Development of the Water Chemistry Program at the University of Wisconsin Madison & Follow-on Activities of Dr. Lee in Developing the Water Chemistry Field

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The Early Years of Water Chemistry

"Water chemistry" was conceived and developed into its own discipline at the University of Wisconsin, Madison (UWMadison) in the early 1960s. Prior to that time, issues dealing with chemicals in, and the chemical character of, natural water and its water quality were viewed principally from a public health from one of two perspectives: treating water to improve its usability for domestic purposes, which was focused largely on disinfection with chlorine, and treating domestic wastewaters to reduce pathogens and to reduce biochemical oxygen demand (BOD) that caused low dissolved oxygen and resultant fish kills in receiving water. Education and professional practice in these "water quality" issues was accomplished under the umbrella of sanitary engineering, a division of civil engineering.

Sanitary engineering educational programs typically included a faculty member with a chemistry background to teach applied chemistry courses such as water and wastewater analysis and to conduct research on chemical aspects of water pollution control. Dr. M. Starr Nicols, who was associated with the Laboratory of Hygiene at the Wisconsin State Board of Health housed on the UW Madison campus, had developed an interdisciplinary Sanitary Chemistry Program that was affiliated with the Department of Civil Engineering. The Sanitary Chemistry Program served primarily as support for Sanitary Engineering students by providing courses that engineers needed to work as engineers in the water supply and water pollution control field. It was administered by a committee of senior faculty in the Departments of Chemistry, Biochemistry, Bacteriology, and Civil Engineering that acted as an independent program advisory faculty in the Graduate School to oversee the program activities and review course and degree programs.

In the 1930s and 1940s Nicols and his colleagues at the Laboratory of Hygiene had studied the utility of copper in suppressing algae in lakes and the effects of DDT and other chemicals on aquatic vegetation. (Inhorn, 2003). Pioneering work had been done in the 1940s by Dr. Clair Sawyer, a graduate of the UW Madison Sanitary Engineering Program, to try to address water quality problems caused by algae in the Madison, WI lakes. However, with the exception of concern for fish kills downstream of domestic wastewater treatment plants, there was little attention given to the effects of chemicals on aquatic life. There was no truly interdisciplinary field of study and practice that integrated principles of chemistry, biology, toxicology, and public health with engineering to examine and rectify impacts of chemicals in water on aquatic organisms or systems.

Dr. Gerald Lawton, a chemist, had been among the prominent PhD graduates of the Sanitary Chemistry Program at UWMadison. From 1950 to 1961 Dr. Lawton served as a member of the faculty of the Sanitary Engineering Program in the Department of Civil Engineering at UWMadison; he taught and conducted research on chemical aspects of water quality investigation and evaluation. In 1961, he accepted an appointment to the position at the UW State Laboratory of Hygiene that had been held by Dr. Nicols.

In the summer of 1961, Dr. G. Fred Lee accepted the faculty position in the Sanitary Engineering Program vacated by Dr. Lawton. Dr. Lee had earned a BA degree from San Jose State College in 1955 with emphasis in public health/sanitary science; a Master of Science in Public Health degree from the University of North Carolina in 1957 with emphasis in water quality and several courses in chemistry, biology, and sanitary engineering; and a PhD degree from Harvard University in 1960 with emphasis in chemistry, public health, and biology. In assuming that position, Dr. Lee indicated to Dr. Gerard Rohlich, head of the Sanitary Engineering Program, his desire to significantly expand the Sanitary Chemistry Program from one that served primarily as support for the Sanitary Engineering Program to one focused on providing a graduate degree education to prepare students with chemistry and chemical engineering backgrounds for careers in water quality investigation and management. In 1963, with essential and strong support from Dr. Rohlich and the members of the faculty committee that had overseen the Sanitary Chemistry Program, Dr. G. Fred Lee began the transformation of the Sanitary Chemistry Program into the Water Chemistry Program within the Department of Civil Engineering. Dr. Lee selected the name "Water Chemistry" for the new program to reflect its emphasis on all aspects of water supply water quality and water pollution control, including impacts of pollutants on water quality independent of their implications for public health/sanitary quality.

A rather unconventional path and persevering and explorative nature led Dr. Lee to develop the Water Chemistry program. In 1954 he enrolled at San Jose State College in what was then called sanitary science, a program that was part of the training for those pursuing a career in public health as a sanitarian. In that program he took a series of courses in the natural sciences including organic chemistry, zoology, entomology, medical entomology, and bacteriology. At the suggestion of his professor of bacteriology he pursued a Master of Science in Public Health degree at University of North Carolina School of Public Health. There, in addition to the public health curriculum that included biostatistics and epidemiology, he learned considerable analytical chemistry and laboratory techniques and took courses in water and waste water analysis, bacteriology, limnology, sanitary engineering (water and wastewater treatment and industrial wastes), instrumental analysis, industrial hygiene, and differential equations. He conducted his thesis research on the disproportionation of chlorine dioxide, which was being used by some water utilities to control chlorophenolic taste and odors that develop during disinfection of the water supply. Dr. Lee's major professor, Dr. Marvin Granstrom, an engineer who did his PhD degree work at Harvard University under Dr. Carroll Morris, encouraged him to continue his studies in sanitary engineering at Harvard under Dr. Morris. This he did, and further augmented his academic background with coursework in instrumental analysis, biochemistry, molecular biology, chemical thermodynamics, NMR, polymer science, and groundwater hydrology, which served as a foundation for his subsequent studies on groundwater quality. The key course that he took in the sanitary engineering program at Harvard was sanitary chemistry taught by Dr. Werner Stumm. Stumm's sanitary chemistry course introduced Lee to the concepts of reaction types: acid-base, precipitation-solubilization, redox, complexation, sorption, etc. and graphical representation of chemical equilibria. The fact that there was no text for that course led Stumm to write his renowned book, “Aquatic Chemistry,” with J. Morgan. That course formed the conceptual foundation of what became the Water Chemistry program at Wisconsin developed by Dr. Lee.

