Issues that Need to Be Considered in Evaluating the Sources and Potential Control of TOC that Leads to THMs for Water Utilities that Use Delta Water as a Water Supply Source

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The waters of the Sacramento River, San Joaquin River (SJR), and the Delta contain sufficient concentrations of total organic carbon (TOC) to cause domestic water utilities that use Delta waters as a raw water supply to potentially experience excessive trihalomethanes (THMs) in treated waters. This is significant because THMs are regulated as carcinogens. As a result of the elevated TOC, the water utilities that use Delta waters as a raw water supply may need to practice additional treatment at additional cost to produce treated waters that meet the US EPA TOC limit of about 2 mg/L and the drinking water MCL for the THMs.

According to LWA (2003),

> *"Disinfectants/Disinfection Byproduct Rule treatment threshold for DBP precursor removal. If average source water TOC is > 2 mg/L and ≤ 4 mg/L, water utilities may be required to remove up to 35% of the TOC in their influent. If average source water TOC is > 4 mg/L and ≤ 8 mg/L, water utilities may be required to remove up to 45% of the TOC in their influent. TOC removal depends on source water alkalinity and treatment technologies used, and is not required when the running annual average TOC in source water or treated water is less than 2.0 mg/L, or if other specific D/DBP conditions are met."*

The excessive TOC in Delta waters leads to the need to determine if it is economically feasible to control the TOC at its sources. Presented below is a discussion of some of the issues that need to be considered in evaluating the sources of TOC for water utilities that use Delta waters as a water supply source. Also, information is provided on issues that need to be considered in evaluating TOC control at the source.

Experience in Domestic Water Supply Chlorination and TOC Issues

G. F. Lee has been involved in domestic water supply chlorination issues since the 1950s when, as a graduate student, his masters degree project at the University of North Carolina, Chapel Hill, NC, School of Public Health involved work on the use of chlorine dioxide to control water supply tastes and odors. That work was published by Granstrom and Lee (1957, 1958). His PhD dissertation at Harvard University (obtained in 1960) was devoted to the kinetics of chlorination of phenols as it relates to domestic water supply tastes and odors. That work was published by Lee and Morris (1962) and Lee (1967) and showed that chlorine attacked the aromatic ring leading to ring scission. It was subsequently found that these reactions lead to THMs. G. F. Lee is familiar with the recent work on THM formation from TOC.

Delta Sources and Types of TOC

TOC is primarily derived from the decay of terrestrial vegetation. Also TOC is derived from some forms of aquatic vegetation, especially those plants that contain lignin. Woodard (2000) compiled a review of the TOC data that have been collected from Delta tributaries and from various locations in the Delta. As discussed by Lee (2000) in his comments on the draft Woodard (2000) report, the current Delta TOC data must be used with caution since Woodard presented total TOC data. Woodard did not (could not) consider that there is refractory (non-degradable) TOC and labile (degradable) TOC. Because of this situation, the TOC data in the Woodard report can lead to erroneous conclusions regarding the sources of TOC that lead to elevated THMs in treated water supplies derived from Delta waters.

The origin of TOC and its significance in aquatic systems is a topic that G. F. Lee has been interested in for over 35 years. While teaching at the University of Wisconsin, Madison, he investigated the relationship between the trophic state of Lake Mendota and its TOC content. Lake Mendota is one of most studied lakes in the world. There is a long history of data on the characteristics of this lake's water. It was found that while the trophic state (algal production) of this lake had increased significantly since it was first measured in the 1920s, the TOC measured in this lake during non-algal bloom conditions did not change over that time period. Lake Mendota has a five-year hydraulic residence time, and therefore the TOC associated with the algal blooms decomposed in the lake water column or sediments. This and subsequent studies by others have shown that the primary source of TOC in waterbodies is terrestrial rather than aquatic vegetation. Refractory TOC is derived from the degradation products of terrestrial vegetation and higher aquatic plants. It is analogous to soil organic matter and resistant to further degradation.

