DRINKING WATER QUALITY ISSUES FOR DELTA SOURCE WATERS

D-000263

STATUS OF THE DELTA

AS A RESOURCE

FOR DRINKING WATER PURPOSES

THE SACRAMENTO -- SAN JOAQUIN DELTA AS A SOURCE OF DRINKING WATER

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THE SACRAMENTO-SAN JOAQUIN DELTA AS A SOURCE OF DRINKING WATER

BRIEFING PAPER
FOR BAY-DELTA OVERSIGHT COUNCIL
April 16, 1993

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Introduction

The Sacramento-San Joaquin Delta is a source of drinking water for about two-thirds of California's citizens. When treated, drinking water from this source generally, but not always, meets current state and federal drinking water quality standards. There are, however, serious concerns about the quality of Delta water as a drinking water source, and the ability of urban water suppliers to meet anticipated future standards.

Drinking water in California is controlled, regulated, and protected through a combination of federal and state regulatory systems. Through these systems, a variety new drinking water standards are in the process of being promulgated.

Many experts believe the quality of Delta waters cannot be protected to the extent desired for an important drinking water source. The watersheds tributary to the Delta drain over 25 percent of the land surface of California; and, in those watersheds, municipal and industrial waste water discharges, drainage from agricultural lands and municipal storm drains, recreational activities, and chemical spills contribute to water quality degradation. Within the Delta, sea water intrusion and drainage from Delta islands further degrade water quality.

In the regulatory arena, there is a current trend toward requirements for more rigorous disinfection to destroy pathogenic organisms. At the same time, the U.S. Environmental Protection Agency has adopted increasingly restrictive requirements for disinfectants and disinfection by-products (potentially harmful chemicals produced as a result of disinfecting drinking water). These two regulatory trends conflict because, generally, the more rigorous the disinfection, the more opportunity for formation of disinfection by-products.

The conflicting regulatory directions are creating concerns for drinking water purveyors throughout the country in meeting their mandate to protect public health; purveyors of drinking water from the Delta are particularly challenged. Compared to other drinking water sources, the Delta has higher concentrations of two constituents which create problems during the disinfection process:

One is bromide, a salt ion of sea water origin which is present in the Delta primarily as a result of sea water intrusion.

The other is naturally occurring dissolved organic carbon which enters Delta waters from a number of sources. Among these are drainage from land surfaces in the watersheds tributary to the Delta, the Bay estuary, the soils of the channels within the Delta, from algae growing in Delta waters and, from drainage of land surfaces within the Delta. The peat islands of the Delta are particularly rich sources of this organic carbon. During some conditions, discharges from Delta islands may cause organic carbon concentrations in Delta drinking water supplies to nearly double.

Bromides and organic carbon react with disinfectants to form disinfection by-products. As the Delta is an enriched source of these materials, meeting more restrictive drinking water regulations for disinfection and disinfection by-products is presenting significant technical challenges to water purveyors.

The concerns of urban water agencies using Delta water are summarized as follows:

> Given the existing points of diversion from the Delta, even with the expenditure of potentially large amounts of money (much larger, for example, than would be required for any facilities that might be built in the Delta), there will not be adequate assurance of continued compliance with existing and future state and federal drinking water standards.
>
> Municipal water agencies go to considerable lengths to assure the safety of their product. When compliance is not attained, public notification is required. Such notifications provoke public anxiety, reduce consumer confidence, and drive customers to use expensive bottled water. For these reasons, the agencies believe non-compliance is simply not an acceptable option. According to this view, better control over source water quality is critical.
>
> Alternatives for the control of source quality could include restriction or selective elimination of drainages which contribute organic carbon to Delta waters; alteration of Delta flow patterns to prevent or greatly reduce sea water intrusion; relocating certain waste discharges; and, constructing facilities to partially or completely isolate the drinking water supply from the Delta. The latter option is widely felt by the urban agencies to offer the most advantages; chief among these would be to enable new drinking standards to be reliably met at reasonable cost.

Members of environmental advocacy groups active in California water issues often believe that, while it is generally best to supply drinking water from the highest quality available source, the environmental cost can, and should, be a limiting consideration. With respect to the Delta, some in the environmental advocacy community believe Delta options involving isolated facilities have crucial disadvantages, even though drinking water supply would be improved.

Some members of environmental advocacy groups have stated the opinion that treatment technology is sufficiently advanced to enable Delta waters to be treated to adequately protect the health of consumers, albeit at considerable cost. Therefore, according to this point of view, continuing to take drinking water supplies from the southern Delta is an acceptable compromise of environmental and public health concerns.

Drinking Water Planning and Management

The Safe Drinking Water Plan for California was published in January 1993 by the Office of Drinking Water, Department of Health Services. This plan was prepared in coordination with a number of other agencies as a response to concern on the part of state legislators over the vulnerability of California's water supplies, as demonstrated by six consecutive years of drought. This document is a comprehensive assessment of the quality, safety, problems, health risks, costs, and regulatory programs associated with drinking water supplies in California. The report also provides a plan with specific recommendations to solve problems and improve drinking water quality. The recommendations are applicable to most of the State's water supplies, but one is particularly relevant to the Delta:

> *To the extent feasible, measures should be taken to prevent degradation of the domestic water transported through the Delta by minimizing the introduction of disinfection by-product precursors from agricultural operations and by controlling seawater intrusion into the Delta. The domestic water supply should be further protected from agricultural drainage and other sources of potential degradation during transport through the State Water Project and other aqueducts.*

Clean Water Act

Section 302 and 303 of the federal Clean Water Act require establishment of tailored water quality standards to support the designated beneficial uses of individual water bodies. Drinking water sources are among the designated beneficial uses of Delta waters.

The National Pollution Discharge Elimination System (NPDES), established by the Clean Water Act, provides for regulation of point source discharges (such as wastewater treatment plant discharges) through permits. This is a primary means of achieving national water quality objectives. Also established were non-point source control programs to control diffuse pollution sources such as surface storm water runoff. The State Water Resources Control Board has primacy for implementing the federal Act in California.

Drinking Water Regulatory System

The U.S. Environmental Protection Agency regulates drinking water under the Safe Drinking Water Act as amended in 1986 (PL 93-523). The drinking water regulations apply to all states; however, individual states may elect to apply for primacy to enforce the Act on behalf of EPA. The Department of Health Services has been granted primacy for enforcement of the federal Act in California.

Not only does the Department enforce federal drinking water quality criteria, but also establishes state drinking water standards pursuant to the California Safe Drinking Water Act (Health and Safety Code, Section 4026 Division 5, Part 1, Chapter 7). These standards, embodied in California Domestic Water Quality and Monitoring Regulations, Title 22, California Code of Regulations, must be no less stringent than those set by the U.S. EPA.

