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Case Studies of Dam Removal and TMDLs: Process and Results

Steve Tuckerman* **and Bill Zawiski**

Ohio EPA Division of Surface Water, Northeast District Office
2110 East Aurora Road
Twinsburg, Ohio 44087

ABSTRACT. *Because of its storied history, the Cuyahoga River in Ohio is often used as a measure of progress toward water resource integrity within the United States. The river has shown dramatic chemical/physical water quality improvements but is still not fully attaining water quality goals due to impacts to the river from non-regulated sources. A section of the Clean Water Act entitled Total Maximum Daily Load (TMDL) provides a process to address these impacts. A TMDL report for the Cuyahoga River near Kent, Ohio recommended modification or removal of two dams to restore habitat and meet water quality objectives in the river. In response to the TMDL, the historic Kent dam was modified in 2004 and the Munroe Falls dam located approximately 5 miles downstream from the Kent dam was removed in 2005. The Ohio Environmental Protection Agency sampled fish and macroinvertebrate communities, evaluated habitat, and monitored dissolved oxygen concentrations in the middle section of the Cuyahoga River near Kent. Data showing marked improvements of the fish community less than 1 year after dam modifications in Kent and improved dissolved oxygen concentrations after the Munroe Falls dam removal are presented. This paper will also discuss and contrast methods of interacting with the public and local governments and propose guidance for future projects.*

INDEX WORDS: *Cuyahoga River, TMDL, dams, river restoration.*

INTRODUCTION

The 1969 fire on the Cuyahoga River and the "death" of Lake Erie were seminal events in the American environmental movement that led directly to the establishment of Earth Day, the formation of the United States Environmental Protection Agency, and the passage of U.S. Public Law 92-500—the Clean Water Act (CWA) (Nelson *et al.* 2002, Browner 2001, Adler 2002). The CWA is the national regulatory framework for managing the quality of the surface waters of the United States. The principal objective of the Act is to "restore and maintain the physical, chemical, and biological integrity of the nation's surface waters" (Section 101[a][2]). Although this goal is fundamentally ecological, the benchmarks by which most regulatory agencies have measured progress tend to be predominated by non-ecological measures such as the chemical/physical quality of point sources and surface waters. (Karr *et al*. 1986, Yoder and Rankin 1995a, U.S. EPA 2000).

Early regulatory programs developed after the passage of the CWA focused on the obvious environmental insults that came from inadequately treated wastewater from factories and domestic sewage treatment facilities ("point sources"). Better wastewater treatment resulting from environmental regulations improved the chemical/physical quality of the nation's waters including the progenitor of the CWA, the Cuyahoga River (U.S. EPA 1994, 2000; Ohio EPA 1999, 1996). However, attainment of chemical criteria is only one, albeit important, part of a very diverse, complex set of attributes necessary to achieve the ecological objective set forth by the CWA (Karr *et al*. 1986). Direct sampling of the aquatic biota has confirmed that it does not necessarily follow that an improvement in chemical/physical water quality will result in meeting the ecological goals of the CWA. Removing the mask of chemical/physical pollutants through improved wastewater treatment revealed more fundamental problems with aquatic systems that are a result of diverse ("non-point") sources of pollution (Ohio EPA 1998, 2000a).

Non-point sources of pollution, hydromodification, and loss of habitat in streams tributary to the Great Lakes can have adverse consequences in the

*Corresponding author. E-mail: steve.tuckerman@epa.state.oh.us

lakes. As directed by Executive Order 13340, the U.S. EPA Administrator convened a "regional collaboration of national significance for the Great Lakes." The resulting national restoration and protection strategy identified as a priority the protection and enhancement of stream habitats that are tributary to the Great Lakes (GLRC 2005). The Lake Erie Lakewide Management Plan, required under the binational Great Lakes Water Quality Agreement, had previously identified habitat loss and degradation as one of the top three stressors that must be addressed to restore Lake Erie (Lake Erie Lakewide Management Plan 2004).

The authors of the CWA recognized that non-point sources or other factors that are not directly regulated by the CWA may prevent or hinder the restoration of impaired water resources. Included in the Act are provisions for the development of Total Maximum Daily Loads (TMDL) to restore impaired water bodies where controls upon point sources alone are insufficient to meet CWA goals. A TMDL is a written, quantitative assessment of water quality problems and contributing sources of pollution to a waterbody. The TMDL specifies the amount a pollutant needs to be reduced to meet water quality standards, allocates pollutant load reductions, and provides the basis for taking actions needed to restore a waterbody. The Cuyahoga River near Kent was not meeting the CWA goals and was placed on a list of "impaired waters" for TMDL development (U.S. EPA 1994).

A TMDL report was prepared for the middle portion of the Cuyahoga River and was approved by the U.S. EPA on 11 October 2000 (Ohio EPA 2000b). The report evaluated the results of previous investigations and outlined several necessary measures to meet water quality standards. Primary were the modification or elimination of the Kent and Munroe Falls dam pools and a establishment of a minimum flow release from Lake Rockwell. The TMDL recommendation for addressing impacts associated with the dams and their impoundments also included minor changes to effluent discharge permits for five wastewater treatment plants in the area. These plants, permitted under the National Pollution Discharge Elimination System (NPDES), faced tiered limits based upon whether actions were taken to address the dams and associated impoundments. The impounded habitats contribute to chemical/physical water quality problems such as low dissolved oxygen and nutrient enrichment. If no actions were taken toward modifying or removing the dams and impoundments, then more stringent NPDES permit limits would be needed to meet water quality standards which would result in costly upgrades for all permitted facilities within the study area. If the dam impoundments were eliminated, only minor changes to existing NPDES permits would be needed to meet water quality standards in the river. The stakeholders in the study area decided to implement the dam modification/removal option.

DESCRIPTION OF STUDY AREA

The Cuyahoga River is located in the glaciated region of Northeast Ohio within the Erie/Ontario Lake Plain (EOLP) ecoregion. The 160 km long river flows in a u-shaped watershed into Lake Erie at Cleveland (see Fig. 1). Land use within the watershed is dominated by urban development, agriculture, forest, and wetlands. The study area extends from Lake Rockwell (the water supply reservoir for the City of Akron) northeast of Kent at River Mile (RM) 57.97, south through the communities of Kent, Stow and Munroe Falls to the downstream boundary near the Munroe Falls dam and RM 48. The drainage area at the downstream boundary is 349 km^2. Tributaries within the study area include Twin Lakes Outlet (RM 57.83), Breakneck Creek (RM 56.82), Plum Creek (RM 53.67), and Fish Creek (RM 52.15).

