National Water-Quality Assessment Program

Effects of Urban Development on Stream Ecosystems along the Front Range of the Rocky Mountains, Colorado and Wyoming

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The U.S. Geological Survey (USGS) conducted a study from 2002 through 2003 through its National Water-Quality Assessment (NAWQA) Program to determine the effects of urbanization on the physical, chemical, and biological characteristics of stream ecosystems along the Front Range of the Rocky Mountains. The objectives of the study were to (1) examine physical, chemical, and biological responses at sites ranging from minimally to highly developed; (2) determine the major physical, chemical, and landscape variables affecting aquatic communities at these sites; and (3) evaluate the relevance of the results to the management of water resources in the South Platte River Basin.

How can urban development affect stream ecosystems?

As land areas urbanize, stream ecosystems can be substantially altered. Impervious surfaces—surfaces that are impenetrable to water, such as parking lots, rooftops, and paved roads—can prevent rainfall from infiltrating into soil and ground water, leading to increased runoff to streams. With rainfall moving to streams more quickly and in greater amounts, streamflow conditions can change more rapidly, the peak streamflows may be higher, and flooding may occur more frequently in urban areas (U.S. Environmental Protection Agency, 1997). Increased runoff to streams often leads to changes in water quality as well. Runoff can transport contaminants to streams from a variety of urban sources, including automobiles (hydrocarbons and metals); rooftops (metals); wood treated with preservatives (hydrocarbons); construction sites (sediment and any adsorbed contaminants); and golf courses, parks, and residential areas (pesticides, nutrients, bacteria) (Pitt and others, 1995). In addition, stream channels in urban areas can be straightened, deepened, and widened from their natural states to promote drainage and prevent flooding (Klein, 1979). Commercial, residential, and industrial development commonly involves soil disturbance, which can lead to increased movement of sediment to the stream, and the removal of vegetation on the streambank, which can lead to loss of sheltered areas and stream canopy cover (Jacobson and others, 2001). The loss of stream canopy cover in turn can lead to greater daily changes in stream temperature (Sinokrot and Stefan, 1993).

These changes in stream hydrology, water quality, physical habitat, and stream temperature in urbanizing areas can have profound effects on aquatic communities of algae, invertebrates, and fish. Periods of high streamflow can eliminate some aquatic organisms, particularly in channelized streams where refuge (seclusion and rest) areas such as boulders and woody debris are lacking (Winterbourn and Townsend, 1991). In addition, higher streamflows are associated with increased movement of sediment to streams, which can affect aquatic communities by decreasing light penetration and photosynthesis and degrading stream-bottom habitat (Waters, 1995). Higher contaminant concentrations and stream temperatures can adversely affect growth, reproduction, species competition, and disease progression within aquatic communities (Fitzgerald and others, 1999; LeBlanc and others, 1997).

How did the U.S. Geological Survey study the effects of urban development?

Most previous studies of stream ecosystems have focused on either pristine areas or highly developed areas; little is known about how the gradual progression of urban development between these two extremes affects stream ecosystems. To address this, the USGS conducted a study from 2002 through 2003 through its NAWQA Program to determine the effects of urban development on the physical, chemical, and biological characteristics of stream ecosystems in the South Platte River Basin. The 28 study streams are located along the Front Range of the Rocky Mountains in the transition zone between the mountains and the plains. Study streams were chosen to represent (1) a wide range in the degree of urban development and (2) minimal natural variability due to factors such as geology, elevation, and climate, which can also affect stream ecosystems and therefore mask the effects of urban development. Stream locations that are strongly affected by wastewater-treatment-plant discharge were not included in this study. Because land use or population density alone often is not a complete measure of urban development, the degree of urban development in each drainage area was represented by a multimetric urban intensity index derived from 16 variables, including land use and land cover (such as developed area), infrastructure (such as road density), and socioeconomic (such as housing density) variables. Stream sites included in this study covered an urban land-use gradient from minimal development (urban intensity index = 0) to a very high degree of development (urban intensity index = 100) in the drainage area (fig. 1).

The objectives of the study were to (1) examine physical, chemical, and biological responses along the gradient of urban development; (2) determine the major physical, chemical, and landscape variables affecting the structure of aquatic communities; and (3) evaluate the relevance of the results to the management of water resources in the South Platte River Basin.

