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EPA

TMDL Case Study

Boulder Creek, Colorado

Key Feature: Combines habitat restoration and PS and NPS controls to meet water quality standards

Project Name: Boulder Creek Enhancement
Location: USEPA Region VIII/Boulder, Colorado/South Platte River Basin/Southern Rockies
Scope/Size: River segment, 4.6 miles
Land Type: High mountains, tablelands with high relief
Type of Activity: Urban/agricultural/grazing
Pollutant(s): Un-ionized ammonia (NH_3)/nutrients
Program Integration: Region/state/local
TMDL Development: No
Data Sources: State/local/academic
Data Mechanisms: Modeling/full-scale testing
Monitoring Plan: Yes
Control Measures: WWTP upgrade/habitat restoration/BMPs

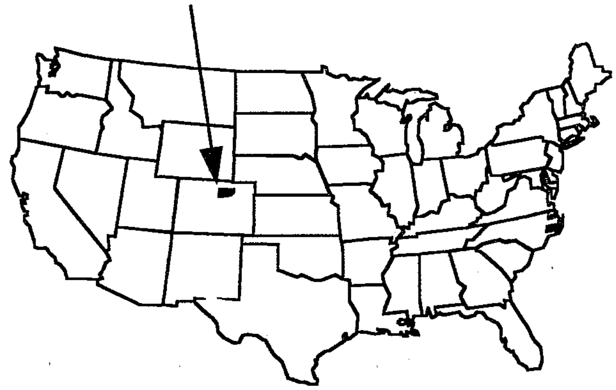

FIGURE 1. Location of the project site in Colorado

Summary: The Boulder Creek Enhancement Project, near Denver, Colorado (Figure 1) demonstrates a holistic approach to water quality improvement and encompasses several aspects of the TMDL process. Although not formally submitted as a TMDL, the enhancement project closely parallels the phased TMDL approach outlined in the TMDL guidance (USEPA, 1991). Following identification of water quality impairment, all possible causes were examined and the location and extent of controls necessary to correct the impairment were identified. An adaptive management plan was developed to implement the proposed controls in phases, a few at a time, to permit monitoring and evaluation of their effectiveness. The implementation plan was modified between phases based on the evaluations.

A use attainability study, one of the first conducted in Colorado, showed that aquatic life in Boulder Creek was impaired. Traditional monitoring indicated that instream concentrations of un-ionized ammonia were exceeded downstream of the city's wastewater treatment plant (WWTP). Pollution contributions from each point source (the WWTP and other dischargers) and nonpoint source (agriculture, cattle grazing, surface mining, and water diversion) along the 15.5-mile stream section below the WWTP were evaluated to determine the most effective strategy for reducing the instream un-ionized ammonia concentrations and improving stream conditions. This required monitoring. Data collected at the WWTP showed it was meeting its effluent limits for ammonia, indicating either that (1) the effluent limits were not strict enough or (2) other factors were responsible for the impaired water quality of Boulder Creek.

Further investigation showed that high water temperature and pH were the primary causes of the un-ionized ammonia excursions. These were linked, in part, to physical degradation of the creek's riparian zone; species diversity and density were low even in reaches with good water quality. Therefore, more stringent effluent limits and plant upgrades alone would not solve the problem. A combination of plant upgrades, best management practices (BMPs), and habitat restoration was needed to improve water quality in Boulder Creek.

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BACKGROUND

The majority of water quality-based permits for toxics in Region VIII are written because of concerns related to un-ionized ammonia and chlorine toxicity. Of particular concern is the exposure of aquatic communities to ammonia discharged from wastewater treatment plants (WWTPs). In 1985, the City of Boulder Department of Public Works needed to renew the NPDES permit for its 75th Street WWTP, a 17-year-old facility operating at nearly 80 percent capacity. A TMDL was developed to determine a wasteload allocation for un-ionized ammonia. The TMDL indicated the need to tighten the plant's un-ionized ammonia discharge limits, because monitoring showed Boulder Creek was exceeding water quality standards for un-ionized ammonia 5.6 and 8.5 miles downstream of the plant's outfall, even though the WWTP was not violating its current discharge limits (Windell et al., 1991).

Subsequent studies, which looked at the watershed in more detail, indicated that WWTP upgrades alone would not solve the problem because the ammonia toxicity was caused largely by the degraded condition of Boulder Creek itself. Below the WWTP, the creek is channelized, its banks are exposed and unstable, there is little or no streamside vegetation to provide shade, and there is a lush growth of instream aquatic vegetation. The resulting high temperature and pH favor the conversion of ammonia to its toxic, un-ionized state.

