

G. Fred Lee & Associates

27298 E. El Macero Dr.
El Macero, California 95618-1005
Tel. (530) 753-9630 • Fax (530) 753-9956
e-mail: gfredlee@aol.com
web site: <http://www.gfredlee.com>

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via email
hanlon.deborah@epa.gov,
hlustick.dwight@epa.gov

Revision of Solid Waste Landfill Criteria - Leachate Recirculation

Deborah Hanlon
Dwight Hlustick
Office of Solid Waste and Emergency Response (5306G)
US EPA (EPA HQ)
401 M St, SW
Washington DC 20460

Dear Ms Hanlon and Mr. Hlustick:

Dr Anne Jones-Lee and I wish to provide comments pertinent to the Agencies current review MSW leachate recirculation. We have been active in review of the benefits and problems of MSW landfill leachate since the mid 1980s. We have published extensively on these issues. Our papers are available from our web site, www.gfredlee.com. Recently we have completed a review paper on this topic for the AWMA national conference that will be held in Salt Lake City in June 2000. This paper is appended to this comments in Adobe pdf format. It presents a summary of our findings on the appropriate use of MSW leachate recirculation. As discussed we support appropriate leachate recirculation . However, as being practiced at many locations it will lead to greater groundwater pollution.

Please contact me if you have questions or comments on our findings on MSW leachate recycle.

G. Fred Lee, PhD, PE, DEE

Appropriate Use of MSW Leachate Recycling in Municipal Solid Waste Landfilling¹

Anne Jones-Lee, PhD and G. Fred Lee, PhD, PE, DEE

G. Fred Lee & Associates
El Macero, CA 95618-1005
gfredlee@aol.com
www.gfredlee.com

ABSTRACT

There is considerable interest today in the so-called “biocell” approach toward municipal solid waste (MSW) landfilling in which leachate is introduced back into the landfill. This approach reduces the cost of leachate management and is said to reduce/eliminate the potential for long term landfill gas production and groundwater pollution. However, a critical review of the typical approach being used today in biocell landfilling in Subtitle D landfills shows that the biocell approach will fall far short of appropriate landfilling of MSW that will prevent long-term gas production problems and groundwater pollution. Today’s minimum Subtitle D landfills can cause groundwater pollution at the time of landfill construction due to the inherent rates of leakage of leachate associated constituents through the liner system. Further, over time the flexible membrane liners’ (FMLs’) ability to collect leachate will decrease as the FML deteriorates. The groundwater monitoring systems allowed by regulatory agencies at minimum Subtitle D landfills have a low probability of detecting leachate polluted groundwaters before significant offsite groundwater pollution occurs. Leachate recirculation in a minimum Subtitle D landfill increases the hydraulic loading of the landfill which can lead to increased groundwater pollution.

One of the principal problems with reintroduction of leachate into today’s MSW landfills as a means of decreasing the time for landfill “stabilization” is that a large part of today’s MSW is disposed of in plastic bags that are not shredded at the time of burial. These plastic bags “hide” the waste from the moisture which would allow increased landfill gas formation rates and leachate generation during the time that the landfill liner system can possibly be an effective barrier to groundwater pollution. While the addition of moisture to shredded municipal waste can greatly reduce the time of landfill gas production, unshredded solid waste will produce landfill gas and leachate over very long periods of time related to the rate of decomposition of the plastic bags.

This paper discusses the problems with current approaches for leachate recycle (biocell landfilling) and recommends how such landfilling should be practiced to achieve increased rates of landfill stabilization while protecting nearby groundwater resources from leachate pollution. Biocell landfilling should be practiced using shredded MSW in a double composite lined landfill in which the lower composite liner is a leak detection system for the upper composite liner. After landfill gas production has essentially stopped, then clean water should be added to the landfill to wash/leach

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the solid waste residues to remove potential pollutants. This washing should be done without leachate recycle. Adoption of this "fermentation leaching" wet cell approach will lead to a rapid stabilization of the fermentable waste components in the landfill and remove those constituents from the landfill that can lead to groundwater pollution. While initially more expensive than biocell landfilling, in the long term the cost will be cheaper than the cost of municipal solid waste management in minimum Subtitle D landfills since the long term "Superfund" cost associated with this approach will be eliminated.

