URBAN RIVER RESTORATION:
BRINGING NATURE BACK TO CITIES

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Rivers are common – but often neglected – resources in cities. Decades of development and pollution have degraded and damaged these vital ecosystems. Many cities are turning their attention back to their rivers, hoping to restore these resources. This paper provides an overview of urban river restoration and its benefits, exploring these concepts in detail by analyzing a planned urban river restoration project on the South Platte River in Denver, Colorado. Redevelopment of the site includes plans for a restored floodplain and discharging recycled wastewater to a stretch of the river that is nearly dry for much of the year. This analysis suggests that floodplain restoration could significantly reduce flood risk for surrounding neighborhoods. Additionally, adding water to the river during dry periods can increase fish habitat and improve water quality. This case study is one example but illustrates many of the potential benefits, and limitations, of urban river restoration. While river restoration can improve water quality, reduce flood risk, increase wildlife habitat, and create popular natural amenities for local residents, it is important to recognize that restoring short sections of rivers cannot alone repair the damage from watershed level impairments.

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SECTION 1: INTRODUCTION

Rivers are everywhere. Most cities have at least one major river – in fact, cities were intentionally built near waterways to ensure access to drinking water, provide a navigation route, and transport away sewage. While larger rivers may be the most visible waterways, cities usually also have a variety of creeks. While less conspicuous, they make up the vast majority of the total length of the channel network, and are vitally important sources of clean water and habitat for plants and animals. Waterways often suffer the consequences of urban expansion, including pollution and confinement. However, many cities are now looking to revitalize their waterways, recognizing the significant social, economic, and environmental benefits of healthy river ecosystems. This paper outlines the threats that urban rivers face and describes how river restoration can be used to improve water quality, reduce flood risk, and provide an important community amenity. To provide a more concrete illustration of these benefits, this paper describes a proposed urban river restoration project on the South Platte River in Denver, Colorado, and quantifies the potential for this restoration to reduce flood risk, improve water quality, and enhance river health.
ALTERATIONS TO URBAN RIVERS
Rivers are common in urban areas, although most are significantly altered from their natural states. The largest impact to urban rivers is modification of natural flows. Urbanization involves a significant amount of hardscape. Road and building construction paves over natural land surface, turning spongy soil that naturally soaks up rainfall into impervious pavement that does not allow infiltration. This causes more water to reach rivers faster than is normal – meaning urban rivers see larger and more frequent high flows than is natural. This can harm local flora and fauna and cause river channels to erode as they are overwhelmed with water. This erosion degrades habitat, can pollute water with eroded soil and contaminants, and can damage bridges, pipes, and other infrastructure. Preventing rainfall from soaking into the ground can also affect river flow in other ways. Groundwater levels may be lower in urban areas, meaning there is less water supplied to rivers during drought or low flow periods, causing rivers to dry up.

Another significant threat faced by urban rivers is pollution. Pollution comes in various forms and from a variety of sources. Some of the most common types of pollution are bacteria and pathogens (e.g., E. coli) from pet waste, leaky sewers, or septic tanks, and nutrients (e.g., phosphorus and nitrogen), which come from wastewater treatment plants, fertilized lawns, and golf courses. Bacteria like E. coli can make humans and pets sick while high levels of nutrients can cause uncontrolled algal growth, which can kill fish and contaminate drinking water.

An additional prominent threat faced by urban rivers is direct modification of river channels. Historically, rivers have been straightened and enlarged to move water more efficiently and reduce flood risk, which destroys habitat and can be devastating for river ecosystems and flora and fauna that depend on them. Additionally, rivers face increasing levels of encroachment, as development often extends to the river’s edge. Building in natural floodplains requires the construction of levees or other structures to protect the new development, keeping more water in the river channel and exacerbating downstream flooding. Additionally, floodplains are important habitat for both terrestrial and aquatic species; cutting them off from river channels devastates these organisms. Smaller creeks are often destroyed completely by being diverted underground into pipes to allow for development in the former channels. This removes important habitat, degrades water quality, and increases flood risk as water is rapidly transported through the underground pipes to larger rivers.

WHAT IS RIVER RESTORATION?
River restoration can address the threats outlined above and restore function to river ecosystems. Restoration has many definitions. In its purest form, river restoration seeks to return a degraded ecosystem to its previous natural and undisturbed state. Unfortunately, it can be difficult to determine what the “pre-disturbance” state was, and can be even more difficult to achieve it. At a more practical level, river restoration attempts to restore some of the function of river ecosystems. These functions may include supplying a sufficient amount of clean water for people and the environment and providing habitat for aquatic and terrestrial species.

