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a long the riverrun

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ABSTRACT

Progress in sustainable water resources development involves several and diverse disciplines and abilities, including ecologists, economists, sociologists, representatives of the public and private sectors and citizens groups, politicians, and others. Environmental engineers are essential co-participants in this multidisciplinary array, providing scientific and technological expertise that is essential in arriving at sustainable solutions. This theme is illustrated 'a long the riverrun' with four cases: cholera, chlorides, cryptosporidiosis and crabs.

Key words | environmental engineering and society, water resources, water treatment, watershed management

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This paper was presented as a lecture for the 2000 Clarke Prize. It is dedicated to Anna Dobbin O'Melia who introduced me to the wonders of water and its environs and to Werner Stumm who showed me my responsibility to sustain them. The paper is about water, its cycles, and its renewals. It is about watersheds, viewed a long the riverrun, from mountain springs to coastal ecosystems. Four cases involving water quality and water resources are considered: (1) cholera and chlorine in Rwanda, (2) chlorides and membranes in Israel, (3) watershed management and water supply for the City of New York, and (4) the ecology of the Chesapeake Bay. Drawing from these examples, the role of environmental engineers and engineering in sustaining our water resources is described.

The title of this paper is taken from the book *Finnegans Wake* by James Joyce (Joyce 1939). This novel is about cycles and renewals, including historic ones and, it can be said, hydrologic ones. The heroine in the book is Anna Livia Plurabelle, woman and mother. She is also water and river, the River Liffey/Livia in Ireland, a river which dies as it reaches the sea and is renewed and recycled and reborn as clouds from the sea bring water back to its source. The book ends with the fragment '. . . a long the' (no period) and begins with the word 'riverrun' (not capitalized). Joyce invites us, after finishing this book of life, history, cycles and renewals, to cycle through it again. The words are rearranged here in more conventional order to form the title of this paper. It can be helpful to consider water resources 'a long the riverrun'.

CHOLERA AND CHLORINE IN RWANDA, 1994

A relatively recent and deadly epidemic of cholera occurred in and around Goma, Zaire (now named Democratic Republic of the Congo) in July and August, 1994 (Goma Epidemiology Group 1995). War, contaminated surface water and geology combined to produce a public health disaster. The war led to the flight of over 500,000 refugees from Rwanda to neighbouring Zaire in July, 1994. Many refugees entered Zaire through Goma, a town with a population of about 100,000. Water was plentiful in nearby Lake Kivu, but there were no facilities to purify and transport sufficient quantities of water for the refugees. Cholera was endemic in the area and the water in Lake Kivu was apparently contaminated with faecal pollution; the indigenous population in the area had developed a resistance to waterborne disease that the new inhabitants did not have. The waters of the lake are clear, giving the impression that they are safe to drink. Although the lake is quite deep, stratification prevented vertical mixing and dilution of land-based inputs. The lake waters also have an alkaline pH that lowers the natural rate of die-off of *Vibrio cholerae*. Geology added a third complication. The ground in the area is hard volcanic rock, making it difficult to dig latrines and graves. Most bodies were left beside roads and other public places to be picked up later by trucks for burial in mass graves. The combination of these factors (war, contaminated water and geology) led to the deaths of almost 50,000 refugees from diarrhoeal disease in one month. The case fatality rate was almost 10%. Of these deaths, approximately 23,800 resulted from cholera. The causative agent was the bacterium *Vibrio cholerae* O1 and the strain was resistant to several common antibiotics.

The high incidence and the rapid rate of transmission of cholera in Goma were related to the consumption of untreated lake water, crowding, poor personal hygiene and the debilitation of the refugee population. Chlorination of drinking water was not available at the start of the outbreak. Considerable efforts to supply adequate quantities of safe water were made by the relief community but took weeks to implement and probably did not influence the course of the epidemic. By the time trucks were able to bring chlorinated water to the people, the cholera epidemic had run its course.