During the early 1960s Lee and his graduate students at the University of Wisconsin, Madison, conducted studies on the amounts of organic matter recovered from natural waters. At that time the US Public Health Service was using activated carbon columns to recover organics from rivers and other waterbodies for study of their characteristics. Several thousand gallons of river water would be passed at a rate of about 0.25 gal/min through a 2 ft long 3 in diameter column of activated carbon. The carbon was air dried and extracted with chloroform or methanol. The extract (carbon chloroform extract (CCE) or carbon alcohol extract (CAE) was dried and weighed. It was found that when the CCE was above about 200 μg/L the water tended to have water supply taste and odor problems. It was also found at that time that, when the CCE from some rivers such as the Ohio River was applied to a shaved mouse's abdominal area, it caused cancerous lesions. Studies by Peterson and Lee (1971) reported that the amount of CCE recovered was dependent on rate of flow through the column and the total flow, where the amount recovered under standard operating conditions was far less than the total organic matter in the water being sampled. They also showed that the natural TOC was bound to the activated carbon more tightly than pollutant organics such as DDT. This caused the CCE to underestimate the organic pollutants in the water being sampled.

Lee and Hoadley (1967) published a review on the forms of organic carbon in waterbodies. They discussed that most of the TOC in marine (non-coastal) waters and in fresh waters is dissolved, i. e., will pass a 0.45 μ pore size filter. From the marine literature there is a potential for some part of the "dissolved" organic carbon to form organic aggregates, which then can serve as particulate food for zooplankton. It has been demonstrated that filtering a sample of water, followed by stirring or aerating, leads to particulate organic matter that can be removed again upon refiltration. The formation of organic aggregates can occur several times after filtering. Organic aggregates may also occur in freshwater systems, although the studies by Lee and his graduate students showed that the fresh water organic aggregates are more fragile and are easily broken up upon vigorous stirring.

DOC is often defined as the fraction of the TOC that is not filterable by a filter with a pore size of 0.45 micron. It is known, however, that an appreciable part of the DOC that will pass through this size filter is particulate – typically considered to be colloidal in nature. It has been found by Plumb and Lee (1974) in studies on the molecular size of the iron TOC associated constituents using Sephedex column for fractionation, that the iron content of the water in which TOC/DOC is present influences the particle size distribution of the DOC, in which high iron tends to cause some of the DOC to occur in particles less than 0.45 micron in diameter.

Gjessing and Lee (1967) and Hall and Lee (1974) published some of the first studies conducted on fractionating TOC. They reported that dissolved TOC is made up of a complex mixture of organics of various molecular weights. Recently, Leenheer and Croue (2003) published a review article on the characteristics of dissolved TOC. At this time the characteristics of the dissolved and particulate TOC that are of concern with respect to THM formation during domestic water supply disinfection are poorly understood. The molecular characteristics of TOC are known to be dependent on a variety of factors, such as the method of concentrating the material prior to study, the inorganic salts that are present with it, the source of the TOC, its age, etc.

Lee and Jones (1991a,b) discussed the significance of algae as a source of TOC in the Delta. As they discussed, algal TOC is largely labile (i. e., degradable) as the algae die and decompose. The carbon in algae is largely mineralized to CO_2 as part of algal decomposition. It is possible to estimate the labile fraction of the TOC if chlorophyll and pheophytin measurements are also made on the same samples. Typically the carbon:chlorophyll ratio in algae is about 25 to 1 (see Bowie, *et al*., 1985). It can be assumed that a similar ratio occurs for carbon:pheophytin. If no pheophytin data are available it can be assumed that the chlorophyll:pheophytin ratio is 1 to 1. This leads to a 50 to 1 ratio of carbon to chlorophyll plus pheophytin. Using this approach a planktonic algal chlorophyll concentration of 50 μg/L yields an algae-derived TOC of 2 to 3 mg/L.