Stream hydrology is significantly influenced by the Lake Rockwell dam and, prior to the implementation of the TMDL, by the Kent and Munroe Falls dams at RM 54.80 and 49.90 respectively. Six significant waste water discharges occur within the study area. Water withdrawals include the City of Akron drinking water supply at Lake Rockwell and irrigation for two golf courses at RM 56.5 and RM 51.35. The next downstream dam is located in Cuyahoga Falls at RM 46.47. The Kent dam (41° 09′ 12″N, 81° 21′ 35″W) is owned by the City of Kent and the Munroe Falls dam (41° 08′ 29″N, 81° 26′ 12″W), at the inception of the project, was owned by a private corporation. Ownership of the Munroe Falls dam was later transferred to the City of Munroe Falls. Dams in Kent and Munroe Falls were originally constructed in the early 1800s to provide water supply and power for local industry. The latest dams were also utilized for the Pennsylvania and Ohio (P&O) canal system. At 3.9 m high, the Munroe Falls dam impounded 5.9 km and the Kent dam at 4.5 m high impounded 1.6 km of the river. The Kent dam is within a National Historic District on the National Register of Historic Places;

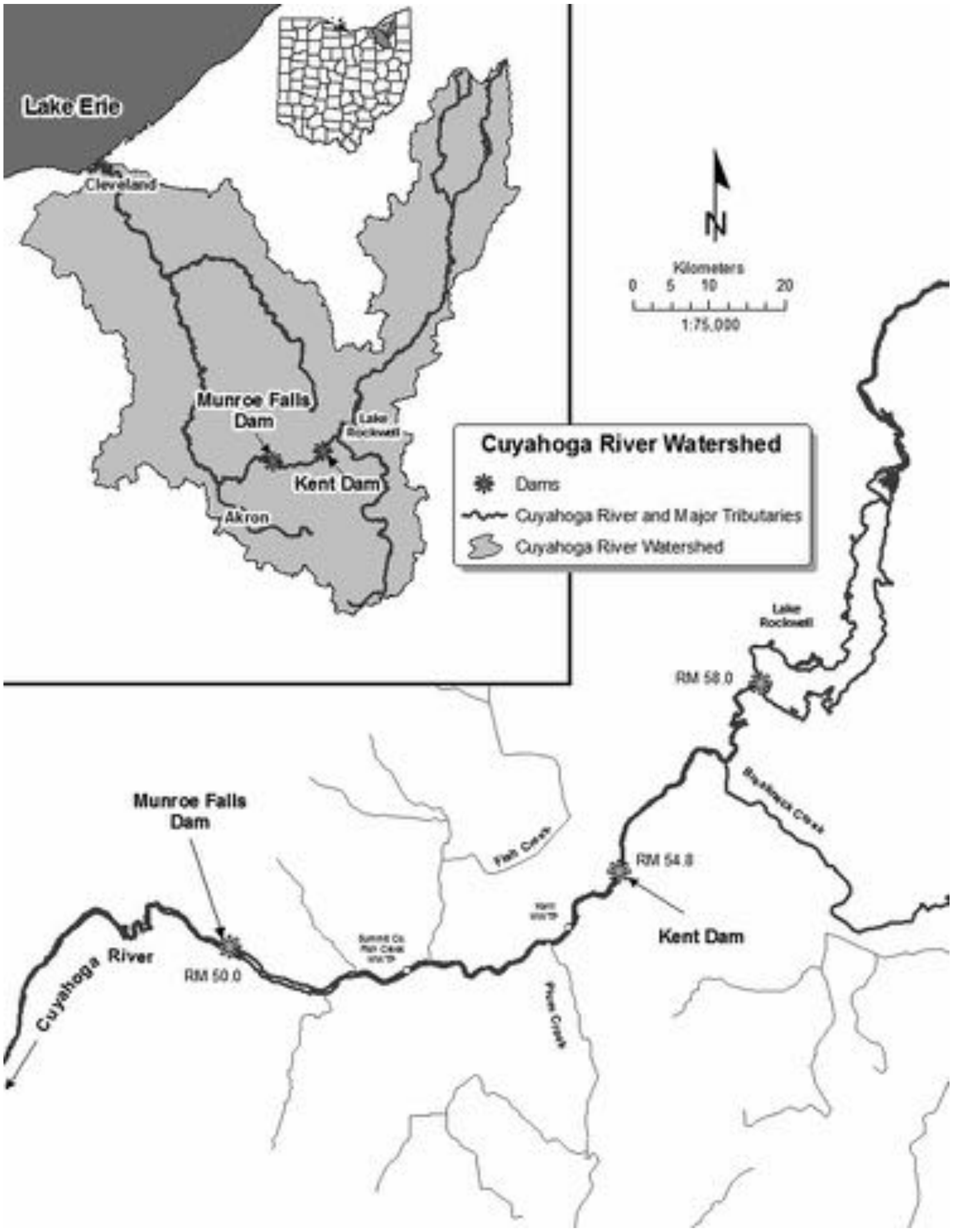


FIG. 1. Project location map showing the Cuyahoga River watershed and the location of the Kent (41° 09′ 12″N, 81° 21 35″W) and Munroe Falls (41° 08′ 29″N, 81° 26′ 12″W) dams. The study area extends from Lake Rockwell to downstream of the Munroe Falls dam. RM indicates the river mile from the mouth of the Cuyahoga River at Lake Erie (RM 0.0).

the Munroe Falls dam was not deemed a historic structure (National Park Service 2006).

Low dissolved oxygen concentrations were documented in the study area prior to the infamous Cuyahoga River fire of 1969 (Simpson *et al.* 1968). Subsequent Ohio EPA studies of the Cuyahoga River indicated that fish communities and dissolved oxygen concentrations did not meet state water quality standards in the study area (Ohio EPA 1994, 1999). The CWA (in Section 305(b)) requires states to submit a biennial report which provides an assessment of surface water quality in the state. Further, the CWA (Section 303(d)) requires states to provide a list of impaired waters (those not meeting water quality standards) with associated causes and sources of the impairments. Beginning with the 1980 305(b) report, impoundments were identified as a source of impairment to this segment of the Cuyahoga River (U.S. EPA 1994, Ohio EPA 1988). These studies and reports were the primary basis for the Middle Cuyahoga River TMDL.

