calculated as the 84% particle diameter divided by bankfull depth. Coefficients in italics had $p < 0.10$; coefficients in bold had $p < 0.05$.

PARAMETER	SUBSTRATE MEASURE		
	D_{16}	D_{50}	Roughness
Urbanization, *n*	17	17	17
% sub-basin	-0.20	-0.35	**-0.60**
% local	-0.12	*-0.49*	**-0.70**
Biotic condition, *n*	18	18	18
B-IBI	+0.27	+0.12	**+0.51**
Total taxa richness	+0.34	+0.17	*+0.43*
EPT richness	**+0.59**	*+0.41*	**+0.50**
Clingers richness	**+0.60**	+0.39	**+0.52**

After *Morley SA & Karr JR. 2002. Assessing and restoring the health of urban streams in the Puget Sound basin. Conservation Biology 16(6):1498-1509.*

Click below for more detailed information on specific topics

Channel enlargement | Road crossings | Bed substrates & biotic condition



Urbanization & basal energy sources

There are two main sources of fixed energy that drive stream food webs:

- Organic carbon produced by **photosynthesis outside the stream**, or allochthonous production
- Organic carbon produced by **photosynthesis within the stream**, or autochthonous production

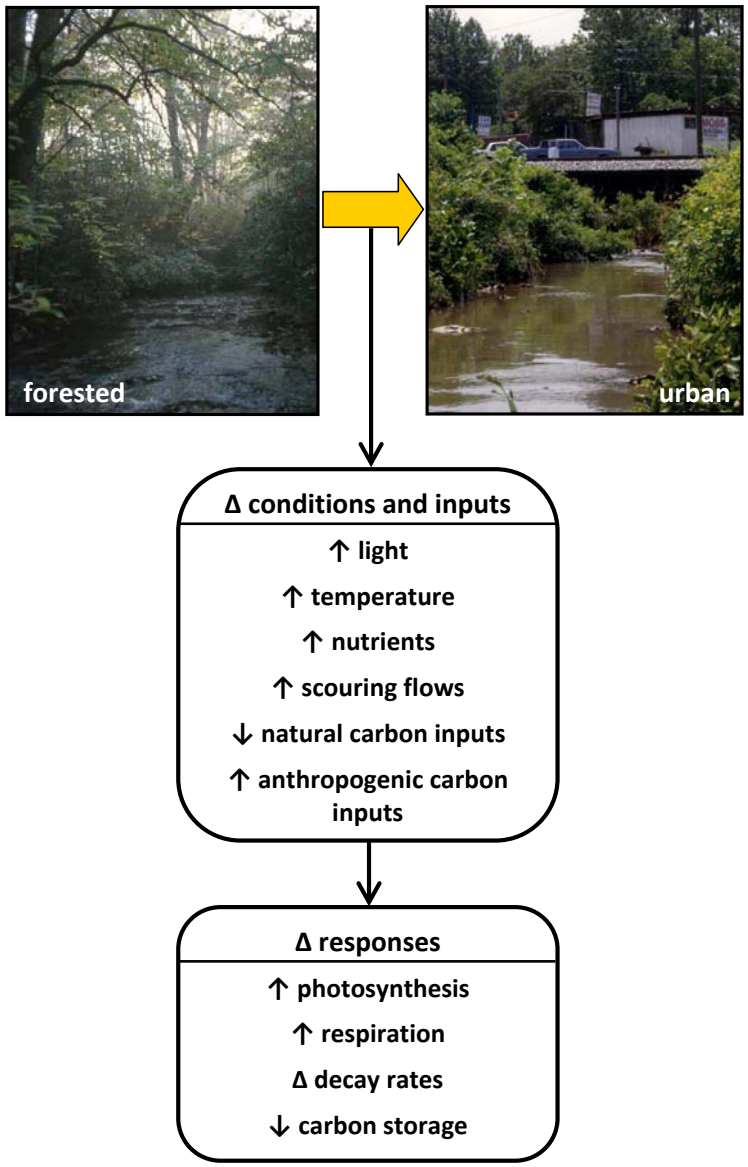
Most streams rely on both allochthonous and autochthonous energy, although the relative importance of each varies with elevation, stream size and other factors. For example, terrestrial carbon is more important in forested headwater streams, whereas autochthonous carbon is more important in open-canopied, mid-sized rivers.

Urbanization alters the energy sources available to stream food webs, as well as the in-stream retention and storage of those basal resources. Key changes associated with urbanization are summarized at right; examples include:

- Increased riparian deforestation, resulting in:
  - increased light and algal production
  - decreased terrestrial litter and wood inputs
- Increased nutrient enrichment, resulting in increased algal production and microbial respiration
- Increased input of sewage-derived particulate organic matter
- Decreased algal biomass, due to scouring flows
- Changes in the relative importance of physical vs. biological factors in determining leaf decay rates

---

Changes in resources can result in changes in the consumer community. For example invertebrate functional feeding groups may change: reduced leaf litter may lead to few shredder invertebrates; increased algal production may lead to increased scrapers; and increased input of particulate organic matter may lead to increased filterers. However, these changes often are mitigated by concurrent changes in habitat and water quality.