According to Woodard (2000) the TOC in the SJR at Vernalis is about 3 to 4 mg/L. It is not unusual for the chlorophyll in the SJR at Vernalis to be 50 to 100 µg/L during the summer and fall. It appears that at times during the summer on the order of 50 percent of the TOC in the SJR that is discharged to the Delta from the SJR watershed could be due to algae that would be expected to die and decompose in the Delta. This means that the SJR watershed during the summer is potentially a far less potent source of refractory TOC for water utilities that export Delta water for domestic water supply than would be predicted based on the Woodard TOC data review. During the winter a greater percentage of the SJR TOC is of non-algal origin since normally during the late fall and winter the algal chlorophyll is much lower than it is in the summer and early fall. There are exceptions to this, however, such as in late January through February 2003, when, under low flow conditions through the SJR Deep Water Ship Channel, a large algal bloom occurred (Lee and Jones-Lee, 2003).

In the fall of 1989, the authors served as consultants to Delta Wetlands, Inc. This led to their conducting an in-depth review of the existing database on TOC in the Delta. Based on their review of the then-unpublished Department of Water Resources data on TOC in Delta Island intake and discharges and Delta tributaries, it was concluded that about half of the TOC found in Delta waters is derived from upstream of the Delta sources and the other half was from in-Delta sources. This conclusion was based on the existing database which did not distinguish between refractory and labile TOC. Those results were published by Lee and Jones (1991a) in an invited paper for the University of California Water Resources Center conference devoted to "Protecting Water Supply Water Quality at the Source."

Jassby and Cloern (2000) published a review of organic matter sources for the Delta. They concluded that tributary-borne TOC is the largest source of TOC for the Delta. In-Delta phytoplankton production and agricultural drainage were reported by them to be secondary sources. They also reported that phytoplankton-derived organic matter is an important component of particulate TOC loading to the Delta.

During the past four years the authors have been involved in a multimillion dollar study of the San Joaquin River Deep Water Ship Channel (DWSC) and the SJR watershed. This effort resulted in a 246-page report devoted to "Issues in Developing the San Joaquin River Deep Water Ship channel DO TMDL" (Lee and Jones-Lee, 2000) and a 280-page Synthesis Report (Lee and Jones-Lee, 2003) on the SJR DWSC and its watershed. The Synthesis Report also provided information on water quality in the South Delta.

Since the mid-1990s G. F. Lee has been active in the Sacramento River Watershed Program (SRWP). The SRWP provides substantial data pertinent to understanding current TOC levels at various locations in the mainstem of the Sacramento River and its major tributaries LWA (2003).

There is a substantial database that has been developed on TOC since the pre-2000 data that were reported on by Woodard (2000). Further, there are chlorophyll data on the SJR since 1999 as a result of the SJR DO TMDL studies. There is need to update the information provided by Woodard, giving consideration to the issues presented in these comments, with particular reference to refractory versus labile TOC.

Wetlands, such as the managed wetlands in the Mud and Salt Slough watersheds, are likely to be important sources of refractory TOC for the Delta. Wetlands discharges are often highly colored, which indicates high TOC. Based on the studies by Hall and Lee (1974), the TOC-color relationship is such that, when the waters are pale yellow, TOC tends to be in excess of 20 to 30 mg/L. Highly colored waters of natural origin tend to have TOC on the order of 50 mg/L or so.

Highly colored water has been reported (Lee and Jones-Lee, 2003) to be a problem in the San Joaquin River Deep Water Ship Channel, where at times the waters in the channel near Stockton are highly colored, apparently due to managed wetlands discharges in the Mud and Salt Slough watersheds. Those discharges are also at times highly colored. The flooding of terrestrial vegetation, such as in managed wetlands, where the vegetation contains higher plants (i.e., lignin) has been found and would be expected to be a source of refractory TOC. An important issue with respect to aquatic vegetation as a source of TOC is that there can be large numbers of algae as epiphytes on the vegetation. The algal part of the total TOC associated with aquatic vegetation would be expected to be labile.