Types of Drinking Water Standards

The National Interim Primary Drinking Water Regulations, 40 CFR Part 141, limit concentrations of constituents in drinking water for the protection of human health. The National Secondary Drinking Water Regulations, 40 CFR Part 143, are for constituents which do not directly affect the health of consumers, but affect aesthetic qualities of the water, such as taste and odor. It is reasoned that aesthetic aspects of drinking water have an indirect effect on consumer health, as persons who are provided water which is unpleasant in character may turn to water sources which are less safe.

The California Primary and Secondary drinking water standards, patterned after the federal standards, appear in Title 22, California Code of Regulations, cited previously. The federal Secondary Drinking Water Standards are not enforceable, but the State Secondary Standards are.

Revision of Drinking Water Standards

The federal Safe Drinking Water Act Amendments of 1986 make specific provision for new regulations. Each three years, 25 new contaminants are to be added to the list of constituents regulated in drinking water.

In addition to regulating specific contaminants, such as lead and copper, EPA has also developed the Surface Water

Treatment Rule which is directed toward increasing the certainty that drinking water is sufficiently disinfected to destroy pathogenic organisms. An Enhanced Surface Water Treatment Rule is under development at the present time, and is expected to be proposed this year.

EPA is presently conducting negotiations for updating its regulations for the class of drinking water contaminants known as disinfectants and disinfection by-products (DDBP's). The negotiation process is expected to conclude in about a month.

Having primacy for enforcement of the federal drinking water standards, the Department of Health Services is heavily involved in developing and enforcing revised drinking water standards. When federal standards are adopted, DHS evaluates the technical basis for the regulations and makes a determination as to whether the federal regulation is sufficiently stringent to meet the specific needs of California. More stringent regulations are proposed as deemed appropriate by the Department.

Federal drinking water standards are developed through a process whereby a Maximum Contaminant Level Goal (MCLG) is first proposed, then established for a contaminant. The MCLG represents the highest level of a drinking water contaminant which will not cause adverse health effects, and does not take into account practical factors such as economics and technical feasibility of attainment. The MCLG is not enforceable.

The Maximum Contaminant Level, an enforceable drinking water standard, is set as near to the MCLG as is economically and technically feasible. Like the MCLG, the standard goes through a process of proposal, comment, revision, and finalization before going into effect. In the case of suspected or known carcinogens, the MCLG is automatically zero, and resulting MCLs are necessarily set as close to zero as is feasible.

Surface Water Treatment Rule

A federal regulation on filtration and disinfection of surface drinking water sources and ground water sources influenced by surface water, known as the Surface Water Treatment Rule, became effective on December 31, 1990. The state regulations for surface water treatment became effective on June 5, 1991. This regulation establishes filtration and disinfection requirements to protect against adverse health effects caused by waterborne microorganisms. An Enhanced Surface Water Treatment Rule is under development at the present time, and is expected to be proposed this year. The new rule will establish even more stringent pathogen removal requirements than the current rule.

Under the federal SWTR, water systems with clean and protected source waters may not have to filter their water if continuous adequate disinfection can be demonstrated. However, California requires all surface water users to employ filtration. Users of Delta waters would not qualify for the federal exemption, even if it were available to California water purveyors, as the Delta is not a protected source of water. Accordingly, all municipal agencies treating Delta water must employ filtration and related processes in their treatment plants.

Disinfection is required using a formula determined by the concentration of the disinfectant and the length of time the disinfectant is in contact with the water. Performance criteria require minimum three-log (99.9%) and four-log (99.99%) removals or inactivation of the pathogenic microorganisms Giardia lamblia, and viruses, respectively. Once disinfection is completed, there must be a minimum residual concentration of disinfectant at the head of the drinking water distribution system.

The requirement for rigorous disinfection means disinfectant concentrations and the period of disinfectant contact with the water must be maintained at specified values to ensure reliable disinfection. As a result, disinfection by-products are given the opportunity to form. As Delta water is enriched in bromides and organic carbon compounds, disinfection by-product formation in these source waters is a particular problem related to the Surface Water Treatment Rule.

Disinfectants and Disinfection By-Products Rule

In 1981, the U.S. Environmental Protection Agency adopted a Maximum Contaminant Level for trihalomethanes (THMs), a class of chlorinated chemical formed when water is disinfected during drinking water treatment (see "Disinfection By-Products" in Appendix). Since promulgation of the current trihalomethane standard, researchers have discovered that, in addition to THMs, a number of other disinfection by-products are produced in drinking water systems. In light of this discovery, and the results of ongoing research into health effects of THMs, the U.S. EPA has proposed an updated rule on disinfectants, THMs and other disinfection by-products. This is known as the DDBP rule.

If adopted, the DDBP rule is scheduled to become effective in 1997. The details of the rule are currently being negotiated among the affected parties. Negotiated regulations, or "RegNegs" are a recent innovation. EPA has discovered that, where agreement can be reached in advance of rule making, the incidence of litigation is reduced, to the mutual benefit of all concerned.

The current negotiations are nearing completion, but are not yet actually complete. Though the final shape of the rule is not yet set, it appears that the new rule will reduce the MCL for THMs to 0.08 milligrams per liter (from the current 0.10 mg/L).

In addition, other disinfection by-products (DBPs) will be regulated. Haloacetic acids are a class of DBPs which will probably be regulated at 0.06 milligrams per liter for the sum of concentrations of individual haloacetic acid types.

Bromates, which are formed when bromides are present and ozone is used for disinfection, are likely to be regulated. The MCL is not yet established, but a range of .005 to .015 milligrams per liter is being discussed. Last it appears that, when organic carbon concentrations in the water exceed 2 milligram per liter, special studies and treatment modifications will be required. The expected new rule will be subject to a further review, probably in 1997 or 1998. At that time, if ongoing research demonstrates the need, an MCL may be set for organic carbon.

Human Health Effects of Disinfection By-products

The health effects of drinking water disinfection by-products primarily concern carcinogenicity. Carcinogens are classified on the basis of the strength of the health effects data which indicate the carcinogenic potential of chemicals. The highest rating is given when sufficient evidence exists that a compound causes cancer in humans. None of the currently known disinfection by-products are so classified, because human health effects data are very limited for these chemicals. Therefore, the carcinogenic ratings for disinfection by-products are based primarily on animal studies.

Cancer risks are normally expressed in terms of the numbers of cancers that would be expected to occur as a result of contact with a chemical at a specified concentration over a lifetime of exposure. For example, a "one in a million risk level of 1 milligram per liter" means that a chemical would be expected to cause 1 case of cancer during lifetime exposure of one million people to the chemical at a concentration of 1 milligram per liter.

As was previously discussed, the Maximum Contaminant Level Goal (MCLG) for carcinogens is automatically set at zero, and MCLs are set as close to that goal as is economically and technically feasible. The general consensus is that the "one in a million" risk level is sufficiently protective of public health, and regulatory agencies commonly seek to provide protection at the one per million risk level.

The following table presents calculated carcinogenic risks associated with disinfection by-products found at levels typical of drinking water supplies in the United States.