In this paper, “river restoration” is used broadly to indicate any change that improves the river ecosystem for human and environmental benefit. There are many common techniques for river restoration (see Table 1, page 26), and choosing the right technique depends on the specific threat(s) being addressed. Importantly, restoration does not only include changes to the river itself. For example, stormwater controls or low impact development that reduces the magnitude and intensity of river flows can be considered restoration. Additionally, reducing or eliminating sources of pollution by encouraging responsible fertilizer use or pet waste collection are also forms of restoration. Since two of the main causes of urban river degradation are altered flows and pollution, addressing these issues have a greater potential to improve river health than any action within the channel itself (e.g., bank stabilization). Still, river restoration will look different depending on goals, constraints, and the problems being addressed.

CASE STUDY:
Floodplain Reconnection in Rahway, NJ

The Rahway River flows through a mostly urban area in eastern New Jersey and is prone to frequent flooding. In the mid-1990s, the City of Rahway purchased 13 homes in a neighborhood adjacent to the river that experienced repeated flooding up to six feet deep. The City and local partners worked together to restore this floodplain site, create a series of wetlands, and provide a recreational area for local residents. Funding for the project was provided by a number of sources, including the City of Rahway, the Wetlands Mitigation Council, New Jersey Department of Environmental Protection, National Oceanic and Atmospheric Association, and the Fish America Foundation.

The funders and other project partners all had different goals for the restoration (e.g., flood protection, wetland creation, habitat restoration), but all saw the potential of the project to reach their goals. Restoration involved lowering the floodplain elevation, constructing a series of wetlands and stormwater ponds, and planting a variety of grasses, wetland plants, and trees. The site provides flood mitigation, enhanced wildlife habitat, water quality benefits, and an important community amenity¹.

1. Riparian habitat restoration
2. Daylighted river at proposed urban core
3. Urban infill of the South Orange NJ Transit commuter rail station
4. Restored wetland
5. Adaptive use for historic pumping station
6. Re-structured playing fields
studies have found that mature forested buffers can remove up to 90% of groundwater pollution, preventing it from entering the river\(^1\). Generally, wider, older, and more connected riparian buffers yield the greatest water quality benefits.

Stormwater controls—either traditional measures like ponds and detention basins or newer approaches including rain gardens and green roofs—can remove pollutants and prevent them from reaching rivers. Stormwater controls function similarly to riparian buffers by removing pollutants in both surface runoff and groundwater, and can be positioned throughout a watershed instead of just adjacent to rivers.

Perhaps the best way to improve urban river water quality is to prevent pollution in the first place. Source reduction strategies vary, but can be as simple as repairing leaky sewage pipes or educating citizens on proper fertilizer and pesticide use, and dog waste collection habits. A number of cities have recognized the importance of this and have developed public education campaigns.

**FLOOD RISK**

Historically, governments have responded to flood risk by building levees and dikes to contain flows in the river channel, and by straightening and dredging rivers to move water more quickly beyond flood prone areas. While these techniques can reduce local flood risk, they actually make downstream flooding worse. Further, these “structural defenses” create an artificial sense of security, encouraging more development in floodplains and putting more people and property at risk. Recently, there has been a trend away from structural flood defenses toward more natural approaches to dealing with floods. This is where river restoration can play an important role.

Instead of building levees that separate rivers from their floodplains, restoring the connections between rivers and floodplains increases local water storage and reduces downstream flooding. Studies have shown that restoring floodplain-channel connections can reduce the size (i.e., peak flow rate) of a flood by 10-25%\(^4\) - \(^5\). Reconnecting floodplains need not be limited to the main river in a city. Restoring floodplain connectivity on the numerous small creeks and tributaries that feed the main channel may actually have a more significant flood reduction benefit by slowing and storing water before it reaches the river.

Other than floodplain reconnection, one of the best strategies for reducing flooding is effective stormwater management. Many urban drainage systems have been built with the goal of quickly and efficiently transporting runoff to the river through pipes and concrete open channels. Storing water where it falls and allowing it to soak into the ground can reduce river flooding, raise groundwater tables, and improve water quality. Regenerative stormwater conveyance is a technique that encourages infiltration by converting traditional stormwater ditches into more naturalized channels with pools that trap and slow the flow. The approach is similar to creek daylighting, which entails bringing creeks out from underground pipes and restoring them to their previous surface channels. Regenerative stormwater conveyance helps to slow the flow of water and can thereby mitigate downstream flooding.

