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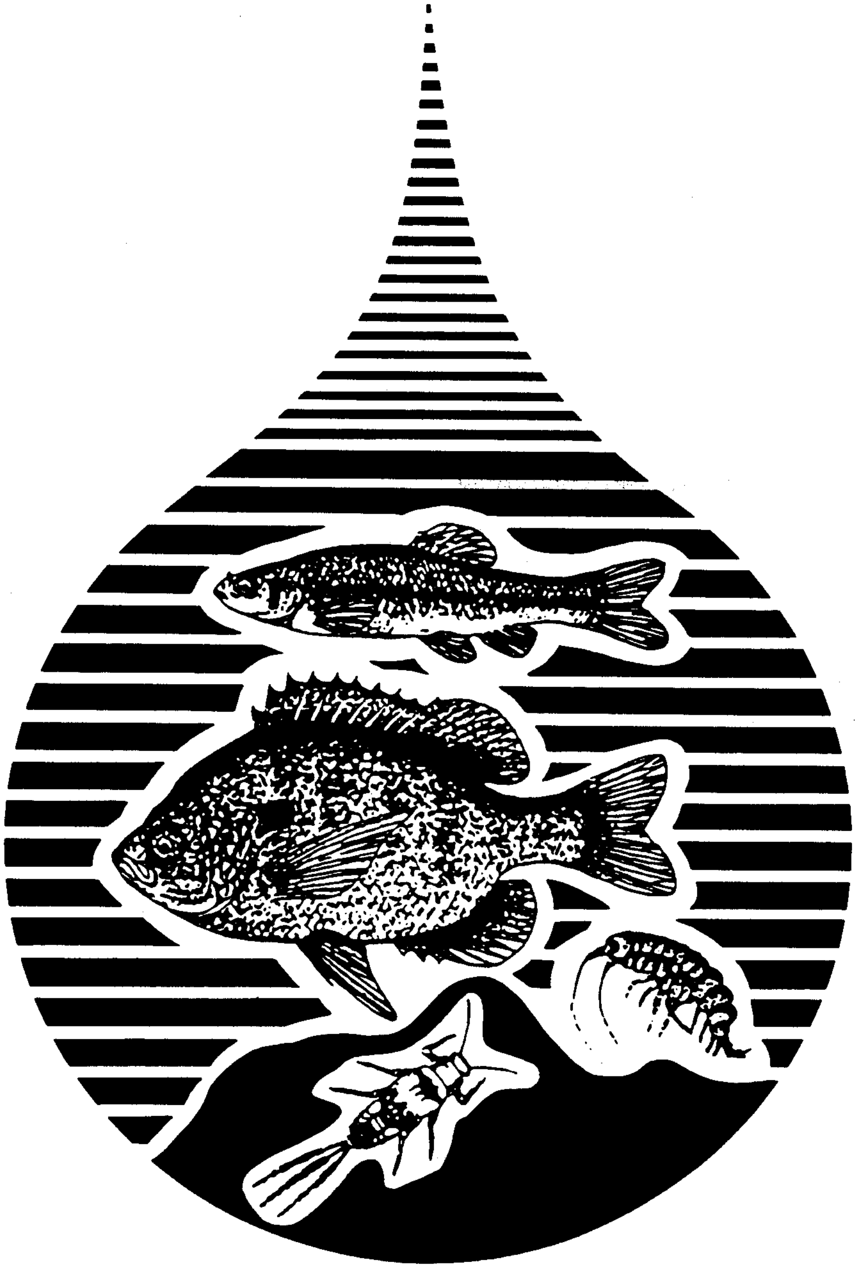

FORWARD

A Historical Perspective on Regulatory Biology

After several years of debate, the United States Environmental Protection Agency (USEPA) has thoroughly recognized the benefit of using biological survey data to assist with the Agency's regulatory decisions for surface waters. The myriad of uses that biological survey data can provide were discussed in the recent "Biocriteria Program Guidance Document" (USEPA 1990a), and examples were presented in the "Biocriteria Development by States" (USEPA 1990b).