Calculated Carcinogenic Risks
of Average Concentrations of Disinfection By-Products
Present in United States Drinking Water

	Disinfectant Used			
	Mean Conc.	**Risk per million exposed persons**		
Disinfection By-product	**(ug/L)***	**Chlorine**	**Chloramine**	**Ozone**
Chloroform	26.4	0.24	0.48	0
Bromodichloromethane	9.1	0.91	0.18	
Chlorodibromethane	5.7	0.29	0.058	
Bromoform	4.4	0.054	0.011	0.025
Dichloroacetic acid	47	0.00034	0.000068	
Trichloroacetic acid	38	54	11	
Chloropicrin	0.8	0.0016	0.00032	
2,4,6-Trichlorophenol	<1	0.017	0.0034	
Formaldehyde	8	0.54	0.11	3.0
Hydrogen peroxide	<1			10
Bromate	<1			50
Projected Mean Risk		56	11	63

* Estimated mean concentration in chlorinated water supplies in the United States (parts per billion).

Summarized from: Bull, R.J. "Health Effects of Disinfectants and Disinfection By-products". Publ. AWWA Research Foundation and American Water Works Association.

The table reflects the expected cancer risks associated with average concentrations of disinfection by-products found in drinking water throughout the United States. Examination of this table reveals that the majority of the calculated risk is attributable of one or two constituents.

The calculated cancer risk from trichloroacetic acid (one of the haloacetic acids being regulated under the new disinfection by-product rule) accounts for over 95 percent of the cancer risk associated with the use of chlorine or chloramine as disinfectants, considerably surpassing the trihalomethanes which are now regulated. Also evident from this table is that, while ozone is favored by some as the alternative disinfectant of choice, where bromides are present, the resulting net health effect of using ozone may not be acceptable as an alternative to chlorine or chloramine. This follows since ozone, in the presence of elevated levels of bromide, forms the disinfection by-product Bromate.

In source waters, such as the Delta, where organic carbon and bromine concentrations are enriched, the risk profile may

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differ considerably from that shown. Brominated haloacetic acids and bromate, for example, may become more important sources of cancer risk. Not enough is yet known about the health effects of disinfection by-products. Two 1992 studies conducted in New Jersey indicated the possibility that some disinfection by-products in chlorinated drinking water are associated with birth defects. Continuing research will be required for definitive conclusions to be reached.

When considering health risks posed by carcinogens, the subject of scientific uncertainty must inevitably arise. The science of identifying carcinogens and predicting their behavior is still in its infancy; thus, all conclusions based on this methodology should be examined very critically. The problem is that, while faulty, the tools currently in use are the best ones, really the only ones, available. The difficult policy decision is whether to go ahead and regulate using the best science available, or to wait until more definitive methods present a clearer picture of true risk. Both sides of this argument have proponents.

Impacts of New Drinking Water Regulations

Municipal agencies purveying treated drinking water of Delta origin would generally be able to continue meeting drinking water regulations if they remained unchanged. The regulations, however, are not going to remain constant. Not only will future regulations require improvements, but the general public is demanding protection of their environment and their drinking water supplies.

The new regulations will be considerably more restrictive than current regulations. Because of the special problems with bromides and organic carbon in the Delta, meeting the standards will require costly treatment process modifications, control of source water quality, or a combination of both.

Capital costs for treatment plant upgrades can be substantial, especially when new facilities such as filters must be constructed. Operational costs will rise as well, reflecting more rigorous plant processes, and significantly increased costs for water quality monitoring and control.

The new DDBP standards will greatly affect municipal agencies using Delta source waters. Currently, THM production in systems using Delta waters at times approaches the current 0.1 milligram per liter limit, particularly when bromide concentrations in the water are elevated due to low flow conditions in the Delta. Reduction of the THM standard by 20 percent will aggravate this problem. In addition, the presence of bromide will cause increased formation of bromine-containing haloacetic acids and complicate the problem of meeting that standard.

Depending on what regulatory level is adopted for bromate, the presence in Delta water of bromides may cause ozone use to become infeasible. Ozone is a strong disinfectant which has been extensively used in Europe for many years, and which has the advantage of not producing chloroform. However, in the presence of bromides, ozonation of drinking water can produce bromoform (one of the THMs) and also bromate. Preliminary health effects data suggest bromate is a relatively strong carcinogen, and it is likely the bromate regulation will be quite conservative.

Municipalities using Delta waters are likely to have to conduct studies and make treatment process changes because of organic carbon, as part of the new regulations for disinfectants and disinfection byproducts.

The new DDBP standards will probably apply to water systems of all sizes, whereas the existing THM standard affects water systems with 10,000 or more customers. This will severely impact the small water systems which have neither the financial resources nor the technical expertise to comply with the potential new standards. Some communities using Delta water, such as Avenal and Huron, are in this category. The State Department of Health Services is aware of the problem. The Safe Drinking Water Plan, cited earlier, contains several recommendations to ease the burden of new regulations on small systems through provision of technical and financial services.

Delta Source Water and Treatment Reliability

A basic tenet of good sanitary engineering practice holds that drinking water supplies should be taken from the best available source. This principle, which has been affirmed by the California Department of Health Services and the State Water Resources Control Board, arises from the fact that conventional water treatment processes, while generally quite effective, do not remove all harmful constituents which may be found in water sources. Therefore, the safety and reliability of water treatment is best assured by protecting the quality of the source water.

Ideally, a drinking water purveyor would maintain complete control over factors influencing the quality of the water supply. In many areas of California, for instance, human contact in drinking water reservoirs and development in the watersheds of the reservoirs are severely restricted or eliminated by the local water supply agency.

In addition, Department of Health Services regulations restrict water contact recreational activities in drinking water supply reservoirs, except for those which are part of the State Water Project. Such restrictions provide an additional margin of safety to the public by not permitting introduction of contaminants which might not be adequately removed through water treatment. Where watershed protection is feasible, it may be very cost effective compared to treatment.

The Delta cannot be similarly protected because the watersheds tributary to the Delta drain a large percentage (about 25 percent) of the land surface of California. The Delta watershed receives municipal and industrial wastewater discharges, drainage from agricultural lands and municipal storm drains, wastes resulting from recreational activities, chemical spills, and other sources of water quality degradation. Within the Delta itself, drainage from Delta islands and sea water intrusion further degrade water quality.

Experience suggests it would be extremely difficult or impossible to restrict human contact with these source waters, or to eliminate activities which can result in water quality degradation. However, improvements can certainly be attained through application of the federal Clean Water Act and State laws, such as the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65).

The issue of Delta source water quality has received considerable study, and continues to be investigated. In 1982, East Bay Municipal Utility District and Contra Costa Water District participated in a joint study, the result of which was the report, Joint Water Quality Study-East Bay Municipal Utility District/Contra Costa Water District. James Montgomery Engineers. September 1983. Trihalomethane forming compounds in Delta waters were found to be at elevated concentrations at the southern Delta export locations, as compared to the Sacramento River. Trihalomethanes were identified as probably the most important health risk associated with this water supply, particularly if chlorine is used in water treatment.