This discussion of cholera is presented here to make three points. First, protection of public health from diseases ranging from cholera to cancer, in addition to providing the historical base for the development of environmental engineering, is an essential objective of modern environmental science, engineering and technology. Second, the need for expertise and experts in environmental management and protection is an international one at present and will, in the future, be even greater in the developing countries of the world as they increase their utilization of resources and technology (including, most unfortunately, the weapons of war). Third, we see that adequate science and technology are necessary but not sufficient to protect human health.

Abel Wolman, one of the great American engineers of the 20th century, was instrumental in the application of chlorine for disinfection of public water supplies in the United States early in the century. He was also involved in framing the charter of the World Health Organization after World War II, assisted the WHO for almost 40 years, and advised more than 50 foreign countries on water supply and sanitation. In a speech to a lay audience in 1983, a decade before the Rwandan public health crisis, he explained his personal goals for WHO in water supply: 'I want water for people to drink and water for people to wash and children that survive. Too many children are still dying.' (ReVelle 1989). The engineering and science needed to halt the cycle of waterborne diarrhoeal diseases are available; the world may simply not be prepared to use them.

This information about cholera in Zaire/Congo was provided by Dr Les Roberts, colleague in the Department of Geography and Environmental Engineering at Johns Hopkins. I am pleased to acknowledge his assistance and grateful for his help.

CHLORIDES AND MEMBRANES IN ISRAEL

For our second example we consider an arid and developed country, Israel. The principal source of surface water in Israel is the Sea of Galilee (Lake Kineret, Lake Tiberias). Inflow to the lake is the Jordan River after it flows through southern Lebanon and northern Israel. The Golan Heights region borders the lake. For political reasons, watershed management of lands tributary to and bordering the lake is difficult. The Israeli Water Project withdraws about 15 $m^3\ s^{-1}$ of water from this lake, lifts this flow 300 m, and carries it in an open conduit south along the Mediterranean Sea to Tel Aviv and the Negev desert. This project provides about one-third of the total water needs of the country. The project was begun soon after the founding of the State of Israel in 1948. Initially, water was used primarily for irrigation in agriculture. Over time, domestic use has increased. At present, treatment involves coagulation, settling and disinfection with chlorine dioxide and chloramines. Concerns about disinfection by-products and protozoan pathogens (*Giardia*) have led to the design of a filtration facility and consideration of other disinfectants. With these conventional technologies in place, the health of the public should be adequately protected. Providing an adequate *quantity* of water is another matter.

Despite considerable efforts at water conservation, water demands in Israel and the region are expected to increase. Extensive water reuse or recycling is practised at present, largely by providing wastewater treatment, subsurface injection of the treated wastewater, and subsequent withdrawal of the resulting 'ground water' for reuse, which is largely agricultural. Irrigation for agricultural use inevitably increases the salt concentration of returned water, and this increase is compounded by additional reuse of the water to meet present demands. As time, water demands and reuse cycles increase, the salt concentration in the water can increase to levels that prohibit its use for agricultural as well as potable purposes. Further reuse will require removal of this salt. For this purpose reverse osmosis membranes are a technically feasible albeit energy intensive solution. Chlorides (salt), not cholera or cancer, may limit the water resources in the area. Unlike the public health crisis in Rwanda, solutions to future water supply problems in Israel and the region reside at a frontier of environmental engineering.

This outline of some water supply issues in Israel is based on conversations with Dr Menahem Rebhun, professor emeritus at the Technion University. I am grateful for his insights and also responsible for any errors of fact or opinion provided herein.

WATERSHED MANAGEMENT FOR NEW YORK CITY

The City of New York supplies about 65 $m^3\ s^{-1}$ of water to some 9 million persons. The water is obtained from three upland watersheds, the Croton, Catskill and Delaware systems, with a combined drainage area of some 500,000 ha. The three watersheds contain 19 reservoirs and three controlled lakes with a total available storage capacity of about 2.1 billion m^3. At present the entire supply is unfiltered; disinfection is provided with free chlorine. The City has a waiver from the US Environmental Protection Agency (USEPA) exempting it from providing filtration for water from the Catskill and Delaware systems. Filtration is planned for the Croton supply.