KEY WORDS municipal solid waste, leachate recycle, groundwater pollution, landfill gas formation

INTRODUCTION

The US Environmental Protection Agency's (US EPA, 1991) Resource Conservation and Recovery Act (RCRA) Subtitle D requirements for municipal solid waste (MSW) landfilling basically prescribe the placement of MSW in a "dry tomb" landfill. In concept, it is intended that such systems keep the buried wastes dry; as long as the wastes are kept dry, they will not ferment and produce landfill gas, or generate leachate. However, the buried wastes remain a threat to groundwater quality for as long as they are in the "dry tomb."

Lee and Jones-Lee (1993a,b; 1998a,b) discussed the problems with the "dry tomb" landfilling approach that preclude its ensuring protection of groundwater quality for as long as the wastes represent a threat. They noted among other problems that liners of the type currently used leak from the time a landfill is placed in service and deteriorate over time; the leachate collection and removal systems depend on the integrity of the liner system and are subject to biological fouling; groundwater monitoring programs typically used are inadequate to detect incipient liner leakage or incipient groundwater pollution by landfill leachate; inadequate attention is given to sufficiently funding the post-closure care of landfill covers that will be required in perpetuity. At best, "dry tomb" landfills postpone groundwater pollution and pass the costs for corrective action, proper waste handling, and lost groundwater resources on to future generations (see Lee and Jones-Lee, 1993c).

There is growing consensus that the "dry tomb" storage of MSW should be abandoned in favor of *in situ* treatment of MSW so as to remove at the outset, components that could otherwise eventually leak from the landfill to pollute groundwater. The "fermentation/leaching wet cell" (F/L wet cell) shows considerable promise for achieving such treatment in a cost-effective manner. In that system, moisture is introduced into the buried wastes to enhance the stabilization of fermentable organics (those that undergo anaerobic bacteriological transformation to methane and carbon dioxide), and to leach the leachable chemicals from the wastes that could otherwise escape the landfill to adversely affect the beneficial uses of groundwater. A potential source of moisture for the fermentation is leachate generated in the landfill. While recycling leachate through the wastes can aid in waste "stabilization," there is considerable misinformation being advanced today about the role of leachate recycle in the "treatment" of MSW to reduce the potential for the leachate to pollute groundwater.

Presented below is a discussion of potential benefits of leachate recycle with particular reference to its potential use in protecting groundwater from pollution by landfill leachate.

APPROPRIATE USE OF MSW LEACHATE RECYCLING IN MUNICIPAL SOLID WASTE LANDFILLING

Leachate Recycle in MSW Management

Lee, *et al.* (1985; 1986), Pohland and Harper (1987), Otieno (1994) and Reinhart and Townsend (1998) discuss that leachate recycle has been used for many years as a means of "disposing" of MSW landfill leachate and to enhance "stabilization" of fermentable organics in MSW. The rate of methane generation is controlled by the amount of moisture present in the waste. In the classical sanitary landfill where no attempt is made to restrict entrance of moisture, landfill gas formation typically takes place for 30 to 50 years. As additional moisture is added to the waste, the rate of methane formation increases. It has been well-documented in the literature that by adding moisture through leachate recycle the period during which methane is generated under ideal conditions in a sanitary landfill can be reduced to 5 to 10 years.

Christensen and Kjeldsen (1989) reported on a study of the impact of the moisture content of MSW on gas production rate. They reported that gas production essentially ceased when the percent moisture in the waste is less than about 20%. The rate of gas production increased with moisture content up to the maximum moisture content evaluated, about 60%. It is possible, although not investigated by them, that higher rates of gas production could have occurred with higher moisture content.