The report, Delta Water Quality: A Report to the Legislature on Trihalomethanes and the quality of Drinking water Available from the Sacramento-San Joaquin Delta was published in 1991 by the State Water Resources Control Board, Department of Health Services, and the Department of Water Resources. This report responded to a requirement of Senate Concurrent Resolution 55 (1990). Provided are the results of a comprehensive survey of municipal purveyors of drinking water from the Delta. A number of problems were identified and, significantly, this statement appears:

> *It is clear that water utilities charged with protecting the public health through treating drinking water from the Delta*

will face serious problems in meeting anticipated state and federal regulations.

Nine urban water agencies participated in a study resulting in publication of the report, Delta Drinking Water Quality Study. Brown and Caldwell Engineers. May 1989. One conclusion of the study was:

> *....due to high concentrations of THM precursors and other organics yet to be regulated in Delta water supplies, the urban water agencies will have to use costly treatment techniques to meet anticipated drinking water standards. As drinking water standards are developed for more constituents, as mandated by the amendments to the federal Safe Drinking Water Act, expensive chemical treatment of Delta water supplies will be required to meet the future standards.*

An ongoing study is the Municipal Water Quality Investigations program, a multi-agency investigation into water factors affecting the quality of Delta source waters used for municipal purposes. Participants include the California Department of Health Services, Office of Drinking Water; State Water Resources Control Board, Central Valley Regional Water Quality Control Board; U.S. Environmental Protection Agency, California Urban Water Agencies, and the State Water Contractors. The Department of Water Resources is the lead agency. Currently, intensive study is being conducted on the effects of Delta island drainage on Delta waters. Studies to date indicate that, during drought conditions, Delta island drainage may contribute up to half the organic carbon in Delta waters.

Reliability is an important concept in water treatment. It is not possible for a water purveyor to constantly monitor drinking water for all constituents which could be of health concern. Instead, water is periodically sampled and analyzed for a wide range of constituents; the quality of the water over a period of time is assumed to reflect the samples which are taken and analyzed. Therefore, it is possible for a quantity of polluted water to enter a treatment plant undetected. In some cases, treatment plant processes may not remove all of the harmful constituents, thus permitting them to reach consumers. Treatment reliability is also influenced by improper operation, human error, and mechanical breakdown.

As it is technically infeasible to maintain continuous monitoring for all constituents of concern, the water purveyors and regulatory authorities have adopted the approach of preventing the source water from being polluted in the first place, thus increasing the ability of a treatment plant to reliably meet quality standards. As has been discussed, this margin of safety cannot be provided to the degree which would be desirable with Delta waters. Therefore, there is a risk of harmful materials reaching consumers.

Having identified this risk, it is also true that, over a number of years, analyses by a number of drinking water purveyors using Delta waters have failed to detect the presence in the drinking water of levels of harmful chemicals which warrant health concern. Harmful bacteria and viruses have, however, been found in Delta waters. While Delta waters fail to meet the objective for source quality protection, this shortcoming has not been demonstrated to present unacceptable risk to the consumer.

Because of the limited feasibility of protecting Delta water from quality degradation, and because of the addition in the Delta of bromides and organic carbon, the Delta is not as high quality a source of drinking water as would be preferred, and is lower in quality than most surface supplies in the State.

However, in spite of the fact that Delta source waters contain some problem constituents, treatment technology has been adequate to date for the water retailing agencies to meet the water quality standards the majority of the time. The proposed new standards discussed earlier will pose difficulties in achieving the present pattern of conformance.

Costs of Poor Quality Water

The costs of poor quality water depend largely on the type of water use and the treatment processes required to improve quality so that it meets standards specified for the intended use. Drinking water standards and those for municipal, industrial, and agricultural water all have water quality requirements that must be met before the water can be beneficially used. New standards, such as the one requiring drinking water filtration, and ones which have lowered the acceptable limit of lead and copper, often result in increased costs of treatment to meet the new standards. In some cases, the cost can be very high, as in the case of the City of San Francisco which was required to construct filtration facilities.

In general, the better the quality of the source of drinking water, the less treatment it requires and, consequently, the less it costs to produce. Many water quality parameters affect treatment costs, including microbiological quality, turbidity, color, alkalinity, hardness, bromide and organic carbon content. For example, the Metropolitan Water District of Southern California treats roughly 2 billion gallons of water per day at five major treatment plants. To meet the existing trihalomethane rule, improvements costing about $5 million were made. To meet a prospective more stringent disinfection by-product rule, improvements costing hundreds of millions of dollars are being studied.

In addition to affecting drinking water, the mineral quality of municipal supplies has a variety of impacts. Hard water (high in calcium and magnesium salts) can cause corrosion, staining, and scale buildup and require excessive use of cleansers. Soft water may attack the metal in plumbing, increasing lead and copper concentrations at the tap.

Many studies have cited the impacts of water quality on the value of water to urban consumers, and all have cited the difficulty of expressing quality impacts in a simple way. A 1989 review of consumer impacts of the mineral content of Delta water proposed a generalized cost of $0.68 per acre foot per milligram per liter of incremental total dissolved solids. The current generalized value would be about $0.80 per acre-foot per milligram per liter (adjusted using the Consumer Price Index), or about 30 cents per pound of dissolved mineral matter in the water.

The impact of this added cost can be quite significant. For example, after an earlier drought, Colorado River water increased in dissolved solids to about 800 milligrams per liter, and the Colorado River Aqueduct was transporting some 2.6 billion pounds per year of minerals, representing a generalized cost to consumers of some $800 million annually.

Studies have also shown that lower water quality in urban supplies increases consumer use of bottled water and home treatment devices. Surveys of California communities indicate that about half of all California residences use some bottled or home-treated water. The collective cost of these choices by the state's residents is over a billion dollars annually. Some of these expenditures would, of course, be made regardless of local water quality.

A less obvious impact of water mineralization is the loss of opportunity to recycle water. The City of Los Angeles, for example, has recently been unable to meet effluent standards for some water reclamation facilities, in part because of elevated salts due to the drought. These factors tend to limit the practicality of reclaiming State Water Project water in Southern California.

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APPENDIX

Alternative Disinfectants

Since it was discovered that chlorine is capable of creating undesirable chemicals in drinking water, a large scale search has been underway to find alternative disinfectant chemicals. The ideal disinfectant would be a powerful oxidizing agent which would completely destroy harmful organisms, while producing no unwanted chemical reactions. Unfortunately, to date, no such ideal process has been found. By its very nature, a compound which can aggressively kill microorganisms must be highly reactive. Therefore, unwanted chemical reactions are to be expected.

In addition to chlorine, other disinfectants including ozone, chloramine, and chlorine dioxide, have been used with varying success to disinfect drinking water. Each has its advantages and disadvantages.

Chlorine has been used for many years in this country, and has established an enviable record of controlling water-borne disease. Chlorine is highly reactive, and is very effective in killing pathogens. Also, it persists in distribution systems and enables distribution piping to be kept disinfected for the safety of consumers. However, chlorine reacts with organic carbon and bromides to form trihalomethanes and a number of other chlorinated and brominated disinfection by-products.