The use of biological survey data to assess the health of our rivers and streams was prompted by some early work conducted by the Illinois State Natural History Survey almost a century ago. This paper specifically reviews the circumstances regarding that first biological survey, and the evolution of more rigorous and objective assessment end-points. Washington (1984) provided a comprehensive review of the history and application of biotic indices, and the information presented here is intended to complement Washington's work.

"Dilution is the Solution"

In 1848, the Illinois and Michigan Canal (I&MC) was opened crossing the continental divide between the Great Lakes drainage system and the Mississippi River drainage. The I&MC connected the South Fork of the South Branch of the Chicago River near the tanneries and packinghouses of the famous Chicago Stockyards with the Upper Illinois River at LaSalle (Figure 1; U.S. Engineers Office 1924). Initially intended for navigation, the I&MC soon became an obvious outlet for the sewage created by a growing population and industrial base, and, beginning in 1869, an average of 167 cfs (maximum 400 cfs) of water was pumped from the Chicago River into the sluggish I&MC, reversing the normal flow of the South Branch into the Illinois River. More direct gravity flow from the Chicago River was provided in 1871 by deepening the summit of the canal, and, in 1884, an additional 1000 cfs was pumped into the river to facilitate the flow. The growth of Chicago's north side also required additional pumping to increase the southward flow of the water and 400 cfs was pumped from Lake Michigan to the Chicago River mainstem. The inadequacy of the I&MC to solve the city's sewage needs, and to keep the city's water intake supply in Lake Michigan from additional contamination, became apparent.

The Sanitary District of Chicago was created by the State of Illinois in 1889 to plan for the city's additional sewerage requirements. In 1892, construction of the 28-mile long Chicago Drainage Canal began adjacent to the much smaller I&MC, connecting the South Branch of the Chicago River (near the West Fork) with the Des Plaines River at Lockport. The Canal, opened in January 1900, was designed to divert up to 14,000 cfs of water from Lake Michigan, resulting in a reversal of the flow of the Chicago River and sewage flowing away from the drinking water supply.

