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Title

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Permalink

<https://escholarship.org/uc/item/27n1v8hw>

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Publication Date

2008-04-01

DOI

10.3733/ucanr.8279

Peer reviewed



Living among the Fish

A Guide to Conservation of Fish Habitat in the Developed Landscape

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California's population is forecast to increase by between 8 and 11 million people within the next 15 years. Residential and commercial development to accommodate this additional population is projected to occupy an additional 373,000 acres of currently undeveloped land in California. This will increase California's urban footprint by 27 percent in 38 counties (Landis and Reilly 2004).

Urbanization has profound impacts on aquatic habitat. Nationwide, almost 81,000 miles of stream have been altered by urbanization, making it second only to agriculture as a cause of stream impairment (EPA 2000). Even modest amounts of urbanization can have adverse effects on fish and their habitats (Paul and Meyer 2001).

California streams and tributaries once supported large populations of coho and Chinook salmon, as well as steelhead and cutthroat trout. That is no longer the case, and several strains of California salmon and steelhead are listed as threatened or endangered under the state and federal Endangered Species Acts. Efforts are underway to develop recovery strategies for salmon and steelhead, but in the meantime human population growth and associated urban development continue to degrade fish habitat both directly and indirectly by changing natural watershed and stream processes.

Some potential impacts of development can be reversed or avoided by exercising informed judgment during the planning and review of proposed projects. The purpose of this publication is to provide guidance to public and private planners and decision makers on how to protect aquatic habitat during land development. Suggestions are also provided on ways to reverse impacts that have already occurred. Although the primary audience for this publication is planners, many of the principles and recommendations will be helpful to others, including land owners, homeowners, and environmental activists.

COLD WATER FISHERIES IN CALIFORNIA

The focus of this publication is on cold-water fish, mainly salmon and trout (salmonids). These are widely distributed throughout California and use freshwater, estuarine, and marine habitats. Salmonids are common in small and large perennial (permanent) streams and are also found in lakes and ponds, particularly at higher elevations with cool summer temperatures. Salmonids prefer aquatic habitats with year-round water temperatures below 68°F, high levels of dissolved oxygen, clear water, and in the case of streams, a stony or gravelly substrate. While fish such as steelhead may be able to withstand higher temperatures for short periods of time, they still require cooler temperatures for optimal growth and survival. Salmonids may inhabit streams with sections that go dry during the summer, or in which lower reaches become excessively hot, by moving to cooler upstream areas that stay wet all year.

Warm-water fish can tolerate higher water temperatures, up to 80°F (even more for short periods), lower oxygen, and mud bottoms. Typical warm-water fish include bass, perch, and catfish. Warm-water fish are commonly found in ponds, lakes, and large streams. They may coexist and compete with cold-water fish in warmer, lower-velocity sections of streams. Warm-water fish may also be found in places where increases in temperature and decreases in water quality have excluded cold-water fish.

SALMONID BIOLOGY

Four salmonid species in California are anadromous, meaning that they spend part of their time in fresh water and part in the ocean. These are the Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), coastal cutthroat trout (*O. clarki clarki*), and steelhead (the anadromous form of rainbow trout, *O. mykiss*). In recent years, chum salmon (*O. keta*) have also been found in California, even though their natural range was thought to be further north.

Salmonid life cycles are complicated and vary from species to species (Thompson and Larsen 2004). In general, salmonids have six important life stages: eggs, alevin, fry, juvenile, smolt, and adult (fig. 1). Adults migrate back from the ocean to their birth streams to spawn. Eggs are deposited and buried by the spawners in gravel nests called redds. The eggs incubate within the redd and hatch in 1 to 3 months.

The resulting alevin rear in the gravel for 1 to 5 months, until they have used up their yolk supply. They then emerge from the gravel as fry. The timing of fry emergence is determined by water temperature during incubation. Normally, fry emerge in the spring, and, depending on the species and stock, juveniles can remain in freshwater streams or lakes from a few days to several years before becoming smolts that migrate to the ocean.

Chinook salmon stocks vary considerably in the length of freshwater rearing they require, a built-in flexibility that can limit the degree to which habitat or flow changes can impact this species. Coho salmon typically remain in their stream-rearing habitat for up to a year after emerging from the redd. Then they spend 2 years in the ocean before returning to fresh water to spawn and die at age 3. Young cutthroat trout spend up to 2 years in fresh water before migrating to the ocean. Those found above migration barriers on coastal streams live out their lives in fresh water.

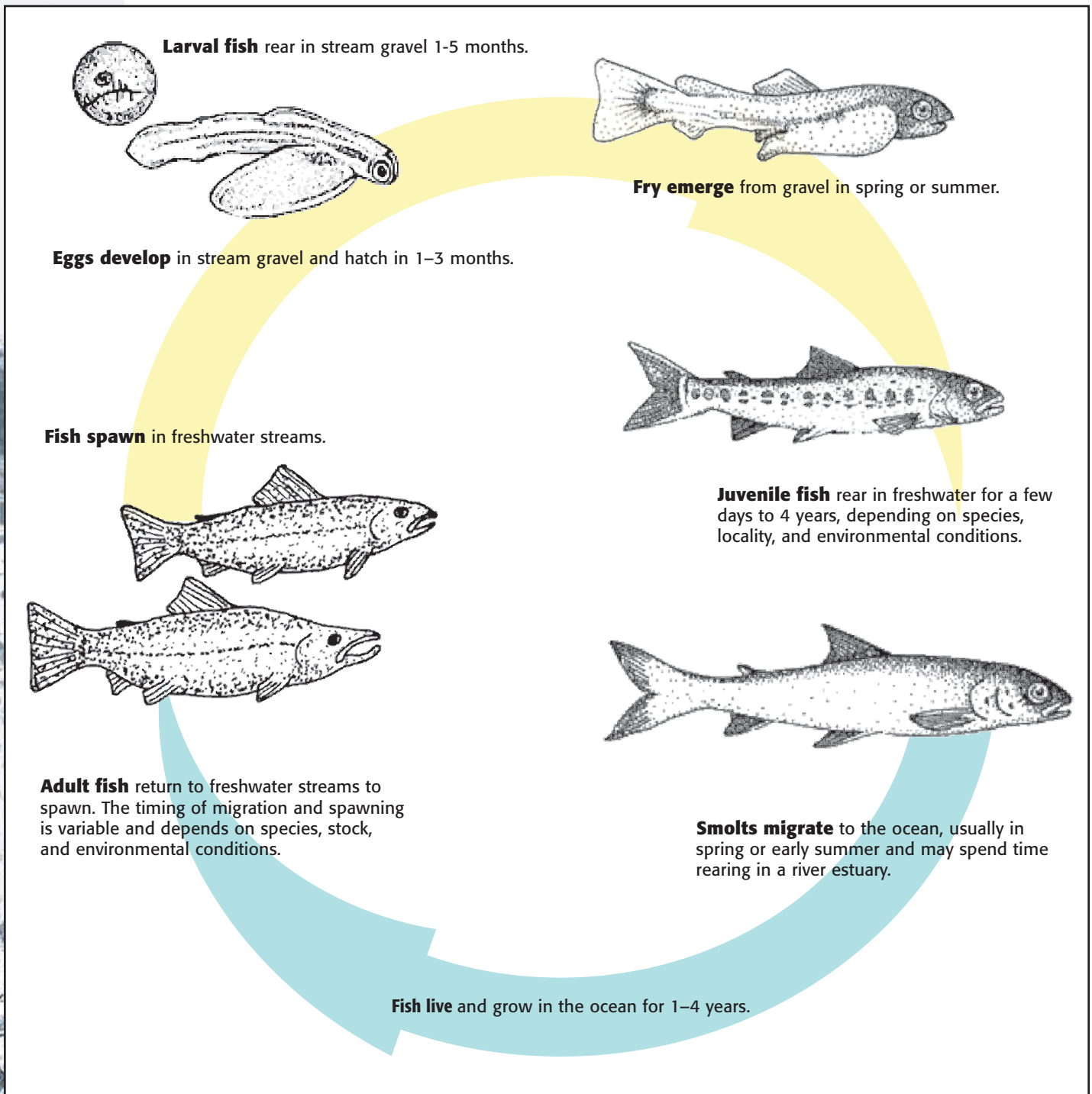
Steelhead may be the most versatile of the salmonids. Steelhead may stay in a stream for 1 to 3 years and in the ocean from 1 to 4 years. Between one-quarter and one-half of steelhead do not die after spawning. They repeat their journey to the ocean and may return to spawn a total of 4 times (Moyle 2002). The flexibility of the species is illustrated by the rainbow trout form, which spends its entire life cycle in fresh water.