Ozone has been a popular drinking water disinfectant in Europe for many years and its use in California is increasing. It is a very powerful oxidizing agent which is effective in killing viruses, bacteria, and other microorganisms. A disadvantage of ozone is that it does not persist in distribution system piping, so another chemical usually must be used for this purpose. Ozone, like chlorine, forms unwanted disinfection by-products, principally bromate.

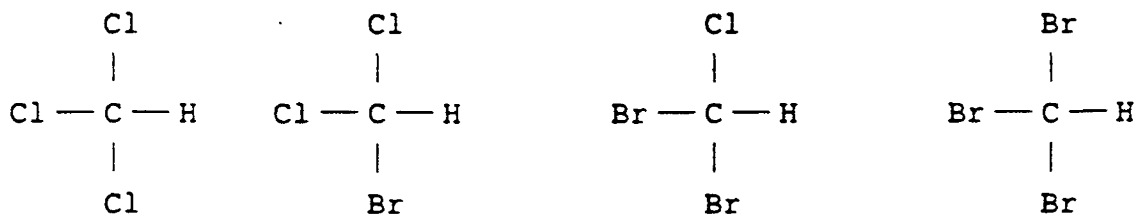
Chloramine is not a very strong disinfectant, but has advantages. It does not react strongly to form trihalomethanes and other compounds. Also it persists in distribution systems, and can be used in conjunction with ozone. There is some question as to whether chloramine is capable of adequately disinfecting distribution systems; and, chloramine in the water can cause health problems for kidney dialysis patients, and can kill aquarium fish if it is not removed before water is used for these purposes.

Chlorine dioxide is a powerful disinfectant and has some other practical advantages, but produces the disinfection by-products chlorate and chlorite, which have significant toxicity, and which may present health concerns if present in drinking water.

Other disinfectants and disinfection processes have been devised, and are being tested currently. The purpose of this discussion has not been to thoroughly address the range of alternative disinfectants, but to indicate to the reader that the problem with disinfectants and disinfection by-products is complex, and involves numerous factors. With respect to the Delta, the important point is that the enriched organic carbon and bromides in the water add significant further complications to the problem of how to safely disinfect drinking water while reducing formation of unwanted by-products.

Disinfection By-products

During the 1970's, researchers discovered the presence of chloroform and three other compounds in treated drinking water supplies, collectively known as trihalomethanes, or THMs. As health effects data indicated chloroform is a potential human carcinogen, in 1981, the U.S. Environmental Protection Agency adopted a Maximum Contaminant Level of 0.10 milligrams per liter (parts per million) for THMs.) The chemical structures of the THMs found in drinking water are depicted as follows:



Chloroform — Dichlorobromomethane — Dibromochloromethane — Bromoform

where: Cl = chlorine
Br = bromine
C = carbon
H = hydrogen

As one can observe, the different chemical species of THMs found in drinking water are composed of combinations of chlorine and bromine on a carbon core. Decaying plant materials produce organic (carbon-containing) compounds which dissolve in water. When chlorine used for drinking water disinfection reacts with the organic carbon, chloroform is formed. Where bromides are also present in the water, they enter the reaction to produce THMs containing combinations of chlorine and bromine. Generally, the more bromide present in a source water, the more brominated THM compounds are produced.

In 1981, the U.S. Environmental Protection Agency established a 0.1 milligram per liter (part per million) Maximum Contaminant Level (MCL) for trihalomethanes in drinking water, computed as a running annual average sum of the concentration of the above THMs, based on quarterly sampling of the drinking water distribution system.

The presence of bromides in the source water complicates the disinfection by-product problem significantly. First, bromine is about twice as heavy as chlorine. As the THM standard is based on weight, it takes fewer molecules of bromine-containing (or brominated) THMs to exceed the standard. In addition, brominated THMs form more quickly than does chloroform. Thus, for a given contact time with chlorine, more brominated THMs will be formed than chloroform.

The health effects of brominated THMs are not the same as for chloroform. Continuing research has demonstrated one of them, dichlorobromomethane, appears to be the most carcinogenic of the THMs found in drinking water. Because of the differing health effects, consideration has been given to regulating the THMs (including bromodichloromethane) separately, though recent indications are that THMs will continue for the next few years to be regulated together.

Finally, bromide in the water leads to formation of other disinfection by-products, some of which are a particular problem when alternative disinfectants are used to avoid the chemical reactions produced by chlorine. These factors are important for Delta source waters because these waters contain relatively high concentrations of bromide from sea water intrusion.

Factors Affecting Delta Drinking Water Quality

A considerable number of factors affect the quality of Delta drinking water sources. Some of them are discussed below.

Diversions and Discharges

The tributaries of the Delta, principally the Sacramento and San Joaquin Rivers, are subject to diversion before the water reaches the Delta. In the Sacramento River, large quantities of agricultural water supplies are diverted, used on adjacent lands and, ultimately, the excess is discharged back to the river. Agricultural diversions also occur from the San Joaquin River, and agricultural drainage is discharged back into the river.

The salt concentration in agricultural drainage is higher than in the applied water as a result of evaporation and transpiration processes which concentrate salt. Also, agricultural activities generally add nutrients and organic carbon to the drainage water. Algae growths are promoted by nutrient and carbon enrichment, and excessive algal growth can cause problems with filter clogging and taste and odor in drinking water supplies. The organic carbon compounds in drainage can also act to form harmful by-products during drinking water disinfection. Livestock are a source of pathogenic organisms which increase the difficulty of attaining satisfactory disinfection of drinking water. Pesticide residues are sometimes, though not often, found in agricultural drainage.

Water diverted and used by municipalities picks up salt, organic carbon, nutrients, and such things as household and industrial chemicals. Sacramento River water is diverted by municipalities, including Sacramento, which treat and distribute the water. Part of this water is collected as wastewater, treated, and discharged back to the river. The discharge from the Sacramento regional wastewater treatment facility, which occurs in the River near Freeport, is particularly significant. Municipal discharges are made to the San Joaquin River upstream of the Delta, such as by the city of Modesto.

Once in the Delta, water is diverted for municipal and industrial uses. Also, municipal and industrial wastewater is discharged to the Delta. Particularly significant is the addition of naturally occurring organic carbon in discharges from Delta islands. Wastewater discharge to the Delta from the city of Stockton is also significant.

Channel Dredging

Maintenance dredging is constantly required in the Delta to maintain channels and island levees. When sediments are dredged, an opportunity is presented for harmful materials residing in the sediment to mobilize into the water and, perhaps, cause water quality problems. In some areas, for instance, mercury deposits from gold rush era mining operations are still to be found in the sediments. Dredging may mobilize these materials, allowing them to enter the food chain. Generally, the ecological effects of dredging are likely to be more important than any impact on municipal agencies treating Delta water.