The City of Boulder proposed the Boulder Creek Enhancement Project to alleviate the un-ionized ammonia problem and defer expensive modifications at the treatment facility. The first step would improve the quality of the effluent at the WWTP using partial nitrification; the second would restore the riparian zone along the river; and the third would restore instream habitats. The second and third steps would be implemented in phases.

This approach to improving instream water quality by using restorative techniques in the riparian zone in conjunction with traditional treatment methods was appealing for several reasons. The estimated cost was far less than the cost of relying on WWTP upgrades alone, and improving the physical condition of the stream and its riparian zone would enhance the aesthetics of the creek, making it more appealing and useful to property owners. Also, if part of the enhanced area could be acquired by the city for use as a public park or greenway, it would add a valuable asset to the community.

Both the State of Colorado and the U.S. Environmental Protection Agency (USEPA) Region VIII believed that the Boulder Creek Enhancement project had merit and agreed to work cooperatively with the local community to implement it. USEPA Region VIII has provided guidance and financial aid to Boulder to support the city's instream monitoring efforts, the development of a water quality model to project diel variations of instream water quality, and construction costs for the plant upgrade. The city of Longmont has also received support for their instream monitoring efforts which provided data used in this project. Volunteers from the community are providing labor and materials to aid in the restoration of this important community resource. Upon completion of the restoration effort, it is intended that a new TMDL that is based on a healthy ecosystem will be developed and permit requirements for the WWTP will be revised.

A CHARACTERIZATION OF BOULDER CREEK

The St. Vrain subbasin (Figure 2) has a drainage area of 978 square miles (USEPA, 1992a). Boulder Creek, from its headwaters in the Southern Rockies to the St. Vrain, drains approximately one-third of this basin. The region is typically mountainous tablelands with high relief. Land in the headwaters is predominantly forested, with some agricultural activity. Western spruce, Douglas fir, pine, southwestern spruce, bentgrass, sedge, fescue, and bluegrass make up the native vegetation. The dominant soil types, boralfs, are moderately erodible. In the Southern Rockies, Boulder Creek flows rapidly through narrow, relatively deep channels; the mountainous terrain aerates and cools the water, providing ideal habitat for native aquatic communities. These reaches of Boulder Creek are considered healthy and functional.

As Boulder Creek flows west toward Boulder, Colorado, it leaves the Southern Rockies and enters the Western High Plains. In their natural state, the plains are characterized by smooth to irregular topography; dry mollisoil soils, which are moderately erodible; and a natural vegetation that includes grama and buffalo grass (Omernik, 1987). Rainfall in the vicinity of Boulder averages about 20 inches per year (USGS, 1985). Natural soil loss ranges from 5 to 14 tons per acre per year, but is reduced in paved or urbanized areas. Most of the land along these stream reaches is urbanized.

The city of Boulder is located adjacent to Colorado's front range in the north-central part of the state. The city has a population of more than 95,000. Wastewater treatment for the city is provided by the 75th Street plant, which discharges an average of 17 million gallons per day into Boulder Creek (Figure 3). Base flow in Boulder Creek at the point of discharge ranges from 10