During the first year of the Water Chemistry Program’s existence, Dr. Lee applied for and received a substantial US Public Health Service training grant specifically to support the development of the program. That training grant and its subsequent renewals provided strong funding for graduate student stipends and laboratory equipment/supplies to support masters thesis- and PhD dissertation-oriented research projects. As part of his effort to advertise the new program and recruit students, Dr. Lee developed and sent program description fliers to many of the chemistry programs across the US. During the 12 years that he directed the Water Chemistry Program, Dr. Lee worked with the University of Wisconsin administration to hire two additional faculty members, and supervised the MS and/or PhD degree work of 71 students.

In 1973 Dr. Lee published a paper that discussed his approach to developing a sound educational program for graduate degrees and environmental/water chemistry:

Lee, G. F., "Graduate Education in Environmental Chemistry," Journ. Chemical Education 51(12):772-774 (1974). http://www.gfredlee.com/Education/Grad-Ed-Environ-Chem.pdf

The emphasis of the UWMadison Water Chemistry Program and of Dr. Lee’s subsequent academic leadership positions was determining the sources, environmental transport/ transformation/fate, and impacts of chemical contaminates in aquatic systems (freshwater and marine surface waters and groundwaters).

Water Chemistry Field Study Support Vehicles

Under the leadership of Dr. Lee the Water Chemistry Program focused much of its graduate student research program on field studies of the chemistry (transport, transformation, water quality effects) of selected chemicals that are of potential importance in impacting water quality. Those studies were facilitated by several vessels specially adapted to enable novel sampling approaches and cutting-edge chemical analyses in the field.

Lee developed one of the first-of-its-kind mobile laboratories in a cargo van that he equipped with facilities and equipment that enabled the conduct of limited, though key, chemical analyses in the field at the time of sampling. For example, he outfitted the van with a 110V gasoline-powered generator and flow cell that enabled water to be pumped from specific locations in a stream and analyzed in real-time for pH, temperature, dissolved oxygen, and turbidity as part of diel productivity studies. That system was also used for the monitoring of dye added to streams for the determination of patterns and rates of water flow in the streams.

A 15-ft Boston Whaler with trailer was adapted for the conduct of sampling on many lakes and streams. It provided a very stable platform for lake sampling.

Shortly after joining the UW Madison faculty to develop the Water Chemistry Program, Dr. Lee requested that the US Navy Office of Naval Research make available a small ship that could be used on Lake Mendota, a large urban lake in Madison, WI, in support of water sampling and on-board laboratory analyses. The Navy made available a 30-ft diesel-powered ship of the type that had been used on large naval vessels, such as aircraft carriers and battleships, to transport ship captains from ship to shore; it was trucked it from Philadelphia to Madison at no cost to the university. Dr. Lee named the vessel *The Kekule* in honor of August Kekule von Stradonitz, the famous German theoretical and structural chemist who, among other accomplishments, identified and described the structure of the benzene ring. Lee chose that name to emphasize the Water Chemistry Program's strong foundation in and focus on chemistry.

The Kekule

The construction of *The Kekule* enabled it to be used for sampling and monitoring studies on Lake Mendota that could not be done in small boats especially during storms, including studies of internal waves on the thermocline during storms. It was also modified in novel ways to meet the needs of Program research, including being outfitted with a 100/220V auxiliary power supply gasoline-powered generator to power sampling and electronic equipment. *The Kekule* was modified to incorporate a sampling well in the center of the boat that enabled protected use of a submersible pump and hose to collect samples of water at selected depths. The pumped water also fed a flow-through system wherein electrode measurements of DO, pH, turbidity, and other parameters could be made.

The Kekule served the Program in research and teaching until the early-1970s. A paper that describes the use of *The Kekule* in a research project in the mid-1960s was published as:

> Lee, G. F. and Harlin, C. C., "Effect of Intake Location on Water Quality," Ind. Water Eng. 2:36-40 (1965). (available at http://www.gfredlee.com/intake.html)

Dr. Lee also requested from the Office of Naval Research a surplus Army DUKW ("duck"), an amphibious 2.5-ton truck/boat that had been used for goods and troop transport during WWII. Dr. Lee drove the donated DUKW from the Army base in Indianapolis, IN to Madison, WI and named it *The Entropy*. Dr. Lee had *The Entropy* outfitted with a large A-frame to assist with sediment sampling in lakes throughout Wisconsin. Perhaps most notably, that modification, in

US Army DUKW (historical photo)

conjunction with DUKW's winch, enabled the collection of a 50-ft piston core sample of Lake Mendota sediment that was used to trace the post-glacial history of the lake over the past 10,000 years. One of major publications from that work is:

Bortleson, G. C., and Lee, G. F., "Recent Sedimentary History of Lake Mendota, Wisconsin," Environ. Sci. & Technol. 6:799-808 (1972). http://www.gfredlee.com/Nutrients/BortlesonSedHistMendota.pdf

In the early 1970s, Dr. Lee had the UW Madison administration declare *The Entropy* surplus, and it was donated to the Wisconsin Dells operation that employed DUKWs as tourist vehicles.

Lee and his Water Chemistry Program graduate students conducted several studies of the aquatic chemistry of selected pollutants in the US Canadian Great Lakes (Lakes Superior, Michigan, and Ontario). The use of large ships provided by government agencies, including a 700-ft US Coast Guard ship, enabled the sampling of water in Lake Superior at depths of more than 1,500 ft.

Water Chemistry Program researchers were also active in sampling Wisconsin lakes in the winter, which required collecting samples through lakes' ice covers. Transport of sampling crews and gear for such sampling was accomplished by toboggans towed by a snowmobile.

Several of the graduate students in the Water Chemistry Program were experienced with SCUBA diving equipment, which enabled unique studies to be undertaken of in-lake and sediment processes. One such study focused on the development of manganese and trace element coatings on rocks in the bottom of northern Wisconsin lakes.

Dr. Lee developed a 10-cm diameter, 1-m long piston corer that enabled the collection of undisturbed sediment cores. That equipment was used in a variety of studies of lake sediments in Wisconsin, Minnesota, Michigan, and Iowa.

The PhD dissertation and Masters thesis research of many dozens of students in the Water Chemistry Program at UW Madison was accomplished with the aid of those research vessels and equipment. Papers and reports that emanated from much of that research are available on our website www.gfredlee.com.

Advancement of the Field

For 25 years after he left UWMadison Dr. Lee held a series of university faculty appointments; new positions were created by several university administrations for Dr. Lee to initiate or expand existing graduate degree programs along the lines of the Water Chemistry program at UWMadison. A summary of many of those activities follows, along with information on major research activities he pursued in each position to demonstrate aspects of the evolution of the field of water chemistry.