In addition to the four species of anadromous salmonids described above, 10 species and subspecies of native resident trout and 3 species of non-native resident trout are found in California. Although several of these fish (e.g., brook trout, *Salvelinus fontinalis*) have the ability to tolerate slightly warmer water conditions than the anadromous salmonids discussed above, they are all cold-water fish that require excellent water quality.

Resident salmonid adults spawn in gravel under conditions similar to those used by anadromous salmonids. Kokanee (landlocked sockeye salmon, *Oncorhynchus nerka*) and brook trout spawn in streams or at lake margins. Juvenile resident salmonids frequently rear and live out their lives in the immediate vicinity of their birthplace. Others may move downstream to larger streams or, like kokanee, migrate to a lake environment.



Figure 1. The anadromous salmonid life cycle. Freshwater stages are indicated by the yellow arrow, and saltwater stages by the blue arrow. The length of time spent at each stage varies with species, population within a species, individuals within a population, and environmental conditions. *Source:* Adapted with permission from Thompson and Larsen 2004.



POPULATION TRENDS OF IMPORTANT SPECIES

Populations of anadromous salmonids have been declining in number throughout the Pacific Northwest for several decades (fig. 2). While accurate historical data are rare, most wild (nonhatchery) stocks are thought to have declined to approximately 10 percent of historical levels. In Northern California approximately 36 percent of coho streams no longer have spawning runs, while in Central California more than 50 percent of coho streams no longer have spawning runs (Weitkamp et al. 1995). At least some of the population decline can be attributed to habitat losses. For example, 48 percent of stream habitat historically accessible to Chinook salmon in the Central Valley has been lost due to the construction of dams and other migration barriers and stream diversions (Yoshiyama et al. 2001). As discussed below, the other factors affecting anadromous salmonid population levels include harvest levels, habitat degradation, predation, and ocean conditions. Planners and developers can mainly influence direct and indirect impacts on habitat quality.

The listing and regulation of anadromous salmonids under the federal Endangered Species Act is a complex process. When a listing occurs, it applies to a species or population (a genetically distinct group) of a species occurring within geographical

regions called an evolutionarily significant unit (ESU) or a distinct population segment (DPS). The exterior boundary of all listed ESUs in California is shown in figure 3. They encompass a substantial part of the state, including coastal counties and several counties in the Central Valley. In addition, in its recovery planning for steelhead in Southern California, the National Marine Fisheries Service is including coastal watersheds as far south as the border with Mexico (Boughton et al. 2006). The state has listed coho salmon under the California Endangered Species Act as well. The boundaries of the affected ESUs are coterminous with the federal boundaries. Several resident trout species, like the Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*), are also listed under the federal and state Endangered Species Acts. Their historic habitat includes inland streams and lakes, mainly in the Sierra Nevada.

Once a species or population is listed as threatened or endangered, a recovery plan is prepared by the responsible federal or state agency. As of 2007, many of these plans were under development in California. Once adopted, the plans will include special measures to be taken to maintain and restore habitat availability and quality for listed fish. Some of these measures will form the basis for mitigation measures and alternatives for urban development.

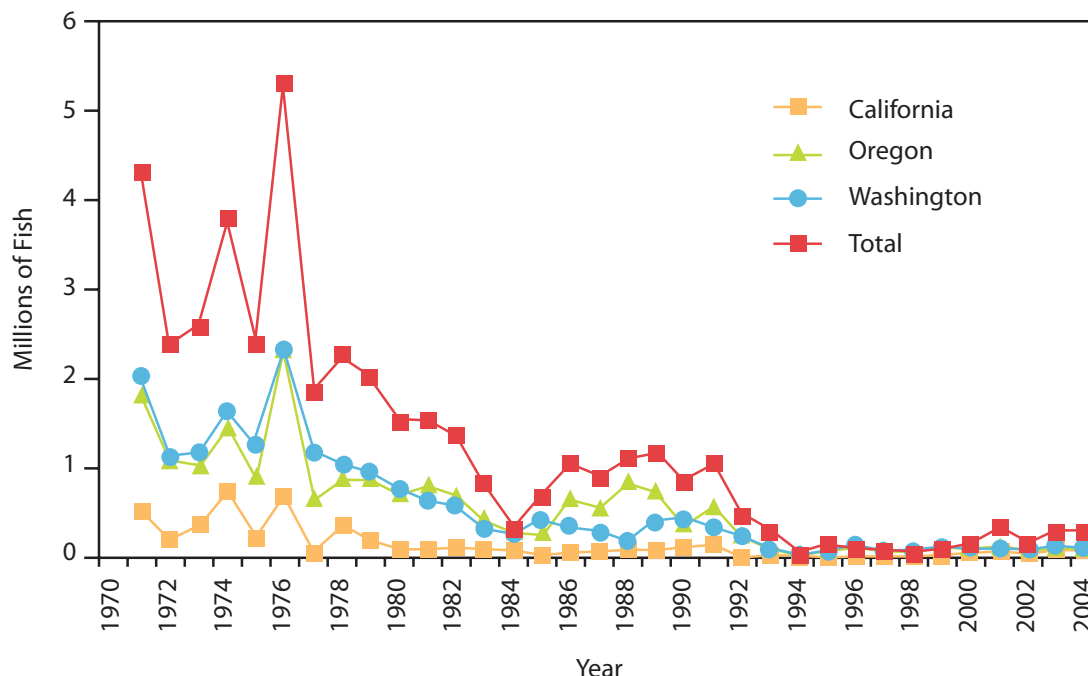


Figure 2. Coho salmon landings for Washington, Oregon, and California ocean troll and sport fisheries. Source: Adapted from Weitkamp et al. 1995.



Figure 3. Land area in California within evolutionarily significant units for salmonids. *Source:* Chris Keithley, CAL FIRE.

Extent of Salmonid ESUs in California as of July, 2006.

REASONS FOR SALMONID DECLINE

Salmon have declined in number and range due to urbanization, stream damming, water diversions, habitat modification, and fish harvest. Urbanization, agriculture, road construction and maintenance, and timber harvesting have contributed to excessive sediment delivery to streams. Stream clearing for flood control and protection of infrastructure depletes the supply of large wood in stream channels, thereby reducing habitat complexity. Large and small dams as well as instream road crossings have created complete or partial barriers to migration upstream and downstream. This can lead to direct mortality (from turbine kill), increased predation, and reduced vigor. Harvest by commercial and recreational fishing and predation by exotic fish species have reduced the numbers of returning salmonids. Hatchery operations have diluted genetic diversity. Finally, fluctuations in climate and ocean conditions such as the El Niño effect periodically reduce ocean food supplies for salmon and may favor their predators.