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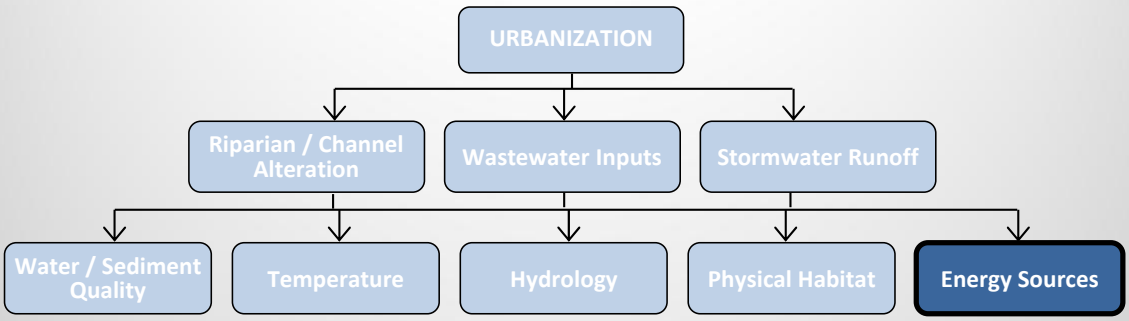
Terrestrial leaf litter | Primary production & respiration | Quantity & quality of DOC



Terrestrial leaf litter inputs & retention

Urbanization can alter terrestrial leaf litter inputs and retention in several ways. Reported effects include:

- ↓ **leaf litter inputs** resulting from riparian alteration and stream burial
  [Carroll & Jackson 2008]
- ↑ **leaf litter inputs** due to increased horizontal delivery (e.g., via stormdrains)
  [Miller & Boulton 2005, Carroll & Jackson 2008]
- **Δ type and timing of inputs** due to changes in riparian taxa
  [Imberger et al. 2008, Roberts & Bilby 2009]
- ↓ **leaf litter retention** due to scouring by high flows and reductions in debris dams
  [Paul & Meyer 2001]

Terrestrial leaf litter processing

Urbanization alters several variables that influence leaf decay, leading to variable effects of urban development on decomposition rates. Reported findings include:

- ↑ **leaf decomposition rates** related to:
  - ↑ **physical abrasion** by high flows
    [Paul et al. 2006, Chadwick et al. 2006]
  - ↑ **snails**
    [Chadwick et al. 2006]
  - ↑ **microbial activity** resulting from ↑ nutrient concentrations and temperatures (Fig 43)
    [Chadwick et al. 2006, Imberger et al. 2008]
- ↓ **leaf decomposition rates** related to:
  - ↓ **shredders**
    [Chadwick et al. 2006, Paul et al. 2006, Carroll & Jackson 2008]
  - ↓ **microbial activity**
    [Paul et al. 2006]
  - ↑ **metal contamination**
    [Woodcock & Huryn 2005, Chadwick et al. 2006]

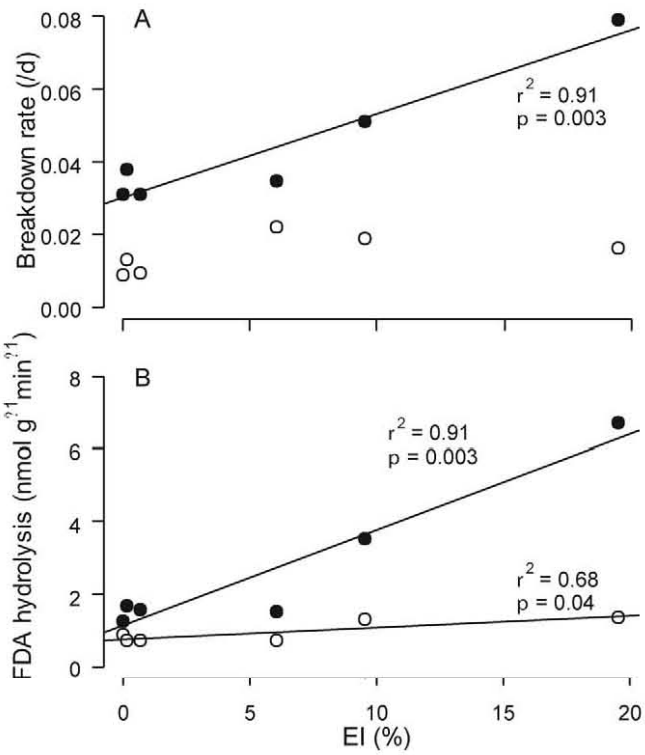
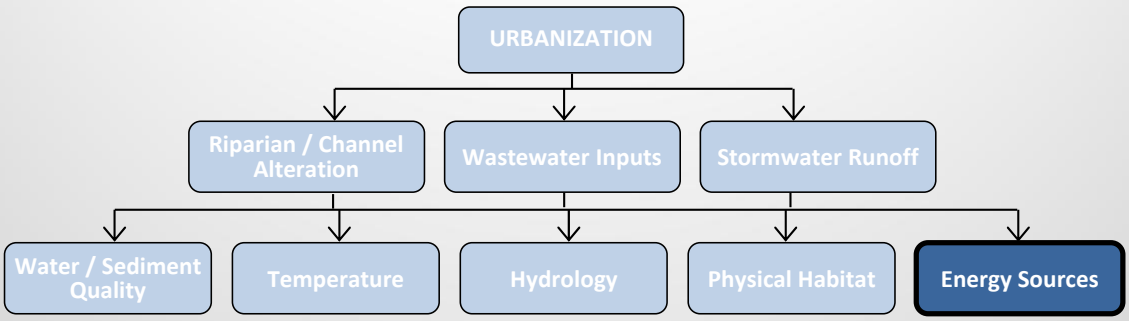