In 1973 Dr. Lee accepted a professorship at the University of Texas at Dallas (UTD) where he worked with the UTD administration to create a new environmental science graduate degree program and to serve as Director for the Center for Environmental Studies he was to create. In those positions he continued his efforts to develop a graduate degree program to educate students for careers in the aquatic sciences/engineering and to conduct research in the water chemistry field. Dr. Lee garnered substantial amount of funding for graduate student-oriented research in several areas; this included his development of an approximately $1-million research program on behalf of the US Army Corps of Engineers devoted to developing dredged material disposal criteria. Through that program, over the course of about five years Lee and his graduate students conducted the first comprehensive and coordinated laboratory and field study to evaluate the release and water quality implications of chemical contaminants in dredged sediments during disposal to develop an approach for assessing potential water quality problems associated with dredged sediment disposal. They pioneered in the development and evaluation of sediment toxicity testing for assessing impacts of sediment-associated chemicals and conditions on aquatic life. Dr. Lee and his graduate students examined the nature, behavior, and aquatic life toxicity of about 30 potential pollutants (including a suite of heavy metals, pesticides, PCBs, nutrients (N &P), sulfides, and oxygen demand) in waterway sediments from about 100 locations across the US; they also conducted extensive coordinated field monitoring of dredged sediment disposal operations involving many of those sediments to measure the release/uptake of those chemicals in the receiving waters. Their work revealed that except for ammonia and manganese, sediment-associated chemicals were generally not leached during disposal and were largely non-toxic.

Among the results of their work was a field-tested laboratory assessment approach for predicting the uptake/release and toxicity of sediment-associated contaminants for use in evaluating the suitability of sediments for open water disposal, which became the framework for the current dredged material disposal criteria. The sediment toxicity testing procedure adopted by the US EPA and US Army Corps of Engineers and still in use today to regulate the disposal of contaminated dredged sediments in open waters was patterned after that developed and evaluated by Dr. Lee's pioneering work.

Dr. Lee led research at UTD for the US EPA to assess the contributions of aquatic plant nutrients (N and P compounds) to lakes and reservoirs from various types of land uses in about 100 watersheds across the US, and to examine quantitative relationships between the nutrient load to a waterbody (lake or reservoir) and the planktonic algal biomass that developed in the waterbody. That effort served as the US portion of the five-year, $50-million international Organization for Economic Cooperation and Development (OECD) Eutrophication Study program, in which the relationship between nutrient loading and eutrophication-response was examined and defined in about 200 waterbodies in 22 countries in Europe and North America, as well as Japan and Australia. In addition to developing the synthesis report for the US OECD study waterbodies, Dr. Lee represented the US on the steering committee for the international OECD studies. Through those studies of Dr. Lee and his graduate students, as well as the results of the international studies, it was found that phosphorus load, normalized based on the waterbody's mean depth and hydraulic residence time, was strongly correlated with the planktonic algal biomass that developed in the summer in the waterbody.

Also with support of the US EPA, Dr. Lee and his graduate students/postdoctoral fellow began research on the impact of organics on the permeability of packed clay columns of the type used to line waste ponds and landfills. That work began what would become Dr. Lee's more than three decades of work in the management of solid wastes in landfills.

The senior administration at UTD changed in the late 1970s. When it became clear that the new administration was not committed to supporting the UTD graduate degree program in environmental sciences, Dr. Lee accepted a new position at Colorado State University to expand its Department of Civil and Environmental Engineering program to include a water chemistry component. There, Dr. Lee pioneered the development and application of a hazard assessment approach for evaluating the potential water quality impacts of chemicals present in, or discharged to, the environment. Dr. Lee, his graduate students, and Dr. Anne Jones undertook a major research effort to evaluate water quality impacts of potentially toxic chemicals in effluents from five different secondary domestic wastewater treatment plants that discharge to four different Colorado Front Range rivers. They developed and evaluated innovative field testing and in-stream toxicity testing protocols and conducted a series of intensive field studies of the fate and persistence of chlorine used for domestic wastewater disinfection and of ammonia in un-nitrified effluent from those domestic wastewater treatment plants. From their work they developed a hazard (risk) assessment approach for modeling the fate and persistence of chlorine in domestic wastewater effluents.

In the 1980s Dr. Lee accepted a new Distinguished Professorship in the Department of Civil and Environmental Engineering at the New Jersey Institute of Technology (NJIT) in Newark, NJ. The NJIT administration was interested in developing a water chemistry-type program focusing on hazardous waste management issues. Dr. Lee was also appointed Director of Site Assessment and Remediation Division of a new multi-university hazardous waste research center housed at NJIT. Through his involvement in the NJIT positions and his private consulting activities, Dr. Lee became heavily involved in issues associated with investigation and remediation of hazardous waste sites, which evolved into a major focus of his professional involvement to this day. He and Dr. Jones-Lee have published extensively on approaches that should be followed in investigating Superfund and other hazardous chemical sites, including so-called brownfield sites where soils and groundwater have been left contaminated with hazardous chemicals from industrial activities.

In 1989, after 30 years of university graduate degree program development, teaching, and graduate student research guidance, Dr. Lee retired from his university career and expanded his part-time private consulting with governmental agencies and industry into a full-time activity in his native California. In the summer of 1989, he was joined in the redirection of his professional career by Dr. Anne Jones-Lee who had worked with Dr. Lee for more than a decade and had held a tenured faculty position in the NJIT Department of Civil and Environmental Engineering. For the past two decades they have continue to work with private, public, and professional entities in the water quality water pollution control field and in the investigation and management of hazardous chemical sites.

Professional Writings

During the course of their professional careers Drs. Lee and Jones-Lee have published more than 1100 professional papers and reports on their studies and involvement in the field of water/environmental chemistry, many of which are available on their website www.gfredlee.com. Their writings cover their work on evaluation of water quality impacts, management, and regulation of aquatic plant nutrients, pesticides, landfills, hazardous chemical site remediation, contaminated sediment, domestic water supply water quality issues, urban and rural/agricultural stormwater runoff, radioactive wastes, mine wastes, groundwater quality protection issues, reclaimed wastewater, the development and appropriate use of water quality criteria and standards, and the development of technically valid, cost-effective approaches for identifying, evaluating, and managing water quality problems. Many of Dr. Lee's publications have evolved from the identification of a chemical or situation for which there was need for stronger or more reliable water chemistry information in order to develop a technically sound investigation or management approach.

