HISTORY OF POLICY AND MANAGEMENT OF WATER RESOURCES IN THE UNITED STATES

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Water policy in the United States is closely linked with the history and management of water resources. This history in what is now the U.S. likely began with the earliest migration of people from Asia some 15 to 18 million years ago. Though these Native Americans were stewards of both land and water, that is not to say that water pollution did not occur from natural or faunal sources during these times and earlier. For example, when three million bison gathered in the spring in the Upper Republican River Basin in what is now Nebraska, the amount of fecal pollution coupled with grazing likely led to significant water quality problems of low dissolved oxygen with excess nutrients and bacteria running off into segments of the river.

In 1607, when the first English settlers landed on the James River in what is now Virginia, they brought with them English common law. As it relates to water, it is now called the Riparian Doctrine, which essentially became the first water policy. In simplest terms, the Riparian Doctrine states that landowners whose land borders water have a right to that water. This policy worked quite well starting in the 1800s, and for more than 200 years it functioned to govern water use and quantity in the eastern U.S. because there was abundant rainfall and, essentially, water for all.

However, in the 19th century, as settlement moved into the arid West, it became clear that the Riparian Doctrine was no longer appropriate because water was less available. Consequently in the states west of the Mississippi River, the prior appropriation doctrine based on Spanish common law became the basis or policy for the allocation of water resources. Simply put, the prior appropriation doctrine states, "first in time is first in right." This means that when water is scarce, the earliest or senior holders of water rights have the first right to water, possibly at the expense of holders of junior water rights. With few exceptions and modifications by federal and state laws, prior appropriation still is policy in the 17 western states.

Much of the western U.S. averages less than 15 inches of precipitation annually. Thus, water is over-allocated and storage in large lakes, reservoirs, and mountain snow pack is essential in supplying water to communities. But this has also meant that rivers and streams that used to flow no longer carry water and no longer meet the sea. In the late 19th century, development was restricted to areas adjoining rivers and streams, but it was postulated that water could be impounded and directed to areas where adequate water could make the desert bloom. At the beginning of the 20th century, the Reclamation Act of 1902 was passed and signed into law. This law created the U.S. Bureau of Reclamation, which, from shortly after inception through the late 1980s, constructed about 600 projects in the 17 western states to bring water to arid areas. Two of the most celebrated projects were Boulder (Hoover) Dam on the Colorado River and Grand Coulee Dam in eastern Washington. This influenced the flow in the rivers dramatically and the Colorado no longer flows to the Gulf of Mexico.

For the most part, the Reclamation Act of 1902 has been successful in economic development; the desert has bloomed, cities have flourished, and production agriculture grew to one of the largest in the U.S. Still, there were unintended or unanticipated consequences. To name a few, the construction of so many dams significantly altered the hydrology of, and biology within, many western states. Spawning areas of native fish, both freshwater and anadromous, were and still are adversely impacted. While the irrigation projects provided additional areas of open water essential for waterfowl migration, in some areas, natural constituents such as selenium that are toxic to fish and waterfowl were released by infiltrating irrigation water.

Water resource problems were not confined to the Western states. In the East, as cities grew larger, industries developed along rivers and streams as did sewage plants. Rivers and streams became convenient dumping grounds for raw sewage and industrial waste. In the 19th and early 20th centuries, epidemics of typhoid and cholera occurred with some regularity. Industrial waste in the Cuyahoga River in Cleveland actually caught fire in 1952 and 1969. Laws addressing wildlife began with protection of birds (and their feathers) with the Lacey Act in 1900. But it was the Pittman-Robertson Act (1947) and the Fish and Wildlife Coordination Act (1958) that provided a tax for conservation efforts of waterfowl and required that there be some type of discussion on the impacts on wildlife regarding water projects, respectively. Thus was some of the beginnings of habitat protection.

An environmental movement finally coalesced in the 1960s that determined our water resources needed more adequate protection. The Clean Water Act (1972), the Endangered Species Act (1973), and the Safe Drinking Water Act (1974) were passed and became law in the early 1970s.

These laws have had at least some positive impact for protecting our water resources by recognizing that wastewater, pesticides, and other industrial wastes were problems for the health of humans, animals, and the environment.

Water quantity and quality are highly linked to what is happening on the land, intertwined with climate. Thus, the land is the source of the contaminants, and the climate—in particular, precipitation followed by runoff—is the driver. We now reside squarely in the Anthropocene period, where humans have changed the landscape dramatically and thus have impacted the further degradation of water resources. There are more people, animals, and wastes (*i.e.*, excreta and wastewater) entering the global waters than ever before in the history of the planet. In addition to human-made legacy contaminants such DDT and PCBs, we are now dealing with pharmaceuticals, antibiotics, antibiotic resistant bacteria, and other personal care products, which are found to be widespread in the environment albeit at low concentrations. Both point sources (*e.g.*, discharges from wastewater or sewage treatment plants) and non-point sources (e.g., nutrients and pesticides from agricultural areas) of pollution are impacting ecosystem services (drinkable, fishable, swimmable waters) as seen via algal blooms due to excess nutrients as well as pathogens, which cause disease in both animals (domestic and wildlife) and humans.