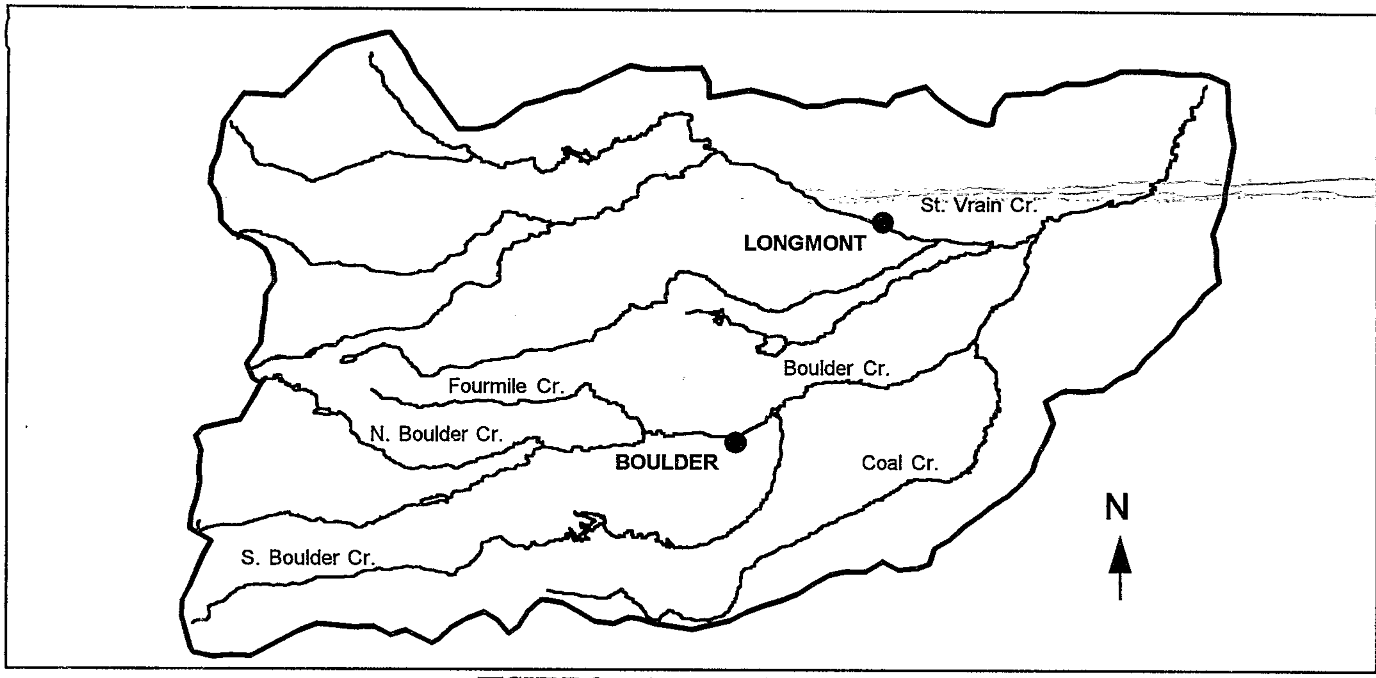

FIGURE 2. The St. Vrain Watershed

to 30 cubic feet per second over 9 months of the year (Rudkin and Wheeler, 1989). Boulder Creek is governed by water rights, however, and during periods of high withdrawals the creek is wastewater-dominated.

Much of the area along Boulder Creek, within and to the east of the city, has been urbanized, but grazing lands and agriculture still constitute a significant percentage of the area's land use. Because the land is less mountainous, the creek assumes a shallow, meandering character as it flows northeast from the city. Boulder Creek is highly channelized along these reaches, which reduces instream reaeration. Ideally, a stream should contain about 50 percent riffle and 50 percent pool to support aquatic life uses, but channelization in Boulder Creek has shifted this ratio to 97 percent riffle and 3 percent pool. Channelization has also shortened the length of Boulder Creek below the WWTP from 30 miles to 22 miles, increasing erosion and sediment loading (Channel 28, 1990). Gravel pits and mining operations located along the channel also discharge sediment loads to the creek.

Un-ionized ammonia concentrations increase as the creek flows through these reaches and away from the city. The critical zone, in which the un-ionized ammonia concentration reaches a maximum, occurs approximately 8.5 miles below Boulder's 75th Street WWTP outfall (Rudkin and Wheeler, 1989). The conditions contributing to the degradation along this stretch include runoff, erosion, agricultural return flows, channelization, destruction of the riparian zone, and mining discharge—in general, poor land use practices. The shallow water depth and lack of cover encourage a lush growth of photosynthesizing aquatic vegetation. This vegetation, in turn, results in higher water temperatures and increased pH, conditions that favor conversion of ammonia to its toxic un-ionized form. Low alkalinity was identified as a cause of the relatively large fluctuations in pH.

Boulder Creek, below the WWTP, is designated to be used as a water supply and for class 1 recreation, class 1 warmwater aquatic life, and agriculture. An inventory of the 15.5-mile segment of river below the WWTP found that the segment was not fully supporting aquatic life uses (Windell and Rink, 1987a). Few of the 33 species of fish expected to inhabit this segment, including the greenback cutthroat trout, were found.