The SJR DO TMDL studies of the SJR watershed have shown that Mud and Salt Slough watersheds are also important sources of algal chlorophyll for the upper SJR. As discussed by Lee and Jones-Lee (2003) the algae that are discharged into the upper SJR multiply on the average about eight-fold by the time the upper SJR waters reach the DWSC. Meanwhile, some of the TOC from the wetlands in the Mud and Salt Slough watersheds is diverted by agricultural irrigation that occurs along the SJR upstream of the DWSC. These diversions could be important during the irrigation season, typically from March through August. During that time the discharges of water and TOC by the managed wetlands is low compared to the spring when the wetlands are flushed. The normal pattern for the managed wetlands is to flood in the late fall and flush-release the water in the spring.

The irrigation diversions will divert a substantial part of the refractory TOC that is discharged by the wetlands in the Mud and Salt Slough watersheds to agricultural lands where a large part of it would be expected to be retained on the land. There are, however, irrigation tailwater discharges from many of the irrigated lands in the SJR watershed. The TOC content and loads in the tailwater discharges are largely unknown. Further, during the fall, when the irrigation season is over, the TOC discharged by the Mud and Salt Slough watersheds is no longer diverted to agricultural lands and therefore is passed through to the Delta. During the late fall/winter/spring, some of the TOC that was diverted during the summer/fall irrigation season to agricultural lands could be flushed from those lands to the SJR in the stormwater runoff.

An important source of nutrients that lead to the high nutrients and algae that are discharged by Mud and Salt Sloughs to the SJR is the subsurface drain waters from the

Grasslands area located in the Mud and Salt Slough watersheds. There is need to determine if the subsurface drain waters that are released from the Grasslands area are a source of refractory TOC.

The Grasslands area in the Mud and Salt Slough watersheds is subject to selenium, TDS and boron TMDLs. The implementation of the TDS/boron TMDLs will likely change the water release patterns from these areas. This in turn could impact the refractory and labile TOC released from these areas. The implementation of the TDS/boron TMDLs should consider the impact on the releases of refractory TOC to the SJR.

Some of the refractory TOC may be very slowly degraded. As reported by Lee and Jones-Lee (2003), studies by Foe of the CVRWQCB and by Litton of the University of the Pacific have found that the BOD of San Joaquin River water is exerted over a 30-or-more-day period, with some part of the total BOD_u exerted after 15 to 20 days or so.

Sacramento River Watershed

The latest SRWP monitoring program report (LWA, 2003) provides information on the TOC content of the Sacramento River at several locations along the river and in several of its tributaries. Many of the samples of the Sacramento River and some of the tributaries contain TOC above the US EPA concentration limit of 2 mg/L that can potentially trigger water utilities that use this water as a raw water source to have to provide additional treatment. This means that the Sacramento River watershed frequently contributes TOC to the Delta at concentrations that contribute to the elevated TOC that is frequently found in the waters that are exported from the Delta at the Banks Pumping Station. LWA indicated that Woodard reported that the average concentration of TOC at the Banks Pumping Station is 3.6 mg/L. Since the Sacramento River typically has low levels of chlorophyll of a few µg/L it is expected that the TOC in this river is largely refractory. This may be especially important since even though the concentrations of total TOC in the Sacramento River are typically lower than those in the San Joaquin River, the much higher flows of the Sacramento River compared with the San Joaquin River could be important in providing greater loads of refractory TOC to the Delta.

The concentration of TOC in the Sacramento River tends to increase along the length of the river from upstream to downstream. There is need to define the sources of elevated TOC for this river. Since some of the tributaries such as agricultural drains that have high TOC also have elevated planktonic algal chlorophyll, it will be important to define TOC sources based on refractory and labile forms which will be mineralized in the Sacramento River and Delta before they reach a water utility treatment plant.

Lee and Jones-Lee (2002a) and California Urban Water Agencies-CUWA (See Lee and Jones-Lee, 2002a) have indicated that an area of particular concern as a source of TOC for the Sacramento River is the discharge of waters from the rice fields in the Sacramento River watershed. There is need to establish a TOC monitoring program of the rice field discharges.