In response to a cholera epidemic in 1832 and a destructive fire in 1835, the City decided to develop an upland supply, drawing water by gravity from the Croton River. Begun in 1837, water from this source first reached the City in 1842. The supply was developed in stages over several decades and completed in 1911. It provides some 10% of the City's present water demand. Using power granted by the State to regulate upland watersheds, the City then developed the Catskill supply, completing it in 1927. This source provides about 40% of the City's water, also by gravity flow. The third component, the Delaware supply, required authorization for the City to withdraw water from the Delaware River watershed. This authority was granted in 1931 and the City completed this system in 1964. Again by gravity flow, this source provides the remaining 50% of the City's water needs.

With an adequate water supply in place and with water consumption declining due largely to conservation efforts including the installation of meters, the City's attention has focused in the past 25 years on the quality of the water in its supplies and at the consumer's tap. Two problems are of principal concern: (1) pathogens (particularly the pathogenic protozoa *Giardia* and *Cryptosporidium*, the causative agents of giardiasis and cryptosporidiosis), and (2) possible cancer-causing chemicals formed in disinfecting the water to control such pathogens. These 'disinfection by-products' or DBPs are formed in the City's system by reactions of free chlorine (added for disinfection of pathogens) with natural organic matter (NOM) which is ubiquitous in all surface water supplies.

In any water supply system, the safety of the water at a consumer's tap depends in large part on the ability of watershed management to prevent contaminants from entering the supply and the ability of a treatment system to remove or inactivate these contaminants before the water enters the distribution network en route to consumers. These two approaches are major components of a 'multiple barrier approach' to providing safe potable water. A central issue for New York City and, indeed, for all surface water supply systems, is this: *how to develop and implement a watershed management strategy that safeguards the health of the citizens of the City while at the same time protecting the rights and economic well-being of the citizens residing in the watershed*. To address these conflicting needs for New York City's supplies, a Memorandum of Agreement (MOA) was developed in

1997 with participation by the City, the State, the US EPA, a Coalition of Watershed Towns, and environmental organizations. Subsequently, the National Research Council was asked to assess the scientific basis of this MOA as a means of protecting the quality of the City's supplies (National Research Council 2000).

Key provisions of the MOA are summarized here. First, a voluntary land acquisition programme was established allowing the City to acquire fee title or conservation easements to vacant water quality sensitive lands. Second, watershed rules and regulations were developed to control a variety of pollutant sources including wastewater treatment plants, septic systems, storm water runoff and storage of hazardous materials. Setback distances were established and some activities occurring near water bodies and wetlands were restricted. Third, watershed protection and partnership programmes were established to preserve the economic and social character of the watershed communities while maintaining and enhancing water quality. Fourth, a watershed agricultural programme was put in place. This involves the voluntary participation of farmers in programmes to reduce pollutant loadings using best management practices (BMPs). Finally, a filtration avoidance determination was made in which the US EPA granted the City a waiver from the EPA's Surface Water Treatment Rule requiring filtration of the City's Catskill and Delaware supplies. This waiver is in place until 2002 with renewal subject to the successful implementation of the Memorandum of Agreement. As a part of the agreement, the City will provide some US$1.5 billion over 10 years to implement the MOA.

Watershed management and water treatment facilities are complementary barriers in providing safe drinking water. As multiple barriers they are both independent and interdependent. They are independent in the sense that the effects of a breakdown in one can be minimized by the effectiveness of the other. They are interdependent in the sense that the safety of the potable water that is produced depends on both. Preventing pollutants from entering a supply and removing the remaining pollutants from that supply both reduce risks to public health and enhance safety.