The same study, backed by additional monitoring and analysis, indicated that potential aquatic life uses could not be achieved, even if discharges at the WWTP were improved, because of the existing degraded physical condition of the habitat. Additional measures were needed to significantly lower the creek's temperature and pH and, subsequently, the un-ionized ammonia concentration. A feasibility study to evaluate the effectiveness of BMPs and restoration measures based on previous studies and additional field data concluded that BMPs would enhance the effects of advanced wastewater treatment (Windell and Rink, 1987c). It also indicated that aquatic life uses could be attained if the aquatic and riparian habitat was restored, nonpoint source pollution was controlled, and poor land use practices were corrected. The following BMPs were proposed: concentrating stream flow in a thalweg (low-flow) channel to lower temperature and reduce aquatic vegetation, fencing off the riparian zone to exclude

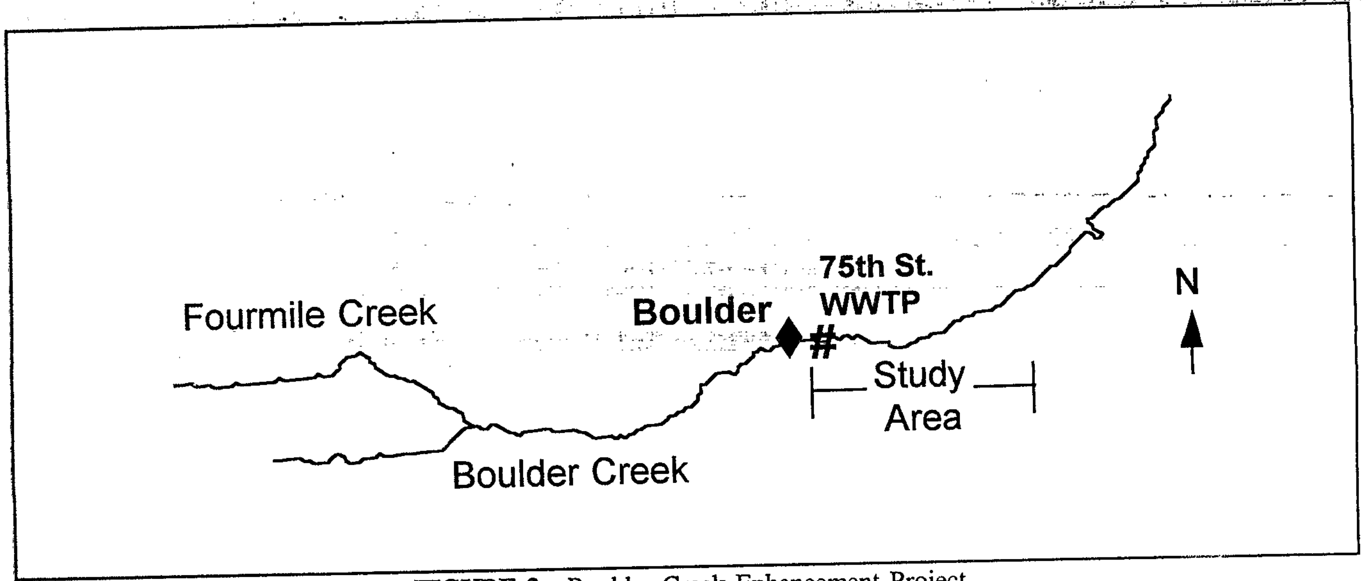

FIGURE 3. Boulder Creek Enhancement Project

cattle, installing biological reaeration structures, enhancing wetland areas, replanting riparian vegetation, and stabilizing banks. After reviewing the study, the city of Boulder authorized support for an aquatic and riparian habitat demonstration project.

ASSESSMENT METHODS

Monitoring

Ongoing monitoring of mid-day grab samples 5.6 and 8.5 miles downstream from the WWTP indicated that un-ionized ammonia concentrations at times exceed the state's standard of 0.06 mg/L for warm-water streams. WWTP effluent data, collected monthly from January 1982 through March 1985, indicated that there were no violations of the total ammonia limit during winter months (November-May) and only three violations during summer months (June-October). The effluent data also showed no exceedance of pH effluent limits that would contribute to the ammonia problem. Because effluent concentrations are well within prescribed limits, instream monitoring data were needed to indicate the source of the problem. Unfortunately, the available data were not sufficient to indicate whether the exceedance was a result of the WWTP discharge or nonpoint source inputs. More detailed data were needed to document the effects of, and relationship between, land use, point source pollution, nonpoint source pollution, and aquatic life potential. Existing data did indicate that nonpoint source pollution contributed about 60 percent of the biological oxygen demand (BOD), 83 percent of total dissolved solids, 82 percent of the nitrate, 30 of the phosphate, and 17 percent of the ammonia loadings (Windell et al., 1991).