Urban Stormwater Runoff as a Source of TOC

Urban stormwater runoff in Stockton has been found to contain 12 mg/L of TOC (Stockton, 1998). Similar concentrations of TOC would be expected to be present in stormwater runoff from Sacramento and other municipalities in the Delta's watershed. Because of the large volumes of water associated with an urban stormwater runoff event, there can be a large pulse of TOC added to the Delta during and following a rainfall runoff event. The BOD_5 of Stockton's stormwater runoff has been found to be about 12 to 15 mg/L. Therefore, considering the ratio between BOD_5 and BOD_u (ultimate) and the ratio between the molecular weights of oxygen and carbon, a substantial part of the TOC in Stockton's stormwater runoff is not likely to be adverse to using the Delta water for domestic supply since it is in a labile-degradable form.

Domestic Wastewaters as a Source of TOC

A review of TOC sources in Kansas by Randtke, *et al*. (1988) (see Lee and Jones, 1991a) showed that treated domestic wastewaters had a TOC of about 10 mg/L, with most of it being dissolved. It would therefore be expected that the cities of Sacramento and Stockton are discharging TOC to the Sacramento and San Joaquin Rivers, respectively. The refractory TOC content of domestic wastewaters will be dependent on the residual BOD in the wastewater effluent. Since domestic wastewaters contain several mg/L of BOD_5 if highly treated, to 15 to 20 mg/L BOD_5 if conventionally treated, appreciable parts of the TOC in domestic wastewater can be labile.

Algae as a Source of THMs

Lee and Jones (1991b) have reported on a situation where THMs were formed from algal TOC. This situation was associated with the early 1990s drought that occurred in California, when the city of Los Angeles stored treated water in an open reservoir. Algae developed in the water that, upon chlorination, produced THMs. Therefore, if a water utility intake has elevated concentrations of algae, and the algal cells are chlorinated, then the algal TOC could be a source of THMs. However, if the algae in a waterbody have a week or more to die and decompose before chlorination then the algal cells will not be a source of THMs.

Benefits of TOC

TOC can be important in enhancing water quality through its ability to form complexes with toxic metals, such as copper, thereby making the copper nontoxic. The US EPA is developing a revised approach for developing a water quality criterion for copper based on the DOC content, where higher dissolved copper can be present than listed in the water quality criteria if the waters contain elevated DOC.

Algal TOC is an important source of food for higher-trophic-level organisms. Further, some of the slowly degradable TOC derived from algae and terrestrial plants can serve as a source of carbon for bacteria and other organisms. Jassby and Cloern (2000) have reviewed this issue with respect to organic matter sources for the Delta and within the Delta.

Delta Flow Pattern Issues
An issue that needs to be considered in Delta TOC management is that the flow patterns of the SJR into the Delta will likely change as a result of the need to increase the amount of the flow of the SJR at Vernalis through the DWSC rather than into the South Delta via diversion into Old River. This means that more of the SJR watershed refractory non-algal TOC and the algal TOC will be introduced into the Central Delta via Turner Cut and Columbia Cut as a result of the state and federal projects export pumping of South Delta water creating a strong cross SJR DWSC flow of Sacramento River water. To the extent that more of the SJR watershed waters enter the Central Delta, there will be an increase in the SJR watershed TOC into the state project export pumps. Also, there will likely be less recirculation of the SJR TOC into the federal project pumps associated with less SJR Vernalis water being diverted into Old River.

There is need to conduct studies on the fate of both the refractory and labile San Joaquin River watershed TOC in the Delta to define the sources and fate of the refractory and labile TOC within the SJR and entering the Delta. Ultimately the TOC sources in the export waters should be defined sufficiently well so that it is possible to trace the sources of TOC in the SJR watershed that go to the export pumps. This information is needed to determine the locations in the SJR watershed at which there is need to attempt to control TOC from sources in the SJR watershed.

An issue that will need to be understood is when the discharges of refractory TOC in the SJR watershed have the greatest impact on TOC of concern to water utilities. Since the rate of export of Delta water for use by water utilities is not constant but varies with season, it may be possible to manage the discharges of TOC from the watershed sources during periods of time when it would be primarily exported to San Francisco Bay where it is not adverse to water quality.