Despite the decades-long awareness of water chemistry, Dr. Lee continues to find that the fundamentals of water chemistry are often lacking, misunderstood, or misused in the evaluation and management of impacts of chemical contaminants on water quality, and especially in the regulations for chemical contaminants. He therefore continues his efforts to educate professionals in the water quality field in the principles of water chemistry that he and others have described since the early 1960s. For example, he and Dr. Jones-Lee have described in a number of their professional papers and reports, including the following, what they termed the "Aquatic Chemistry Wheel."

> Jones-Lee, A., and Lee, G. F., "Modelling Water Quality Impacts of Stormwater Runoff: Why Hydrologic Models Are Insufficient," Chapter 4 IN: Modelling of Pollutants in Complex Environmental Systems, Volume I, ILM Publications, St. Albans, Hertfordshire, UK, pp.83-95 (2009). http://www.gfredlee.com/Runoff/HydrologicModelsInadeq.pdf

An excerpt of that paper that describes and discusses the "Aquatic Chemistry Wheels" follows.

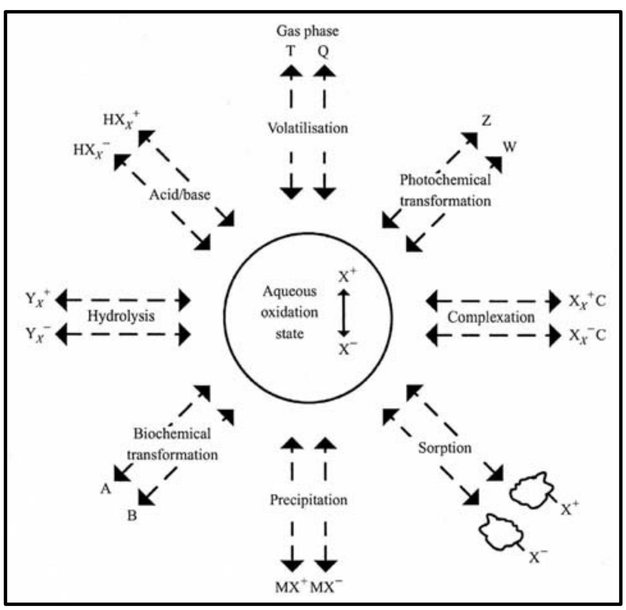
"*4.3 AQUATIC CHEMISTRY*

There is a general lack of understanding and consideration of the importance of aquatic chemistry in water quality evaluation and management. Aquatic chemistry can be complex and not easily modeled, and requires a more in-depth understanding than many in the field possess. It can also be more challenging to explain why the removal of particular "chemicals" in a situation is not warranted for water quality protection than it is to cause the development of a *treatment works. That notwithstanding, it has been well known since the late 1960s that the total concentrations of potentially toxic constituents in the water column and/or sediment are an unreliable basis for estimating the water quality impacts on the beneficial uses of a waterbody as designated by the Clean Water Act.*

The reason why total concentrations of a selected chemical(s) are unreliable in assessing water quality or use-impairment is that many chemical constituents in aquatic systems exist in a variety of chemical forms, only some of which are toxic or otherwise available to adversely affect water quality. This is shown conceptually in the aquatic chemistry "wheel" presented in Figure 4.1. The forms of a chemical can have vastly different degrees of impact on the beneficial uses of a waterbody (such as aquatic life propagation, or the wholesomeness of aquatic life used as food). The forms in which a chemical exists in a particular aquatic system depend on the nature and levels of detoxification materials in the water and sediments. These materials, such as organic carbon, sulfides, carbonates, hydrous oxides and clay minerals, react with potentially toxic forms of chemicals, yielding chemical forms that are non-toxic, less toxic, or otherwise less available to aquatic life. The reactions that actually take place, and the toxicity/availability of the various forms of chemicals that are created through these reactions, depend both on the nature of the particular contaminant and on the characteristics of the aqueous environment being considered.

Represented at the "hub" of the wheel in Figure 4.1 is a chemical in its readily measured total state independent of its impact on water quality. The spokes about the hub represent reactions into which a chemical can enter in aqueous environmental settings (volatilization, photochemical transformation, complexation, adsorption and absorption, precipitation, biochemical transformation, hydrolysis, and acid/base transformation), and the resulting products formed. The bioavailability of those transformation products can be more or less than that of the available form at the hub. The extent to which a particular chemical participates in each of

Figure 4.1
Aquatic Chemistry Wheel



these reactions to generate the transformation products depends on the nature of the chemical and the characteristics of the aqueous environmental setting, and is controlled by the kinetics (rates) and thermodynamics (positions of equilibrium) of the reactions. The total concentration of a chemical includes the most available form at the hub as well as the less-available/ unavailable transformation products at the spokes of the diagram. Using the total concentration of a chemical contaminant as a measure of impact presumes that all of the forms are equally and totally available.

While shown simplistically in Figure 4.1, these reactions are often not readily modeled mathematically in a manner that accurately represents a real aquatic system. Rarely is information developed on the amounts of the active forms of detoxification components of water and/or sediments, or on the characteristics of the reactions that occur with the potentially toxic or available forms. Therefore it is not possible to predict, based on typical chemical analyses, the toxic or available forms of potential pollutants such as heavy metals, selected organics or nutrients that impact the beneficial uses of a waterbody of concern to the public."

Since the 1960s, aquatic organisms have been one of the primary focal points of pollution control; in some respects, they are more sensitive to chemicals' adverse impacts than humans. In aquatic systems, they are the ultimate integrators of all the chemical interactions represented in the "aquatic chemistry wheel." Thus, carefully developed aquatic organism testing, along with proper accounting for hydrologic, habitat, and other characteristics of receiving waters, provides a more reliable assessment of impacts of chemical contaminants than chemical analysis and speciation. Dr. Lee was among the pioneers in the development, evaluation, and application of toxicity testing to assess the availability and impacts of chemicals in aquatic systems, and remains a firm advocate for proper use of toxicity testing in water quality evaluation, regulation, and management in the context of understanding the underlying chemistry.