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**SECTION 2: BENEFITS OF RESTORATION**

**WATER QUALITY**

A variety of restoration techniques have water quality benefits. For example, floodplain restoration can provide areas for sediment and pollutants to settle out of the water. The extent of these benefits is dependent on two factors: how large the restored floodplain is (i.e., how much water it can hold) and how often it floods. The larger the floodplain and more frequently it floods, the greater the water quality benefits. Floodplain restoration is subject to limitations in urban areas where land is expensive and frequent flooding may not be compatible with potential adjacent land uses. Still, restoring even relatively small floodplains can remove a significant portion of the pollutant load carried by rivers\(^6\).

Similar to restored floodplains, riparian buffers can significantly improve water quality by intercepting pollutants before they reach the river. Functional riparian buffers consist of strips of vegetation adjacent to rivers that act as filters that trap pollution in surface runoff as well as biochemical reactors that transform and remove pollutants in groundwater. Much of the scientific research has focused on quantifying removal of chemicals, specifically nitrogen, in groundwater.
BENEFITS

The threats faced by urban rivers not only impact their value to humans, but also reduce their value for other species. Poor water quality, loss of channel and floodplain habitat, and increased streamflow and erosion all negatively impact fish, birds, and other aquatic and terrestrial species. Restoration that addresses these impairments can significantly benefit river and riparian ecology. River restoration is typically targeted to benefit fish. For example, adding wood to rivers, restoring floodplain and side channel habitat, and removing dams or other migration barriers can improve habitat for the fish themselves, as well as the insects they feed on. Still, a major barrier to healthy fish populations is poor water quality, and restoring habitat without addressing water quality issues may not be ultimately successful.

Other species can also benefit from urban river restoration. Riparian zones along rivers are unique and important habitats, and restoring these areas provides a variety of ecological benefits. Not only do they provide local habitat, but riparian areas are also important corridors that facilitate species movement – especially in cities which have sparse and disconnected natural areas.

There are a number of social and economic benefits of

CASE STUDY:

Restoration of Strawberry Creek, Berkeley, CA

Strawberry Creek flows through the middle of the campus of the University of California, Berkeley. Since the campus was founded in the late 1800s, the creek has been straightened, re-routed, and diverted into underground pipes. By the 1980s, the remaining aboveground portion suffered from poor water quality and excessive erosion due to inadequate stormwater controls.

In 1987, restoration of the creek began. Eroding streambanks were stabilized using logs, vegetation, and other natural engineering techniques. An extensive campaign was initiated to locate and fix leaky sewage pipes that were contributing to high bacteria levels in the creek. Finally, a coordinated public education initiative was undertaken to inform residents about the poor quality of the creek and encourage reporting of pollutant issues. These three efforts drastically improved water quality and creek habitat. In 1987, a native fish species was reintroduced to Strawberry Creek and by the 1990s, the biological condition of the creek had improved significantly. Strawberry Creek serves as the centerpiece of the UC Berkeley campus and provides a valuable educational opportunity for university students.
People have an innate attraction to nature, and to rivers in particular. In urban environments where natural areas are in short supply, healthy urban river corridors can provide important connections to the natural world. In addition to providing human connection to nature, there are direct social and economic benefits of restored urban rivers. Pedestrian and bike trails, including those commonly built along urban rivers, can have significant recreational and human health benefits. An analysis from Nebraska found that for every $1 invested in trail infrastructure, there were $3 in direct medical benefits from encouraging outdoor physical activity.9 There are also direct economic benefits of recreation in urban rivers. Fishing and boating (kayaking and canoeing) are increasing in popularity in urban streams and rivers, supporting outdoor retail suppliers and the tourism industry. Fishing and boating both require clean water and healthy river ecosystems. Additionally, river restoration can boost nearby property values. For example, even a small urban river restoration project in Australia increased nearby property values by 5%.10 In Taiwan, the value of new residential development along the restored Laojie River increased 20-50% (see case study to left).

CASE STUDY: Restoration of the Urban Laojie River in Taiwan

The Laojie River flows through Taoyuan City, Taiwan. A section of the river through the heart of the city was restored beginning in 2011. The largest part of the project involved daylighting a half-mile section of river by removing a large concrete culvert topped with shops that covered the river channel. The river is highly confined within the city with concrete walls on both sides, which limited the extent of restoration, although some naturalized and vegetated streambanks could be constructed. In addition, a series of parks and pedestrian paths were built to improve river access and recreation.