In cooperation with the Sonoma County (CA) Department of Public Works, EMCON (1975; 1976) conducted one of the most comprehensive and definitive studies of the impact of leachate recycle on the chemical characteristics of MSW landfill leachate. A set of landfill test cells (measuring 18x18x2.4m (60x60x8ft)-deep) was developed; each cell was filled with about 477 mtons (525 tons), about 909 m³ (1000 yd³), of MSW. Each cell received leachate that had been produced within the cell, or clean water, or no supplemental moisture, or one of various other treatments. The chemical characteristics of the leachate were determined periodically over a 4-year period. It was found that during the test period, the test cell that received recycled leachate produced methane at the greatest rate; by the end of the test, the rate of methane formation had been significantly reduced.

The test cell that received only clean water, with no recirculated leachate, also produced methane at a rapid rate, but the rate was initially somewhat slower than that of the cell that received recycled leachate. Methane formation from stabilization of the fermentable organics in the waste in that test cell was also almost completed during the 4-year period. By contrast, the test cell that received no moisture other than atmospheric precipitation that penetrated the clay cover (which was not designed to be a "low-permeability" cover of the type being developed today for "dry tomb" landfills), produced very little methane by the end of the 4-year test period.

As might be expected, the groundwater pollution potential of the leachate produced in each of the three test cells at the end of the 4-year test period was different. The leachate from the test cell that had received only precipitation that naturally penetrated the cover had characteristics similar to those of classical MSW sanitary landfill leachate; it contained a wide variety of chemical contaminants in concentrations that would represent a significant threat to beneficial uses of groundwater. At the end of the 4-year test period, the leachate from the test cell that had received recycled leachate also still contained a wide variety of chemicals in concentrations that would represent a significant potential to pollute groundwater. The leachate from the test cell that had received clean water during the test period had somewhat less potential to pollute groundwater than that from the cell that had received recycled leachate. It was evident that the clean-water washing (leaching) of the wastes effected the lowering of concentrations of constituents that represented a significant potential for groundwater pollution. That was not accomplished in the test cell that received recycled leachate.

The Sonoma County studies further demonstrated that recycling of leachate in an MSW landfill does significantly enhance the rate of landfill gas production and stabilization of the fermentable components of the MSW. The stabilized MSW residues developed after leachate recycle, however, were still a significant threat to groundwater quality. These authors (Lee and Jones-Lee) conclude from the Sonoma County studies, as well as the information in the literature, that leachate recycle as it has been practiced will not produce MSW residues that are no longer a significant threat to groundwater quality.

While it is evident from the literature that leachate recycle can significantly hasten the rate of stabilization of fermentable components of MSW, there are significant amounts of material in normal MSW that are not converted to methane and carbon dioxide under anaerobic conditions (i.e., are not fermentable). It is also clear that some of the fermentation residues, as well as non-fermentable materials in typical MSW contain readily leachable components; because of those components, leachate developed has a significant potential to pollute groundwater hydraulically connected to the landfill area. Therefore, leachate recycle *per se* does not address the primary concern about the landfilling of municipal solid wastes, namely groundwater pollution by leachate-derived constituents. This was demonstrated in the Sonoma County study discussed above.

Some landfill owners/operators practice leachate recycle as a means of reducing the costs of leachate treatment. By recycling the leachate back into the landfill, the amount of leachate that must be treated by other means can be lessened. This is especially effective when the leachate is sprayed over the surface of the landfill and given significant opportunity to undergo evaporation and evapotranspiration. However, that approach does not remove many of the contaminants in MSW landfill leachate; re-introduction of the leachate into the landfill replaces the chemical contaminants in the landfill or at its surface where they remain subject to leaching and transport to the surface waters and groundwaters of the region.

Another significant factor that must be considered today in assessing the utility and effectiveness of MSW leachate recycle is the fact that much of the garbage received by MSW landfills is in plastic bags. Such bags significantly obstruct the contact between the recycled leachate and the fermentable components of the solid waste. This would detract from the appearance of accelerated fermentation

noted with leachate recycle. The results of the laboratory studies by various investigators, as well as the Sonoma County studies, would be expected to be significantly different if significant amounts of the waste were contained in plastic bags that inhibited contact between the recycled leachate and the waste.