In his water chemistry research, consulting activities, and involvement in the development of regulatory approaches for chemicals in the aquatic environment, Dr. Lee continues to emphasize the difference between a "contaminant" and a "pollutant" that is reflective of the role of aquatic chemistry in affecting the impacts of chemical contaminants on water quality/beneficial uses of waters. If a chemical present in a water or sediment has the potential to adversely affect water quality/beneficial uses of a water, it is considered to be a "contaminant." If that chemical exists in that water in chemical forms and concentrations, and for sufficient exposure durations, to adversely impact the beneficial uses of that water, that chemical is considered to be a "pollutant." Water chemistry studies have demonstrated, as expected based on the factors reflected in the "aquatic chemistry wheel," that many chemicals exist in aquatic systems in a variety of chemical forms (species) only some of which are toxic or available to adversely impact human health and/or aquatic life. Hence the measurement of the total concentration of a potentially hazardous chemical in a water is not indicative of an adverse impact. Dr. Lee uses the term "potential pollutant" to describe a contaminant that has not received adequate characterization to determine whether or not it is present in forms and for sufficient durations to adversely impact the beneficial uses of a waterbody.

Post University Career Activities

In 1989, Dr. Lee retired from university teaching to focus on full-time consulting and professional outreach; he and Dr. Jones-Lee have continued to be active in promoting the understanding of the principles of water chemistry and their application to investigating and solving water quality problems through both their consulting and public service activities. They have continued a broader outreach by maintaining their website that makes downloadable copies of many of their reports and papers available at no-cost, providing a no-cost stormwater quality newsletter, presenting papers at conferences, giving invited lectures and short-courses, and providing litigation support services. Described below are some of the topic areas in which Drs. Lee and Jones-Lee have more recently been involved.

Delta Water Quality Management. Improving the management of water quality in the Sacramento San Joaquin Delta and its tributaries in the Central Valley of California has been a major area of work. During the early 2000s Drs. Lee and Jones-Lee served as principal investigators on a CALFED-supported $2.5-million study of the low-dissolved oxygen (DO) problem in the San Joaquin River Deep Water Ship Channel near the Port of Stockton, CA. Since 2004 they have donated the time they have spent on their ongoing activities on water quality management issues of the Delta, which is a hydrologically complex and highly manipulated system.

Because the principles of water chemistry continue to be neglected in the regulation and management of Delta water quality, the more than 75 papers and reports they have developed on their Delta water quality work focus on incorporating principles of water chemistry into regulatory approaches; those writings are available in the Watershed Studies section of their website. In the near future major changes will be made in the way that tributary water flows into and through the Delta. It will be critical that principles of water chemistry be properly considered in flow-manipulation decisions made by the regulatory agencies in order to address existing water quality issues and avoid the creation of new problems.

Developing Protective Landfills. Dr. Lee has also been focusing professional activity on working to improve the management of municipal solid wastes (MSW) in landfills for the protection of public health and environmental quality. In the 1970-1980s Dr. Lee's and others' research showed that the plastic-sheeting/compacted clay liners used in landfills would, at best, provide containment of solid waste-associated chemicals for a very small portion of the time that the wastes in the landfills will be a threat to pollute groundwaters when contacted by water. Again, the environmental chemistry of materials deposited in landfills has not been adequately incorporated into practice and regulations. Through their consulting with governmental agencies and public groups they have developed about 100 papers/reports, which are available on their website, that discuss deficiencies in today's MSW landfills and landfilling regulations, as well as how practices of landfilling of non-recyclable waste components can be improved to provide more reliable long-term protection of public health/welfare and water resources in the sphere of influence of the landfill by proper incorporation of principals of water chemistry and groundwater hydrology. Dr. Lee is a member of the editorial board for the Journal Remediation.

Contaminated Sediments. A third major area in which Drs. Lee and Jones-Lee are currently involved is improving the environmental chemistry/toxicology foundation for investigating, regulating, and managing pollutants and potential pollutants in sediment, i.e., sediment-associated chemicals can impair the beneficial uses of a waterbody. Dr. Lee and his graduate students demonstrated in the 1970s that the majority of the potential pollutants in aquatic sediments are in chemically/biologically inert forms; they are largely non-toxic and unavailable forms to adversely affect aquatic life. The technically valid approach for evaluating and regulating chemically contaminated sediments involves a combination of water chemistry aquatic toxicology information to identify and control toxic components of sediments that are causing adverse impacts. However, because of limited understanding of water chemistry among regulators and environmental advocates and limited funding of regulatory agencies, regulatory approaches being advanced are based on total concentrations of chemicals in sediments and statistical co-occurrence-based approaches. While these approaches were demonstrated to be technically invalid in the 1970s, they continue to be used by some groups within the US EPA and parts of the California Water Resources Control Board regions to regulate contaminated sediments; they are also advocated by some environmental groups. Despite their invalidity, these approaches are inexpensive and administratively expedient to implement; they do not require any knowledge of water/sediment chemistry or the professional literature. However, while the development and implementation of technically sound approaches may be initially more expensive, in the long run they will cost public and private interests less by not causing over-regulation, by not diverting funds to non-problems instead of addressing real problems, and by providing more reliable protection of public health and environmental quality and remediation of real problems. Many of Dr. Lee's papers/reports on these issues are available on their website in the Contaminated Sediments section.

Urban Stormwater Runoff Water Quality. Drs. Lee and Jones-Lee have pioneered in developing, and continue to advance, technically valid, cost-effective management of chemicals contaminants in urban stormwater runoff. They continue to find that some environmental groups and regulatory agencies persist in trying to regulate urban stormwater runoff-associated chemicals based on meeting US EPA national water quality criteria. From his background, experience, and decades of work in water quality criteria/standards development, Dr. Lee finds, as does the US EPA, that the current national water quality criteria are not appropriate for regulating urban stormwater runoff-associated potential pollutants. Drs. Lee and Jones-Lee have published several papers on why that approach is not technically valid, and on the need to incorporate aquatic chemistry and toxicology into evaluation, management, and regulation of stormwater-associated chemicals in order to appropriately and reliably regulate real pollutants in urban stormwater runoff. Drs. Lee and Jones-Lee have faced similar issues in their work in the area of regulation of agricultural stormwater runoff-associated potential pollutants. Dr. Lee is a member of the Journal Stormwater editorial board.