COMPONENTS OF HIGH-QUALITY AQUATIC HABITAT

Although many would agree that dams and water diversions are the most important development impact on anadromous salmonids, habitat

degradation can have profound local effects on resident fish as well. Preventing habitat degradation begins with maintaining natural stream channels in areas undergoing land development. The main function of a natural stream is to move water, sediment, and woody debris from higher to lower points in a watershed, often over long distances. Fish and other aquatic organisms have evolved to do well in stream channels with particular sediment, water, and debris loads. Their habitat needs are met by natural channel shapes and forms.

In general, channels with a variety of pools and fast-water stretches (riffles) provide the best cold-water fish habitat (fig. 4). Rocks and large pieces of wood create pools and riffles and provide cover for fish. In riffles where the surface flow is turbulent, the flowing water delivers insects for food and the broken surface provides cover from predators. Riffles are also locations where the water's oxygen content is replenished. Plunge pools are formed where water falls over a boulder or log. The falling water scours a deep hole where juvenile and adult fish often hide (fig. 5). Logs, root wads, boulders, or stream banks can cause backwater pools to form as water swirls around the obstacle (Opperman et al. 2006).

The vegetation on, near, and overhanging the water provides plant materials that are consumed by aquatic animals. Riparian vegetation includes hardwood and softwood trees, shrubs, and herbaceous vegetation. Plant roots stabilize banks, and the vegetative canopy shades the water to minimize solar heating. Some aquatic insects spend part of their life cycle in riparian vegetation. Since adequate riparian vegetation is important to insects, it is also important to fish that eat those insects.

Cool water and high oxygen content are critical to maintaining salmonids and the aquatic insects they feed on. Cold-water fish, amphibians, and insects can tolerate only relatively narrow ranges of temperature. The amount of oxygen dissolved in the water affects the ability of organisms to breathe. Low dissolved oxygen content is often associated with stagnant water or water that has been enriched with nutrients. These factors may lead to algal blooms. When the algae dies bacteria decompose it but use up oxygen in the process, which may result in a fish kill. Furthermore, temperature and dissolved oxygen content interact. At higher water temperatures less oxygen can be dissolved, which compounds the stress for cold-water species.



Figure 4. Channel habitat in Cow Creek, east of Redding, California. Several large logs provide shelter for rainbow trout and other native fish species. Downstream of the logs a deep pool has formed, providing additional shelter. A riffle in the back of the photo provides spawning gravel. Photo: L. Thompson.



Figure 5. Pools provide resting places for in-migrating adult salmonid spawners as well as rearing habitat for juveniles who must spend 1 to 2 years in fresh water before outmigrating to the ocean. *Photo:* R. Harris.

Salmonids require clean gravel stream bottoms to lay their eggs. Although different species require different sizes of gravel, in general, the larger the fish, the more capable it is of building its redd in larger substrate sizes. As a rule, a fish can build a redd in gravels with a diameter equal to approximately 10 percent of its body length. Spawning fish can clean the stream bottom to some extent when they build their nests, but excessive fine sediment can impair the survival of eggs.

IMPACTS OF DEVELOPMENT ON AQUATIC HABITAT

Any development that changes the input of water, sediment, or wood to a channel, removes riparian vegetation, or degrades water quality will degrade the quality of habitat for fish and other aquatic species. Urban and residential development, as well as low density development on the urban fringe, can cause serious impacts on fish habitat (Harris and Kocher 1998). Streams with “urban stream syndrome” (Paul and Meyer 2001) have flashier runoff, elevated concentrations of nutrients and contaminants, and altered channel shape, and tend to have non-native fishes tolerant of these conditions.

Storm Water Runoff

A major cause of habitat degradation is urban storm water runoff delivered to streams by curb gutters and storm sewers. These facilities drain the precipitation that runs off roads, driveways, roofs, and parking lots instead of allowing the water to soak into the ground, as it would have before development. Researchers have found that the biological quality of a stream is affected by the percentage of the watershed it drains that is covered by impervious surfaces. As a watershed is urbanized, a higher percentage of precipitation runs off instead of soaking into the ground (fig. 6).

Runoff from urban watersheds reaches streams faster and in greater quantities than it does in an undeveloped watershed. An increase of 10 to 20 percent of impervious surface in a watershed may double the amount of runoff reaching local streams. Increased flow gives the stream more power, leading to increased erosion and more frequent flooding. Studies have found that when a watershed has 10 to 15 percent impervious cover, there is a drastic change in fish communities (Paul and Meyer 2001). This threshold is crossed even in fairly low-density development. Traditional single-family residential areas have a typical total impervious surface coverage of 40 percent and above (Arnold and Gibbons 1996).

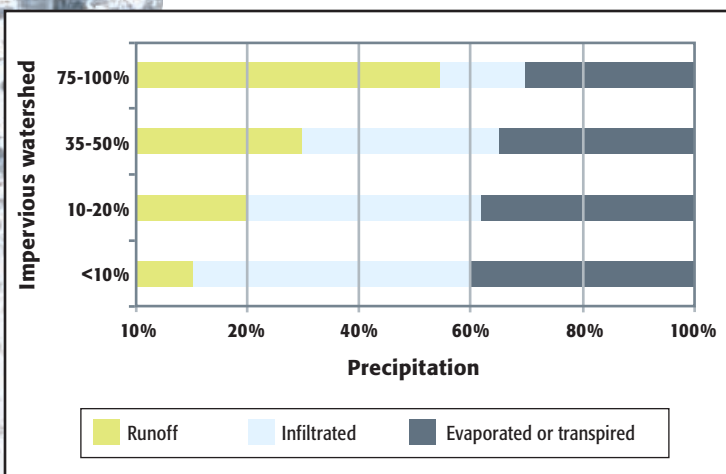


Figure 6. Changes in flows with increasing impervious surfaces in urbanizing catchments. *Source:* Adapted from Paul and Meyer 2001.



Figure 7. A small landslide has been caused by this construction project, increasing the likelihood of downstream sediment impacts on fish habitat downstream. Photo: R. Harris.

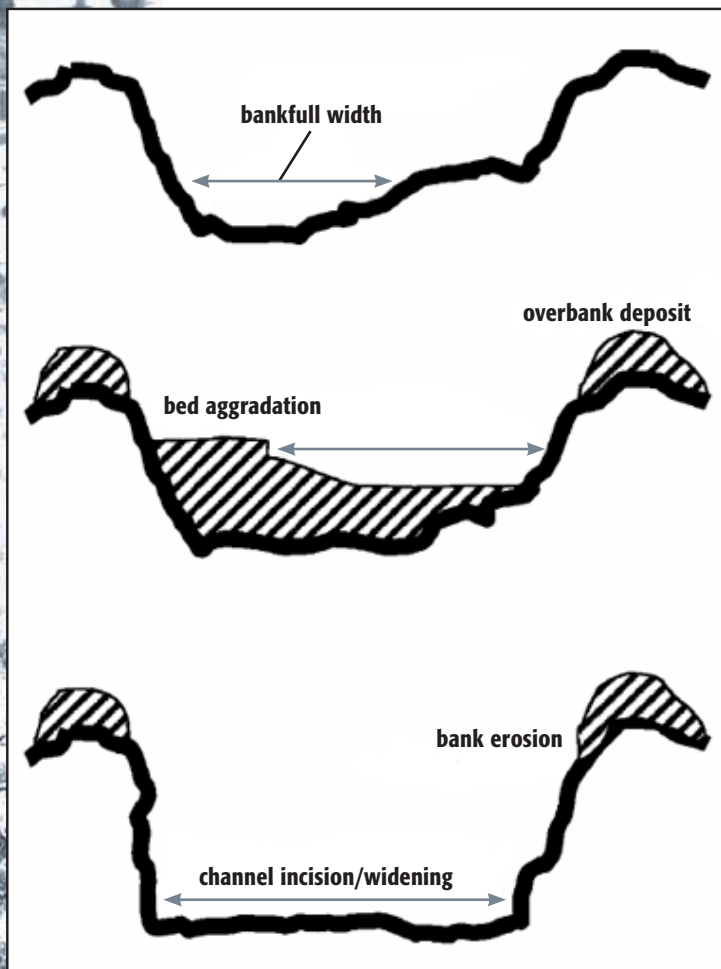


Figure 8. Channel changes associated with urbanization. Source: Reprinted with permission from the Annual Review of Ecology and Systematics, vol. 32, ©2001 by Annual Reviews, www.annualreviews.org.