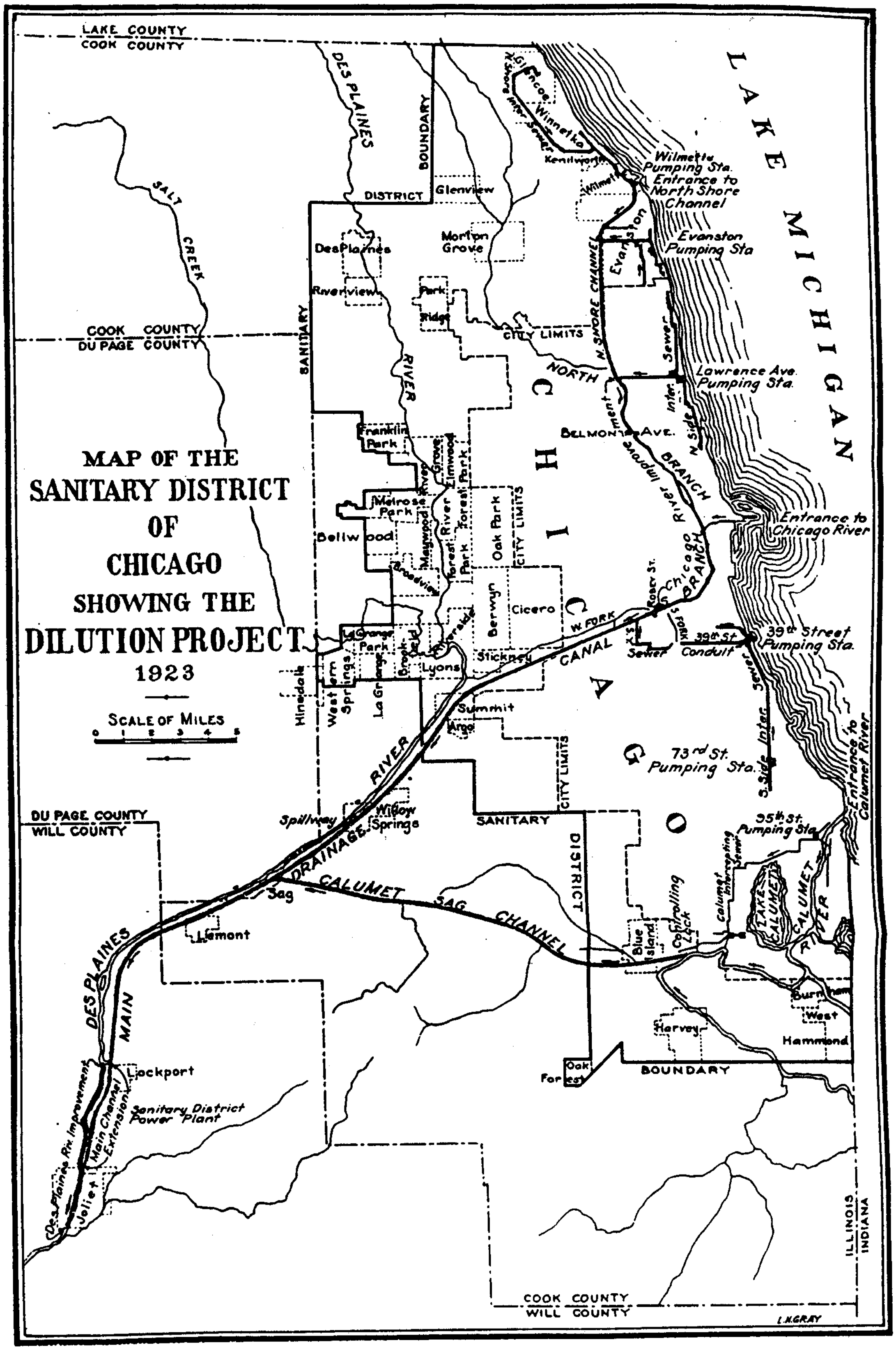

Figure 1 (from US Engineers Office 1924)

The population and industrial growth of the city required several pumping stations to be added to adequately "flush" the raw sewage downstream. Construction of the North Shore Channel from 1908-1910 which connected Lake Michigan with the Chicago River north of the city added about 1000 cfs. Sewers were soon built along the lakeshore communities eventually diverting all sewage in the Sanitary District from Lake Michigan into the Des Plaines River basin. The expansion of the far south side district resulted in the construction of the Calumet-Sag Channel, which was completed in 1922. The channel connected the Little Calumet River with the Chicago Drainage Canal 22 miles downstream, diverting an additional 500 cfs from Lake Michigan.

"Poisoning the Mississippi?"

As one can imagine, this diversion of raw sewage from the Chicago River system into the Des Plaines River did not please the downstream communities, although Chicago's drinking water supply was no longer contaminated. Before the Chicago Drainage Canal was officially opened, the State of Missouri brought suit against the State of Illinois and the Chicago Sanitary District on January 17, 1900 seeking an injunction from opening the Canal (Leighton 1907). The suit charged that the drainage of the "sewage matter from nearly the whole City of Chicago and a portion of Cook County" would "poison the waters of the Mississippi and render them unfit for domestic uses". The defendants claimed, however, that the Mississippi River water would actually be cleaner due to the dilution water from Lake Michigan (approximately 9:1).

Due to the interstate nature of this dispute which affected State sovereignty, the United States Supreme Court became involved. After years of gathering facts and assembling the nation's expert water quality scientists, engineers, and sanitarians, the testimony provided by these experts was deemed to be overwhelmingly in support of the State and Sanitary District's position. On February 19, 1906, the United States Supreme Court concluded that not only did the State of Missouri not prove it's case, but that the Chicago Drainage Canal (i.e. Sanitary and Ship Canal) substantially improved the quality of the nearby Illinois River (Leighton 1907).