Organochlorine Pesticides and PCBs. Throughout Dr. Lee's professional career he has been active in investigating the sources, fate, transformations, bioaccumulation, and impacts of organochlorine pesticides and PCBs. In the 1960s he and his graduate students studied these aspects of DDT, chlordane, endrin/dieldrin, and toxaphene, including their transport in groundwaters. Those studies were some of the first conducted in the US on the occurrence of PCBs in water, sediments, and fish tissue.

As discussed elsewhere in this write-up, organochlorine pesticides and PCBs were among the contaminants included in their laboratory and field investigation of the release of sediment-associated contaminants associated with disposal of sediments dredged from US waterways. Those studies included evaluation of the release of those pesticides and PCBs upon suspension of the sediments in the water column, as well as residues that accumulate in fish at some locations. In the 2000s he and Drs. Jones-Lee reviewed 30 years' worth of data for the California Central Valley Regional Water Quality Board (CVRWQCB) on the occurrence of organochlorine legacy pesticides in fish in Central Valley California waters relative to tissue-residue levels associated with increased cancer in those who use the fish as food. That study reviewed information on concentrations of PCBs in fish tissue relative to critical concentrations developed for the protection of public health.

Drs. Lee and Jones-Lee reviewed the occurrence of PCBs in water, sediments, and fish in the Hudson River, NY, for the US EPA in connection with evaluation of approaches being considered for remediation PCBs in the river sediments. More recently they conducted a review of PCBs in the water, sediment, and fish of the Fox River in Wisconsin focusing on paper mill wastewater discharges as a source of PCBs.

In recent years Drs. Lee and Jones-Lee have found that regulatory agencies at the federal and state levels are improperly assessing the water quality/bioaccumulation potential of PCBs in sediments that have been contaminated with PCBs by using so-called "sediment quality guidelines" that are based on the total concentrations in sediments in a co-occurrence framework. Such regulatory approaches ignore the aquatic chemistry of these contaminants as well as the fact that very low concentration of PCBs in water can bioaccumulate to hazardous levels within fish. While the concentrations of organochlorine legacy pesticides are slowly decreasing in the aquatic environment and fish, the concentrations of PCBs in fish tissue are not decreasing even though they were banned from use in the late 1970s. There is need for intensive study of the water chemistry of PCBs to better regulate PCBs in fish that cause significant hazards to public health.

Mercury as a Water Pollutant. Beginning in the 1960s and continuing today Dr. Lee has been active in investigating the occurrence of mercury in waterbodies and its excessive bioaccumulation in fish. His studies in the 1960s focused on mercury that was being found in fish in Wisconsin Rivers that was derived from the generation of chlorine used by papers mills through releases from electrolysis cells located at river dams. In the 1970s mercury was one of parameters that was monitored in Dr. Lee's Corps of Engineers studies of contaminated sediments. In the 1980s Dr. Lee was a consultant to the American Dental Association on impacts of waste dental amalgam discharged by dentists' offices. More recently Drs. Lee and Jones-Lee have followed the studies conducted by the CVRWQCB on the sources, transport, and bioaccumulation of mercury in California Coast Range streams from mercury mining and mercury that originated in the gold mining areas of the Sierra where it had been used in the recovery of gold. Dr. Lee served as a member of the steering committee for the CALFED-supported study of mercury sources, and concentrations in tributary rivers and within Delta waters and fish. Drs. Lee and Jones-Lee developed a report on the sources of mercury in Putah Creek water and fish as part of their serving as TAG advisors for the University of California Davis Superfund site on the UCD campus. Mercury associated with tailings from historic mining operations has over time been deposited in soils along Putah Creek during periods of flooding; those soils have become associated with the Superfund site and contribute to the mercury currently found in area fish.

Groundwater Quality Protection Dr. Lee's work on groundwater quality protection began in the 1960s when he worked with the USGS to develop a statewide groundwater quality monitoring network in Wisconsin. The graduate student research that he supervised at UWMadison included a PhD dissertation devoted to investigating the transport of pesticides in groundwater in the sandy area of Wisconsin. He was involved in evaluating septic tank wastewater disposal systems as a source of nutrients for lakes and reservoirs. His studies at Wisconsin included investigating the pollution of groundwater by a Madison city landfill. For the past four decades he has been involved in evaluating the impacts and potential impacts of more than 90 existing municipal landfills and new/proposed landfills, on groundwater quality in the US, Canada, and abroad.

Beginning in the 1970s, Dr. Lee initiated research for the US EPA National Groundwater Research Center on the interaction between organics and clay liners that were being used for waste disposal pits and landfills. In the 1980s that work included evaluation of the ability of plastic sheeting HDPE liners used in landfills to prevent groundwater pollution by landfill leachate for as long as the wastes in the landfill would be a threat.

For several years Dr. Lee was a member of the editorial board of the Journal *Ground Water* for papers on groundwater quality. He was a US EPA invited reviewer of proposed changes to the regulations for shallow water Class V injection wells. In the 1980s he and Dr. Jones published a paper on the potential for new permitted hazardous waste disposal landfills to pollute groundwaters.

> Lee, G. F. and Jones, R. A., "Is Hazardous Waste Disposal in Clay Vaults Safe?" J. American Water Works Association 76:66-73 (1984).

That paper, which discussed the unreliability of landfill liners that are being used for the prevention of groundwater pollution by hazardous wastes, was judged by the Water Resources Division of the American Water Works Association as the "Best Paper" published in the Journal in 1984. He and Dr. Jones received the Charles B. Dudley Award – an American Society for Testing and Materials award for contributions to Hazardous Solid Waste Testing – for the paper:

> Lee, G.F. and Jones, R.A., "Application of Site-Specific Hazard Assessment Testing to Solid Wastes," IN: Hazardous Solid Waste Testing, ASTM STP 760, American Society for Testing and Materials, pp. 331-344 (1981).
> http://www.gfredlee.com/HazChemSites/hazassesstest.pdf

That paper discussed the unreliability of the US EPA TCLP testing procedure for the evaluation of the potential for a solid waste to pollute groundwater.