Sedimentation

Another factor in habitat degradation is the sediment input to streams during earth-moving operations associated with development. Improperly conducted grading can deliver excess fine sediment to streams (fig. 7). Excessive sediment reduces the habitat quality of streams for aquatic insects and the fish that feed on them, as well as filling in pools where fish rear. Excessive sediment in a stream may contribute to filling in spaces between particles of gravel, reducing oxygen supply to insects and young fish. The impacts on fish may be slowed growth or mortality.

Stream Channel Changes

Increased runoff along with increased sedimentation may have a dramatic impact on the shape of natural stream channels (fig. 8). Before development, the stream in the figure is narrow and deep (A). Increased sediment from construction sites is then deposited in the channel and on its banks, making the channel more shallow (B). Increased runoff caused by creation of impervious surfaces causes the channel to downcut and widen in order to accommodate the increased flow (C).

The resulting channel provides less habitat for fish (fewer pools and riffles). Bank erosion triggered by upstream urbanization may prompt local landowners and jurisdictions to harden banks to stabilize them (fig. 9). Depending on the method used, bank stabilization may result in permanent losses of riparian vegetation and negatively impact water temperature, large wood recruitment, and leaf inputs to the stream.

Riparian Vegetation

Removal of riparian vegetation weakens stream banks, allowing them to erode more easily during flood events. Stream channels may migrate back and forth across their floodplain at an excessive rate or erode adjacent upland slopes. This accelerated erosion causes excessive sedimentation that can reduce habitat quality by filling pools and gravels with fine sediment. Reduction of the riparian canopy reduces stream shading, which may increase stream temperatures to a point lethal to salmonids. Also, runoff that is no longer filtered by streamside vegetation is likely to carry sediment and other pollutants directly into streams.

Channelization

Stream channels overloaded with excess urban runoff and sediment may cause erosion and flooding. A conventional solution to this has been to straighten and channelize the



Figure 9. Gabion bank protection on San Francisquito Creek, Palo Alto, California, undertaken to stabilize the bank and reduce erosion. *Photo: R. Harris.*



Figure 10. This section of San Francisquito Creek has been hardened and a flood wall erected to protect streamside property on the left side of the photo. Riparian vegetation has been cleared along the right side to maintain channel capacity. *Photo: R. Harris.*



Figure 11. This culvert is a barrier to most fish that cannot make the jump into the culvert nor swim against the fast flow. *Source: Courtesy FishXing, <http://stream.fs.fed.us/fishxing/gbu/photos.html>.*

stream (fig. 10). Although less common today than formerly, these practices are still used, particularly in areas of high property values.

Channelization of streams can obstruct fish passage at high flows, since velocities may be too high for fish to swim upstream against. This may be a particularly important issue for adult fish that migrate upstream to spawn during winter storms when flow volumes are high. Water velocities may also increase beyond the ability of young fish to swim while feeding. Hardening the channel with concrete or riprap simplifies the habitat and provides less overhead cover and refuges from predators. It also decreases the abundance of macroinvertebrates, reducing survival rates and food sources for fish.

Migration Barriers

Another major symptom of urban stream syndrome is the creation of barriers that prevent anadromous fish from migrating upstream to spawn or downstream to the ocean. Anadromous fish migrate to the ocean and back at least once during their life cycle. Resident trout also move up and down streams to seek food, shelter, spawning habitat, and cooler water. In intermittent streams, fish may need to move to find areas that stay wet during the dry season.

The main obstacles to fish passage are stream crossings by roads, including culverts, bridges, and low-water crossings. Culverts typically focus stream water into a narrow pipe or box. This may increase water velocity beyond that which a fish can swim against (fig. 11).

Structures may be positioned so high above the channel that the jump height is excessive for most fish (fig. 12). Culverts too large for the stream they carry may widen the flow to the point that it is too shallow for the fish to navigate. Culverts with no natural resting place downstream may not allow fish to find a spot from which to make their jump. Unless properly designed, any stream crossing can interfere with fish migration (fig. 13).

Water Quality

Degraded water quality due to pollutants in runoff from urban and suburban areas is also a major problem for aquatic life (fig. 14). Runoff that leaves impervious surfaces such as parking lots and roads as well as runoff from landscaped areas that are overirrigated and fertilized often carries excess nutrients such as nitrogen and phosphorous and toxics such as pesticides, heavy metals, and organic compounds. Streams also receive these pollutants through deposition of urban air pollution. Excessive nutrients may overstimulate the growth of algae and aquatic plants in water bodies, leading to cultural eutrophication (fig. 15). Adverse effects on fish and other aquatic organisms are



Figure 12. The double box culvert on the left was a complete barrier for all age classes of salmonids on Minot Creek in Northern California due to stream velocity, depth, and leap height. It was replaced by the bottomless concrete arch culvert on the right. The project opened up 2.5 miles of upstream habitat to salmonids. Source: Courtesy FishXing, <http://www.stream.fs.fed.us/fishxing/case/>.



Figure 13. Low water crossings, also known as Arizona crossings, can pose a migration barrier to fish under certain flow conditions. Photo: R. Harris.



Figure 14. Storm water flowing off this parking lot carries pollutants to Honda Creek in Santa Barbara in April 2000. Photo: L. Thompson.



Figure 15. Algae and other aquatic plants cover the surface of the Salinas River in August 2005 in Paso Robles, California. Dissolved oxygen levels in the river were too low to support sensitive fish species such as steelhead. *Photo:* L. Thompson.



Figure 16. Intermittent section of Mission Creek in Oak Park in Santa Barbara. The stream bed has been hardened with concrete downstream of the bridge. During the dry season this prevents groundwater from replenishing the flow, while during the wet season it causes the stream to erode and undercut downstream of the concrete. The stream banks in the reach upstream of the bridge have been lined with concrete to protect the foundations of streamside buildings. *Photo:* L. Thompson.

primarily due to depletion of dissolved oxygen in the water. Invasive aquatic species can then come to predominate in these water bodies, since they can often outcompete native fish and aquatic vegetation under altered stream conditions.

ALTERED STREAM FLOW

Another consequence of increased impervious surfaces is the reduction in the natural recharge of groundwater that occurs when rain soaks into the soil. This effect, in combination with groundwater withdrawal for irrigation or domestic use, has lowered the water table in many urban areas, causing perennial streams to go dry for at least part of the year. Lack of water reduces the available habitat for fish and can cause adverse effects on riparian vegetation.

Streams with reduced flow may be excessively warm for resident fish and other organisms during the summer. Fish living in higher temperatures and crowded into available water are more prone to suffer from disease and parasites.

In some cases, stream flow is artificially increased by returns from urban irrigation and treated effluent discharges. In central and southern California, some formerly intermittent streams have become perennial in this manner. These return flows are often either highly polluted or super-clean, with nutrient levels below normal.

These factors discussed combine to create the urban stream syndrome, making it difficult for cold-water fish to live among us. Urban planners and residents of urban areas are challenged to create new urban and residential development that can avoid these impacts and also reverse the impacts of existing development (fig. 16).