Physical characteristics included habitat, measured once between July and August 2003, and stream hydrology and

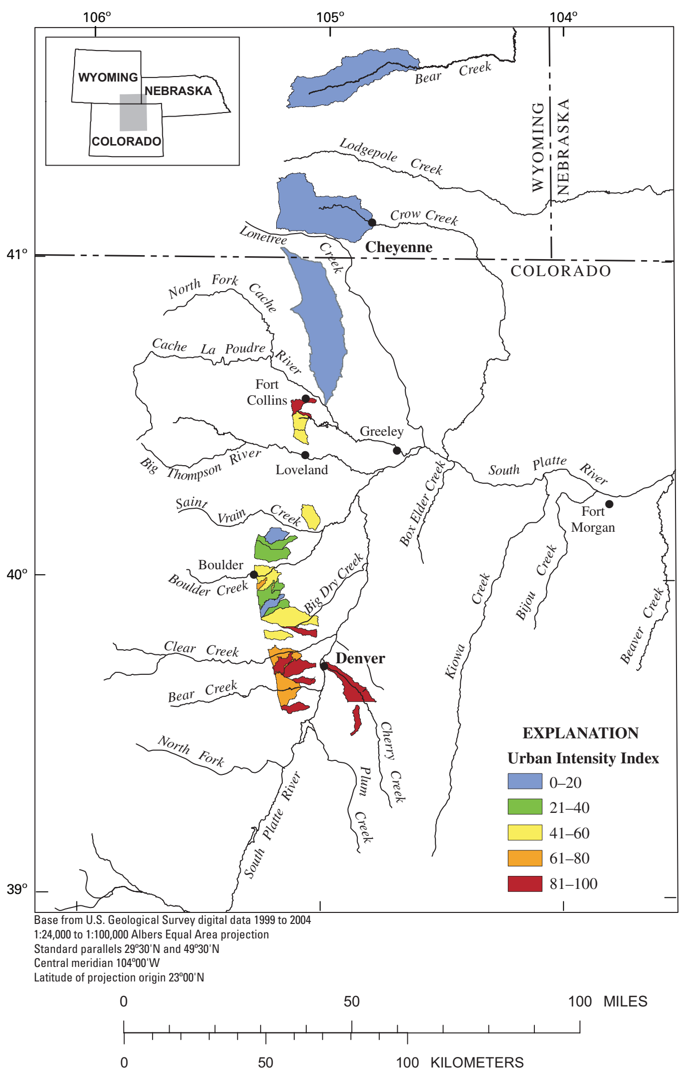

Figure 1. Location and range of urban-intensity index values of the 28 study streams.

water temperature, measured on an hourly basis throughout the study. Chemical characteristics included nutrients, pesticides, major ions, and fecal bacteria, measured twice each during base-flow conditions in June and August 2003, and hydrophobic organics collected from semipermeable membrane devices (SPMDs). SPMDs are passive samplers that were placed in each stream for 4 to 6 weeks between May and June 2003 to concentrate trace levels of hydrophobic organic contaminants like polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). The chemicals concentrated in the SPMDs were analyzed for concentration and potential toxicity. Biological characteristics included algae and invertebrate communities, measured once during June 2003, and fish communities, measured once during August 2003. In all, 52 urban variables (including the urban intensity index), 153 physical variables (including 53 habitat, 50 stream hydrology, and 50 stream temperature variables), 225 chemical variables (including 96 base-flow and 129 SPMD variables), and 75 biological variables (including 19 algae, 30 invertebrate, and 26 fish variables) were included in the study.

Major Findings

Commonly observed effects of urban development on physical, chemical, and biological characteristics of stream ecosystems, such as increased flashiness (more rapid rise and fall of stream levels during and after storms), higher and more frequent peak flows, increased concentrations of chemicals, and changes in aquatic communities, generally were not observed in this study.

Physical Characteristics

Only one strong relation was found between the physical characteristics (stream hydrology, temperature, and habitat) and measures of urban development—decreases in stream temperatures occurred more rapidly as the percentage of high-intensity development near the stream increased (fig. 2). In urbanizing areas, inputs of ground water to the stream can decrease as more impervious surfaces are created. Because ground-water temperatures generally fluctuate less than stream temperatures, inputs of ground water can moderate stream temperatures; thus, with less ground water entering the stream, stream temperatures may be falling more quickly.

None of the hydrology variables were related to any of the fish variables, and only a small number of the hydrology variables were strongly related to a few of the invertebrate and algae variables—increased flashiness and higher peak streamflows were related to changes in algae and invertebrate communities associated with still-water habitats. During high streamflows, organisms living in still-water habitats can be carried downstream in faster moving water. When periods of high streamflow occur more often in flashier streams, it can be difficult for organisms that prefer still-water habitats to persist.

None of the habitat or stream-temperature variables were strongly related to any of the invertebrate, algae, or fish community variables.