In the 1990s Dr. Lee began investigating and developing reports and papers on issues concerning the ability of the US EPA "dry tomb" approach for landfilling solid and hazardous wastes to protect public health and environmental quality for as long as the wastes pose a threat. This work led Drs. Lee and Jones-Lee to develop their "Flawed Technology" review of the technical basis for why that approach will not protect groundwater from pollution by landfill leachate for as long as the wastes in the landfill will be a threat to generate leachate when contacted by water. They update that review approximately annually with new information on these issues.

Over the past five decades Dr. Lee has served as an advisor to public agencies including states, counties, and municipalities, water utilities, national environmental groups, and local citizens' groups evaluating potential public health and environmental quality impacts of new or expanded municipal landfills, federal and state Superfund sites, brownfield areas, and mine waste piles. He has also published several papers and reports on deficiencies in the state of California regulations governing land disposal of municipal and industrial liquid wastes, and irrigated agriculture for the protection of groundwater quality.

Continuing Education/Professional Outreach
After about 10 years of conducting research on the chemical aspects of water quality management issues, Dr. Lee found that the results of his and his graduate students' research in water chemistry were not being incorporated into the development and implementation of water quality management programs. In an effort to address this issue Dr. Lee became active in various avenues of continuing professional education and professional outreach.

Development of Water Quality Standards/Regulations. To encourage and facilitate the incorporation of the principles of water chemistry principles into the water quality standards and regulatory approaches for pollutant sources Dr. Lee has had a long history of reviewing and commenting on emerging, pending, and existing regulations, testifying in litigation, and assisting governmental agencies in developing new or revised regulations concerning impacts of chemicals on water quality. This has included the development of water quality standards and regulations for point and non-point-sources of toxics and nutrients to surface and groundwater, impacts of solid and hazardous waste management approaches on groundwater quality, and impacts of sediment-associated chemicals. He has found that regulatory agency staff members generally have limited understanding of environmental chemistry; the training and roles of chemists on agency staffs have typically restricted to the conduct of water and wastewater analyses; evaluation of pollutant "chemistry" is considered to be a table of analytical results. Rarely have the kinetics and thermodynamics of chemical reactions that a potential pollutant undergo in the environment in question been incorporated into regulatory programs. Focus has been on total concentrations, not on the availability of the chemical forms present. For some chemicals, analytical methods have been inadequate to reliably detect concentrations at the low levels at which they could cause adverse impacts. These and other deficiencies have frequently resulted in the unreliable, inadequate, or excessive regulation of chemicals in aquatic systems; most often, the result is over regulation of a chemical based on total concentrations rather than on toxic/available forms.

Dr. Lee continues to find that water quality regulations, evaluation and "screening" protocols, decision matrices, management approaches, and remediation measures often do not reflect an understanding of fundamentals of water/aquatic chemistry, or of the technically sound interpretation of laboratory toxicity test results. Such deficiencies are likely related to the complexity of aquatic chemistry and it interrelationship with biological systems, the comparatively little attention to applied aquatic chemistry in the education of those in decisionmaking roles, and the fact that proper attention to these issues requires a more case-by-case approach to water quality evaluation and management than is bureaucratically, politically, and/or ostensibly economically expedient. There is also an erroneous perception that a "quick and dirty" assessment is adequate for "screening." The fact is that screening based on unreliable approaches simply generates unreliable screening assessments; funds could be wasted on continued evaluation of non-problems while leaving unexamined areas in which problems could be occurring.

Some of the worst offenders in perpetuating these deficiencies are regulators and some members of environmental groups/organization who insist that regulations to be kept simple, and maintain that consideration of factors that inherently reduce impacts of chemicals in natural waters (i.e., aquatic chemistry) is tantamount to acquiescing to polluters. This has led to the promulgation of inadequate and unreliable regulations for some sources of chemicals in the environment including urban stormwater runoff, municipal solid waste landfills, contaminated sediments, and others. Another major problem in developing technically valid regulations of chemicals in the environment is a lack of funding to support water chemistry investigations. Without adequate funding regulatory agency staff members who do understand principals of water chemistry cannot incorporate them into a regulatory program; this results in a brute force non-chemical approach to the management of a potential pollutant. Throughout the past 40 years Dr. Lee has attempted to try to incorporate more water chemistry principals into regulatory programs.

Water Quality Criteria and Standards Development. Dr. Lee has also been active over the past five decades in the development and review of water quality criteria and standards. During the 1960s he served as an advisor to the Wisconsin Department of Natural Resources on the development and implementation of water quality criteria and standards. In the early 1970s Dr. Lee served as an invited peer reviewer for the National Academies of Science and Engineering's "Blue Book of Water Quality Criteria - 1972." In the late 1970s, he served as an invited member of the American Fisheries Society Water Quality Panel that conducted a review of the US EPA's 1976 Red Book of Water Quality Criteria. In the early to mid-1980s he served as a US EPA invited peer reviewer for the 1986 Gold Book of Water Quality Criteria development approach and for several of the specific chemical criteria. During the 1960's through the mid-1970s he served as an advisor to the International Joint Commission for the US-Canadian Great Lakes in developing water quality objectives for the Great Lakes and their implementation. His pioneering work on PCBs in the 1960s led to his being selected to head the US Public Health Service committee on developing drinking water standards for PCBs.

A key component of water chemistry as defined by Dr. Lee is the appropriate analysis of waters, wastewaters, and natural waters, and appropriate interpretation of analytical results relative to water quality/beneficial use characteristics. Dr. has been a member the American Public Health Association (APHA) et al. committee for review of methods for inclusion in its "Standard Methods for the Examination of Water and Wastewater" since 1960. He has been active in reviewing each revision of those standard methods overall, as well as in reviewing specific methods for a variety of parameters including heavy metals, nitrogen, phosphorus, and aquatic life toxicity. Dr. Lee was active for many years in a number of American Society for Testing and Materials (ASTM) committees. In the early 1960s he was active in ASTM Committee D19 on chemical analysis of water and wastewater, established in 1932. ASTM Committee E35 on

Pesticides was established in 1973 to address issues of pesticide application. Dr. Lee was involved early in the formation of that committee; he initiated and then chaired the Committee E35 subcommittee devoted to modeling the fate and persistence of pesticides. That subcommittee evolved into ASTM Committee E47 on Biological Effects and Environmental Fate in 1980. Those activities within ASTM also served as a springboard for the development of the Society of Environmental Toxicology and Chemistry (SETAC), which was founded in 1979. Dr. Lee served on the editorial board of the Journal of the Society for Environmental Toxicology and Chemistry for a number of years.