MAINTAINING HEALTHY STREAMS

Although urban stream syndrome is a common result of land development and urbanization, it is not inevitable. New development designs and techniques can reduce impacts on aquatic habitat and maintain its productivity for salmonids. The most effective and cost-efficient strategy is to control the location and design of development (Riley 2002). Methods are available that reverse existing impacts, but these can be complex and expensive to implement. Avoiding impacts before they occur is far superior but requires advanced planning. First and foremost, streams should be maintained in as natural a condition as possible. Preventive measures should be taken for streams occupied by salmonids and for watercourses upstream of salmonid habitat that influence downstream conditions.

Riparian Buffers

A key strategy for protecting aquatic habitat is to maintain streamside areas in a natural state by establishing streamside



Figure 17. The vegetation on the left of this photo is a riparian buffer that is permanently reserved to protect San Francisco Creek from an adjacent housing development in Palo Alto, California. The buffer has been fenced and a walking trail established. *Photo: S. Kocher.*



Figure 18. Providing long-term management for streamside open space is just as important as designating the area for protection. *Photo: S. Kocher.*



Figure 19. Prefabricated bridge crossing on a coastal stream in Ventura County, California. *Photo: L. Thompson.*

management zones, or riparian vegetation buffers (fig. 17). Intact riparian vegetation protects water quality by filtering runoff, stabilizing stream banks, and shading the stream. It is a source for large wood and other vegetative input to the stream. Managed properly (fig. 18), these zones can provide essential habitat for a wide variety of terrestrial and aquatic plants and animals. The buffer should be wide enough to allow the stream to migrate naturally across its floodplain without endangering adjacent property.

Riparian protection ordinances typically require that development be set back from streams, and they also restrict what can be done within the buffer zone (Firehock 2002). Some of the most effective and innovative residential subdivisions create a separate stream-side parcel owned by a homeowner's association or municipality that will maintain it in perpetuity.

Maintenance of Natural Channels

In most urban areas streams are either partly or fully channelized. The opportunities for maintaining streams in a natural state are therefore more promising in areas undergoing new development. Fortunately, local, state and federal permitting agencies commonly require stream protection measures, particularly if listed species are involved. The challenge in an existing urban area is to resist conventional flood control and channelization approaches even if a stream has already been degraded. Protecting riparian corridors and provisions for development setbacks from streams are important tools for preserving residual natural stream reaches.

The impact of stream crossings by roads and other infrastructure can be minimized by installing bridges that span the active channel and floodplain (fig. 19). Combining infrastructure such as pipelines with road crossings can reduce the total number of crossings. Culverts should be sized and designed to allow fish passage where necessary. Designs that minimize damage to the natural channel, such as open-bottomed arch culverts, should also be emphasized (fig. 20).

In cases where some treatment of the channel is needed to stabilize banks, several "fish-friendly" practices are available to reduce the impacts on aquatic habitat. In general, fish-friendly practices refrain from permanently hardening the channel (fig. 21), and they incorporate riparian vegetation as extensively as possible (fig. 22).

Maintaining Fish Passage

Maintaining the shape of the natural channel where possible and refraining from installing obstructions such as grade control structures is also vital for ensuring that fish can migrate through a stream reach. Although any installations in a fish-bearing stream will be subject to



Figure 20. A natural-bottomed arch culvert installed on a fish-bearing stream minimizes impacts on fish habitat and migration. *Source:* Keller and Sherar 2003, used with permission.



Figure 21. This rock weir has been installed to absorb the energy of the stream and reduce its ability to erode the banks. This helps reduce the need to install other bank-hardening measures that would impair aquatic habitat. *Photo:* R. Harris.



Figure 22. This stream bank stabilization project involved excavating an unstable stream bank and stabilizing it with a bioengineered structure that incorporates riparian vegetation. *Photo:* R. Harris.

permitting requirements to maintain passage, planners can go the extra distance by suggesting alternatives to conventional treatments (DFG 2004). These include approaches such as natural-bottomed crossings and innovative bank protection measures, as illustrated in figures 19 to 22. It is also very important to keep enough stream flow in the channel to accommodate passage (Lang et al. 2004) especially when designing bypass channels for flood protection.

Erosion and Sediment Control

Most California cities and counties have grading ordinances that require installation of erosion and sediment control measures to reduce the amount of sediment reaching streams during construction and earthmoving. Measures that are commonly required include silt fencing, seeding and mulching, and restrictions on construction during the rainy season (fig. 23).

Although controlling these one-time sources of sediment is very important for avoiding urban stream syndrome, it is equally important to reduce the amount of sediment reaching streams from existing activities. One major source of chronic sediment input is road systems. In low-density residential areas, low-volume roads are often constructed to convey residential traffic. Unpaved roads that are improperly designed or maintained often erode, becoming a chronic source of stream sedimentation (fig. 24).

Road upgrading projects designed to improve aquatic habitat by reducing the amount of sediment reaching streams are increasingly common in California, especially in rural areas with endangered salmonids. Guides are available to landowners (Kocher et al. 2007) and municipalities (Five Counties Group 2002; FishNet 4C 2004) on upgrading low-volume roads to reduce stream sedimentation.

In more-urbanized areas, paved road systems can also contribute to sedimentation of stream channels. Sediment from unpaved ditches and debris from vegetation management or street sweeping can reach streams if not handled properly.

Water Conservation and Quality Management

Fish need water to swim in. It is crucial that water withdrawals for commercial and domestic use be minimized to allow adequate stream flow for aquatic habitat. Urban areas that import water from elsewhere can have an effect on aquatic habitat upstream or downstream.

Water use can be reduced in residential settings by installing low-volume toilets, replacing leaky plumbing, using newer, more water-efficient appliances such as front-loading washers, and using filtered gray water for



Figure 23. This barrier was placed to prevent sedimentation during road construction. *Photo: S. Kocher.*



Figure 24. Erosion caused by ditch water leaving the ditch and traveling across the road. *Photo: S. Kocher.*

toilet flushing and irrigation (fig. 25). Rain catchment systems such as cisterns and rain barrels can also be installed in new homes and during remodeling to serve a household’s nonpotable water needs. Many of these steps can be taken in existing buildings. Utility companies and some jurisdictions have incentive programs aimed at promoting these practices.

More than half of residential water use often goes to outdoor landscaping. Water use in landscaping can be reduced by 20 to 75 percent with improved landscaping techniques (DWR 2005). This can be accomplished through efficient garden and landscaping designs that limit turf areas, soil preparation, mulching and efficient irrigation (Geisel and Unruh 2001; Hartin et al. 2001; SSWQP 2007).

Conservation technologies are also available for commercial settings. A study conducted by the Seattle public utilities department found that the dual-flush toilet (with a choice of a lower or higher flush volume) reduced water use by 24 percent. Waterless urinals or those using recaptured gray water also dramatically lower water consumption in commercial buildings.

Some municipalities offer incentives for installation of water conservation measures in new development. Cities can also reduce water use on a larger scale by developing innovative water recycling programs that treat domestic waste water for agricultural and landscape irrigation, groundwater recharge, and creating wetlands. California currently has at least 200 water recycling facilities that recycle at least 1,000 acre-feet of water per year (Freeman n.d.). Altogether, the California Department of Water Resources estimates that an additional 1.5 to 2.5 million acre-feet of urban water conservation is possible statewide (DWR 2005).

Public agencies as well as private citizens play a crucial role in preserving water quality through their landscape maintenance practices. Most jurisdictions would benefit from following landscape maintenance best management practices. These include integrated pest management to reduce the potential for pesticide use and runoff (Flint et al. 2003). Lawn management practices that reduce the need for fertilization are also vital for reducing the potential for nutrient runoff (SSWQP 2007; Henry et al. 2002).