The restoration activities provided some socio-economic benefit, including increased property values near the river. Additionally, new buildings have been constructed facing toward, rather than away from the river, which was common before restoration. The project is expected to provide some flood benefits, but city officials struggled to effectively communicate flood risk reduction to the public. Still, there was widespread support from residents, largely driven by the perceived aesthetic and recreational value of the restoration.8

SUMMARY

Restoring urban rivers has the potential to provide a number of benefits. These include improved water quality, reduced flood risk, enhanced ecological function, and enriched recreation and social value. Still, it is important to temper expectations. Many restoration projects are small scale – with modifications to only a short stretch of river – and may not be sufficient to address the large-scale problems affecting the river. Looking at the entire watershed is essential to identify the primary threats for a given river. From there it is possible to select the most effective techniques for addressing specific sources of degradation at a given location. Additionally, river restoration in urban areas is especially difficult because of lack of available land, the complex causes of river degradation, and social, regulatory, and jurisdictional conflicts. Despite these caveats, river restoration efforts can help improve urban rivers and our connection to them.
The previous section described the benefits of urban river restoration, but leaves unanswered questions of how to achieve these benefits. There are a number of resources available that detail the restoration process—from watershed assessment and planning to design and implementation—as well as provide guidance on specific techniques. The goal here is to provide a brief overview of the process and describe common pitfalls.

**RIVER RESTORATION STEPS**

1. **Identifying specific threats and restoration needs**
   - This requires looking at the whole watershed to determine the largest threats faced by the river. For example, high flows from urbanized areas might be causing erosion, or high levels of E. coli might be harming wildlife and limiting recreation.

2. **Identifying project goals**
   - Project goals can include socio-economic (e.g., improved aesthetics and recreation) and ecological benefits (e.g., reduced pollution and improved fisheries). Support from all stakeholders, including the public, is essential, and residents should be involved throughout the restoration process—before project planning through implementation.

3. **Selecting appropriate restoration techniques**
   - Different restoration techniques are appropriate to achieve different goals, although many techniques simultaneously provide multiple benefits.

4. **Project prioritization**
   - The planning process should be done at the watershed scale, identifying the most important sources of river degradation and best opportunities for restoration. Prioritizing these projects by restoration goals is important, but often the deciding factors come down to constraints such as jurisdictional boundaries, spoil, land ownership, and public support.

5. **Design and implementation**
   - Once projects are selected, they are designed and built to meet project goals.

6. **Monitoring and evaluation**
   - Monitoring is essential to assess if restoration was successful. This requires monitoring before, during, and after project implementation. Monitoring should be targeted to the specific project goals. For example, if a goal is ecological benefit, monitoring may focus on fish and invertebrate populations in the river.

Typically, river restoration follows six general steps, described above.

**GUIDING PRINCIPLES FOR ECOLOGICAL RESTORATION**

1. **Start with a guiding image of a healthy, dynamic river.**
   - This vision should guide the project team through the entirety of the project.

2. **Ecological condition is measurably improved.**
   - This should be the ultimate goal of all ecologically-focused restoration.

3. **The river system is resilient and more self-sustaining post-restoration.**
   - Rivers are ecosystems and should be self-sustaining and resilient without requiring significant outside maintenance.

4. **No lasting harm should be done to the river.**
   - Specific restoration strategies should be selected so that project implementation does no lasting harm to the river.

5. **Complete pre- and post-project assessment.**
   - Monitoring is essential for determining restoration success.

Above are five guiding principles for ecologically-focused restoration projects.

Whatever the goals of an individual project, it is important to recognize that river restoration is an ongoing process. Rivers are dynamic ecosystems that are constantly changing. River restoration should therefore take an adaptive management approach. An adaptive management approach means considering restoration efforts as kind of experiment, which includes monitoring the river after a restoration project is completed and being willing to change or adapt river management if restoration goals are not being met.

**CASE STUDY:**

Restoration of Boone Creek, Boone, NC

Boone Creek flows from the mountains of western North Carolina through the densely populated town of Boone. The city and local university (Appalachian State) recognized the degraded condition of Boone Creek and have implemented several restoration projects. Restoration efforts include streambank stabilization to protect nearby roads and parking lots, and daylighting a short section of stream. These projects have protected local infrastructure, reduced flood risk, and improved the aesthetics of the creek, while receiving broad public support.