In the early 1970s, Dr. Lee became an advisor to the President's Council on Environmental Quality (CEQ) in Washington DC helping to develop programs for screening new or expanded use chemicals for potential environmental impact. This work evolved out of the widespread occurrence of environmental pollution by PCBs, DDT and other organochlorine pesticides and mercury. Also during the 1970s Dr. Lee was a member of a group representing chemical companies, regulatory agencies and universities that develop “Pellston” workshops devoted to developing approaches for screening chemicals for environmental impact. In the late 1970s, the efforts of this group led to the development of the environmental hazard assessment approach for evaluating the expected toxicological impacts and water quality assessment for new or expanded use chemicals that could cause large scale environmental pollution. Those efforts ultimately led to the development of the Toxic Substances Control Act (TSCA). Drs. Lee and Jones-Lee have published extensively on the development of water quality criteria and their implementation into state standards to appropriately regulate water quality impacts without significant over-regulation of wastewater and other discharges.

Lee and Jones-Lee Stormwater Runoff Water Quality Newsletter. In the 1990s regulations being developed for potential pollutants in urban stormwater runoff were focused on achieving compliance with US EPA worst-cased-based water quality criteria/standards. This was a technically invalid approach destined to cause massive expenditures by the public to remove heavy metals and other potential pollutants from runoff while effecting little or no improvement in receiving water quality. Again, the problem in the regulations was the absence of consideration of the fundamentals of aquatic chemistry that control the forms, behavior, and impact of chemical contaminants. In an effort to call attention to this issue, Drs. Lee and Jones-Lee published several papers and reports, which are available on their website in the Surface Water Quality section Urban Stormwater subsection at http://gfredlee.com/pswqual2.htm#runoff. In addition, beginning in the late 1990s, Drs. Lee and Jones-Lee have written and self-published an approximately monthly “Stormwater Runoff Water Quality Newsletter” that discusses issues and timely topics concerning evaluation of the impacts of chemical constituents in urban and rural stormwater runoff. The newsletter is made available by email at no cost to its approximately 8,000 subscribers. Past issues of that newsletter are available at http://www.gfredlee.com/newsindex.htm.

Development of the Journal, Environmental Science & Technology. In the 1960s Dr. Lee found that none of the existing professional journals focused on research and issues in water chemistry or served to reach target professionals. To address this void, Dr. Lee approached the Water Air and Waste Division of the American Chemical Society (ACS) to develop a publication committee to work toward the development of a suitable journal for publication of papers on chemical aspects of water quality management. The Division appointed him to the task; he developed a questionnaire for the Division membership and found that there was interest in developing a new journal in this field. Dr. Lee contacted ACS publications to ascertain its interest in launching the new journal but the ACS publications staff expressed no interest. Dr. Lee next contacted the private publishing companies about their interest in developing a new journal devoted to publishing water chemistry papers. One of the major technical journals expressed an interest. When Dr. Lee informed the ACS publications staff of that interest, ACS publications changed its mind. The journal, Environmental Science and Technology (ES&T) was launched and Dr. Lee served for many years on its editorial board. Through the efforts of several editors, ES&T has become the journal that Dr. Lee originally envisioned was needed in the environmental chemistry field.

Lectures, Tour Speaking and Short Courses. Especially during the four decades of his academic and professional career Dr. Lee was also dedicated to providing invited lectures, university extension courses, and short courses to students and professionals to promote and enhance the understanding and incorporation of the fundamentals of water chemistry in water quality management. For 22 years he served, without personal remuneration, as an ACS (American Chemical Society) tour speaker. In that service, local ACS sections select from an offering of topics and speakers for presentations to the local section meetings; ACS then arranges for several-lecture tours in a geographical region by its tour speakers. Dr. Lee's lecture topics over the years included the role of N and P compounds in causing excessive fertilization of waterbodies, carcinogens in domestic water supplies, municipal landfills as chemical systems, regulating urban stormwater runoff water quality, managing contaminated sediments, and hazardous chemical site management issues.

Dr. Lee also presented dozens of two-day short courses to professionals to provide in-depth discussion and interchange on a variety of timely topics including development of protective municipal landfills, management of contaminated sediments, managing water quality effects of urban stormwater runoff, and control of excessive fertilization of waterbodies. The domestic short-courses were sponsored by American Society of Civil Engineers, American Water Resources Association, National Groundwater Association, University of California Extensions Berkeley, UCLA, Davis, Riverside, and Santa Barbara and the Hazardous Materials Control Research Institute. In addition, Dr. Lee presented short-courses in the USSR, Hong Kong, Argentina, Spain, the Netherlands, Norway, Japan, Columbia, South Africa, Israel, Jordon, and India, with the later sponsored by the United Nations.

Overall

In 1961 Dr. Lee set out to develop a graduate degree program at the University of Wisconsin Madison to educate individuals with chemistry and chemical engineering undergraduate degrees in the chemical aspects of water quality investigation and management. He defined the focus of the field he named "water chemistry" as the integrated application of the principles of chemistry, aquatic biology, and environmental engineering to defining and managing water quality problems caused by chemicals in water and sediment. During his 30-year university graduate-level teaching and research career, he supervised the MS and PhD work of almost 100 students conducted about $5-million in research, and developed about 500 professional papers and reports on that research. Since retiring from university teaching and research in 1989, he and Dr. Jones-

Lee have served as private consultants to governmental agencies, public interest groups, and private concerns to apply the principles of water chemistry/aquatic chemistry to addressing real-world problems and developing technically sound water quality regulations, through their firm, G. Fred Lee & Associates. They have continued their dedication to public and professional service by continuing to publish the results of their work, maintaining a website that provides general information and downloadable copies of many of their more than 1100 papers and reports, and publishing a no-cost stormwater quality newsletter. What started out as a concept of a new chemical-oriented field of study has matured into a recognized, essential, although often inadequately incorporated, component of the water quality management field.

Inhorn, S., “The Wisconsin State Laboratory of Hygiene: A Century of Service and Progress,” Wisconsin Medical Journal 102(6):11-15 (2003)