Unreliable Discussion of the Potential Problems with MSW Leachate Recycle

Over the years there are many papers, reports and a book that discuss/promote MSW leachate recycle. With few exceptions the authors of these papers, etc., fail to discuss the potential problems with leachate recycle. These problems have been discussed in the solid waste management literature (see Lee, *et al.* 1985, 1986; Lee and Jones 1990; Lee and Jones-Lee, 1993b, 1994a,b, 1995a, 1996) over the past 15 years. States have reviewed these issues and concluded that these problems are sufficient to prevent leachate recycle. Yet these issues are not discussed by many of those who wish to promote MSW leachate recycle. A notable exception is Magnuson (1996). The landfill owners, regulatory agencies and the public are entitled to a balanced discussion of the advantages and disadvantages/potential problems of MSW leachate in minimum Subtitle D landfills sited where the increased groundwater pollution can occur than is occurring today (see Lee and Jones-Lee 1995b).

Fermentation/Leaching Wet-Cell Approach

Lee and Jones (1990) and Lee and Jones-Lee (1993b) described an *in situ* fermentation/leaching wet-cell treatment approach by which it should be possible to treat MSW to produce a residue that represents little long-term threat to groundwater quality. The concept is to stabilize the fermentable components of MSW employing leachate recycle, and then to actively leach the residues to remove and treat those components that would otherwise eventually leak from the landfill and pollute groundwater. Wastes would be shredded prior to placement to reduce impediments to contact of the liquid with the waste components. A double-composite-lined landfill with appropriate liner leak detection systems would be used; a reverse groundwater gradient liner system (hydraulic trap) may be employed where indicated to provide additional protection against groundwater pollution.

It is expected that leachate would be recycled through the landfill for a period of 3 to 5 years; that should provide sufficient time for the fermentation of those components that are subject to anaerobic fermentation to methane and carbon dioxide. At the end of the leachate recycle period, clean water would be added to leach the waste; leaching should be practiced until the leachate produced no longer represents a significant threat to groundwater quality. Depending on the design of the landfill cells and the hydraulic loading, it is estimated that a leaching period of 15 to 20 years should be sufficient to produce MSW residues that are no longer a significant threat to groundwater quality. If during the course of the leaching period, leachate were to pass through the upper-composite liner, it would be necessary to stop the leaching process, exhume the wastes, and treat them to produce non-polluting residues.

The fermentation/leaching wet-cell approach for *in situ* treatment will initially be more expensive than the conventional "dry tomb" landfilling owing to the additional costs of treating the leachate

produced in the clean-water washing of the garbage. The magnitude of the increased cost is highly site specific and depends on the methods used for leachate management. However, in the long term, the F/L wet-cell approach would be less expensive since it has the potential to eliminate the need for, and very high cost of, providing landfill cover maintenance *ad infinitum*, and since it would significantly reduce the potential for having to spend funds to try to clean up leachate-contaminated groundwaters near the landfill, and replace lost groundwater resources.

It is important to distinguish the "fermentation/leaching wet-cell" approach discussed by Lee and Jones-Lee (1993b) and briefly described above, from what some refer to as a "wet cell" landfill that only incorporates leachate recycle. As noted above, thorough leaching of the wastes with clean water is essential to reducing the pollution potential of MSW landfill leachate.

Permitting of Leachate Recycle

In the review conducted by Lee, *et al.* (1985), it was found that a number of states, such as New Jersey, prohibited leachate recycle because of the increased potential for groundwater pollution associated with the increased hydraulic loading on the landfill. As discussed by Lee, *et al.* (1985), the more rapid onset of groundwater pollution is a real, potentially significant problem that needs to be properly addressed if leachate recycle is to be practiced. It is clear that leachate recycle should not be practiced in an unlined landfill or a landfill that does not have a highly reliable liner leak detection system.