METHODS

Kent Dam Project

The Kent dam is the last of several dams that were constructed in the city in the 1800s for power and later for the P&O Canal. The existing Kent dam is the oldest masonry dam in Ohio and the 19th oldest masonry dam in the United States. It is also the second oldest arched dam in the United States and the only masonry dam in the country that is attached to a canal lock (Pers.com. Doug Fuller, Kent Historical Society, 2002). In 1913, both the dam and canal lock were severely damaged in a flood and the dam was partially rebuilt in 1925 (Grismer 1932). The Kent dam is within the Kent Historic District which is on the National Register of Historic Places. The Kent community has strong ties to its history and the historic properties of the dam were the prime focus of community opposition to alterations of the dam structure to meet water quality goals.

Ohio EPA's principal objectives, as stated in the "Middle Cuyahoga River TMDL Report," were to meet the water quality standards for dissolved oxygen, to meet aquatic life standards by restoring suitable habitat, and to provide fish passage through the study area. The primary objectives of the Kent community were to have a free flowing river and to preserve the historic Kent dam and spillway. The City of Kent elected to become the Kent dam project leader in response to the TMDL report and the issuance of a new discharge permit at the city's wastewater treatment plant. The new permit would have imposed very stringent pollutant limits unless both the Kent and Munroe Falls dams were removed. The city initiated the "Kent Dam Pool Water Quality Improvement Project" in March of 2000. The study phase of the project included the creation of the Kent Dam Advisory Committee (KDAC), which consisted of a 19 member panel of interested stakeholders. This committee was invited to be an integral part of the study process for the purpose of ensuring that all pertinent information relating to the project was discovered and made available to the city administration for the city's consideration. The primary objectives of the KDAC were to meet the environmental objectives of the TMDL report while preserving the historic Kent dam and spillway. The city's engineering consultant, along with the assistance of the KDAC members and city administration, evaluated several ideas and concepts considering the historical, cultural, and aesthetic aspects of the Kent dam.

The process included six formal meetings, two of which were community based forums held at the local high school in 2000. An important determination from the KDAC meetings was that Section 106 of the National Historic Preservation Act (NHPA) was applicable to the Kent dam project. The NHPA assures that there is a formal process to identify and mitigate potential adverse effects to a historical structure subject to jurisdiction under Section 106 of NHPA.

The final recommended Kent dam project consisted of removing a concrete wall constructed after the 1913 flood, allowing the Cuyahoga River to flow around the historic arched masonry dam. The masonry dam was then converted to an artificial waterfall as mitigation for the alteration of the dam structure. Additional historic mitigation included documentation, education and interpretation of the historic structures on the site. River channel sculpting and stream and riparian restoration were performed both upstream and downstream of the dam. The project was dedicated on 19 May 2005 (Fig. 2).

Munroe Falls Dam Project

The history of the dams located in Munroe Falls is similar to the dams in Kent. Munroe Falls' dams provided water for the P&O Canal and process water and power for industry. The most recent dam was built in the early 1900s and was used primarily to provide water for a nearby paper mill. The dam was determined to not be a historic structure. The Summit County Department of Environmental Services (DOES) was the project leader for the Munroe Falls dam project. The Fishcreek WWTP, operated by DOES, discharges into the (former) dam pool at RM 51.85 which greatly affected their permitted discharge loadings to the river. Because of the stagnant conditions and low dissolved oxygen regime in the former dam pool, the effluent limits for this facility were very stringent. The TMDL determined that the most restrictive effluent limits for the Fishcreek WWTP and the other WWTPs in the study area would not have to be imposed if the Munroe Falls and Kent dams were modified or removed.

During early informal discussions, the City of Munroe Falls expressed its desire to maintain a "significant water feature" in the river as well as the water supply then being used by local industry. The Ohio EPA objectives were the same as for the Kent dam project described earlier. DOES staff presented three options and solicited input at a public meeting for a recommended design. The selection of the three options that were presented to the public differed from the KDAC approach where the Kent community chose the alternatives and recommended a preferred design. Otherwise, both the Kent and Munroe Falls dam projects followed the same basic framework for evaluating the projects.

The final selected design at Munroe Falls was to lower the dam from 4 to 2 meters and to build a fish passage structure around the modified dam. The dam project began in mid-August, 2005 by removing sandstone blocks from the top three rows of the dam and lowering the level of the river 0.6 meters at a time. Significant changes to the original design were made during the course of the project because of site conditions. First, while modifying the dam, the contractor found a rock ledge at the dam which could create a "significant water feature." Secondly, the local paper mill closed and the industrial water supply was no longer needed. Lastly, the lowered dam pool did not meet the aesthetic approval of the community at the projected final design pool elevation. As a result, Ohio EPA, Summit County DOES, and the City of Munroe Falls agreed to modify the project by removing the dam completely and allowing the river to flow freely, exposing a river feature that had been hidden for over 100 years. The Munroe Falls dam removal and river and riparian restoration project was dedicated 27 October 2006 (Fig. 3).

Monitoring

Aquatic community sampling in the middle portion of the Cuyahoga River was conducted in 1984, 1991, 1996, 1999, 2000, 2004, and 2005 (all data