Although the restoration projects were touted as improving the ecology and returning Boone Creek to a “natural mountain stream,” this has not happened. Studies on the creek have shown that the largest causes of impairment are altered flows, high temperatures, and pollution from road salt. None of the restoration projects addressed these threats and therefore have not meaningfully improved the ecological integrity of the stream. The Boone Creek case study demonstrates the common disconnection between project objectives (e.g., “restore” a natural stream) and project realities. The benefits of restoration projects were real (reduced flooding, protected infrastructure, and improved aesthetics), but still failed to address the root causes of creek degradation.

11. Typifies, river restores follow six general steps, described above.

12. Above are five guiding principles for ecologically-focused restoration projects.

13. Whatever the goals of an individual project, it is important to recognize that river restoration is an ongoing process. Rivers are dynamic ecosystems that are constantly changing. River restoration should therefore take an adaptive management approach. An adaptive management approach means considering restoration efforts as kind of experiment, which includes monitoring the river after a restoration project is completed and being willing to change or adapt river management if restoration goals are not being met.
The South Platte River drains the eastern slope of the Front Range of Colorado, flowing through the Denver Metro area and continuing across the eastern plains before joining the Platte River in Nebraska. The basin provides drinking water for several million residents, irrigation water for thousands of acres of farmland, recreational amenities for both residents and visitors, and habitat for fish and wildlife.

### SOUTH PLATTE WATERSHED DISTURBANCES

There are three major disturbances to the river ecosystem that threaten all these water uses.

1. **Flow alteration:** Rivers and creeks throughout the South Platte watershed have been dammed and diverted for water supply and flood risk management. Dams and diversions have significantly altered natural flows on the South Platte. Typically, mountain snowmelt causes a large flood peak at the beginning of every summer. Because of water and storage, annual flooding is significantly smaller than natural flooding, which has had catastrophic effects on fish and other wildlife. The impacts are felt as far away as Nebraska, where low river flows threaten the survival of several endangered species.

2. **Pollution:** Polluted runoff from cities and farms in the South Platte watershed contaminates drinking water, kills fish and wildlife, and prevents residents from safely enjoying the river. Major types and sources of pollution are nutrients from fertilizers, urban wastewater, urban stormwater runoff, and bacteria from wastewater and stormwater. High levels of E. coli, an indicator of human pathogens, make the South Platte unsafe for swimming or other contact. Nutrient pollution – primarily nitrogen and phosphorus – can spur excessive algal growth, which harms aquatic life.

3. **Channel modification:** In the Denver metro area, development has encroached on the South Platte River and its tributaries. These channels have been straightened and narrowed, transforming the river from a wide, shifting, braided channel into a simplified, canal-like river. Such modifications, and the construction of levees, have disconnected the river from its floodplains, destroying important habitat and transferring flood risk downstream.

Flow alteration, pollution, and channel modification all significantly impact the health of the river.

* To provide an illustration of the potential benefits of urban river restoration, the effects of a small restoration project at the National Western Center complex were modeled and results are presented below.

### SOUTH PLATTE RIVER, DENVER, CO

### REDEVELOPMENT OF THE NATIONAL WESTERN CENTER

The National Western Center is a 250-acre site located on the banks of the South Platte River just north of Denver’s city center. This property is the site of the annual National Western Stock Show, a 100+ year old stock exchange and unique cultural celebration of western agricultural heritage. The property is currently being redeveloped with the goal of creating a more engaging and welcoming site, including reconnecting residents to the South Platte River. Plans call for floodplain restoration to create natural areas along the river, improving riparian habitat, and reducing flood risk. Some of the proposed redevelopment scenarios would “re-wet” a section of river downstream from the National Western Center site – an area that sometimes runs dry because of withdrawals for drinking water and irrigation. River restoration on a large urban river is rare; most projects are on smaller creeks. The South Platte River restoration planned as part of the National Western Center redevelopment is therefore a unique and exciting opportunity to revitalize a portion of this river.
**ANALYZING BENEFITS OF URBAN RIVER RESTORATION**

Restoring connectivity to the Platte River is an important goal of the National Western Center project. To understand how proposed parts of the project would benefit the river ecosystem and the people who depend on it, we examined three issues:

1. **Reducing Flood Risk**: A significant part of the redevelopment plan involves removing physical barriers—a sewage line and railroad—and restoring a natural floodplain. A restored floodplain would provide important habitat and help reduce flooding risk in nearby communities by keeping more water in the channel and out of neighborhoods. These flood reduction benefits were quantified using floodplain modeling.