Lee and Jones-Lee (1994c, 1998a,b) discussed problems inherent in trying to use conventional groundwater monitoring systems, with vertical monitoring wells spaced hundreds to a thousand or so feet apart, for the detection of incipient liner leakage or incipient groundwater pollution from a lined MSW landfill. Based on the manner in which lined landfills leak from point sources in the liners, and the manner in which leachate moves in groundwater systems in "finger" plumes, such conventional monitoring systems have a low probability of detecting incipient groundwater pollution by landfill leachate at the point of compliance before widespread groundwater pollution has occurred.

Because of the inherent unreliability of single-composite liner systems that depend on the monitoring of groundwater to detect liner-leakage of landfill leachate, the authors strongly recommend against the practice of leachate recycle in a single-composite-lined landfill of the type prescribed as the US EPA Subtitle D minimum prescriptive standards.

Leachate recycle should only be allowed at those landfills sited where groundwater pollution by leachate is considered to be of no consequence, or that incorporate a double-composite liner system in which the lower-composite liner is part of a leak detection system designed to determine when the upper-composite liner fails to prevent leachate transport through it. Further, as described by Lee and Jones-Lee (1993a, 1998a), sufficient funds must be available in a dedicated trust fund derived from waste disposal fees to exhumate the wastes and treat them to produce non-polluting residues that

may be safely buried in a landfill, when the upper-composite liner fails to prevent leachate transport through it.

As a stop-gap approach, a landfill owner/operator may try to prevent further passage of leachate through the upper-composite liner once it is detected in the liner leak detection system, by immediately ceasing leachate recycle and trying to prevent entrance of moisture into the landfill through the cover. While costing more than the amount of money typically provided for landfill cover maintenance during the post-closure care period, it may be possible to isolate MSW from moisture that can generate leachate for those landfills sited above the watertable by using appropriate leak detection systems in the cover and aggressive maintenance *ad infinitum* as discussed by Lee and Jones-Lee (1998a). It is clear that any leachate recycle project must plan for the inevitable failure of the liner system to manage leachate and have the funds available in a dedicated trust fund to address the failure when it occurs.

It is in the best interest of protecting groundwater resources for future generations to allow properly conducted leachate recycle as part of fermentation/leaching treatment of wastes. As part of revisions of solid waste management regulations, provisions should be included for leachate recycle in double-composite-lined landfills in which the lower composite liner is part of a liner leakage monitoring system, and where adequate funds have been set aside in a dedicated trust fund to properly address all plausible worst case scenarios for liner failure, *ad infinitum*, including waste exhumation and treatment. Leachate recycle should not be allowed in single-composite-lined landfills. Further, leachate recycle should be recognized as only providing stop-gap relief from leachate treatment costs; it will not eliminate or even significantly reduce the potential for groundwater pollution by solid waste components. Regulations prohibiting the *in situ* treatment of MSW should be amended to allow fermentation/leaching wet-cell treatment in properly designed and constructed double-composite-lined landfills of the type recommended in this discussion.

At this time the US EPA is reviewing the need to revise Subtitle D regulations so that it is easier for landfill owners to recycle MSW leachate. If these regulations do not address the numerous problems associated with MSW leachate recycle, then these regulations should not be adopted. Simply discharging MSW leachate into a minimum Subtitle D landfill could increase groundwater pollution.

CONCLUSION

As it has been practiced, leachate recycle does not produce MSW residues that are not significant threats to groundwater pollution. Leachate recycle should not be practiced in a single-composite-lined landfill that relies on groundwater monitoring to detect the failure of the composite liner to prevent significant transport of leachate through it. Leachate recycle can and should be practiced in appropriately designed and constructed double-composite-lined landfills in which the lower-composite liner serves as a leak detection system for the upper-composite liner. Leachate recycle must be followed by clean-water leaching (washing) of the fermented solid waste residues in order

to remove those components of MSW that represent threats to groundwater quality by their presence in leachate.