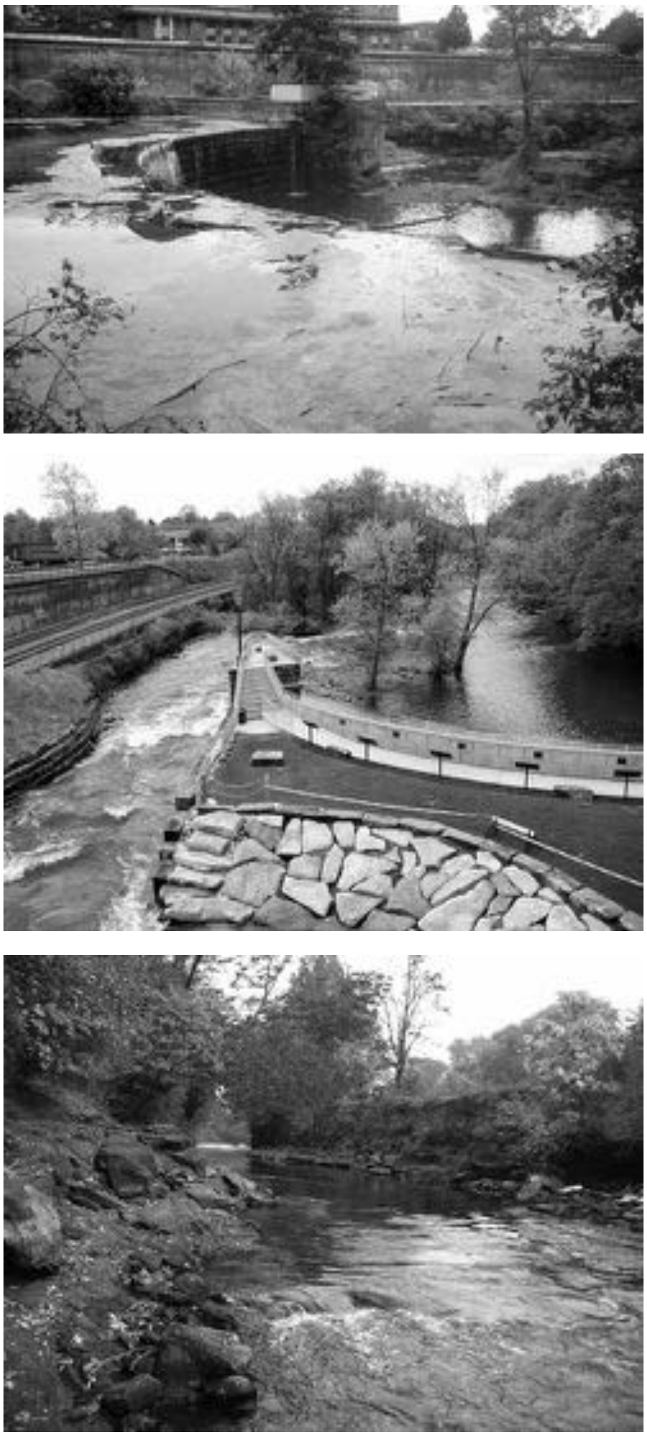


FIG. 2. Cuyahoga River in Kent, Ohio. The top photograph was taken before the dam bypass. Note aquatic macrophytes and stagnant appearance. The middle photo shows the river flow bypassing the historic masonry dam via the old lock structure. The educational/historic signage and the arched dam artificial waterfall are visible in the middle of the photograph. The waterfall was constructed to mitigate impacts to the historic dam structure. The bottom photo was taken after the dam bypass approximately 500 meters upstream from the dam showing excellent stream morphology in the former dam pool.

FIG. 3. The Cuyahoga River in Munroe Falls, Ohio. The top photograph was taken before the dam removal from the north dam abutment, looking upstream. Note the aquatic macrophytes along the shorelines. The bottom photograph was taken from the site of the former dam after dam removal.

are available from the author upon request). The 6 October 2004 sampling was the first fish community sampling in the Cuyahoga River after the Kent dam project began. The sampling was performed at a single location in portions of the former dam pool which were not disturbed by project activities. Subsequent fish and macroinvertebrate collections in both Kent and Munroe Falls project areas were made on 5 and 6 July 2005. The 2005 collections were made after the completion of the Kent project but before the lowering of the Munroe Falls dam. Automatic water quality sensors were deployed in 1999 and 2002 prior to the start of the projects and in 2006 after the dams were bypassed or removed. Because of disturbance by extensive stream bank work late in 2006, no post removal biological sampling was performed in the Munroe Falls area.

Ohio EPA relies on a tiered approach in attempting to link the results of administrative activities with true environmental measures. Ohio EPA incorporated biological criteria into the Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745-1) regulations in 1990. These criteria consist of numeric values for the Index of Biotic Integrity (IBI) and Modified Index of Well-Being (MIwb), both of which are based on fish populations, and for the Invertebrate Community Index (ICI), which is based on aquatic macroinvertebrate populations (Ohio EPA 1987). Criteria for each biotic index are specified for each of Ohio's five ecoregions described by Omernik and Gallant (1988) through direct reference to "least impacted" reference sites in each ecoregion. While biological communities are inherently variable, the use of multi-metric indices and two organism groups in Ohio standards reduce this variability (Yoder and Rankin 1995a). A Qualitative Habitat Evaluation Index (QHEI) based upon readily observed characteristics of stream habitats was developed by Ohio EPA to further reduce variability caused by habitat in evaluating fish populations (Rankin 1989). Coefficient of variation from nearly 1,000 sites in Ohio for the IBI was found to have less variability than chemical laboratory analysis and inter-laboratory bioassays (Yoder and Rankin 1995a).

The IBI integrates 12 fish community metrics describing species richness and composition, trophic composition, and fish abundance and condition. IBI scores range from 12 (no fish) to 60. The MIwb is also a fish community index but integrates the number of individuals, biomass, and the Shannon Diversity Index calculated for both numbers and weight. MIwb scores range from 0 (no fish) to 12. The QHEI scores can range from 0 to 100 with the higher score indicating better fish habitat. A QHEI score of 60 or better indicates that the stream habitat is suitable for maintaining at least a warmwater habitat fish community. The ICI is an aquatic macroinvertebrate community index that measures ten structural and community metrics and ranges from 0 (no aquatic macronvertebrates) to 60 (Ohio EPA 1989b). These criteria, along with the existing chemical and whole effluent toxicity evaluation methods and criteria, figure prominently in the monitoring and assessment of Ohio's surface water resources. The biological criteria derived from fish and aquatic macroinvertebrate communities are the principal arbiters in Ohio of whether the goals of the CWA are being achieved.

Fish collections for determining IBI and MIwb were made with pulsed direct current electrofishing equipment. For shallow water sites, electrofishing was performed using Ohio EPA wading methodology. Deep water sites were sampled with an electrofishing equipped jon boat per Ohio EPA boat sampling methodology. Fishing zones were 200 m for wading sites and 500 m for boat sampling sites (Ohio EPA biocriteria are calibrated for the sampler type). Fish were netted and placed in a live well before being sorted by species, counted, checked for external anomalies, and weighed. The fish were returned to the river after weighing. Fish collection and QHEI habitat evaluation forms were then completed (Ohio EPA 1989b).