Storm Water Management

Changing traditional methods of storm water management is important for maintaining water quality in fish-bearing streams. Traditional practices are primarily designed to reduce flood risk by maximizing the speed and efficiency with which accumulated runoff drains into streams and away from property. This direct

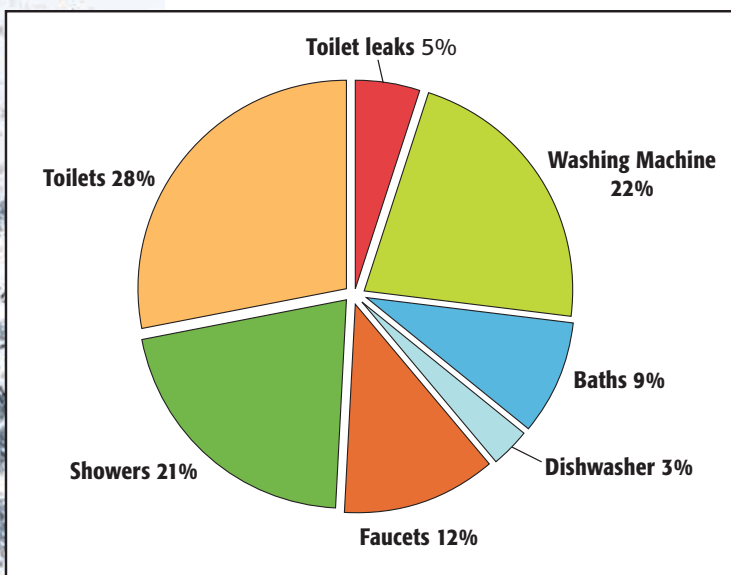


Figure 25. Typical inefficient indoor water use of 80 gallons per person per day. *Source: Woodwell et al 1995, used with permission.*



Figure 26. This detention basin captures flow coming off the road surface and ditch. It catches sediment and allows storm water to soak into the ground. *Photo: S. Kocher.*



Figure 27. This former agricultural pond has been expanded to function as a retention pond for a rural subdivision. *Photo: R. Harris.*



Figure 28. Swales retain rainwater and grow rain gardens to enhance the neighborhood. *Source: © 2005, Seattle Public Utilities, used with permission.*

connection must be broken if the stream is to retain a natural stream flow pattern. Disconnecting impervious surfaces from directly discharging into streams can be achieved by retaining runoff for treatment or infiltration in catch basins, retention basins, and other storm water management features.

Use of storm water retention methods has become fairly commonplace across California. Basins like those shown in figures 26 and 27 collect and detain storm water from yards, roads, and driveways for retention and infiltration in one central location.

The relatively new field of low-impact development (PSAT 2003) seeks to go even further by redesigning traditional development to retain water on each individual site, eliminating the need for centralized drainage or retention systems. With the many innovative designs and technologies now available, experts estimate that good urban design can reduce imperviousness caused by new development by up to 50 percent (Schueler and Claytor 1997).

One example is Seattle's Street Edge Alternative project that involved installing storm water retention swales for each residence along the narrow strip between the road and sidewalk (fig. 28). In addition, the street was narrowed, reducing overall impervious surfaces by 11 percent (fig. 29). Two years of monitoring data showed that the project reduced the total volume of storm water leaving the street by 98 percent for a 2-year storm event.

Construction of impervious surfaces can also be minimized through lot design. A recent analysis of 40,000 residential parcels in Madison, Wisconsin (Stone 2004), found that increasing the density of residential developments creates less impervious area per bedroom built because lots have less frontage (less road and sidewalk length) and smaller setbacks (less driveway) (fig. 30). Stone projected that reducing average lot size from 36,000 to 18,000 square feet, frontage from 63 to 45 feet, and the front yard setback from 36 to 24 feet would reduce the total impervious area created by 30 percent. Reducing street width by 3 feet and increasing street intersection densities to 140 per square mile would reduce imperviousness by another 10 percent. Stone estimated that adopting these zoning and subdivision changes in Madison would reduce the amount of impervious surfaces created by projected residential growth through 2020 by 38 percent.

Retrofitting or renovating already-created development to improve storm water retention through permeable paving and "green" roofing is also becoming more common. Many different types of permeable pavements are available and are in wide use (fig. 31). These can allow infiltration of up to 80 percent of falling rainwater if maintained properly.



Figure 29. Seattle's Street Edge Alternatives project involved calming traffic by narrowing and curving the roadway and installing storm water retention swales. (Inset: street before the project.) Source: © 2005, Seattle Public Utilities, used with permission.

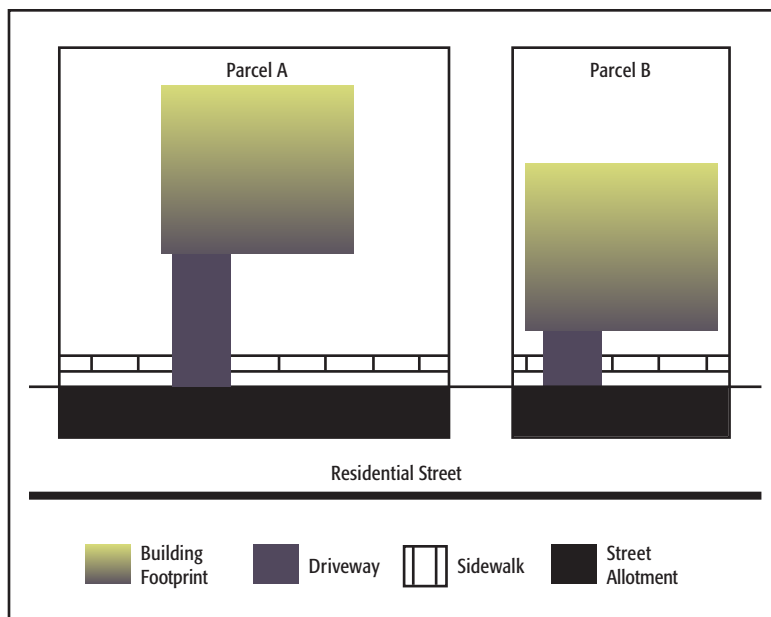


Figure 30. Subdivisions creating parcels modeled on Parcel B reduce impervious surface created per bedroom by 30 percent when compared to Parcel A. Source: Stone 2004, used with permission.



Figure 31. Permeable paving blocks reduce the impervious surface area in this parking lot. *Photo: Eban Bean.*



Figure 32. Green roofing installed to reduce runoff from a commercial building. *Source: © Roofscapes, Inc., used by permission; all rights reserved.*