TOC Downstream of the Delta
According to LWA (2003), Woodard (2000) reported that TOC in the Delta water at the Banks export pumps averages about 3.6 mg/L. Studies need to be conducted to understand the fate of TOC exported from the Delta to the point at which the water is treated for water supply use. Some of the TOC exported from the Delta will decrease and additional local sources of TOC will be added to the conveyance system and storage prior to treatment. The details of these processes should be defined to be sure that a Delta watershed TOC control effort is effective in reducing the TOC at the point at which the water is treated by each of the domestic utilities that export Delta water.

Control of TOC at the Source
Lee and Jones-Lee (2002b) recently completed an evaluation of the potential to control TOC at the source with water discharge/runoff management and treatment. They concluded that little is known about the specific sources and situations in the Central Valley that lead to TOC export from various types of land use under various water management approaches. Since TOC is primarily derived from leaching of organics from vegetation such as dead leaves and agricultural crop residues, it will be important to conduct on-field studies of the amounts of refractory and labile TOC discharged from

representative land use/runoff situations in the Sacramento and San Joaquin River watersheds and within the Delta. The objective of such studies should be to develop TOC export coefficients that estimate the amounts of TOC exported from each type of land use/vegetation type in grams of TOC type per unit area of land per unit time or runoff event. Particular attention should be given to the potential for some of the TOC in these sources to be labile.

Lee and Jones (1991a) summarized the information that is known on the concentrations of TOC from various types of land use. Randtke, *et al*. (1988) reported that the TOC in no-till farmland in Kansas was about 7 mg/L while two different cornfields' runoff had TOC of about 17 mg/L. Each type of agricultural land use and land having various characteristics (e.g., soil type, slope, vegetative cover, etc.) as well as water management approaches would be expected to have a different TOC export coefficient. Further, the characteristics of the TOC with respect to forming trihalomethanes will likely be different depending on its origin. Randtke, *et al.* (1988) reported that the THM formation potential for runoff from one cornfield was about 1000 μg/L. For another cornfield it was about 600 μg/L. The TOC from both cornfields was about 17 mg/L. The TOC content, form, and THM formation potential associated with various types of agricultural settings will need to be investigated in the San Joaquin and Sacramento River watersheds. Eventually through such studies it will be possible to begin to formulate approaches that have the potential to reduce the refractory TOC discharges that are of significance in contributing to THMs in water supplies that utilize Delta waters as a source. As part of the TOC management studies that would evolve from defining the important sources of TOC for the Delta and within the Delta, it will be important to develop reliable cost of control information so that it will be possible to evaluate the cost of TOC control options.

The Delta TOC/THM issue is part of the long-standing attempts by water utilities to develop a peripheral canal to divert lower TOC content Sacramento River water around the Delta and thereby minimize the additional pickup of TOC from Delta agriculture and the San Joaquin River watershed.

TOC Trading. Recently the US EPA announced a national program of "pollutant trading" which would allow greater and less-expensive control of TOC per unit load at one location and less control at another to achieve the same overall control of TOC from the watershed at lower total cost. It may be possible to develop TOC trading within the Delta and its watersheds. It will be important that the TOC trades properly consider all of the factors that influence TOC discharge from a particular location and its impact on THM formation at a water utility treatment works that uses Delta waters as a source. Without this approach, the TOC trades could be unreliable and ineffective.

Management of TOC Source Issues. The US EPA has not established a national water quality criterion for TOC and will not likely do so, since the water quality problems of TOC are usually highly local. There are many situations where discharges of elevated TOC are not adverse to receiving water quality and, in fact, may be beneficial. The US EPA Source Water Quality Protection Program has no regulatory authority with respect to controlling constituents in a water supply's watershed, such as TOC, that are potentially adverse to the raw water quality. Since the US EPA has not developed water quality criteria for TOC, water quality standards will have to be established through State – and, in California, Regional – Boards. Adopting TOC objectives would likely be difficult in the Central Valley, because of the disconnect between the origin of the TOC from agricultural activities, managed wetlands, and urban areas and where the TOC is a problem to water utilities outside of the Delta, located in the San Francisco Bay area and in Southern California.