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Qualifications to Undertake This Review

My (Dr G. Fred Lee) work on municipal landfill impact matters began in the mid-1950s while I was an undergraduate student in environmental health sciences at San Jose State College in San Jose, California. My course and field work involved review of municipal solid waste landfill impacts on public health and the environment.

I obtained a Master of Science in Public Health degree from the University of North Carolina, Chapel Hill in 1957. The focus of my masters degree work was on water quality evaluation and management with respect to public health and environmental protection from chemical constituents and pathogenic organisms.

I obtained a PhD degree specializing in environmental engineering from Harvard University in 1960. As part of this degree work I obtained further formal education in the fate, effects and significance and the development of control programs for chemical constituents in surface and groundwater systems. An area of specialization during my PhD work was aquatic chemistry.

For a 30-year period, I held university graduate-level teaching and research positions in departments of civil and environmental engineering at several major United States universities, including the University of Wisconsin-Madison, University of Texas at Dallas and Colorado State University. During this period I taught graduate-level environmental engineering courses in water and wastewater analysis, water and wastewater treatment plant design, surface and groundwater quality evaluation and management, and solid and hazardous waste management. I have published over 850 professional papers and reports on my research results and professional experience. My research included, beginning in the 1970s, the first work done on the impacts of organics on clay liners for landfills and waste lagoons.

In the 1980s, I conducted a comprehensive review of the properties of HDPE liners of the type being used today for lining municipal solid waste and hazardous waste landfills with respect to their compatibility with landfill leachate and their expected performance in containing waste-derived constituents for as long as the waste will be a threat.

My work on the impacts of municipal solid waste landfills began in the 1960s where, while directing the Water Chemistry Program in the Department of Civil and Environmental Engineering at the University of Wisconsin-Madison, I became involved in the review of the impacts of municipal solid waste landfills on groundwater quality. In the 1970s, while I was Director of the Center for Environmental Studies at the University of Texas at Dallas, I was involved in the review of a number of municipal solid waste landfill situations, focusing on the impacts of releases from the landfill on public health and the environment.

In the 1980s while I held the positions of Director of the Site Assessment and Remediation Division of a multi-university consortium hazardous waste research center and a Distinguished Professorship of Civil and Environmental Engineering at the New Jersey Institute of Technology,

I was involved in numerous situations concerning the impact of landfilling of municipal solid waste on public health and the environment. I have served as an advisor to the states of California, Michigan, New Jersey and Texas on solid waste regulations and management.

In the early 1980s while holding a professorship in Civil and Environmental Engineering at Colorado State University, I served as an advisor to the town of Brush, Colorado on the potential impacts of a proposed hazardous waste landfill on the groundwater resources of interest to the community. Based on this work, I published a paper in the Journal of the American Water Works Association discussing the ultimate failure of the liner systems proposed for that landfill in preventing groundwater pollution by landfill leachate. In 1984 this paper was judged by the Water Resources Division of the American Water Works Association as the best paper published in the journal for that year.

In 1989, I retired after 30 years of graduate-level university teaching and research and expanded the part-time consulting that I had been doing with governmental agencies, industry and community and environmental groups into a full-time activity. A principal area of my work since then has been assisting water utilities, municipalities, industry, community and environmental groups, agricultural interests and others in evaluating the potential public health and environmental impacts of proposed or existing hazardous, as well as municipal solid waste landfills. I have been involved in the review of approximately 50 different landfills in various parts of the United States and in other countries.

Dr Anne Jones-Lee obtained a bachelors degree in biology from Southern Methodist University and a PhD degree in Environmental Sciences from the University of Texas at Dallas in 1978. For 11 years she taught and conducted university graduate level environmental engineering and environmental sciences courses and conducted research on various aspects of water quality management. She and Dr. G. Fred Lee have worked together as a team since the mid 1970s.