Historically the Federal Water Pollution Control Act controlled interstate pollution, and the discharge of untreated sewage in the early 1900s led to many waterborne disease outbreaks primarily of typhoid and dysentery. Several large water projects developed because of water quality problems including New York City's water resources associated with the Croton (1842), the Catskill (1915), and the Delaware (1945) watersheds as opposed to use of the Hudson River, which was known to be quite polluted at the time. In addition, the City of Chicago began reversing the river system to move sewage from Lake Michigan down the Mississippi River, which, while proposed in 1885 by the civil engineer Lyman Edgar Cooley, "the Chicago Sanitary and Ship Canal" was not completed until 1920.

Under the Clean Water Act however, wastewater treatment to achieve "swimmable" and "fishable" goals were enacted, and each state is responsible for any discharges that affect the navigable waters of the U.S. One of the tools for assessment is the "total maximum daily load" rule, which looks at waters that are impaired for their designated uses including as a water supply, recreational venues, and fishing. There are over 43,000 impaired waters with over 73,000 impairments (single waters may have multiple impairments). Many of these impairments are due to the presence of fecal bacteria with little information on the source of the pollution.

In Michigan, in fact, the state has begun to address water quality issues across the entire Lower Peninsula by examining the source of the fecal pollution at the watershed scale. New technology that allows greater precision, droplet digital polymerase chain reaction (ddPCR) was used for microbial source tracking (MST) for bovine and human markers along with data on E. coli. Results identified some non-point sources of fecal pollution including septic tanks and animal manure during different flow regimes. Animal and human contamination were not correlated with E. coli. Different mechanisms were shown to be associated with the various fecal pollution sources including groundwater and overland runoff impacts on surface waters in Michigan and key watersheds were identified for further assessment and restoration.

Our nation is still confronted by serious water contamination problems like the 2014 chemical spill in West Virginia's Elk River, which is associated with 10,000 gallons of coal-washing chemicals impacting the drinking water of 300,000 people, creating illnesses and fear. While there were no fish kills, the effects on mammals may not be known for years. Massive toxic algal blooms affected the city of Toledo's water supply

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(2015) and fresh and marine water resources in Florida (2016). Indeed even lead in our tap water along with Legionella pneumonia-causing bacteria, which occurred in Flint Michigan (2014-2015) recently grabbed national attention. A combination of change to a more contaminated river supply (Flint River from Lake Huron), poor attention to treatment, inadequate infrastructure, and improper water quality testing and response were some of the issues uncovered in Flint, many of which are also affecting other communities.

New technologies allow us to detect contaminants that may adversely impact both humans and fauna in concentrations of parts per trillion. New molecular tools provide the needed diagnostics to trace the source of the pollution as well as the pathogen risks. This means that our knowledge of what is "safe" is changing.

Contamination problems are expensive and time-consuming to solve. The following suggestions are offered to help alleviate these problems. First, attempt to deal with contamination problems on watershed levels. Streams do not respect political boundaries, and we can now use major advanced diagnosis and models to address water quality and quantity; thus, problems can be addressed based on hydrodynamic systems. Second, we need much better cooperation between federal, state, and local organizations that have water resource responsibilities. There are more than 25 federal agencies that have water resource responsibilities whether their mission is development, management, protection, or assessment. We certainly need to start by gaining a more thorough understanding of each sector's water uses and water-management priorities; thus, better knowledge sharing and integration around water is going to be essential. Better coordination leads to less overlap and duplication of water-resource responsibilities. Third, consider stricter enforcement of environmental laws already on the books. In developing regions of the world that are implementing the United Nations (UN) Sustainable Development Goal 6 (SDG6), we must ensure availability and sustainable management of water and sanitation for all SDG6 regions. By focusing on ecosystems, biodiversity, water quality, and quantity, it will help other countries to create good environmental laws (see sustainabledevelopment.un.org/sdg6). Fourth, provide more public education about water resources beginning in elementary schools. Finally, consider market-based incentives to users who accept responsibility for problems they may cause. Thus some form of a system for "polluter pays", where those who have caused the contamination contribute to the costs of the needed restoration. If some of these suggestions are adopted, we may be able to sometime in the future congratulate ourselves on a job well done. ■

Richard A. Engberg retired in July 2015 after serving 15 years as technical director of the American Water Resources Association. One of his specialties was national water policy. Previously, he spent 9.5 years dealing primarily with selenium contamination from agricultural sources as manager of the National Irrigation Water Quality Program for the U.S. Department of the Interior. Prior to that, he spent 26 years with the U.S. Geological Survey, where his last position was district chief, Water Resources Division, Iowa District. Currently he is chairman of the board of directors of the Renewable Natural Resource Foundation, an environmental policy organization headquartered in North Bethesda, Md.; science writer for the Middleburg (Va.) *Eccentric* newspaper; archivist for the U.S. Geological Survey Retirees Organization; and member of the Alumni Advisory Board, Geosciences Department, University of Nebraska, Lincoln.

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