Chemical Characteristics

Only two base-flow chemicals measured in August were strongly related to measures of urban development—sulfate concentrations increased in more rapidly growing areas and suspended-sediment concentrations decreased as housing age increased (fig. 2). The increasing sulfate concentrations may have been due to increased use of and runoff from impervious areas such as roads in urbanizing areas. The decreasing sediment concentrations may have resulted from stabilization of the land surface in older communities, where more mature vegetation and lack of land disturbance from new construction may decrease the amount of sediment in runoff.

In June, none of the base-flow chemicals were strongly related to any measure of urban development. Snowmelt runoff in the larger study streams originating in the mountains occurs during June, increasing streamflows throughout the month; smaller study streams originating in the plains have much lower streamflows during this month. This natural variability in hydrologic conditions likely contributed to the lack of clear relations between urban development and water chemistry in June.

Of the 129 SPMD-based measures of concentration and potential toxicity, only 5 were detected often enough at the study sites to compare to measures of urban development. Three of those five (concentrations of the PAHs pyrene and fluoranthene and a measure of potential toxicity from a group of chemicals including PCBs, PAHs, dioxins, and furans) were strongly related to nearly one-half of the urban variables. The most important urban variable describing the pattern of the response in potential toxicity and PAH concentrations was distance from the stream site to the nearest road, indicating that automobile exhaust is most likely the largest source of the PAHs fluoranthene and pyrene in the study area.

Automobile sources may be localized enough that the transport of PAHs to the study sites would have been minimally affected by water management (diversions, transfer between stream basins, and reservoir storage and release) upstream, whereas the transport of chemicals like nutrients and pesticides from more dispersed upstream sources may have been subject to greater disruption by water management. The stronger response of SPMD-based measures of PAH concentration and potential toxicity to urban development also may be a result of the SPMD deployment period; during the 4-to-6 week deployment, the SPMDs were exposed to multiple storm-runoff events. In contrast, nutrient, pesticides, major ions, and fecal bacteria were measured on two single days during base-flow conditions.

Although there were very few strong relations between chemistry variables and urban development, nutrient, pesticide, and major ion concentrations in base-flow were strongly related to biological community response (fig. 2). Fish communities were related to the amount of fine suspended sediment and chloride concentrations. Suspended sediment can damage stream habitat, clog gills, and bury eggs, factors that may have contributed to the observed decrease in the total number of fish species present as suspended-sediment concentrations increased. The amount of algae increased as total nitrogen and nitrite plus nitrate concentrations increased, likely because algae require nitrogen for growth. Invertebrate communities were related to total nitrogen, nitrite plus nitrate, and total herbicide concentrations. As nitrogen and herbicide concentrations increased, fewer sensitive invertebrate species were present, indicating that increased nutrient and herbicide concentrations adversely influenced invertebrate communities in the study streams.

Biological Characteristics

Only one fish variable was strongly related to measures of urban development—the percentage of fish that consume insects and plant material decreased as the percentage of housing over 60 years old increased (fig. 2). As previously described, fish communities also were related to the amount of fine suspended sediment and chloride concentrations. None of the algae or invertebrate variables was strongly related to any measure of urban development. Instead, also as described, the amount of algae was related to total nitrogen concentrations, nitrite plus nitrate concentrations, and the duration of high streamflows, and invertebrate communities were related to the