This complementarity complicates decisions about investment in public water supply. Clearly treatment is essential (Rwanda). At times watershed management is difficult (the Israeli Water Project) and treatment must assume both roles. For New York City and many other supplies throughout the world, however, both watershed management and water treatment are feasible and should be implemented. Arriving at an appropriate allocation of available funds and other resources between these two barriers is, however, a complex issue. When conventional treatment is put in place, watershed management is often neglected. Raw water quality can deteriorate, an important barrier is not developed, and treated water quality can be compromised by unforeseen events in the watershed and in the treatment system. When watershed management is emphasized at the expense of providing adequate water treatment, similar problems can arise. The appropriate balance involves some basic programme for each barrier with the balance of effort on the two barriers depending on local and regional issues and constraints. For New York City's watersheds, this balance can involve management of pathogen inputs in the watersheds from agricultural and other non-point sources, control of phosphorus inputs to reduce the production of aquatic or autochthonous NOM in the system's reservoirs, and management if possible of NOM from land-based or allochthonous sources. Improvements in treatment may also be needed. In order to address possible new regulations regarding *Cryptosporidium* and also to meet new regulations for disinfection by-products, disinfectants other than free chlorine may be needed and additional treatment for the removal of pathogens and NOM may be required to adequately protect public health. There are very significant challenges for environmental engineering at the present time and for the foreseeable future in developing comprehensive and synergistic strategies and technologies for watershed management and treatment for public water supplies a long the riverrun.

THE CHESAPEAKE BAY ECOSYSTEM

The Chesapeake Bay was formed at the end of the last ice age and is, geologically speaking, quite young. Since its formation it has been subject to continual modification and reworking by natural processes. Humans have been involved in this reshaping process at least since colonial times. In recent decades human activity has accelerated in significant ways with effects that are briefly summarized below. An excellent review of nutrient loadings and their management in the last few decades is provided by Malone *et al*. (1993). Their work is the basis for much of the information presented herein.

The Chesapeake Bay is about 320 km long and ranges in width from about 6 km at Annapolis, Maryland, to 50 km at its widest point near the mouth of the Potomac River. It is also shallow, with an average depth of less than 10 m, with the exception of a deep channel running along its length, believed to be the remnant of the ancient Susquehanna River Valley. This shallow depth contributes to a limitation in the Bay's dissolved oxygen resources, noted again below. The surface area of the waters of the Bay is considerable, in excess of 570,000 ha. The drainage area of the watershed is, however, much larger than the surface area of the Bay itself, about 28 times as great. The potential for substantial inputs of anthropogenic pollutants is therefore very significant. Pollutants derived from a very extensive watershed are focused on an aquatic ecosystem with a comparatively small surface area and a shallow depth (Boynton 1997).

In 1940 H. L. Mencken wrote that 'Baltimore lay very near the immense protein factory of the Chesapeake Bay, and out of it ate divinely.' The Chesapeake Bay has been a very productive and diverse ecosystem. In recent decades, however, both population and land use in the Chesapeake Bay watershed have changed significantly. Population has increased from about 5 million at the end of World War II to some 15 million today. Forested lands have increased, agricultural land use has decreased, and urban and residential land use has grown substantially.

Symptoms of eutrophication began to appear in the Bay and its tributaries in the late 1960s, with alarms expressed by scientists and federal officials. Massive algal blooms, oxygen depletion and fish kills were observed in portions of the Bay. Declines in submerged aquatic vegetation (SAV), now considered as an important indicator of the ecological health of the Bay, began to be reported at that time. Commercial and recreational fisheries were in decline. Harvests of oysters and the American shad declined in the early 1960s; a decline in the striped bass harvest started in the middle of the 1970s. It was not until the early 1980s, however, that state officials accepted the position that the Bay and its aquatic resources were impaired to the extent that significant action was needed.