To assist in characterizing the problem, a use attainability study was completed. The study included an inventory of macroinvertebrates, fish, riparian vegetation, aquatic vegetation, land use, and nonpoint source pollution inputs over a 15.5-mile reach downstream from the facility (Windell and Rink, 1987a). The results showed that habitat degradation, as well as high levels of un-ionized ammonia, was impairing aquatic life uses.

Biweekly, 24-hour water quality sampling was conducted over a year to help identify the extent and possible causes of the problem (Windell and Rink, 1987b). The results showed that un-ionized ammonia varies on a diel basis, reaching highest levels not when ammonia concentrations are highest, but when temperature and pH conditions favor conversion of ammonia to its un-ionized form. Data collected by the Colorado Department of Health, Water Quality Control Division (1986), indicated that high temperatures and pH values occurred frequently. Temperatures were observed to range from 32°C in November to 80°C in May; at times, pH values in excess of 9.0 were recorded. Another water quality report consisted of spring and fall synoptic studies (Windell and Rink, 1988). This study revealed that when pH and temperature were high, excursions of the water quality standard occurred daily during these seasons. Numerous other studies have provided data for the Boulder Creek Enhancement Project (Windell and Rink, 1992), and the conditions in Boulder Creek will continue to be inventoried, monitored, and reported in order to assess and quantify existing and changing conditions in the creek.

Modeling

The flow and pH data from these monitoring studies, as well as information assembled for the 1985 TMDL, including nitrification rates, background water quality, and point and nonpoint source contributions to Boulder Creek and its tributaries, were essential for developing a mathematical model to simulate the diel variations of instream water quality (Chapra, 1989). A model was completed and reviewed, but results of the verification indicated that the conditions in Boulder Creek, particularly the pH, were too sensitive and variable to be accurately calibrated. The highly variable sediment loads, hydraulics, weather, and algal growth left a full-scale demonstration project as the only practical means of testing the effectiveness of selected BMPs for reducing un-ionized ammonia concentrations in the creek.

POLLUTION CONTROL AND RESTORATION EFFORTS

Point Sources

The first step of the Boulder Creek Enhancement Project was to improve the quality of effluent at the WWTP. In 1991, the city of Boulder upgraded and expanded the 75th Street WWTP to meet the stricter discharge limits required by Colorado's Water Quality Control Division in its 1986 NPDES permit (permit number CO-0024147). Both solid and liquid waste treatment were improved. The most extensive effort involved addition of a nitrification trickling filter (NTF) to increase removal of ammonia from the liquid waste stream. The new facilities have also reduced total suspended solids and BOD to levels significantly below permit requirements. Sludge processing and removal also have been improved. Although the plant is expected to continue to meet applicable water quality standards through the year 2010, the city is continuing to refine its new trickling filter/solids contact system. This system provides high-quality secondary effluent to the NTF.

The city submitted a request to the Water Quality Control Division to consider retaining current NPDES limits for un-ionized ammonia over the upcoming permit period (1991-1996). This would allow time to evaluate the results of the creek enhancement project on the instream concentrations of un-ionized ammonia. It is hoped that the instream water quality conditions can be met after completion of the enhancement project because placing still-higher restrictions on plant effluent would require very expensive modifications and yield limited results.

Nonpoint Sources

Initial Phases

The second and third steps of the Boulder Creek Enhancement Project were to improve the riparian zone along the river and restore instream habitats. The goal of Phase I was to provide cost-effective water quality improvement, control nonpoint source pollution, and achieve aquatic life uses by reducing un-ionized ammonia concentrations, pH levels, and temperature in the creek. Phase I involved the design and construction of six BMPs over a 1.3-mile reach that passes through the center of a heavily grazed cattle ranch. These BMPs included constructing high-tensile, wildlife-compatible fencing to exclude cattle from the riparian habitat; stabilizing streambanks using log revetments; planting crack willow and cottonwood in the riparian zone; replacing channelized berms with sculpted or terraced streambanks; excavating 0.5 mile of thalweg channels on concave meander bends; and creating three boulder aeration structures (USEPA, 1992b).

Critical zones were established for each BMP so that, in addition to evaluating the combined effect of the measures, the impact of each BMP could be evaluated separately. Baseline data were collected prior to BMP construction, and data was also collected during construction and after implementation. Instream monitoring included monthly sampling for water quality, flow, and temperature, as well as fish inventories and evaluation of canopy density, ground water levels, and physical habitat. To date, there has been little monitoring of BMP effectiveness.