Quantitative aquatic macroinvertebrate were collected at each site using five modified Hester-Dendy multiple-plate artificial substrate samplers (HD). The use of artificial substrates reduces variability of aquatic macroinvertebrate due to habitat (substrate) differences. Each set of five HDs has a total surface area of 2.3 m^2. The HD sets were lashed to concrete blocks and placed in the river. Stream velocity measurements were taken to ensure a minimum velocity of 0.9 cm/sec over the deployed sampler sets for lotic sites. After 6 weeks, the samplers were carefully retrieved and preserved in a solution of approximately 10% formalin. The preserved samples were taken to the Ohio EPA Environmental Assessment Section laboratory for identification to the lowest taxonomic level. In addition to the HD samples, qualitative aquatic macroinvertebrate collections were made with dip nets and direct collection from all available substrates until, by gross examination, no new taxa were collected. A station description sheet was completed for each sampling location (Ohio EPA 1989a).

Automatic water quality sensors were placed near the river thalweg and were floated approximately to mid-depth. Measurements for dissolved oxygen, pH, temperature specific conductivity, and stream stage were collected every 15 minutes for at least 48 hours (Ohio EPA 2006a).

RESULTS AND DISCUSSION

Process

The initial concentration of regulatory programs on point source controls led to the perception that the goal of the CWA was to merely achieve discharges of treated wastewater as clear as a swimming pool rather than meeting the broader goals of chemical, physical, and biological integrity. The resulting presumptions of a reliance on chemical/physical water quality criteria alone follow: 1) *any* exceedance of a chemical water quality criterion is bad; 2) the observation of no exceedances is good; and, 3) the control of toxic chemicals will result in the attainment of CWA goals. In fact, well intentioned, but simplistic quests for clear and/or chemically cleaner water have fostered management strategies which have actually resulted in *increased* net damage to the environment because of an over-reliance on these easily measured but sometimes flawed presumptions (Yoder 1991b). The relatively narrow focus on discharger water quality has lead to disparities in the public understanding of environmental processes and widely varied expectations regarding the goals, objectives, and results of water quality management and water pollution control in general. Thus, attempts to improve water resources outside of traditional point source controls, such as dam removal, are often met with skepticism by public officials and the public at large (Cheng and Daniels 2005) even though impairments associated with dams such as low dissolved oxygen and biological community impacts are well documented (Allan 1995).

Public perception and understanding of water quality management may be changing. One indication is the response from a City of Kent citizen survey that revealed an approximately 75% positive response to eliminate the Kent dam pool to aid in the restoration of the Cuyahoga River. Another indication of changing public attitudes is the increasing number of dam removals in the United States initiated for environmental restoration. Dams that are no longer performing a function are being removed across the United States to reduce impacts and restore water resources (Maclin and Sicchio 1999). There are approximately 75,000 registered dams greater than 1.8 meters in height in the United States and 2,694 registered in Ohio (U.S. Army Corps of Engineers 1996, Ohio Department of Natural Resources 2006). The National Research Council estimates that the total number of dams of all sizes is much greater, approaching 2.5 million, and by the year 2020 more than 85% of them will be near the end of their operational lives (NRC 1992, FEMA 1999). This implies that there will be an increasing number of dams that will be evaluated for removal for stream restoration. It seems that many of the dams that are removed for ecological reasons are located along the sea coasts for restoring runs of anadromous fishes (Maclin and Sicchio 1999). However, freshwater fishes are also negatively impacted by dams (Trautman 1981). In Ohio, 42% of watersheds have been subjected to hydromodification, including dam impoundments, identified as a "high influence" source of stress that impacts streams (Ohio EPA 2006b).

As dam removal, especially removal of small dams, begins to take a more prominent place in environmental management, developing criteria for decision-making becomes a critical issue. The apparent momentum for dam removal has resulted in several organizations providing information and materials to assist in dam impact evaluations and dam removals. One of these organizations, the Heinz Center, provides a decision making framework for potential dam removals (Fig. 4). This framework was used successfully in both the Kent and Munroe Falls dam projects. Public participation is as important in TMDL development as it is in the Heinz Center framework. Public involvement in watershed management within the study area started much earlier than the development of the TMDL or the thought of dam modification/removal. In the 1990s there were several informal water rights disputes within the study area. In an attempt to resolve these disputes, Ohio EPA initiated a series of seminars in the mid 1990s. These seminars were designed to educate political leaders and the general public about basic concepts of water and water resource integrity and, specifically, how the concepts played in the Middle Cuyahoga River watershed. It was believed that a better understanding of watershed concepts would result in an enlightened self interest that would promote regional cooperation and prevent escalation of the informal disputes. Although these seminars did not stave off litigation (Ohio Supreme Court 2006), the meetings formed a good foundation of trust and knowledge (City of Kent 2002). We believe that this early investment in public participation was a major contributor to the successful implementation of the Middle Cuyahoga River TMDL, Ohio's first approved TMDL.

Public education and outreach are especially important in implementing projects outside of regulatory authority. For example, the words pollutants and pollution are seemingly synonymous terms, but the differences can be very large and need to be properly conveyed to avoid confusion and misinterpretation. The CWA grants authority to regulate *pollutants*, but does not grant authority to regulate

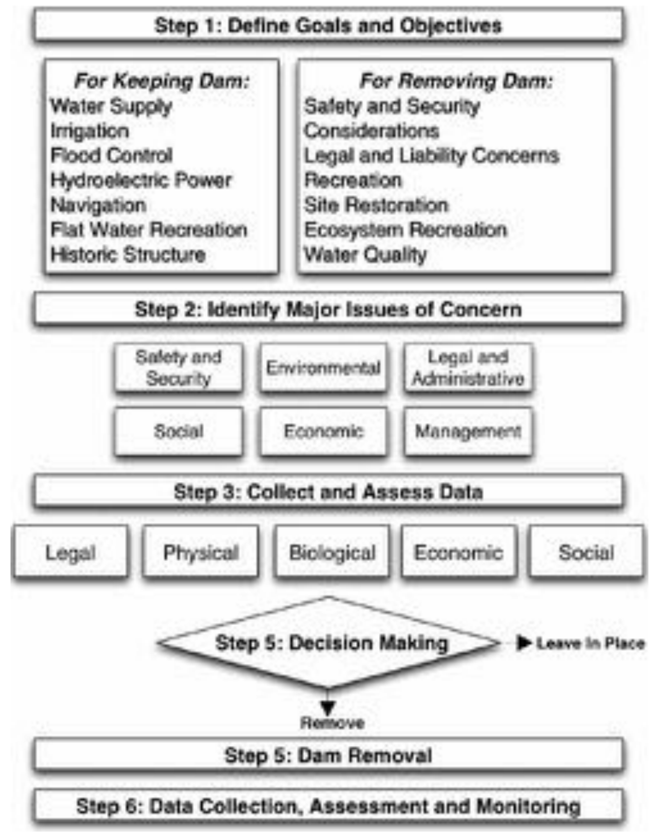


FIG. 4. Framework for dam removal (modified from Heinz Center 2002).