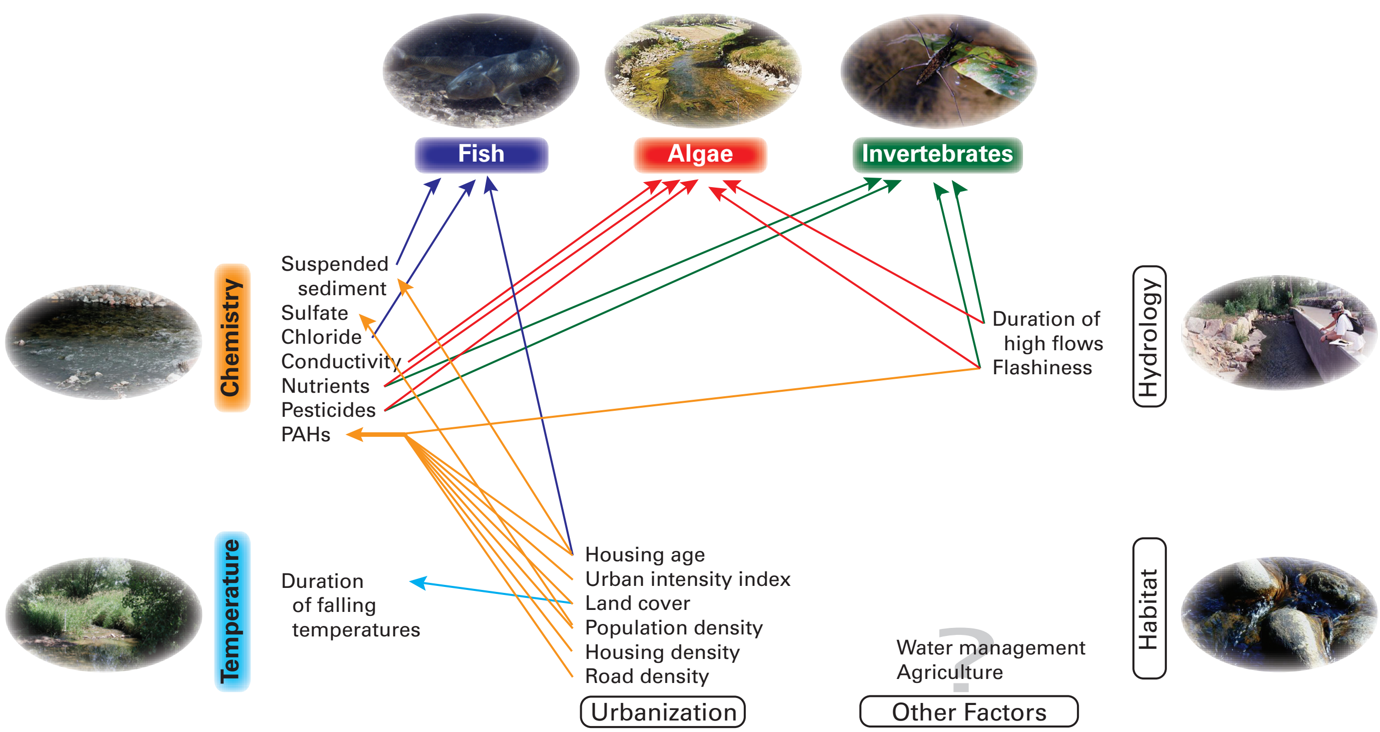

Figure 2. Relations between 52 urban variables, 225 chemistry variables, 50 hydrology variables, 53 habitat variables, 50 stream-temperature variables, 26 fish variables, 19 algae variables, and 30 invertebrate variables were examined. The strong relations are indicated in this diagram. ?, relations unknown. Fish photograph by Jeremy Monroe, Freshwaters Illustrated. Used with permission.

frequency of rising and falling streamflow, the duration of high streamflows, total nitrogen concentrations, nitrite plus nitrate concentrations, and total herbicide concentrations (fig. 2).

How does the Front Range compare to other parts of the world?

Urban development has been established as a significant stressor on stream ecosystems in many parts of the world. In this study, the link between urban development and stream ecosystems was not found to be as strong in transition-zone streams along the Front Range of Colorado and Wyoming. Under natural conditions, aquatic communities in streams in the plains typically are more tolerant than those in less extreme habitats (Matthews, 1986), but historical records indicate that aquatic communities in these streams were more diverse before the advent of irrigated agriculture, localized pollution events, and water management (Jordan, 1891; Ellis, 1914). Human changes such as streamflow modifications and habitat alterations have occurred for nearly 150 years in the study area (Fausch and Bestgen, 1997, and citations within). Early surveys noted impaired aquatic communities in this region as early as 1900 (Ellis, 1914), and historical evidence from the past 150 years indicates that several species no longer exist at certain locations (Kondratieff and Baumann, 2002; Cordeiro, 1999; Fausch and Bestgen, 1997; McCafferty and others, 1993). Present-day aquatic communities are composed primarily of tolerant species even in areas of minimal urban development; when development does occur, these communities may already be resistant to disturbance. The effects of urban development on stream ecosystems are stronger in other parts of the world, where development may occur in areas with previously undisturbed and more sensitive aquatic communities.

In addition to the effects of historical stressors on aquatic community structure, it is possible that current (2006) water-management practices in the study basins are having an effect. In the absence of natural, unaltered hydrologic conditions, more sensitive taxa may be unable to reestablish in transition-zone streams. In addition, the movement and storage of water may lead to a disconnect between the land surface and streams, resulting in in-stream physical, chemical, and biological characteristics that are to some degree independent of land-cover characteristics.

The lack of a strong link between urban development and stream ecosystem response in transition-zone streams along the Front Range does not mean that urban development has no effect on stream ecosystems in this region. Rather, it is likely that these ecosystems are affected by multiple interacting stressors, including but not limited to urban development, agriculture, and water management. Maintenance or protection of stream ecosystems likely will involve supplementing the best management practices currently used in urbanizing areas with additional steps to mitigate the effects of other stressors that may be as or more important. Identifying the most important stressors ultimately will allow for better management of stream ecosystems in the face of continued urban development.

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URL: http://pubs.water.usgs.gov/SIR2006–5101A/

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