2. **Re-wetting the River**: There are proposed plans to bring reclaimed wastewater to the site. This water will be used on site for non-potable uses, including irrigation and potentially toilet flushing. Any additional reclaimed wastewater would be discharged to the river. Potential benefits for the river include providing more fish and aquatic animal habitat to a stretch of channel that is nearly dry for parts of the year. The added area of fish habitat was quantified using hydraulic modeling.

3. **Improving Water Quality**: Discharging reclaimed wastewater to the river can improve water quality by diluting pollutants already in the river. The potential for dilution was quantified for two pollutants: phosphorus and nitrogen.

**RESULTS**

**Reducing Flood Risk**

An important design consideration of the National Western Center site redevelopment is restoring the riparian area along the South Platte River. The river will be given more room by relocating a sewer line and railroad track, and by constructing a new proposed floodplain. A new floodplain has many ecological and social benefits, including potentially reducing flood risk in surrounding areas. Restoring the floodplain would allow more water to be stored in the river during floods, reducing the amount of water that floods into surrounding neighborhoods. Standard flood modeling was performed for three different sized floods: the 100-year (Figure 2), 50-year (Figure 8), and 25-year floods (Figure 9), which have a 1%, 2%, and 4% chance of happening in any given year, respectively. Put another way, the 100-year, 50-year, and 25-year floods have a 26%, 45%, and 70% chance of happening at least once over a 30-year mortgage. Flood depths were modeled for current conditions and for post-floodplain restoration. The industry standard flood model, HEC-RAS, was used to simulate steady flow conditions in the stretch of the South Platte through downtown Denver.

Figure 1 shows changes in water levels for the three different flood events. For all flood sizes, the majority of the area showed either shallower water, or areas that went dry (i.e., they currently flood but will not after the floodplain is restored). There were also small areas that had deeper water post-restoration or showed no change. Many of the areas with deeper water were either on the redeveloped National Western Center site, on a small naturalized area downstream, or in the channel itself (see Figure 2 below and Figures 8 and 9 on pages 22-23).

For all flood sizes, there are significantly reduced flood depths (brown) in the residential neighborhood to the west of the National Western Center site. The area of much deeper water (blue-green) on the National Western Center is the restored floodplain. Flood depths and extents are also reduced for smaller, but more likely, flood events (50- and 25-year floods). There is, however, slightly deeper flooding possible for the National Western Center site itself. This analysis only considers flooding from the South Platte River. Flooding from small creeks or drainage ditches was not analyzed.
floodplain along the South Platte River at the National Western Center site could significantly reduce flood risk for the surrounding neighborhoods. The Urban Drainage and Flood Control District also plans to restore floodplains along much longer stretches of the river, which could have even more substantial flood reduction benefits.

Bringing reclaimed wastewater to the National Western Center site would provide a useful water source for irrigation and other non-potable uses. Additionally, any water that is not used on site would be discharged to the river, which is important because currently much of the river flow is removed by a diversion ditch. The result is that a nearly two-mile downstream stretch of river often runs dry during parts of the year. Bringing reclaimed wastewater to the National Western Center site and discharging extra water to the river would re-wet the impacted stretch of the South Platte, providing important habitat for fish and other aquatic animals.

The benefits of this river re-wetting were quantified by modeling how full the channel would be at different flows under current and future conditions. Currently, flows in this section of the river sometimes drop as low as 5 cubic feet per second (cfs); 1 cfs is about the flow rate of a single fire hose. For comparison, upstream of the ditch, river flows never drop below 50 cfs and are usually greater than 100 cfs. Bringing reclaimed wastewater to the site would add 30 cfs to the river. The benefits of the additional water can be visualized in Figure 3. The blue shows areas in the channel with water under two different low flows: 30 cfs and 15 cfs. Currently, 40% of the time there is less than this much water in the channel (top) and 15% of the time, there is even less water (bottom). If recycled wastewater is brought to the site, water would never drop below these levels.

The frequency that the river had different levels of water was examined for three different conditions: current
conditions (no reclaimed wastewater), future conditions (reclaimed wastewater), and without the ditch removing flow at all (“natural” conditions). Figure 4 shows how frequently the river channel has varying amounts of water (area of the channel that is wet). Adding recycled wastewater to the river would increase the number of days that the channel is wet but would not return the river to “natural” conditions.