all *pollution*. In environmental regulations, pollution is defined as anything that can have an adverse impact on water resources. Examples of pollution include chemicals, physical substances, urbanization, floodplain alteration, and hydromodification (e.g., channelization and dams). Pollutants are specific substances that may have an adverse impact on water resources, are measurable, and can be assigned a loading (e.g., 10 kg per day of phosphorus). In Ohio, dams can be ordered to be removed for safety, but cannot be ordered removed for environmental reasons. Therefore, dam modification/removal was a recommendation in the TMDL, not a statutory requirement. As a result, environmental restoration by dam removal must be done through education and incentives. That is, authority granted under the CWA contains a stick for *pollutant* reduction, but can only offer carrots for some *pollution* abatement. And although the choices may be clear, the ultimate decision on whether to proceed with dam modification/removal or other "pollution" abatement is a local decision not imposed by federal or state regulation.

Both dams in the study area were icons for the cities affected and figured prominently in the cities' logos and history. When the idea of breaching the dams was first presented, the reception was cordial considering the reaction an outside regulator could elicit when broaching the subject of removing a community icon. Although contentious, the Kent dam process appeared to be more orderly because of the preliminary work by the KDAC and extra community involvement in the process. Presentations were made at six city council meetings and two public meetings prior to the final decision to proceed. There appeared to be more resentment by the general public in the Munroe Falls area where only one public meeting was held and two presentations were made to city council prior to the decision to proceed. After the project started, there were several more council meetings that were required to deal with new issues resulting from the change in the project design toward complete removal of the dam.

Aquatic Life Results

The full environmental impact associated with dam removal is rarely documented. Often studies are performed just to demonstrate the "return" of a high profile or keystone species. Little work has been done, however, to demonstrate a return of full aquatic resource integrity (Shuman 1995, Doyle *et al.* 2000, Bednarek 2001). Planned studies and those presented here are an attempt to assess broader aspects of water resource restoration through dam removal.

In previous investigations, IBI and MIwb scores decreased downstream from Lake Rockwell near RM 57 relative to the free-flowing reach upstream of the reservoir at RM 64.2. The decline in IBI and MIwb scores were a result of water withdrawal by the City of Akron and subsequent de-watering of the river channel (Ohio EPA 1999). Prior to the resolution of local water disputes and the development of the TMDL, there was often no flow from Lake Rockwell during summer low flow conditions (City of Akron 1996–2002). Declines in IBI scores were also measured in the free flowing reach immediately downstream from the Munroe Falls dam. These declines were attributed to chemical/physical water quality problems and increased algal productivity in the dam pools associated with enriched conditions. Further declines occurred near RM 48.0 due to the influence of the impoundment from the next downstream dam in Cuyahoga Falls. The fish collections contained few habitat sensitive round-

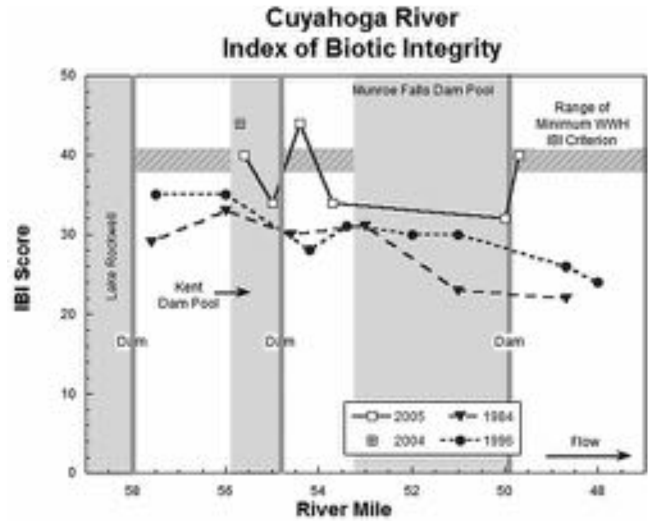


FIG. 5. Selected Index of Biotic Integrity (IBI) scores for fish communities in the study area. IBI scores are higher outside of impounded dam pools. The 2005 sample near river mile 55 was sampled just after the completion of heavy construction and stream restoration in the channel. Ohio EPA criteria for warmwater habitat for the Erie Ontario Lake Plain ecoregion is 38 units for wading sites and 40 units for boat sites. IBI resolution is ± 4 units. Connecting lines are for clarity in grouping collection dates only and are not intended to interpolate IBI scores between sampling stations. Data from years with only one or two sampling points are not included to improve clarity.

bodied suckers and gravel spawning fish, and a higher relative abundance of tolerant fishes. (Ohio EPA 1999).

The first fish community sampling in the Cuyahoga River after the Kent dam was bypassed occurred on 6 October 2004. The sampling was performed in portions of the former dam pool which were not disturbed by project activities. Subsequent fish and macroinvertebrate collections were made on 5 and 6 July 2005 in both the Kent and Munroe Falls project areas. The 2005 collections were made after the Kent dam project was completed, but prior to the start of the Munroe Falls dam project. The scores from these collections and from selected previous studies are presented in Figures 5–7. These data indicate that the fish community as measured by the IBI very quickly responded positively to the elimination of the Kent dam pool (Fig. 5). As important, the site immediately down-