Early concerns were focused on thermal pollution from power plants and these efforts probably had the effect of distracting attention from real problems. As early as the late 1960s, however, excess inputs of nutrients (nitrogen and phosphorus) from sewage, agriculture and natural sources were proposed by some as the Bay's most important problems. This view was accepted by scientists, regulators and managers in the 1980s and subsequent actions have focused on nutrient controls. Wastewater treatment plants have been constructed to remove nitrogen and phosphorus from these point source inputs. Phosphate has been banned from use in detergent formulations. Sediment inputs from non-point sources have been reduced by the implementation of best management practice facilities (BMPs) for urban and (voluntarily) agricultural non-point sources.

The Chesapeake Bay Commission, created by the legislatures of both Maryland and Virginia, signed the 1987 Chesapeake Bay Agreement. The centrepiece of this agreement was a commitment to reduce total loads of nitrogen and phosphorus to the Bay by 40% by 2000. And this commitment addressed the entire watershed, a long the riverrun, from mountain streams to coastal waters. Efforts to reduce phosphorus inputs to the Bay have been fairly successful. Wastewater treatment plants remove phosphorus from point sources. Since phosphorus adsorbs readily to sediments, when BMPs are installed for sediment control from non-point sources, they can remove some phosphorus from these inputs. In contrast, nitrogen control is more difficult and is the principal focus of present efforts to 'save the Bay'.

One difficulty in achieving this commitment to reduce inputs of nitrogen by 40% is that total inputs are not known accurately. Non-point source inputs of nitrogen are particularly difficult. For example, a significant portion of the agricultural nitrogen inputs to the Bay occurs in groundwater flows to the Bay. Neither the magnitudes of these flows nor the concentrations of nitrogen in them are known well. A second difficulty is that some inputs are very difficult to control even if they are known. For example, a considerable fraction of the nitrogen inputs to the watershed is by atmospheric processes, originating outside the watershed from such sources as power plant emissions to the west.

While there is good agreement that a reduction in nutrient inputs (especially nitrogen) will reduce eutrophication and its drain on the Bay's oxygen resources, it is not clear how long it will take for input reductions to achieve these water quality improvements. Recovery of SAV is also expected but the timing and extent of this recovery is not known. Finally, the relationships between nutrient inputs and the development of ecosystem health and fisheries resources (including the blue crab, a favourite regional delicacy) are not well established. There is a great deal more environmental science and engineering to be learned and implemented as efforts continue to 'save the Bay'.

ENVIRONMENTAL ENGINEERING AND SOCIETY

Challenges to our water resources will be with us for the foreseeable future, arising from synergistic combinations of demographic, economic and technological growth and development. New environmental issues will surely emerge even as solutions to present problems are achieved and toxic residuals from unwise past practices are remediated or controlled.

Falkenmark (1998) has assessed the role and responsibility of engineers in society, noting that 'It is on the products of engineers that modern society is founded.' Furthermore,

> 'The provision of the life support components involves interferences with the landscape that hosts the natural resources needed for these purposes (biomass, energy sources, minerals, freshwater). There is a need for physical manipulation of both land and water pathways. Chemical manipulations are generated by waste production, but also by the introduction of agricultural chemicals to increase the crop yields as necessary. The benefit intended is the satisfaction of societal needs. But—due to the natural rules operating in the landscape—there will also be environmental side effects in the landscape as a consequence of the interferences: air quality degradation, land productivity degradation, water quality degradation, and, as higher order effects, ecosystem degradation.'

Here we follow Falkenmark and write that 'it is on the products (both structural and non-structural) of environmental engineers that sustainable water resources can be developed'.

Environmental engineers seek to satisfy human and societal needs for water resources while protecting the rights of individuals and the integrity of ecosystems. While solutions involve diverse disciplines and abilities—ecologists, economists, sociologists, representatives of the public and private sectors and citizens groups, politicians, and others—environmental engineers provide scientific and technological expertise that is essential in arriving at sustainable solutions.