A direct effect of dredging is to temporarily increase the turbidity of the water in the vicinity being dredged, but this problem is generally of little significance to municipal entities using Delta waters. Limited data collected by the Department of Water Resources indicate the sediments of the Delta channels are generally not major sources of toxicants, and it is doubtful that drinking water MCLs would be approached as a result of dredging activities there.

Drought

During dry periods, reservoir releases are efficient in maintaining a fresh water environment in the Delta. Yet, reservoir releases provide imperfect salinity control. During conditions of protracted drought, water available for reservoir releases can be severely limited, further reducing the efficiency of salinity repulsion. The most significant effect of the recent drought on Delta drinking water quality was increased sea water intrusion resulting from low fresh water outflows.

Bromides from sea water, in particular, cause serious problems with control of disinfection by-products. And, at times, the secondary drinking water standards for chloride and sodium have been approached as a result of sea water intrusion. During the 1977 drought, sodium concentrations in Delta water delivered to Contra Costa County were such that health authorities notified the public that persons on salt limited diets should consult with their physicians concerning the advisability of consuming the water.

A less obvious effect of drought-related low flow conditions is the reduced capacity to dilute contaminants. The discharge rates of wastewater treatment facilities, for example, tend to remain relatively stable in times of drought, while the flow of the receiving water is markedly reduced. The result is a greater concentration of nutrients and other constituents in the receiving water, as compared to periods when dilution volumes are higher. This concentration effect is important in the dilution of river discharges, such as from the Sacramento plant, but are less so in tidally influenced areas, such as Carquinez Strait.

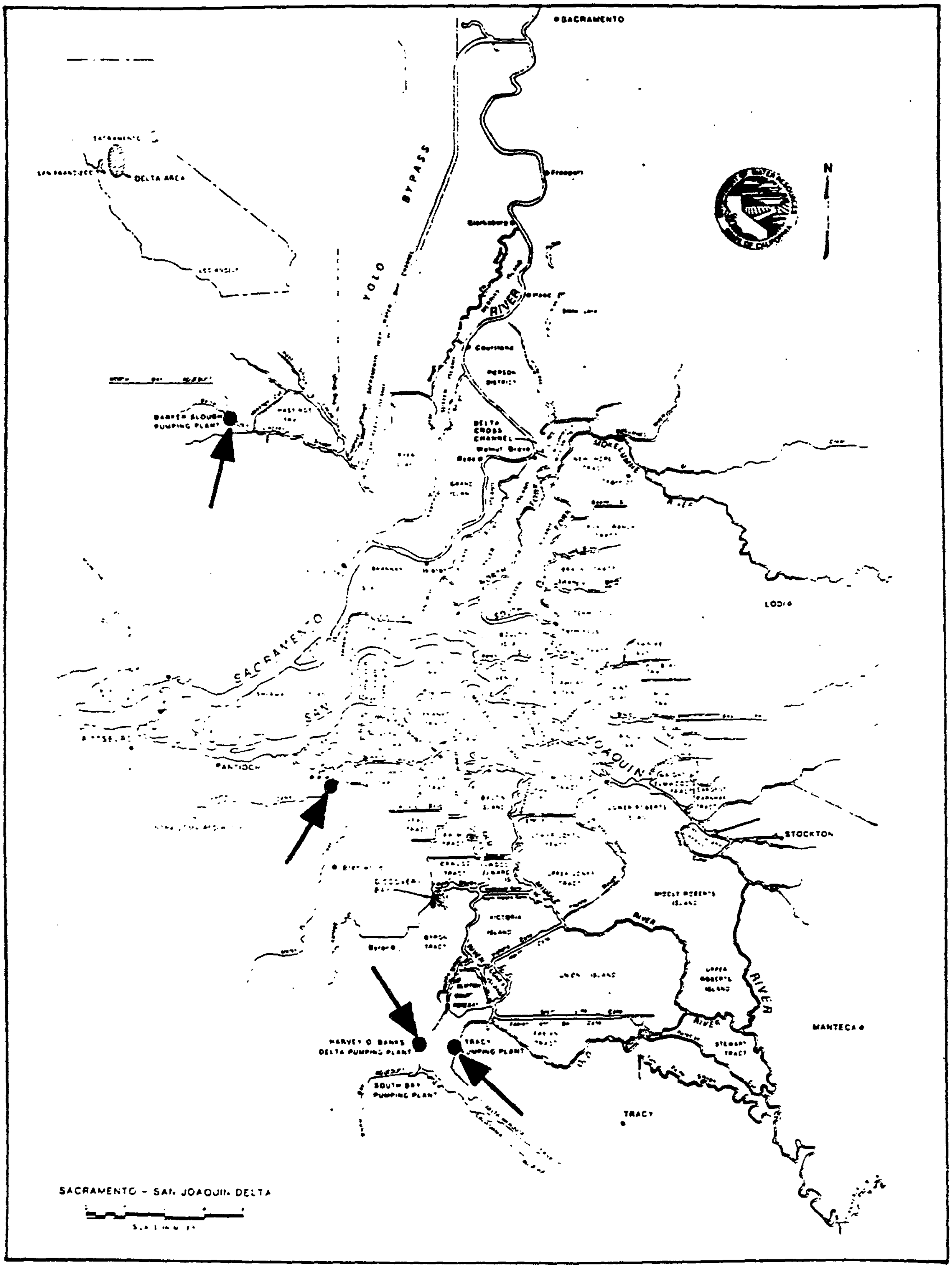
Another effect of drought conditions is to increase problems associated with recycling waste water as a result of the increased salt load in the water being recycled. Especially in Southern California, where recycling can be quite cost effective, increased salt loads discourage use of the recycled water for such purposes as landscape irrigation and ground water recharge.

Locations of Export Facilities

Water is diverted into the North Bay Aqueduct of the State Water Project from Barker Slough in the North Bay. The quality of this water is influenced by local surface drainage and, perhaps, by the wastewater discharge from the City of Vacaville. This facility has waste stabilization lagoons which discharge to a waterway that enters Cache Slough.

Water is diverted into the California Aqueduct of the State Water Project from Clifton Court which connects, through Rock Slough, to Old River in the southern Delta; the Central Valley

SACRAMENTO-SAN JOAQUIN DELTA
EXPORT LOCATIONS



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Project diverts water directly from Old River in the southern Delta, south of Clifton Court (See Figure 1). The State Water Project and Central Valley Project connect at O'Neill Forebay, located near Los Banos in the San Joaquin Valley. Therefore, drinking water supplies transported to Southern California reflect the quality of both export locations.

The Contra Costa Water District diverts water through Contra Costa Canal which connects to Old River north of Clifton Court, in the Central Delta. The quality of the water diverted is significantly influenced by salinity intrusion. Also, the water diverted by the district is influenced by local surface drainage into Rock Slough and Contra Costa Canal from adjoining lands.

Hydrologic Conditions

During wet years when fresh water outflows are high, Delta waters have low concentrations of minerals, as salts throughout the watersheds are diluted, and as ocean salinity is thoroughly repelled from the Delta. In dry years, the mineral quality of Delta waters is worse due to less effective salinity repulsion and reduced dilution volumes.