Figure 43. ***Pittosporum undulatum*** **(closed circles) and** ***Eucalyptus obliqua*** **(open circles) leaf breakdown rates (A) and microbial activity in leaves, estimated by fluorescein diacetate (FDA) hydrolysis (B), vs. % effective imperviousness (EI). Breakdown rates and microbial activity increased with % EI for the more readily transformed leaf litter of introduced** ***Pittosporum*****, but effects on native** ***Eucalyptus*** **were minimal.**

From ***Imberger SJ et al. 2008 More microbial activity, not abrasive flow or shredder abundance, accelerates breakdown of labile leaf litter in urban streams. Journal of the North American Benthological Society 27(3):549-561.*** **Reprinted with permission.**

Click below for more detailed information on specific topics

Terrestrial leaf litter | **Primary production & respiration** | **Quantity & quality of DOC**



Primary production & respiration

Primary production, or the fixation of inorganic carbon into organic carbon (e.g., plant biomass), provides most of the autochthonous carbon produced in streams. Algae are usually the dominant stream primary producers, although other plants (e.g., macrophytes, mosses) also may be important in certain systems.

Effects of urbanization on algal biomass and primary production may include:

- **↑ primary production or algal biomass** (Fig 44, Table 8) resulting from:
  - ↑ nutrients
  - ↑ light and temperature
  - ↓ grazers
- **↓ primary production or algal biomass** resulting from:
  - ↑ scouring due to high flows
  - ↑ fine sediment and ↓ sediment stability
  - ↑ toxic pollutants
  - ↑ grazers
- **Δ assemblage structure**


Courtesy of Tetra Tech

Many of the factors influencing primary production in urban streams also affect respiration. **Respiration does not always show a clear pattern with urbanization, but often is elevated in streams receiving wastewater discharges** (Gücker et al. 2006 [Table 8], Wenger et al. 2009). These increases in respiration can lead to **large oxygen fluctuations and oxygen deficits** in urban streams (Faulkner et al. 2000, Ometo et al. 2000, Gücker et al. 2006 [Table 8]).

Click below for more detailed information on specific topics

Terrestrial leaf litter | **Primary production & respiration** | Quantity & quality of DOC