Dr. Anne Jones-Lee and Dr. G. Fred Lee have published extensively on the issues that should be considered in developing new or expanded municipal solid waste and hazardous waste landfills in order to protect the health, groundwater resources, environment and interests of those within the sphere of influence of the landfill. Our over 40 professional papers and reports on landfilling issues provide guidance not only on the problems of today's minimum US EPA Subtitle D landfills, but also how landfilling of non-recyclable wastes can and should take place to protect public health, groundwater resources, the environment, and the interests of those within the sphere of influence of a landfill. I make many of my publications available as downloadable files from my web site (www.gfredlee.com).

In the early 1990s, I was appointed to a California Environmental Protection Agency's Comparative Risk Project Human Health Subcommittee that reviewed the public health hazards of chemicals in California's air and water. In connection with this activity, Dr. Jones-Lee and I developed a report, "Impact of Municipal and Industrial Non-Hazardous Waste Landfills on Public Health and the Environment: An Overview" (Lee and Jones-Lee, 1994a), that served as a basis for the human health advisory panel to assess public health impacts of municipal landfills.

In addition to teaching and serving as a consultant in environmental engineering for over 39 years, I am a registered professional engineer in the state of Texas and a Diplomate in the American Academy of Environmental Engineers (AAEE). The latter recognizes my leadership roles in the environmental engineering field. I have served as the chief examiner for the AAEE in north-central California and New Jersey, where I have been responsible for administering examinations for professional engineers with extensive experience and expertise in various aspects of environmental engineering, including solid and hazardous waste management.

My work on landfill impacts has included developing and presenting several two-day short-courses devoted to landfills and groundwater quality protection issues. These courses have been presented through the American Society of Civil Engineers, the American Water Resources Association, the National Ground Water Association in several United States cities, including New York, Atlanta, Seattle and Chicago, and the University of California Extension Programs at several of the UC campuses, as well as through other groups. I have been and continue to be an American Chemical Society tour speaker, where I am invited to lecture on landfills and groundwater quality protection issues, as well as domestic water supply water quality issues throughout the US.

SUMMARY BIOGRAPHICAL INFORMATION

NAME: G. Fred Lee

ADDRESS: 27298 E. El Macero Dr.
El Macero, CA 95618-1005

SOCIAL SECURITY:
573-42-8765

DATE & PLACE OF BIRTH:
July 27, 1933
Delano, California, USA

TELEPHONE:
530/753-9630
(home/office)

FAX:
530/753/9956
(home/office)

E-MAIL: gfredlee@aol.com WEB PAGE: <http://www.gfredlee.com>

EDUCATION

Ph.D. Environmental Engineering & Environmental Science, Harvard University, Cambridge, Mass. 1960

M.S.P.H. Environmental Science-Environmental Chemistry, School of Public Health, University of North Carolina, Chapel Hill, NC 1957

B.A. Environmental Health Science, San Jose State University 1955

ACADEMIC AND PROFESSIONAL EXPERIENCE

Current Position:

Consultant, President, G. Fred Lee and Associates

Previous Positions:

Distinguished Professor, Civil and Environmental Engineering, New Jersey Institute of Technology, Newark, NJ, 1984-89

Senior Consulting Engineer, EBASCO-Envirosphere, Lyndhurst, NJ (part-time), 1988-89

Coordinator, Estuarine and Marine Water Quality Management Program, NJ Marine Sciences Consortium Sea Grant Program, 1986-1988

Director, Site Assessment and Remedial Action Division, Industry, Cooperative Center for Research in Hazardous and Toxic Substances, New Jersey Institute of Technology et al., Newark, NJ, 1984-1987

Professor, Department of Civil and Environmental Engineering, Texas Tech University, 1982-1984

Professor, Environmental Engineering, Colorado State University, 1978-1982

Professor, Environmental Engineering & Sciences; Director, Center of Environmental Studies, University of Texas at Dallas, 1973-1978

Professor of Water Chemistry, Department of Civil & Environmental Engineering, University of Wisconsin-Madison, 1961-1973

Registered Professional Engineer, State of Texas, Registration No. 39906

PUBLICATIONS AND AREAS OF ACTIVITY

Published over 850 professional papers, chapters in books, professional reports, and similar materials. The topics covered include:

Studies on sources, significance, fate and the development of control programs for chemicals in aquatic and terrestrial systems.