Fencing off the riparian zone was critical to the success of Phase I. Unless cattle were successfully excluded from the riparian zone, the impact of all other BMPs would have been minimal. The landowner granted a protective easement that covered more than 40 acres. This area was fenced in to provide a 120-foot-wide buffer between grazing land and the stream. Stretched steel wire on hammered posts provided inexpensive and durable fencing. Cattle crossings were designed as rigid, hinged double gates that could exclude cattle entirely, or could be opened to provide a temporary corridor across the creek. Because this was a nontraditional use of fencing, many of the design elements needed to be tested by observing field operating conditions. Sections of the fencing had to be rebuilt and redesigned. Cattle crossings were particularly challenging because it was necessary to fence across the creek, subjecting the structure to water-borne debris and runoff. Both the original gate design and permanent crossing corridors constructed of PVC mesh suspended from cables are now used, depending on the conditions at each site. The permanent crossings allow passage of debris and boaters under the fence while providing a visible barrier to the cattle.

Phase I, which was completed in the spring of 1990, yielded positive results. Not only did instream conditions improve, but community cooperation and interest in the demonstration project were very high. This success spurred approval of Phase II, which extended restoration efforts over another 1.1 miles of the creek. Phase II reduced the impact of return flow from an irrigation ditch by rerouting it through existing and constructed wetlands (USEPA, 1992b). Although cattle grazing along the Phase II reach did not pose a serious problem, streambank revegetation was badly needed. The individual plantings used to revegetate during Phase I were only moderately successful; therefore, Phase II tested "wattles" and "brush layering." Wattles are horizontal bundles of willow cuttings buried at or near the creek bank. Brush layering is the backfilling of willows into the streambank parallel to the water surface, with the growing tips projecting into the stream (Rudkin, 1992). Construction of rock/willow jetties to break up erosive currents was also tested. This method was less expensive and less time consuming than using riprap or other traditional construction methods.

Adaptive Strategies

Communication and availability of the project team to deal with rapidly changing conditions proved to be an important consideration in the design and construction process. Atypical runoff, rapid erosion, and hydraulic modifications as a result of the project necessitated field modification of the original design. Team members had to respond quickly with methods to protect previously completed work and new designs to fit the continuously changing system.

Phase III added an additional 0.5 mile to the project. No cattle were trampling the creek and its banks in this section, and the channel was not as severely eroded, but the adverse effects of surface gravel mining posed a new challenge. Planning called for biotechnical streambank stabilization, revegetation, and creation of wetlands. A chief aspect of this phase was to reduce channel abrasion by creating low-flow channel over approximately 0.25 miles of the project area.

Although conditions were less severe along the Phase III reach, the project was complicated by the need to reevaluate planting methods and plant species use in the bioengineering design. The crack willow used in Phases I and II, though prevalent along many front-range streams, is not an indigenous species. Peachleaf willow was used instead to be consistent with Boulder's policy of encouraging native plant species. The brush-layered vegetation demonstrated effectiveness in resisting erosion, even during high flow conditions.

Changes in the planting method used for the cottonwood included replacing the whip plantings with pole plantings. The larger, 10- to 12-foot poles showed more success, and this technique was recommended for replanting the less successful areas from previous phases. It was also determined that spring plantings had a better survival rate than the fall plantings done in Phase I. Winter moisture was more predictable, but uncertainties in spring weather conditions seemed to be outweighed by good growth conditions immediately after planting.

Boulder provided a site within the Phase III project area, construction support, and equipment for a graduate research project investigating the establishment of cottonwoods from seed along riparian corridors. A separate research project to investigate growth of the peachleaf willow was initiated at the same time. These are multiyear projects that may provide valuable information on the propagation of the two species. The first project has already reported that critical soil and moisture conditions can be determined and can have significant impact on seedling survival. Future study will provide information on the most cost-effective methods of providing proper seed growth conditions as a component of the BMP.

As it is designed, Phase IV of the demonstration project will involve a 1.7-mile reach, bringing the total number of restored creek miles to 4.6. Phase IV includes aspects of the first three phases and incorporates the design changes made after evaluating the effectiveness of previous methods. Results from the first three phases support expanded use of riparian plantings combined with the use of rock buttresses placed to protect vegetation in the earlier stages of development. A unique aspect of Phase IV is the proposed use of abandoned gravel mines to remove solids from runoff (USEPA, 1992b). The basins discharge to wetlands to polish the runoff water a bit more before it enters the stream.