"Bureaucracy in the 1800's"

Today's bureaucracy is painted with pictures of government required permits, licenses, and unnecessary delays, but such was the case even in the 1800's. In fact, a crucial permit was not obtained related to the building of the Chicago Drainage Canal because it was not thought to be necessary (U.S Engineer Office 1924).

A primary concern in the late 1800's was the defense of this country, under the authority of the War Department (now Department of Defense). One of the main mechanisms for defense mobilization was through navigable waterways, and their maintenance to serve in that capacity was of great importance. Maintenance of all navigable waterways in this country was the primary impetus for the Rivers and

Harbors Appropriation Act of 1899 (30 Stat. 1151 1899). Before any major alterations of a waterway were to be conducted, a Federal permit was required, but the Chicago Sanitary District did not apply for the permit until 1896, four years after construction was begun. The Federal government conceded the permit later that year, but stated that "the authority shall not be interpreted as approval of the plans of the Sanitary District of Chicago to introduce a current into the Chicago River." The Federal government also issued a temporary and revocable permit to open the canal in 1899 and eventually modified the permit in 1903 restricting the flow through the South Branch of the Chicago River to a maximum of 5833 cfs in winter when navigation is closed, and a maximum of 4167 cfs the rest of the year.

"Dilution was NOT the Solution"

Beginning in 1907, the Sanitary District made several permit applications for increasing the allowable flow in the river system through the diversion of water from Lake Michigan. Each application was denied by the War Department which stated in 1907 that diversion greater than the values permitted in 1903 would not be allowed. Despite the denial of Federal permits and even a Federal Court suit seeking to enjoin the District from constructing the Calumet-Sag Channel which would divert even more water, the construction of the North Shore and Calumet-Sag Channels continued, and was soon completed (U.S. Engineer Office 1924).

Arguments for both sides in this law suit were heard in Federal Court beginning in 1915, and in 1920, the United States District Court gave an oral opinion that the United States government was entitled to an injunction. After a motion of reconsideration was filed by the Sanitary District, the District Court issued a formal decree in 1923 supporting the injunction sought by the United States government. After an appeal to the Supreme Court, the decision made by the District Court was upheld on January 5, 1925.

The Supreme Court decision affected not only the illegal diversion of waters from Lake Michigan, but also the mitigation of adverse effects and actual damage caused by the diversion on the ecology of the Illinois River. To comply with both the need to dispose of sewage without additional diversion of water from Lake Michigan and to improve the poor ecological conditions of the Illinois River resulting from the now illegal diversion, the Sanitary District of Chicago committed over $125 million to construct/improve the sewer system and build the first wastewater treatment plants in the area. It was demonstrated that dilution alone no longer provided adequate protection of the streams and rivers and the era of physical and biological wastewater treatment arrived (Sanitary District of Chicago 1925).

"Early Biological Surveys"

It is likely that the immediate outcome of the law suits filed against the Sanitary District would not have adequately addressed the impacts on the Illinois River if it had not been for the work of Stephen Forbes, the Director of the Illinois State Laboratory of Natural History. In fact, the District Engineer from the U.S. Engineer Office documented the damage to the Illinois River based upon the work conducted and initiated by Forbes, and included that information in a 1924 report submitted to the War Department supporting the Federal government's case before the Supreme Court (U.S. Engineer Office 1924).

Forbes opened a permanent field biology station on the Illinois River in 1894 to document the effects on the stream biology as a result of the opening of the Chicago Drainage Canal in 1900. The planning for that station included investigating not only the effects due to periodic flooding of the river due to the increased flow, but also the direct effects from the pollution added from the Canal (Forbes 1928).