Mineralization and Eutrophication

As water passes over and through soils, it picks up soluble minerals (salts) present in the soils because of natural processes, such as geologic weathering. As the water passes through a watershed and is used for various purposes, concentrations of dissolved minerals and salts in the water increase, a process called mineralization. As Sierra Nevada streams flow into the valleys, they typically pick up 20 to 50 milligrams per liter (parts per million) of dissolved minerals, which is equivalent to about 50 to 140 pounds of salts per acre-foot.

The increased concentration of minerals also results from municipal uses of water. Water passing through a typical municipal water supply system, including sewage treatment before discharge, typically increases in salt load by about 150 to 200 milligrams per liter. Industrial usage usually contributes to mineralization, which can be less than or far greater than that resulting from municipal use, depending on the industry.

Sea water intrusion is a major source of mineralization of Delta waters. Eutrophication results from addition of nutrients (nitrogen, phosphorus, and many necessary micronutrients) to water exposed to sunlight. In the presence of sunlight, algae and other microscopic organisms are able to use the available nutrients to increase their populations.

Slightly or moderately eutrophic water, such as is found in Delta channels, can be healthy, and can support a complex web of plant and animal life. However, water containing large populations of microorganisms can be undesirable for other purposes such as drinking water. Some types of microorganisms can produce compounds which, though not directly injurious to human health, may cause the water to smell and taste bad, and which can be costly and extremely difficult to remove in treatment plants.

Levee Failure

When a Delta levee fails, water from the surrounding channels rushes in, thus causing Delta water to flow toward the island which is flooding. During low flow conditions, the result can be serious salinity intrusion into the Delta. In June 1972, a levee failure on Andrus Island caused it to flood, with the result that large quantities of salt water intruded into the Delta. Not all of the salt-laden water could be repulsed and, ultimately, had to be exported and delivered to consumers. In the State Water Project, the increased salinity was measurable for many months.

In the event of significant levee failure from any cause, the Delta could be rendered unusable by massive salinity intrusion. In such an event, as was the case in 1972, the saline water could probably not be pushed out without physical modification of the Delta, and might have to somehow be exported and used or disposed of. Such an event would seriously disrupt water service to Contra Costa County, the South Bay, San Joaquin Valley, and Southern California. Over 20 million Californians in these areas are supplied water from the Delta.

Expert opinion is divided on the likelihood of extensive Delta levee failure resulting from large seismic events. Those who believe the probability of such failures is significant point out that the consequences of massive levee failure due to this cause would be very serious. Other specialists who have studied seismic activity in the Delta area believe the probability of catastrophic seismic events in the Delta is relatively low.

Delta Operations

Operation of the Delta can have important effects on the quality of the water. For instance, the Delta cross-channel is a major conduit for passage of higher quality Sacramento River water into the Delta. Concerns over loss of endangered species are likely to affect operation of the Delta cross channel which is, in turn, likely to affect flow patterns and water quality.

Phytoplankton Growth

During the warm months, it is not uncommon for algae blooms to occur in the Delta. Algae are microscopic organisms which, like terrestrial plants, have the capacity to photosynthesize. When light, nutrient, and temperature conditions are right, algal populations may surge to reach very large numbers. This is termed a "bloom". In the Delta, diatom blooms are the most common. Microscopic diatoms are encased in shells or "frustules" composed mostly of silicon, which cause treatment plant filters to become clogged. Also, diatom blooms in the Delta have caused significant taste and odor problems for municipalities in the South Bay who take Delta water.

Agricultural Cycles

Agricultural cycles produce seasonal effects on the Delta. The summer irrigation period and the winter soil leaching period result in seasonal variation in certain water quality constituents such as organic carbon, salt, and selenium.

Tides

The Delta is a tidal estuary, which means it is influenced by tidal action. Tidal action causes the current in many places within the Delta to reverse its direction four times daily. Therefore, when one speaks of Delta flow, it is generally understood that one is referring to net, as opposed to instantaneous flow. Even during "low flow" conditions, massive amounts of water move back and forth across the Delta through tidal action, though the net flow may be small. The relationship of tidal stage to fresh water outflow determines how effectively salinity is repulsed from the Delta. When the tide is high, salt water tries to rush into the Delta, and must be repelled by fresh water flowing outward from the Delta. During low tides, the flow is toward Suisun Bay and out to sea.

Pollutants

A number of specific pollutants have the capacity to affect the quality of Delta drinking water, and are discussed below.

Arsenic

Arsenic is a toxic element which is also classified as carcinogenic. The current drinking water MCL is 0.05 milligrams per liter. However, the U.S. EPA is expected to propose a revised standard in late 1993 or in 1994.

In California, arsenic occurs naturally in many places. Ground water in the state is frequently found to contain elevated levels, though it is not very concentrated in Delta surface waters, or most other surface water bodies in the state.

Health effects research has indicated the current MCL does not adequately protect the health of consumers. To protect at the "one in a million risk level" (see discussion on health effects of disinfection by-products), current data suggest the MCL would have to be very low. Expectations are, therefore, that the MCL will be lowered, perhaps to as little as 0.002 or 0.005 milligrams per liter. For purposes of comparison, typical arsenic concentrations in the lower Sacramento River, lower San Joaquin River and southern Delta are 0.002, 0.003, and 0.003 milligrams per liter, respectively.

Arsenic presents some special problems. One is that it is difficult to remove by treatment. Another is that analytical problems make it difficult to analyze arsenic at low levels. Both problems are likely to affect the technical feasibility of setting a new MCL for arsenic at the "one in a million" risk level. As it is not yet clear what the new MCL will be, it is not now possible to assess the impact on municipalities using Delta water.

Asbestos

Asbestos occurs naturally in many places throughout California and in the watersheds of the Delta. In some places, asbestos deposits have been disturbed by mining or other activities, and contribute significantly to the concentrations found in the water. The accepted analytical method for asbestos involves counting fibers magnified by means of an electron microscope. The analysis is error prone, and concentrations of asbestos in water supplies can be highly variable. For these reasons, existing data are inadequate to enable firm estimates of the concentrations of asbestos in Delta waters.

The MCL for asbestos in treated drinking water is 7 million fibers per liter, of a length greater than 10 micrometers in length. Because it is effectively removed through treatment plant filtration and related processes, asbestos concentrations in treated drinking water from the Delta routinely meet the standard.

Bromides

Aside from the question of source water protection as it concerns treatment reliability, the Delta has some special water quality problems. Fresh water flowing from the Delta toward San Francisco Bay meets saline water from the Bay and Pacific Ocean. When fresh water flows are high, the salt water is effectively repelled from the Delta; however, during low flow periods, saline water pushes farther inland, and can commingle with the fresh water in the Delta. This is a natural phenomenon, but is influenced by the configuration of Delta facilities, and operation of those facilities.