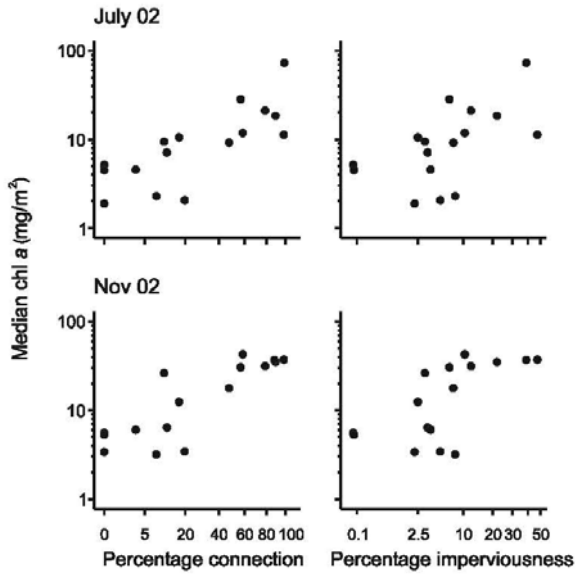


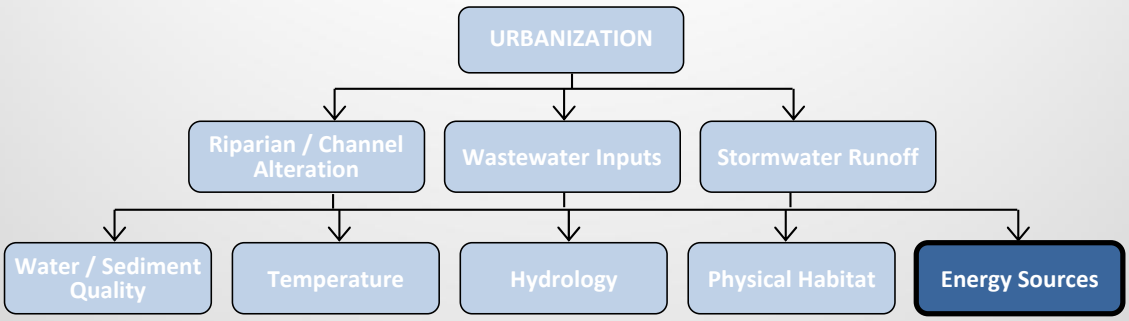
Figure 44. Median chlorophyll *a* at 16 Australian streams on 2 sampling dates, vs. % drainage connection and % imperviousness; % connection (but not % imperviousness) explained a significant amount of variation in chlorophyll *a* in both sampling periods.

From ***Taylor SL et al. 2004. Catchment urbanisation and increased benthic algal biomass in streams: linking mechanisms to management. Freshwater Biology 49:835-851.*** Reprinted with permission.

Table 8. Gross primary production (GPP) and community respiration (CR_{24}), both measured in g O_2 m^{-2} d^{-1}, at an upstream reference site and a downstream wastewater-impacted site on a lowland stream in Germany.

SEASON	PARAMETER	UPSTREAM	DOWNSTREAM
SPRING	GPP	2	2
	CR_{24}	11	24
	GPP:CR_{24}	0.15	0.10
SUMMER	GPP	32	47
	CR_{24}	32	59
	GPP:CR_{24}	1.0	0.8
WINTER	GPP	0.1	< 0.1
	CR_{24}	6	18
	GPP:CR_{24}	0.01	< 0.01

Modified from *Gücker B et al. 2006. Effects of wastewater treatment plant discharge on ecosystem structure and function of lowland streams. Journal of the North American Benthological Society 25(2):313-329.*



Quantity & quality of dissolved organic carbon (DOC)

DOC can play an important role in many streams—for example, by providing a key energy source for stream food webs via bacterial assimilation, or by influencing the bioavailability of metals and other toxics.

Urbanization can affect both the quantity and quality of DOC in streams. Point (e.g., wastewater discharges) and non-point (e.g., impervious surfaces, turf grass) sources can contribute DOC to urban streams. Riparian/channel alteration can alter DOC inputs and processing. In many cases, the quality of these DOC resources will vary.

For example, Harbott & Grace (2005) used bacterial extracellular enzyme activity to examine how urbanization affects DOC bioavailability. They found that:

- DOC concentrations **increased with catchment effective imperviousness** (EI) (Fig 45)
- The activity of individual enzymes varied with EI, indicating **changes in DOC sources** (and thus bioavailability) with urban development
  - In **less urbanized streams**, DOC sources were **more diverse** and more dependent on **microbial detrital material**
  - In **more urbanized streams**, DOC sources were more dependent on **peptides**, perhaps due to processing of **filamentous algae**

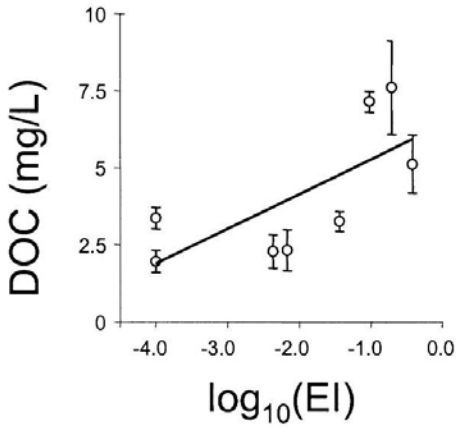


Figure 45. Relationship between catchment effective imperviousness (EI) and dissolved organic carbon (DOC) concentration in eight streams east of Melbourne, Australia (r^2 = 0.05, p = 0.051).

Reprinted with permission from ***Harbott EL & Grace MR. 2005. Extracellular enzyme response to bioavailability of dissolved organic C in streams of varying catchment urbanization. Journal of the North American Benthological Society 24(3):588-601.***

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Terrestrial leaf litter | Primary production & respiration | Quantity & quality of DOC

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