With respect to the Delta TOC/THM management issues, since all of the water utilities that are impacted are outside of the Central Valley Regional Water Quality Control Board's jurisdiction (i.e., they are in other regions), there will be reluctance on the part of the Central Valley Regional Water Quality Control Board to adopt water quality objectives which could be used to regulate Central Valley agricultural interests, for the benefit of non-Central Valley water utilities. This is especially true when it is possible for water utilities to solve the TOC problem through additional treatment at the treatment plant. There will be need to examine whether it is more cost-effective to control the excess TOC at the treatment works, rather than at the source, especially since only a small part of the exported Delta water is used by water utilities. The remainder is used by agriculture, where the TOC is not a problem – it may be a benefit. San Joaquin River irrigation diversions may add organic matter as a soil conditioner to the soils, although this may be a small source compared to terrestrial vegetation.

It is likely to become extremely difficult to get support of irrigated agriculture and managed wetlands managers who are federal and state agencies and private duck clubs to agree to control TOC in their discharges for the benefit of water utilities located in the Bay area or in Southern California, hundreds of miles downstream outside of the Delta.

Organization of Future TOC Management Studies

The approach that should be followed to develop the information needed for formulating a technically valid, cost-effective Delta export water TOC program should involve an individual to take the lead on organizing and conducting a multimillion dollar per year monitoring and evaluation program over at least 5 years, of the potential TOC sources and their characteristics/fate in the Delta and its tributaries. A TOC advisory panel representing the stakeholders pertinent to managing TOC should be appointed to work with the project PI in its development. This project should be funded by CALFED as a Directed Action project. Because of CALFED funding requirements, the first phase of the project would be conducted over a three-year period.

The project should consist of two major tasks: TOC source identification and pilot demonstration projects on TOC control. The assessment of refractory TOC sources in the Sacramento River and San Joaquin River watersheds and the Delta should be done through selective, periodic (biweekly) monitoring and event-based monitoring (associated with major high-flow periods) of selected tributaries/sources in the Delta and its watershed. Monitoring should also be conducted along the mainstems of the SJR and the Sacramento River and their major tributaries and within the Delta in the Deep Water Ship Channel, Old River, Turner Cut, and Columbia Cut, and at various locations in

Middle River. Measurement of TOC, chlorophyll, pheophytin, BOD, EC, tributary flow and supporting parameters should be made over a two-year period. Monitoring should also be conducted from the location of the Banks export pump to various water supply intakes that use Delta water as a source, to define the changes in refractory TOC concentrations along those flow paths. This monitoring program should include special-purpose studies that evolve from the monitoring program based on the ongoing monitoring data review as it shows the need to conduct studies to explain the monitoring data. The third year of monitoring should be focused on those areas that need additional attention to better define sources of refractory TOC. To the extent possible, this project's monitoring program should be coordinated with other on-going monitoring programs and TOC studies.

The pilot refractory TOC management studies should be conducted on those TOC sources that contribute the greatest refractory TOC loads to the Delta that are exported from the Delta. Representative TOC sources, considering agricultural practices and conditions that influence TOC export from the source, should be selected for pilot study. Information should be collected on the cost of TOC control for each of the study sites. The pilot studies should be defined based on the first year's monitoring results and should be initiated in the second year of the study. The pilot TOC control studies should continue in a follow-up project that would be initiated after the completion of the three-year project. Of particular concern will be the examination of the year-to-year variability of TOC releases and the options for TOC control in those years when the releases of greatest significance occur. All monitoring should be done in accord with SWRCB QA/QC requirements.

Overall

A review of the existing information on TOC, chlorophyll/pheophytin and BOD has shown that there is a potential that, at times, part of the TOC that is contributed to the Delta from San Joaquin River sources and in urban stormwater runoff is in a form that can be degraded through bacterial respiration and thereby not contribute to the TOC of importance to water utilities that use Delta water as a source. It will be important that all future TOC studies examine this issue to provide the data needed to determine if this is an important issue that needs to be incorporated into the development of a TOC management plan for the Delta and its tributaries.

Questions or comments on this discussion should be directed to Dr. G. Fred Lee at gfredlee@aol.com.

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