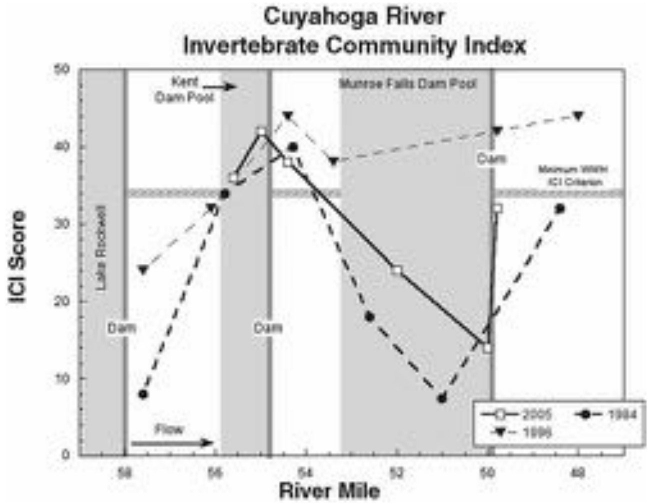


FIG. 6. Selected Modified Index of Well Being (MIwb) scores for fish communities in the study area. Connecting lines are for clarity in grouping collection dates only and are not intended to interpolate MIwb scores between sampling stations. MIwb scores are generally higher outside of impounded dam pools. The 2005 sample near river mile 55 was sampled just after the completion of heavy construction and stream restoration in the channel. Ohio EPA criteria for warmwater habitat for the Erie Ontario Lake Plain ecoregion is 7.9 units for wading sites and 8.7 units for boat sites. MIwb resolution is ± 0.5 units. Data from years with only one or two sampling points are not included to improve clarity.

stream from the dam did not seem to suffer degradation from sediment transport or other effects from implementation of the project. The site immediately upstream from the dam near RM 55.0 did not meet the MIwb criterion for fish communities immediately following project completion (Fig. 6). This collection was made less than two months after the 20 May 2005 project dedication in an area where an access road was installed and removed and subject to extensive earthmoving and reconstruction activities in and along the river. It's believed that there was insufficient time between the project completion and sampling to allow the fish community to recover from the extensive activities in and along the river.

The Munroe Falls project was dedicated 27 October 2006. Some stream bank restoration projects are not yet finished and are expected to be completed in 2007. An electro-shocking demonstration during the summer of 2006 collected a high number of intolerant (i.e., environmentally sensitive) fish species including *Micropterus dolomieui dolomieui* (smallmouth bass), *Nocomis micropogon* (river chub), and *Hypentelium nigricans* (northern hog sucker) in a river reach 50 meters upstream to 50 meters downstream from the former Munroe Falls dam. There were few tolerant fish such as *Cyprinus carpio* (common carp), *Pimephales notatus* (bluntnose minnows), and *Catostomus commersoni commersoni* (common white suckers) collected in the 2006 electroshocking demonstration while these populations predominated prior to the dam removal (Ohio EPA 1999). The IBI and MIwb indices were not calculated from this collection because the electro-shocking demonstration did not follow Ohio EPA sampling methodology. Post construction sampling is planned in 2007 to fully assess the aquatic community and attainment of water quality standards.

In previous investigations prior to the Kent and Munroe Falls projects, macroinvertebrate community health declined as indicated by an ICI score of 50 (Exceptional) at RM 64.2 upstream from Lake Rockwell to an ICI score of 26 (Fair) at RM 57.6 immediately downstream from Lake Rockwell. Low (no) flows and hypolimnetic releases of low dissolved oxygen and elevated ammonia from Lake Rockwell were probable sources of impact in 1984 and 1996. Communities continued to improve down river from the Lake Rockwell dam until the Munroe Falls dam pool where the ICI scores started to decline. Sampling in 2005 indicated that the Kent dam project did not significantly affect the macroinvertebrate community in the river as measured by the ICI (Fig. 7).

Prior to the dam projects, modified habitat attributes in the study area that were limiting to aquatic life outnumbered positive warmwater habitat attributes. Modified habitat attributes common throughout the impounded river segments included silt covered and embedded substrates, poor channel development, low sinuosity, no fast current, and no riffles. The Kent project improved the habitat in the former Kent dam pool as measured by the QHEI. A QHEI score was calculated for the site near RM 55.0 in 1998, prior to the Kent dam bypass. That QHEI score was 50.0 and compares to 68.5 in 2005 after completion of the project. Habitat evaluations have not yet been conducted in the Munroe Falls dam pool after dam removal (Fig. 8).

Prior to the dam projects, median dissolved oxygen concentrations were below the 5 mg/L average criterion in the Kent and Munroe Falls dam pools.

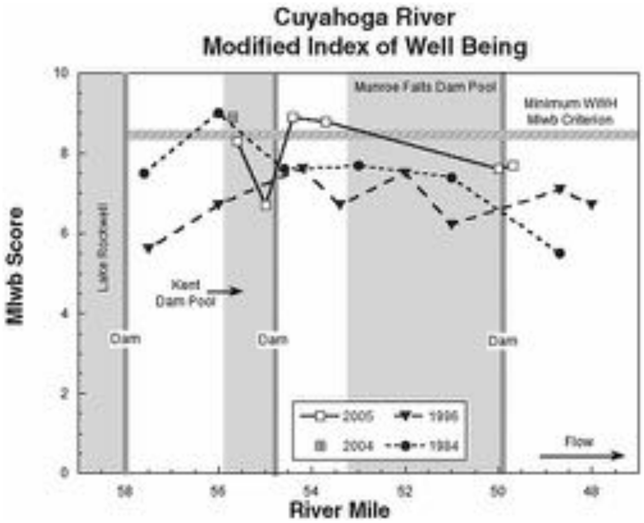


FIG. 7. Selected Invertebrate Community Index (ICI) scores for aquatic macroinvertebrate communities the study area. Connecting lines are for clarity in grouping collection dates only and are not intended to interpolate ICI scores between sampling stations. ICI scores are depressed in impounded dam pools compared to free flowing segments. Ohio EPA criterion for warmwater habitat for the Erie Ontario Lake Plain ecoregion is 34 units. ICI resolution is ± 4 units. Data from years with only one or two sampling points are not included to improve clarity.