Analytical methods for chemical contaminants in fresh and marine waters.

Landfills and groundwater quality protection issues.

Impact of landfills on public health and environment.

Environmental impact and management of various types of wastewater discharges including municipal, mining, electric generating stations, domestic and industrial wastes, paper and steel mill, refinery wastewaters, etc.

Stormwater runoff water quality evaluation and BMP development for urban areas and highways

Eutrophication causes and control, groundwater quality impact of land disposal of municipal and industrial wastes, environmental impact of dredging and dredged material disposal, water quality modeling, hazard assessment for new and existing chemicals, water quality and sediment criteria and standards, water supply water quality, assessment of actual environmental impact of chemical contaminants on water quality.

LECTURES

Presented over 750 lectures at professional society meetings, universities, and to professional and public groups.

GRANTS AND AWARDS

Principal investigator for over six million dollars of contract and grant research in the water quality and solid and hazardous waste management field.

GRADUATE WORK CONDUCTED UNDER SUPERVISION OF G. FRED LEE

Over 90 M.S. theses and Ph.D. dissertations have been completed under the supervision of Dr. Lee.

ADVISORY ACTIVITIES

Consultant to numerous international, national and regional governmental agencies, community and environmental groups and industries.

**Surface and Groundwater Quality Evaluation and Management
and
Municipal Solid & Industrial Hazardous Waste Landfills**

<http://www.gfredlee.com>

Dr. G. Fred Lee and Dr. Anne Jones-Lee have prepared professional papers and reports on the various areas in which they are active in research and consulting including domestic water supply water quality, water and wastewater treatment, water pollution control, and the evaluation and management of the impacts of solid and hazardous wastes. Publications are available in the following areas:

- Landfills and Groundwater Quality Protection
- Water Quality Evaluation and Management for Wastewater Discharges, Stormwater Runoff, Ambient Waters and Pesticide Water Quality Management Issues
- State Stormwater Quality Task Force Activities
- Impact of Hazardous Chemicals -- Superfund, LEHR Superfund Site Reports
- Contaminated Sediment -- Aquafund, BPTCP
- Domestic Water Supply Water Quality
- Excessive Fertilization/Eutrophication
- Reuse of Reclaimed Wastewaters
- Watershed Based Water Quality Management Programs:
 - Sacramento River Watershed Program,
 - Delta -- CALFED Program, and
 - Upper Newport Bay Watershed Program
 - San Joaquin River Watershed DO and OP Pesticide TMDL Programs

Stormwater Runoff Water Quality Science/Engineering Newsletter

For Further Information Contact:

Dr. G. Fred Lee, PE, DEE
G. Fred Lee & Associates
27298 East El Macero Drive
El Macero, California 95618-1005
ph: (530) 753-9630, fx: (530) 753-9956, E-mail: gfredlee@aol.com

Municipal Solid Waste Landfills and Groundwater Quality Protection Issues Publications

Drs. G. Fred Lee and Anne Jones-Lee have prepared several papers and reports on various aspects of municipal solid waste (MSW) management and hazardous waste management by landfilling, groundwater quality protection issues, as well as other issues of concern to those within a sphere of influence of a landfill. These materials provide an overview of the key problems associated with landfilling of MSW and hazardous waste utilizing lined "dry tomb" landfills and suggest alternative approaches for MSW management that will not lead to groundwater pollution by landfill leachate and protect the health and interests of those within the sphere of influence of a landfill. Copies of many of these papers and reports are available as downloadable files from Drs. G. Fred Lee's and Anne Jones-Lee's web page (www.gfredlee.com). Copies of these papers and reports listed below as well as a complete list of their publications on this and related topics are available upon request.

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