WATER

The Clarke Lecture was presented on 16 June 2000, the first Bloomsday of the new millennium. Each Bloomsday is a commemoration of 16 June 1904, a day in Dublin in the life of Leopold Bloom, waterlover, described in the novel *Ulysses* by James Joyce (Joyce 1922). Joyce and Bloom speak for us all in the following excerpt:

> 'What in water did Bloom, waterlover, drawer of water, watercarrier . . . admire?
> Its universality: its democratic equality and constancy to its nature in seeking its own level: its vastness in the ocean of Mercator's projection: its climatic and commercial significance: its . . . capacity to dissolve and hold in solution all soluble substances including millions of tons of the most precious metals: its slow erosions of peninsulas and downwardtending promontories: its alluvial deposits: its weight and volume and density: its imperturbability in lagoons and highland tarns: its . . . properties for cleansing, quenching thirst and fire, nourishing vegetation: its infallibility as a paradigm and paragon: its metamorphoses as vapor, mist, cloud, rain, sleet, snow, hail: its . . . variety of forms in loughs and bays and gulfs and bights and guts and lagoons and atolls and archipelagos and sounds and fjords and minches and tidal estuaries and arms of sea . . .'

For a more recent description, we turn to the poem titled *Water* by Wislawa Szymborska (1981), winner of the 1996 Nobel Prize for Literature. The poem ends as follows:

> 'Whatever whenever wherever has happened
> is written on the water of Babel.'

Szymborska follows the hydrologic cycle and recycle of water in space from the ocean to clouds over Paris to a river in her native Poland, and also in time, from a broken water jug in an ancient Phoenician city to a drop of rain on her hand today. As we work to sustain our water resources and their associated ecosystems, we can add to the waters of Babel and write that *whatever, whenever, wherever has happened is written on the waters of Babel, Lake Kivu, the Sea of Galilee, the streams and reservoirs of the Catskill and Delaware watersheds, the Chesapeake Bay and, in fact, the waters of the world*. From greenhouse gases and global climate change that are altering the global hydrologic cycle, through regional watershed management approaches to agricultural and other non-point sources a long the riverrun, to new treatment technologies for pathogens and toxic chemicals, the 21st century will pose wonderful challenges to environmental sciences, engineering and technology in sustaining water resources from mountain springs to coastal ecosystems, a long the riverrun.

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REFERENCES

Boynton, W. R. 1997 Estuarine ecosystems issues on the Chesapeake Bay. Chapter 4. In *Ecosystem Function and Human Activities: Reconciling Economics and Ecology* (eds R. D. Simpson & N. L. Christensen, Jr). Chapman and Hall, New York.

Falkenmark, M. 1998 Dangerous gap between engineers and environmentalists, outlook through a freshwater lens. In *Science, Technology, and Society–University Leadership Today and for the Twenty-First Century*. Stockholm Papers in Library and Information Science, Kungl Tekniska Hogskolan, Stockholm.

Goma Epidemiology Group 1995 Public health impact of Rwandan refugee crisis: what happened in Goma, Zaire in July, 1994? *The Lancet* **345**, 339–344.

Joyce, J. 1922 *Ulysses*. Reset 1961, Random House, Vintage Books, pp. 671–672.

Joyce, J. 1939 *Finnegans Wake*. Faber & Faber Limited, paperback edition by Mandarin Paperbacks, London.

Malone, T. C., Boynton, W. R., Horton, T. & Stevenson, T. 1993 Nutrient loadings to surface waters: Chesapeake Bay case study. In *Keeping Pace with Science and Engineering, Case Studies in Environmental Regulation* (ed. M. F. Uman). National Academy Press, Washington, DC.

National Research Council 2000 *Watershed Management for Potable Water Supply: Assessing the New York City Strategy*. National Academy Press, Washington, DC.

ReVelle, C. 1989 Abel Wolman 1892–1989. *Eos*, 29 August 801, 806.

Szymborska, W. 1981 Water. In *Sounds, Feelings, and Thoughts: Seventy Poems by Wislawa Szymborska* (translated by M. J. Krynski & R. A. Maguire). Princeton University Press, Princeton, New Jersey.