Finally, the number of days the channel would be fully wet by month was examined. Fully wet means that there is adequate water in the channel to connect the upstream and downstream ends, providing sufficient habitat for fish and other aquatic organisms. Examining how this changes by month is important because fish require different habitat depending on the season. For example, in winter there should be sufficient water that fish can survive in unfrozen areas. In summer, areas with more water stay cooler than shallower areas, allowing fish to survive the summer heat. Figure 5 shows that the percentage of days with a fully wet channel would increase for all months, but especially in the winter, which can be critical for fish survival.

Efforts in Denver to reduce the amount of pollution reaching the river are ongoing, and the redevelopment of the National Western Center site could play a role in improving water quality. It has been said that “dilution is the solution to pollution.” While this isn’t always the best approach, re-wetting the river with high-quality recycled wastewater would help dilute contaminants in the river and potentially improve water quality. Water quality data collected by the City of Denver were used to determine how much of an impact re-wetting the river has on water quality. The analysis focused primarily on nutrient pollutants: nitrogen and phosphorus. Figure 6 summarizes water quality data from the South Platte just upstream of the National Western Center property. The horizontal lines are the maximum limits under forthcoming Colorado regulations that will go into effect in 2022 (CO Regulation 31). Nearly all observations are above these limits. Typical values of nitrogen and phosphorus in reclaimed wastewater were used to calculate new in-stream concentrations after this higher quality water is discharged into the South Platte. Figure 7 shows boxplots of these nutrient concentrations before and after this dilution. Water quality would be improved by discharging reclaimed wastewater into the river, but concentrations of phosphorus and nitrogen would not be reduced below water quality standards. This suggests that additional effort is still needed to reduce sources of water quality pollution elsewhere in the watershed. It is also important to recognize that while dilution may reduce concentrations, it is actually increasing the total amount of nitrogen and phosphorus in the river. Lower concentrations are good for the river but increased mass of contaminants could cause problems if it accumulates in downstream lakes and reservoirs.

**Figure 4.** Percent of days where the channel has at least a certain amount of area with water. Lines are for three different conditions: current, future (with reclaimed wastewater), and what would happen if the ditch did not remove any of the flow (“natural” conditions).

**Figure 5.** Percent of days when the river channel is fully wet by month under current and future (with reclaimed wastewater) conditions.

**Figure 6.** Summary of water quality data from the South Platte River just upstream of the National Western Center site. Horizontal lines on each plot indicate an upper limit per upcoming water quality regulations.

**Figure 7.** Boxplots show distributions of phosphorus (orange) and nitrogen (blue) concentrations before (left) and after (right) re-wetting the river. Water quality is improved, but concentrations are not quite reduced below forthcoming state standards (horizontal lines).

**Takeaway:** Bringing reclaimed wastewater for use on the NWC site can reduce use of potable water and have significant benefits for restoring river habitat. Fish and other animals need water to live and re-wetting the river would increase their chances of survival.

**RESULTS**

**Improving Water Quality**

of the National Western Center site could play a role in improving water quality. It has been said that “dilution is the solution to pollution.” While this isn’t always the best approach, re-wetting the river with high-quality recycled wastewater would help dilute contaminants in the river and potentially improve water quality. Water
Figure 8. Map showing changes in water depth post-floodplain restoration for the National Western Center site and surrounding neighborhoods for the 50-year flood.

Figure 9. Map showing changes in water depth post-floodplain restoration for the National Western Center site and surrounding neighborhoods for the 25-year flood.
CONCLUSION

provide habitat for both aquatic and terrestrial species. The benefits examined here are potentially significant, but it will be important to monitor the project after it is completed to ensure these benefits are realized.

GLOSSARY

Adaptive management – An approach to environmental management that recognizes the uncertainty in complex ecosystems and that continual monitoring is required. Based on monitoring results, management should be changed as necessary to meet project goals.

Algae – A term for aquatic, photosynthesizing organisms that can range from single cells to large plants. Explosions of algal growth (called blooms) can contaminate drinking water and suck all the oxygen from water, killing fish.

Bank stabilization – Techniques to reduce erosion of streambanks, usually by increasing soil resistance to erosion (e.g., by planting vegetation).

Creek daylighting – Taking creeks that were placed into underground pipes and restoring them to natural surface channels.

Floodplain – Areas adjacent to rivers that are periodically inundated when water overflows the river banks. Flow – The rate of water movement in rivers (in volume of water per time).