Bromide is a salt ion which is present in sea water. When exported with Delta water, they cause problems with water treatment, discussed previously in this paper. Bromide concentrations are higher in the Delta than in most of its tributary streams. For instance, bromide concentrations in the Sacramento River (at Greene's Landing below Sacramento) average about 0.03 milligrams per liter; by comparison, bromide concentrations in water exported from the southern Delta into the State Water Project averages about 0.35 milligrams per liter, roughly a twelve-fold increase.

The San Joaquin River can be considered a source of bromides to the Delta. Near Vernalis on the lower San Joaquin River, bromide concentrations average about 0.42 milligrams per liter, a concentration which is similar to that observed in the southern Delta.

It is quite possible that a source of bromides exists in the Coast Range, west of the San Joaquin Valley, where ancient marine sediments are to be found. However, the presence of bromides in San Joaquin River water also reflects the irrigation cycle, whereby water is drawn from the Delta through the federal Central Valley Project, is transported and used on Valley agricultural lands, and is ultimately returned to the San Joaquin River as agricultural drainage. Through this mechanism, bromides are circulated from the Delta to the Valley and back to the Delta. Of the two sources of bromides in San Joaquin River water, the more important probably is recirculation of bromides from the Delta.

Organic Carbon

The natural process of plant decay causes naturally occurring carbon-containing compounds to be dissolved into water coming into contact with soils. During rainy periods, water flowing from land surfaces throughout the watershed carries organic compounds into Delta drinking water supplies. Within the Delta, the soils of the channels can contribute dissolved organic carbon containing compounds; such compounds can be produced by algae growing in Delta waters; and, organic compounds may enter the Delta through the Bay estuary as a result of salinity intrusion.

A number of Delta islands contain peat soils which are very rich in organic carbon. Data collected by the Department of Water Resources indicate that, during the recent drought, Delta island drainage contributed about half the organic carbon present at the export pumps.

Discharges of island drainage are most significant during the winter and summer months as a result of the agricultural production cycle of summer irrigation followed by winter salt leaching. While the effects of Delta island drainage are pronounced during low flow conditions, their contribution of organic carbon is expected to diminish during high flow conditions when tributary streams bring it into the Delta and higher flows dilute the island discharges.

In addition to island drainage, organic carbon in the Delta can come from the soils of the Delta channels, from growths of algae and other aquatic plant life, from tributary streams, and from the other parts of the estuary. As a result of these influences, concentrations of dissolved organic carbon compounds in Delta waters are considerably higher than in most of the Delta tributaries. The Sacramento River (at Greene's Landing below Sacramento) typically contains about 2 milligrams per liter dissolved organic carbon, and the lower San Joaquin (near Vernalis) contains averages about 4 milligrams per liter.

By comparison, water from the southern Delta which is drawn into the State Water Project averages about 4 milligrams per liter, about twice the concentration found in the Sacramento River, and about the same as is found in the San Joaquin River. (Please refer to the "Disinfection By-products" section of this paper which indicates the likelihood of a 2 milligram per liter objective being placed on organic carbon in drinking water.)

When water containing dissolved organic compounds is disinfected during the water treatment process, the chemical used for disinfection can react to form compounds which are of health concern in drinking water. This problem is discussed in more detail under "Disinfection By-products".

Upstream mine drainage

In a number of locations in the watersheds tributary to the Delta, abandoned mines discharge acid drainage which is high in concentrations of potentially toxic metals such as copper and cadmium. Collectively, these comprise the largest source of toxic metals to the Delta. Still, levels present in Delta waters are well below MCLs and, therefore, do not present a significant threat to municipal users of Delta waters.

Pathogens

Pathogenic microorganisms found in water supplies fit the broad categories of viruses, bacteria, and protozoa. The Surface Water Treatment Rule, which is mentioned in this document, was promulgated primarily to address the problem of protozoan and viral resistance to destruction. Bacteria such as Legionella and heterotrophic plate count (HPC) bacteria are more susceptible to normal disinfection, and should be very effectively destroyed by implementation of the rigorous requirements of the Surface Water Treatment Rule.

Giardia lamblia and Cryptosporidium sp. (which is not currently regulated) are particular protozoa found in drinking water supplies which can be pathogenic to humans. These organisms are capable of encapsulating themselves in protective cysts which are quite resistant to destruction by disinfection. Fortunately, pathogenic protozoa, due to their relatively large sizes, can be effectively eliminated by adequate filtration. And although viruses are much smaller, they can be effectively neutralized with a combination of filtration and disinfection processes.

Other pathogens such as E. coli and fecal coliform are addressed in the federal Total Coliform Rule which established microbiological standards and monitoring requirements applying to all public water systems. The State of California has analogous total coliform regulations which can be found in Title 22, Chapter 15 of the California Code of Regulations.

Selenium

The federal drinking water MCL for selenium is 0.05 milligrams per liter and, although the present State MCL is 0.01 milligrams per liter, the Department of Health Services is in the process of adopting the federal MCL. Concentrations of selenium in the Delta are typically at or below 0.001 milligrams per liter, with the exception of the San Joaquin River as it enters the Delta. In the San Joaquin River watershed, natural selenium deposits exist which contribute selenium to agricultural drainage water from the Valley.

As the San Joaquin River is the recipient of significant quantities of valley agricultural drainage, selenium concentrations in the river are frequently higher than in other Delta tributaries. Selenium levels in the lower San Joaquin River are typically about 0.002 to 0.003 milligrams per liter, but concentrations as high as about 0.005 milligrams per liter are not uncommon during winter months when agricultural drainage is prevalent.

All reliable evidence indicates selenium concentrations in Delta waters are at all times well below the established federal and state MCLs for drinking water.

Urban Pollutants

In urban areas, water quality is influenced by several nonpoint sources of pollution, such as recreational activities, drainage from industrial sites, runoff from streets and highways, discharges from other land surfaces, and aerial deposition. (Nonpoint sources of pollution are those which do not originate in any one place and are, therefore, not easily controlled.) In California, storm water runoff, a major source of non-point pollution, is regulated by the State Water Resources Control Board on behalf of the U.S. Environmental Protection Agency.

Industrial production and municipal activities produce a number of substances that end up in municipal and industrial wastewater discharges. In California, discharge of untreated sewage into the environment is not permitted. The National Pollution Discharge Elimination System regulates "point" discharges of waste water into the nation's waterways. Under this system, California uses facilities to treat waste water to render it free of certain disease carrying organisms, and to reduce its environmental impact.

Most of the industries in California discharge to a publicly owned waste water treatment plant and only indirectly to the environment. These industries are required to provide pre-treatment of their industrial waste prior to its discharge to the municipal waste water treatment plant. Like municipal discharges, industrial discharges are subject to regulation through the NPDES. When industries discharge directly into the environment, they are required to have an NPDES permit.

Synthetic chemicals (chemicals manufactured by humans) are very widespread. Unfortunately, normal waste water treatment plant processes may not completely remove all synthetic chemicals which may be present in the water. As a result, some synthetic organic chemicals, especially from agricultural and industrial waste water, are discharged into the state's waterways.

SACRAMENTO-SAN JOAQUIN DELTA EXPORT LOCATIONS