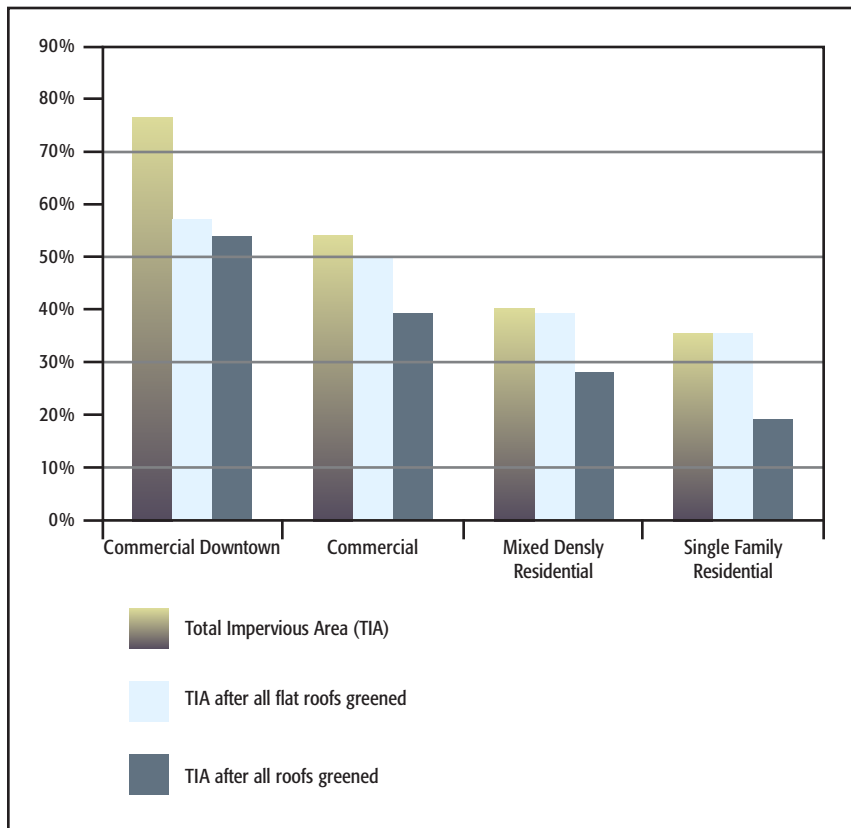


Figure 33. Projected reduction in total impervious surface area (TIA) by greening roofs in different zoning classes in Madison, Wisconsin. Mixed-density residential has 24 units per acre; single-family residential has 4 units per acre. *Source: adapted from Carter and Jackson 2007, used with permission.*

Cost Savings to Developers from Low Impact Development

Residential

The 80-acre residential Somerset subdivision in Prince George’s County, Maryland, installed open drainage swales and rain gardens on individual lots to capture runoff, eliminating the need for detention ponds, curbs, and gutters. Rain gardens occupy 300 to 400 square feet of 10,000-square-foot lots. Each rain garden cost \$150 to excavate and \$350 to vegetate. Installation in 200 homes cost \$100,000. This is substantially less than the \$400,000 that would have been needed to construct conventional detention ponds. The cost savings totaled \$4,000 per lot. Space savings also allowed for development of six extra lots. Future detention pond maintenance costs were avoided as well.

Commercial

A new 270-unit apartment complex in Aberdeen, North Carolina, saved \$175,000 on storm water construction costs (72 percent) by eliminating most conventional underground storm drains. Instead, bioretention areas, depressions, grass channels, wetland swales, and specially designed outfalls were installed (fig. 34).



Figure 34. An outfall weir disperses storm water into a shallow area for infiltration. Photo: Deven Lindenberg, BLWI.

Vegetated, or green, roofs are common in Europe. Green roofs involve installing a sealing barrier, planting medium, and plants on the roof (fig. 32). The plants take up rainwater, which slows and reduces the total annual storm water runoff volume from the parcel. Additional benefits include extending the service life of the roof, reducing energy costs, and conserving land area that would otherwise be required to provide storm water runoff controls such as detention basins.

Widespread installation of green roofs in urban centers can produce a significant reduction in the total impervious area in a watershed. A recent study concluded that greening all flat roofs in the downtown commercial zone of Athens, Georgia, would reduce the amount impervious surface area in that zone from 78 percent down to 58 percent (fig. 33). This was predicted to reduce runoff volume by 40 percent for small precipitation events (Carter and Jackson 2007).

COSTS SAVINGS OF AVOIDING STREAM IMPACTS

Careful land use planning can save many costs over time. Streams with urban stream syndrome are more likely to flood and cause property damage. Stream bank stabilization structures installed to treat degraded streams are also costly and are not always entirely effective.

Low-impact development not only reduces future costs of treating degraded streams, it also reduces construction and infrastructure costs considerably. This is because traditional development requires extensive storm water systems such as gutters, drainage pipes, wide streets, and detention basins, which can be quite costly to install. Reducing these components typically more than offsets the costs of low-impact techniques such as rain gardens, cisterns, and permeable surfaces. The U.S. Environmental Protection Agency (EPA) estimates that low-impact development projects cost 25 to 30 percent less than conventionally developed projects (EPA 2005). These cost savings can be realized by both municipalities and private developers (see sidebar).

The city of Seattle found that the natural drainage system developed in their Street Edge Alternative project cost 25 percent less than traditional roadside development because the project reduced the need for costly infrastructure such as pipes and holding tanks (table 1).

Table 1. Cost analysis of LID versus traditional development in Seattle’s Street Edge Alternative project

Street Edge Alternatives (SEA)	Low impact development (LID)	Traditional
components	one sidewalk per block new street paving	two sidewalks per block new street paving
community benefits	traffic calming high neighborhood aesthetic	no traffic calming no neighborhood aesthetic
watershed benefits	high protection for aquatic habitat mimics natural process bioremediation of pollutants	high protection from flooding some water quality benefit
cost per block (330 linear feet)	\$325,000	\$425,000

Source: Courtesy Seattle Public Utilities.

Table 2. Actions needed to conserve fish habitat during residential and commercial development

Objective	Development actions needed to conserve salmonid habitat
Maintain riparian vegetation.	<ul style="list-style-type: none"> • Establish wide riparian buffers and restrict activities within them. • Manage riparian areas for growth of large trees that can contribute wood to the stream in the future.
Maintain natural channels.	<ul style="list-style-type: none"> • Never channelize streams. • Avoid creation of levees and flood walls that separate streams from their floodplains. • Don't build in floodplains. • Minimize bank stabilization and use fish-friendly techniques.
Maintain fish passage.	<ul style="list-style-type: none"> • Minimize stream crossings and use bridges or arched culverts whenever possible. • Maintain adequate stream flow for salmonids.
Minimize sediment input.	<ul style="list-style-type: none"> • Control sediment from construction and grading. • Upgrade unpaved and low-volume roads. • Control sediment created from street sweeping and ditch and stream clearing.
Minimize storm water runoff increases.	<ul style="list-style-type: none"> • Use lot and subdivision design to minimize impervious surfaces. • Use pervious paving in high-volume areas. • Promote green roofing in commercial districts. • Retain storm water on individual sites.
Conserve water by minimizing use.	<ul style="list-style-type: none"> • Use water-conserving domestic appliances and toilets. • Install water-conserving landscaping. • Establish water recycling in residences and commercial buildings and throughout municipalities.

Municipalities can also reduce costs by actively protecting critical parts of their watersheds from development. The City of Auburn, Maine, spent \$570,000 to acquire 434 acres of land around Lake Auburn. The city was able to maintain water quality standards without building a new filtration plant. This saved the city \$30 million in capital costs and \$750,000 in annual operating costs (EPA 2005).

PUTTING IT ALL TOGETHER

Clearly, avoiding urban stream syndrome in order to maintain aquatic habitat takes a concerted effort throughout the land development process. Each of the actions described above is necessary to maintain natural stream processes and minimize impacts on salmonid habitat. A summary of recommended actions is provided in [table 2](#).

POTENTIAL FOR URBAN STREAM RESTORATION

In most urban areas, stream habitat has already been degraded. Habitat may be degraded to the point that it cannot maintain a salmonid population without active restoration efforts. Watershed and stream restoration projects are active measures taken to improve streams and return them to a healthier, more natural state. Restoration projects can be quite diverse, focusing on changing land use, improving channel shape, reducing sediment and pollutant input, increasing riparian vegetation, restoring spawning gravels, enhancing fish passage, and restoring streams' connections to floodplains (Riley 1998).

Because landownership and land use patterns remain relatively fixed once established, few urban streams can be entirely restored to a state ideal for salmonids and other aquatic species. But many urban streams can be rehabilitated and their condition improved for fish and aquatic life. Projects such as planting riparian vegetation, upgrading roads, and revegetating upslope areas can be quite successful in improving local stream or watershed conditions. In some watersheds, simply restoring migration corridors through urban areas to allow fish access to more pristine upstream spawning and rearing habitats can be effective for increasing fish abundance.