Habitat – The physical environment that a species inhabits. In rivers, this includes the right depth, speed, and quality of flowing water.

Infiltration – Water soaking into soil.

Low impact development – A type of stormwater management to minimize how site development alters natural water infiltration and runoff.

Potable – Drinkable. Non-potable includes all other water uses.

Recycled wastewater – Treated water from wastewater treatment plants that is further cleaned (typically to at least meet drinking water standards from 1980) and often used for irrigation and other non-potable uses.

Regenerative stormwater conveyance – Alternatives to stormwater ditches that mimic natural channels, encouraging infiltration.

Riparian buffers – Vegetated strips along streambanks.

Riparian zone – The area adjacent to rivers, including riparian buffers and floodplains.

River restoration – Improvements to river ecosystems for human and environmental benefits.

Sediment – Includes mineral grains ranging in size from boulders to clay. Finer sizes (e.g. silt and clay) are of primary concern as water pollutants.

Stormwater management – Management of rainfall runoff in urban areas to reduce flooding and river erosion.

Watershed – An area of land that collects rainfall and snowmelt and channels it to rivers. Because water flows across all of this land surface, anything on the landscape affects the amount and quality of the water that reaches the river.

CITATIONS


PHOTO CREDITS

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Table 1. Summary of common river restoration practices. The relative magnitude of different benefits is indicated (+ = low to +++ = high).

<table>
<thead>
<tr>
<th>Restoration Practice</th>
<th>Description</th>
<th>Water Quality</th>
<th>Flood Risk</th>
<th>Ecological</th>
<th>Social &amp; Economic</th>
<th>Benefits to river</th>
<th>Broader benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riparian buffers</td>
<td>Vegetated strips of land along river channels. Benefits are greater for wider (perpendicular to river) and longer (parallel to river) buffers.</td>
<td>+++</td>
<td>+</td>
<td>+++</td>
<td>+</td>
<td>Filter pollutants, slow down water, habitat, provide wood/leaves/etc. to in-stream biota, stabilizes streambanks, reduces water temps</td>
<td>Terrestrial habitat, recreation, urban cooling</td>
</tr>
<tr>
<td>Bank stabilization</td>
<td>Techniques that make the bank more resistant to erosion and collapse. Can include rock structures and/or vegetation (especially willows).</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>Improved habitat, reduced pollution (e.g., sediment) to river</td>
<td>Protect infrastructure (bridges, pipes, etc.), improved safety</td>
</tr>
<tr>
<td>Floodplain reconnection</td>
<td>Reconnects the river channel to its floodplain, possibly by lowering floodplain elevation, raising the channel bed, or breaching levees.</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>Trap pollutants, habitat, slow down flows, reduces erosion</td>
<td>Reduce flood risk, improved recreation, urban cooling</td>
</tr>
<tr>
<td>Stormwater/Green Infrastructure</td>
<td>Traps rainfall to slow its transport to the river channel. May be temporary storage or encourage infiltration to groundwater. Techniques include retention/detention ponds, rain gardens, and green roofs.</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>Reduce pollutant reaching river, reduce magnitude of peak flows, increase low flows</td>
<td>Urban cooling, reduced flooding, improved habitat</td>
</tr>
<tr>
<td>Dam removal</td>
<td>Removal of dams to increase connectivity and allow fish passage.</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>Allow fish passage, improved habitat</td>
<td>Improves safety, reduces local flooding, increases recreation</td>
</tr>
</tbody>
</table>

Creek daylighting: Restoring creeks that have been routed to underground pipes/culverts to surface channels. ++ 4 +++ 4 Restores habitat, slows flows, improves water quality Restores downstream flood risk, creates a community amenity May increase fish numbers which enhances recreational fishing

Habitat structures: Rock or wood structures that can improve aquatic habitat. ++ 4 Restored habitat, typically targeted to fish; may also provide bank stabilization benefits

Table 2. Additional useful resources for urban river restoration.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological Riverfront Design: Restoring Rivers, Connecting Communities</td>
<td>A planning document that provides principles to achieve ecological benefits in urban riverfront revitalization projects. These range from general (e.g., encourage public participation in the process) to specific (e.g., limit floodplain development).</td>
<td><a href="https://www.csu.edu/cerc/documents/EcologicalRiverfrontDesign.pdf">https://www.csu.edu/cerc/documents/EcologicalRiverfrontDesign.pdf</a></td>
</tr>
</tbody>
</table>