Between 1894 and 1899, Kofoid (1908) studied the river's plankton populations, life histories and how they were affected by environmental factors including sewage. This baseline study was later used by Forbes and Richardson (1913) and Purdy (1930) to document the river's assimilative capacity and decline of the plankton populations due to the opening of the Chicago Drainage Canal

After increasing the number of monitoring stations on the river, Stephen Forbes and Robert Richardson (1913) published their first report on the conditions of the Illinois River. They defined the degradation via pollutional zones (septic, polluted, contaminate, and clean water), similar to that of Kolkwitz and Marsson's (1908) Saprobic Index. However, the Saprobic Index was based upon bacteria and protozoa while Forbes and Richardson's zones were based on water chemistry, plankton, benthic macroinvertebrate and fish populations. Their surveys conducted between 1909 and 1911 documented 107 miles of water below the mouth of the Chicago Drainage Canal to be polluted before recovery fully occurred.

"Development of the First 'Biotic Index'"

In 1921(a), Richardson found 146 miles of the river to be polluted based on their work conducted between 1913 and 1915 and in 1920 concluded that 226 miles of the Illinois River was now polluted with 146 miles of near anoxic conditions (1921b). Based on their data collected over seven years, they reported between 8 and 16 additional river miles per year were classified as polluted. Richardson began to rely heavily on defining pollution zones based on pollution tolerances for the biota, focusing heavily on the benthic macroinvertebrate community due to their role in the food chain.

The last report on the pollution biology of the Illinois River conducted by Richardson was published in 1928, and proved to be the predecessor to the more recent biotic indices. The study added data collected between 1924 and 1925 and also marked the change of responsibility for the river surveys to the State Water Survey. In this classic report, he detected shifts in water quality based on observing the benthos alone, although he preferred to also use chemical data to better define the pollutional zones. He further refined the pollutional zones (called septic, pollutional, subpollutional, and clean water; Richardson 1925) based on "index values" of the benthos which used specific taxa as indicators.

"Development of Biological Assessment Methods"

Based on the work conducted by Forbes and Richardson, the use of benthic macroinvertebrates as indicator organisms was founded and the concept of biotic indices introduced. Although the work was similar in concept to the "Saprobic Index" developed by Kolkwitz and Marsson (1908), Forbes and Richardson used organisms at higher trophic levels. The work conducted by Forbes and Richardson forms the basis for some of our current regulatory biology programs supported by USEPA.

Richardson (1925,1928) decided that numerical abundances of each index group was not as significant as their relative abundances and overall occurrences. For instance, he reported the number of pollution tolerant Tubificid worms in the river to range from under 1000 to over 350,000 per square yard in pollutional zones, and Chironomids to range from zero to over 1,000 per square yard. Richardson also reported seasonal and habitat changes as responsible for much of the numeric variability at a given site, supporting the use of the occurrence of a species as the better index measure.

Wright and Tidd (1933) actually applied the numerical abundance of oligochaetes to assess the degree of pollution. They reported values of less than 1000 m^{-2} as indicating negligible pollution, between 1000-5000 m^{-2} as mild pollution, and over 5000 m^{-2} was severe pollution (Washington 1984). Washington felt this work was the "original index", apparently unaware of Richardson's earlier work with "index values" for benthos. Ruth Patrick (1950) developed a "histogram" based upon seven taxonomic groups and assigned stream classes of healthy, semi-healthy, polluted, very polluted, and atypical based upon the comparison of predominance of three of the taxonomic groups with the other four.

"Biotic and Diversity Indices"

It took several more years for an improved assessment end-point to be introduced. In 1955, Beck published a biotic index which produced a numerical end-point that could more easily be interpreted by biologists, as well as the engineering and management dominated discipline. Beck's index was based upon two classes of benthos: intolerant and facultative, assigned a weight value of 2 and 1, respectively. Therefore, the higher the index value, the healthier the stream is assumed to be. In the next two decades Washington reported several biotic indices, but Chutter's (1972) biotic index ushered in a new era for these indices.