Enhancement efforts undertaken in urban streams must improve current stream conditions and promote the natural processes that shape them. Efforts that rehabilitate channels and restore riparian habitat alone may not lead to long-term improvement unless natural stream processes are also restored. Booth (2005) contrasts short-term and long-term restoration activities and objectives for urban streams ([table 3](#)). He suggests that projects with short-term objectives, such as installation of instream structures to improve fish habitat, are worthwhile for addressing acute problems and are generally feasible under many different management settings; but they are unlikely to produce permanent improvements in urban stream biotic health. Permanent improvements require activities such as storm water reinfiltration to restore natural stream processes to the urban watershed.



Table 3. Short- and long-term objectives for urban stream restoration

Time Scale	Objectives	Actions
short term	• Eliminate point sources of pollution.	• Monitor water chemistry of local point sources.
	• Reconstruct physical channel elements to resemble equivalent undisturbed channels.	• Complete fish-passage projects . • Install stream structures such as boulders or logs.
	• Provide habitat for self-sustaining biotic communities.	• Plant riparian vegetation and fence riparian areas.
long term	• Avoid future channel impacts.	• Avoid land use near channels through preserves or zoning. • Avoid road and utility stream crossings.
	• Restore natural hydrologic process.	• Rehabilitate upland hydrology through storm water infiltration and/or low-impact development. • Reduce water withdrawals.
	• Restore natural channel process.	• Reconnect floodplains with streams.
	• Restore natural woody debris process.	• Establish riparian-zone vegetation communities.

Source: Adapted from Booth 2005.



Figure 35. This bioswale was installed during a road widening project in Menlo Park, California, to mitigate for the additional runoff caused by additional impervious surfaces. The swale is constructed with a layer of aggregate under the soil and is planted with wetland species. The curb along the road has gaps to allow water to flow into the swale. A catchment was installed (under the grate) to allow sediment to settle out of the storm water before discharge to the creek. Photo: R. Harris.

A study investigating the potential for stream restoration through redesign of storm water systems used modeling to predict effects on aquatic habitat from dispersed small-scale storm water treatments (Walsh et al. 2005). Treatments did not reduce the total amount of impervious cover in the watershed but did reduce the effective impervious cover (impervious area connected to streams) by retaining flow and disconnecting it from streams, for example, through the construction of bioswales (fig. 35). Researchers found that a large effort would be required before instream ecological health would improve. The assessment suggested that reducing the amount of effective imperviousness (impervious area connected to streams) to 2 percent is possible even for a watershed with a total impervious cover of up to 50 percent. The authors conclude that urban stream restoration through retrofit of storm water systems, while an intensive effort, is possible in most suburban and exurban areas.

Restoration and retrofitting efforts undertaken to improve aquatic habitat once streams have been degraded can be costly. Efforts across the country to “daylight” streams that were once confined in culverts involves acquisition of property or easements, excavation, rough grading, hauling of fill, purchase of materials for streambed and channel structures, landscaping materials, and labor. Project planners often estimate the full cost at \$1,000 per linear foot of stream (Pinkham 2000). Stream bank stabilization projects can cost up to \$100,000 per linear foot for concrete channelization, compared to \$100 per linear foot for vegetative methods such as reforesting the riparian buffer area (Firehock and Doherty 1995).

The key to cost-effective urban stream restoration actions is to identify watersheds that have low urbanization and fairly high quality stream conditions. In these watersheds, development strategies that protect the existing quality of these systems and improve management of the watersheds should be adopted. In places where rehabilitation is likely to be successful, improving flow regimes and near-stream conditions are top priorities because of their demonstrated biological benefits (Booth 2005).

WORKING COOPERATIVELY

Cooperative stream and watershed protection efforts have increased over the last few years. Landowners have formed watershed councils or organizations to work on stream protection as groups. Some resource conservation districts (RCDs) work with landowner associations on large-scale conservation problems and may be involved in coordinating landowners for stream protection. Contact your local RCD or University of California Cooperative Extension office for more information on cooperative conservation efforts occurring in your area.

The recognition that active restoration is needed if anadromous fish populations are to return to former levels has stimulated state and federal agencies to create a number of programs that share the costs of landowner restoration efforts. These agencies also provide technical assistance with restoration planning. Efforts may include improvement of roads and crossings, elimination of barriers to migration, riparian restoration, and stream channel habitat enhancement. Contact your local Department of Fish and Game office for more information on these programs.

RESOURCES

The following agencies and organizations can provide further information about development impacts and restoring aquatic habitat.

California Department of Fish and Game (DFG), (916) 445-0411, <http://www.dfg.ca.gov>.

Find a list of regional offices and contact information online at <http://www.dfg.ca.gov/regions/regions.html>.

Center for Watershed Protection, <http://www.cwp.org/>. Provides local governments and watershed organizations with technical tools for protecting streams, including watershed planning, restoration, research and training, stormwater management, and better site design.

Local Government Commission, (916) 448-1198, <http://www.lgc.org/>. Provides technical assistance and networking to local elected officials and community leaders working to create healthy, walkable, and resource-efficient communities.

Low Impact Development Center, <http://www.lowimpactdevelopment.org/home.htm>. Provides information on protecting the environment and water resources through site design techniques that replicate preexisting hydrologic site conditions.

National Fish and Wildlife Foundation, Western Partnership Office (Portland), (503) 417-8700, <http://www.nfwf.org/>. Find out about grant programs and partnerships at this organization's Web site.

Natural Resources Conservation Service (NRCS), California Headquarters, (530) 792-5600, <http://www.ca.nrcs.usda.gov>.

NOAA Fisheries, Southwest Regional Office, (562) 980-4000. <http://swr.nmfs.noaa.gov>.

Resource Conservation Districts (RCDs), (916) 457-7904, <http://www.carcd.org/wisp/rcdmap1.htm>.

Salmonid Restoration Federation, <http://www.calsalmon.org/>. Promotes restoration, stewardship, and recovery of California native salmon, steelhead, and trout populations through education, collaboration, and advocacy.

Smart Growth Network, <http://www.smartgrowth.org/>. A partnership between the EPA and nonprofit and government organizations to encourage development that serves the economy, community, and the environment.

U.S. Fish and Wildlife Service (FWS), (916) 414-6464, <http://www.fws.gov>. Find California offices online at <http://www.fws.gov/offices/directory/>.

University of California Division of Agriculture and Natural Resources, <http://ucanr.org>. Find an online list of Cooperative Extension county offices at <http://ucanr.org/ce.cfm>.



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METRIC CONVERSIONS

English	Conversion factor for English to metric	Conversion factor for metric to English	Metric
foot (ft)	0.3048	3.28	meter (m)
mile (mi)	1.61	0.62	kilometer (km)
acre (ac)	0.4047	2.47	hectare (ha)
square foot (ft ²)	0.0929	10.764	square meter (m ²)
square mile (mi ²)	2.59	0.386	square kilometer (km ²)
acre-foot (ac-ft)	1,233	0.000811	cubic meter (m ³)
Fahrenheit (°F)	$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \div 1.8$	$^{\circ}\text{F} = (^{\circ}\text{C} \times 1.8) + 32$	Celsius (°C)



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Fish Habitat in Freshwater Streams. Publication 8112. 2004. Farm Water Quality Planning Reference Sheet <http://anrcatalog.ucdavis.edu/pdf/8112.pdf>.

Lawn Watering Guide for California. Publication 8044. 2001. <http://anrcatalog.ucdavis.edu/pdf/8044.pdf>.

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Publication 8279

ISBN-13: 978-1-60107-523-9

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This publication has been anonymously peer reviewed for technical accuracy by University of California scientists and other qualified professionals. This review process was managed by the ANR Associate Editor for Natural Resources.

pr-4/08-SB/RW