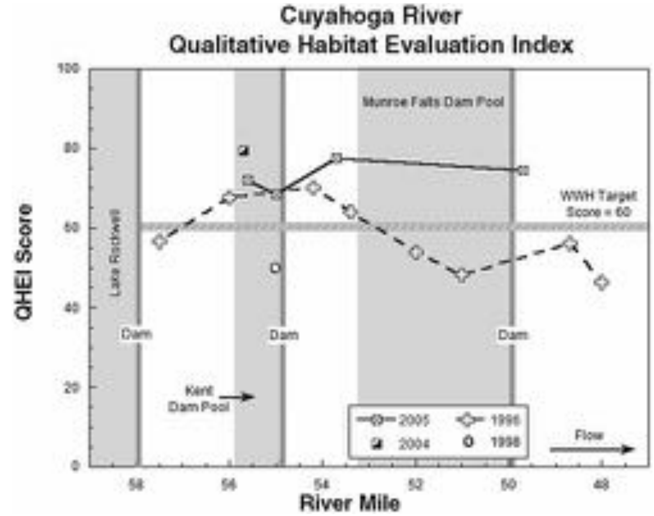
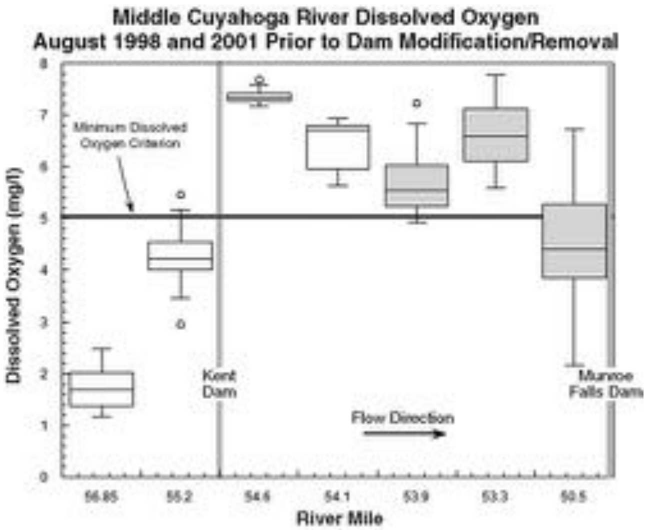


FIG. 8. Qualitative Habitat Evaluation Index (QHEI) scores for the middle Cuyahoga River study area. QHEI scores of 60 or better indicate that the habitat is suitable to support at least a warmwater habitat fish community. Lines provided to group data collected in same time frame and do not interpolate habitat quality between sampling locations.

Dissolved oxygen concentrations in the Cuyahoga River improved significantly from pre- to post-dam bypass/removal (Fig. 9). All dissolved oxygen sampling was conducted in August during the period of time when flows are typically lowest and temperature typically highest. A computer model simulation of dissolved oxygen in the study area was performed as part of the TMDL study (Ohio EPA 2000b). The model simulation was performed using the critical conditions of maximum wastewater treatment plant loading, a minimum release from Lake Rockwell of 0.15 m^3/sec, the 7 day–10 year low flow and the Munroe Falls dam in place at 2 m high. Although the model conditions and the instream conditions differ, the dissolved oxygen appeared to respond to the changes in the river as predicted by the model.

CONCLUSION

The dam removal projects associated with the Middle Cuyahoga River TMDL demonstrate that dam removal is a viable option for restoration of biological as well as the chemical physical integrity of water resources, thus meeting the goals of the Federal Clean Water Act. Often, dam removal is as much about education, social science, and politics as it is about biology, engineering, or the earth sciences. Early community involvement in the decision-making process made a contentious situation workable. Compromises and flexibility allowed the community to resolve apparently conflicting goals of meeting community desires and the goals of the CWA. The practical experience from the planning process and implementation gained through these projects can be used as a resource in addressing similar situations within Ohio and elsewhere as regulators seek to restore water bodies to meet Clean Water Act goals. The process outlined in the Heinz Center report (2002) provides a useful method for investigating and evaluating dam removals. Ecological restoration and historical preservation can be at cross purposes and early involvement of all stakeholders is very important to achieving a successful outcome. Although not everyone may begin the process with identical goals, open discussion and involvement can result in compromise and creative solutions that can result in successful projects. Our experience leads to several recommendations for



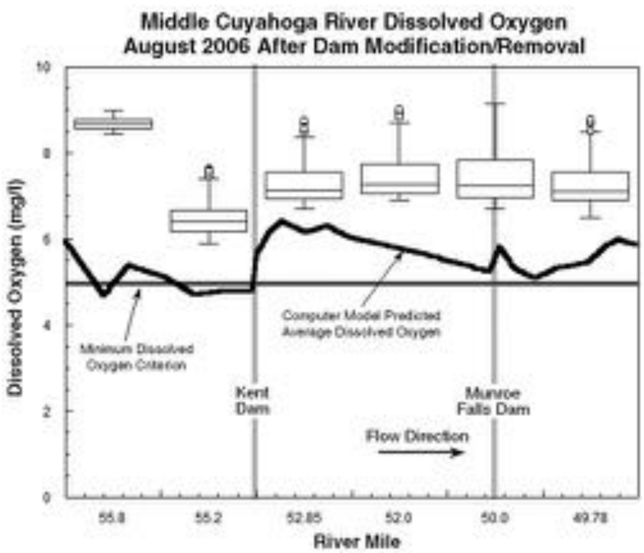


FIG. 9. Box and whisker plot of dissolved oxygen from automatic sensors in the Cuyahoga River. The box represents the 25th to 75th percentile of recorded values. The horizontal line inside the box represents the median concentration. Ohio water quality standard for 24 hour average is 5.0 mg/L. The upper graph is for measurements taken prior to the dam bypass/removal in 1996 (not shaded) and 2001 (shaded). The lower graph shows post removal concentrations. The line in the bottom graph is the predicted average dissolved oxygen concentration from a computer model simulation at critical conditions of maximum waste water loading, minimum release from Lake Rockwell of 3.5 MGD and Q7-10 flow and the Munroe Falls dam lowered to 2 m.

comprehensive planning and evaluation and successful project outcomes:

1. Adhere to an established decision-making process that is in place at the onset of a project. We believe that the Heinz Center report (2002) is a good starting point.
2. Establish clear goals and outcomes at the onset of the project such as desired or required water quality improvements, historical preservation, and recreation and community values.
3. Select project leaders that are experienced and comfortable with public interaction. Community interaction and consequently trust is not a guarantee and must be earned. Working through often-heated discussions is crucial to project success. Final outcomes may have much more to do with public perception and local politics and less to do with the empirical information.
4. Manage the project with a local, respected official or advocate, if possible.
5. Maintain flexibility of project personnel and contractors during the dam removal process. Unexpected challenges are encountered during every project. The use of good science and engineering will enable any challenge to be worked through toward successful project completion.

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