Chutter studied South African streams and assigned specific tolerance values ranging from 0 to 10 for various taxa which accounted for both the number of individuals and the number of taxa. The results were also presented in a 0 to 10 fashion with an average biotic index value of 0-2 regarded as clean-water, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted. This index was the predecessor to the widely used Hilsenhoff Biotic Index (1977) in the midwestern United States which was initially based on a 0-5 scale which included many more taxa than Chutter's.

Hilsenhoff's index was based on taxa from Wisconsin using genus/species classifications of the aquatic insects. Hilsenhoff updated his index in 1982 and 1987 to revise the index values and include new taxa, and in 1988 he developed a very popular family-level biotic index.

The development and use of diversity indices for water pollution assessment was thoroughly reviewed by Washington (1984). Essentially, the use of diversity as an optimal measure of stream community response has been widely used since the 1960's, but the theoretical diversity which is based on calculating the evenness of the number of individuals among the assembled taxa was not developed, nor intended, for the application to natural systems.

One of the first diversity indices based on information was published by Shannon (1949) as H'. Washington (1984) stated that it was eventually termed the Shannon-Weiner Index because Weiner (1948) independently published a similar measure. Washington further explains that the confusion with erroneously calling the index the Shannon-Weaver index began when Shannon published his work in a book coauthored by Weaver.

Possibly the first use of diversity indices for assessing water quality, particularly the Shannon-Wiener Index, was by Wilhm and Dorris (1966) and further explained by Wilhm (1967) who described the ranges of H' associated with clean, moderately polluted, and substantially polluted streams.

"New Assessment End-Points"

The major asset of both diversity and biotic indices is that they both reduced the relatively complex interactions and pollution responses of an aquatic community into a single number for water quality management purposes. However, neither of these indices were successful in describing the overall "health" of the aquatic communities under a variety of conditions. Little information is available on whether both of these indices were widely used together, or if an attempt was made to develop a single end-point based on assigning a score to each index. However, it was clear that a better tool was need to more consistently and accurately characterize the aquatic communities.

In 1981, James Karr published the Index of Biotic Integrity (IBI), based on supporting the 1972 Clean Water Act's objective to restore and maintain the physical, chemical, and biological integrity of the nation's waters. The IBI was based on 12 individual indices, or metrics, based on fish species composition, trophic composition, and abundance and condition. Each metric was given a score (index value) based upon specific ecological expectations,and the twelve scores were added to provide a single site assessment end-point. The scores resulted in "integrity classes" for streams of excellent, good, fair, poor, very poor, or no fish (Karr et al. 1986).

The IBI can be termed a "composite index" because it combines several community attributes into a single index value. This overall concept, and the IBI in particular, has been demonstrated to be very successful for water quality, or water "resource" evaluations and is widely used by a number of regulatory agencies (Dodd et al. 1990; Cunningham and Whitaker 1989). It did not take long before this concept was successfully applied to benthic macroinvertebrates as well. Jeff DeShon at the Ohio Environmental Protection Agency (OEPA) developed the Invertebrate Community Index (ICI) in 1986 which is based on ten structural and functional metrics the OEPA biologists had subjectively used for a number of years (Ohio EPA 1987a-c).

Based on the enormous success of the IBI as an assessment end-point, USEPA independently began the development of an IBI-type index for benthos. In 1989, USEPA published another set of composite indices called Rapid Bioassessment Protocols (RBPs) for benthic macroinvertebrate and fish communities (Plafkin et al. 1989). The benthic community metrics were based on very general structural and trophic relationships that could be applied nationally, and the primary fish assessment method was the IBI. The RBPs are best used with regionally-defined (ecoregions) reference sites which can be validated for specific States by modifying the RBP metrics, as done by Bruce Shakelford (1988) in Arkansas.

Currently, the USEPA water quality standards program is requiring each State to adopt narrative biological criteria within the next three years, and eventually numerical biocriteria. Development and implementation of biocriteria would not be successful without these composite indices. These new assessment end-points have truly changed the way regulatory agencies can, and will, utilize biological survey data.

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1990 MPCB Meeting Coordinator

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