Costs

Overall project cost has included the costs of gathering data for planning and evaluating results, construction, materials, labor, and time. Funding for these activities has come from federal, state, city, local, and private organizations. The value of the project has also been augmented by the donation of labor, time, and materials.

Monitoring is being conducted by a variety of agencies. USEPA Region VIII is assisting the cities of Boulder and

Longmont with the cost of instream monitoring. City officials authorized funding for two long-range planning studies, a use attainability study, two water quality studies, and a feasibility study. Aquatic and Wetland Consultants, Inc. performed all of these. Two monitoring studies were funded by the University of Colorado Undergraduate Research Opportunities Participation Program (Windell and Rink, 1992). The first was a study on the interaction of riparian vegetation and water temperature, funded for $700. The second study, funded for $2,500, covered follow-up monitoring of nonpoint source pollution controls after implementation. One study on the interaction of riparian vegetation, temperature, and fish population in Boulder Creek was funded for $2,500 by the W.L. Sussman Foundation (Windell and Rink, 1992). Monitoring data are also provided by the U.S. Geological Survey and the Colorado Water Quality Control Division. The WWTP monitors and reports effluent flows and concentrations as part of the permitting process. A portion of the funding for modeling was provided by USEPA.

The 1991 upgrade of Boulder's 75th Street WWTP was the largest capital project in the city's history, costing a total of $23 million. Seventy-six percent of the total improvement cost ($17.5 million) was expended to remove additional ammonia; the remainder was spent on sludge processing and disposal. Costs of the treatment plant upgrade were covered by the city of Boulder, with some assistance from the USEPA Construction Grants program.

The total funding for Phase I of the demonstration project was $125,000. Colorado provided 60 percent of this under the state's nonpoint source control program; the remaining 40 percent was provided by the city of Boulder. With donated time, labor, and materials, the total worth of Phase I is estimated at $426,000 (Windell et al., 1991). Phase II funding, at $125,000, was similar to that of Phase I (Windell and Rink, 1992). Phase III of the project was funded for $75,000 (Windell and Rink, 1992), and Phase IV is estimated as having an on-the-ground budget of $225,000. The total cost of the completed enhancement project is currently estimated at $1.3 to $1.4 million (R.E. Williams, Assistant Director of Public Works for Utilities, City of Boulder, personal communication, March 28, 1991).

CONCLUSION

Short-term results are most readily available for cost, constructability, and durability. Each phase of the restoration has included a post-project review to evaluate the success of design, materials, and construction methods. Results of these evaluations have been put to use in subsequent phases, as was discussed earlier. The channel may take some time to recover and stabilize after construction of instream modifications. Because of this, the effects of newly created thalweg channels and streambank revetments may not be measurable for a year or more. Improvements of the natural system caused by plantings will take even longer to assess. Cottonwood shading may require 5 to 10 years to show measurable results.

Follow-up monitoring, which is often expected to provide rapid answers following construction, will be a long-term undertaking requiring accumulation of data as the project matures. So far, monitoring has shown that vegetative plantings are much more stable and effective than predicted. Revegetation may prove even more effective for stabilizing streambanks than revetment or riprap. Altering planting and harvesting techniques for Phases I and II showed that these were critical factors in ensuring the survival of riparian plantings. Regardless of which methods were used, however, plantings grew extremely well when the site was prepared properly and the plants were adequately watered and protected from grazing and erosion.

The Boulder Creek Enhancement Project is now well established as a full-scale laboratory to test the feasibility and effectiveness of combining off-site nonpoint source control measures with traditional point source treatment to achieve water quality goals. Both the State of Colorado and USEPA have praised the project for its use of alternative technology. In 1992, USEPA awarded the project a Regional Pollution Prevention award. USEPA has also used the project as a model for a national pollutant loading training course. Riparian restoration has provided multiple rewards, improving wildlife habitats and water quality as well as removing some of the burden of meeting water quality goals from point source dischargers.

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This case study was prepared by Tetra Tech, Inc., Fairfax, Virginia, in conjunction with EPA's Office of Wetlands, Oceans and Watersheds, Watershed Management Section. To obtain copies, contact your EPA Regional 303(d)/TMDL Coordinator.