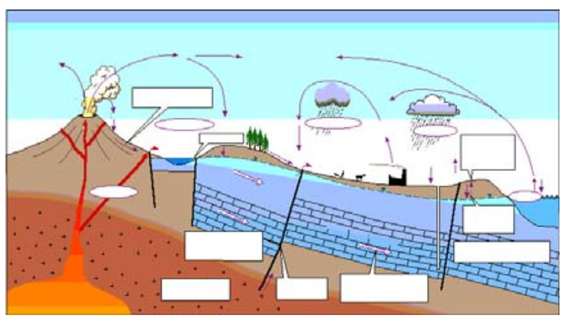
Comisión Nacional del Agua (CNA)
Secretaría de Salud de México

FINAL REPORT
"TASK-FORCE MEETING"
DEFLUORIDATION SYSTEMS FOR LATIN AMERICA AND THE CARIBBEAN

Washington, DC 18-22 October 2004



Pan American Health Organization

Regional Office of the World Health Organization

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Pan American Health Organization
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DEFLUORIDATION SYSTEMS FOR LATIN AMERICA AND THE CARIBBEAN

I. BACKGROUND SECTION

Approximately 10 million people in Mexico live in regions with high naturally occurring fluoride. Reports and scientific publications on fluoride occurrence in Mexico indicates that fluoride levels as high as 5 milligrams per liter (mg/l) have been measured consistently in some drinking waters, and up to 95 percent of the residents around Durango may be consuming water in excess of 2 mg/l. Although fluoride is an important nutrient which has been shown to be effective in reducing dental caries, moderately high levels above 2.0 mg/l can result in moderate dental fluorosis, a cosmetic staining of the teeth. Consumption of water with excessively high levels above 6 to 10 mg/l for some populations may result in health impacts including severe dental fluorosis and in extreme cases, skeletal fluorosis.

In October 2004, an expert panel composed of scientists, health policy makers, and water and sanitation experts from Mexico, PAHO and CDC (Appendix 1), met in Washington, D.C. to evaluate the current status of fluorosis in Mexico and provide recommendations to Mexico regarding fluorosis.

The objectives of this meeting were three fold:

- To review the most current data on fluoride use and fluorosis in Mexico.
- To review current technical approaches to defluoridation systems.
- To present a preliminary proposal on management of fluoride exposure for Mexico and other parts in the Americas, where fluorosis is a problem.

Using the existing scientific evidences and public health reports as reference, the expert panel formulated recommendations and a preliminary proposal to address the fluorosis problems in Mexico.

The following report is a working document and it is put forward by the expert panel to PAHO and Mexico, for consideration and appropriate actions.

I.1 PAHO's Multi-Year Plan for Fluoridation Programs in the Region and Surveillance Approaches to Fluoride

In 1994 the Pan American Health Organization, Regional Office of the World Health Organization (WHO) drafted an initial strategy to implement caries prevention programs in the Region of the Americas, utilizing both water and salt fluoridation. The strategy emphasizes caries prevention by ensuring that any fluoride deficiency in the population of the Region is satisfied by the ingestion of fluoride either through the traditional means of water or salt. It was PAHO's intention along with more than 38 member governments to pursue national programs of salt and water fluoridation for the majority of the 37 member countries in the Region.[1] The Regional Strategy called for feasibility assessments, measurement of oral health status, development of fluoride surveillance system, assessment of the salt industry's capacity to fluoridate salt, cost-benefit studies and follow up evaluations.

[1] Pan American Health Organization, Directing Council: Provisional Agenda. "Oral Health." Washington, D.C. PAHO, 16 July 1997. 15 p. (Annexes).

The importance of disease prevention was the cornerstone of PAHO's oral health policy for the Region of the Americas. The policy, as outlined in PAHO´s Regional Oral Health Plan, emphasizes oral diseases prevention by ensuring comprehensive oral health programs and pursuing sustainable oral health interventions for the majority of the 38 Member States. The most recent data on oral health indicates a wide range of oral health conditions. For example, dental caries affect 90% of school-age children and is the most prevalent disease in the Americas. DMFT (this means the number of decayed/missing/filled teeth) at age 12 range from 0.63 to 6.0.

The fluoridation plan launched by PAHO called for the measurement of the baseline oral health status. Over the interval of the last 12 years PAHO has assisted most countries to carry out DMFT surveys. Table I.1 presents the most recent data on DMFT[2] for the various countries of the Region.

[2] Health in the Americas. *Pan American Health Organization.* Scientific Publication: 587. Vol I, 2002: 191-199.

Table I.1 Oral Health data in the Region of the Americas

Country	DMFT-12
Anguilla	2.5 (91)
Argentina	3.44 (87)
Aruba	2.9 (90)
Bahamas	1.3 (00)
Barbados	0.84 (01)
Belize	0.63 (99)
Bermuda	0.2 (89)
Bolivia	4.67 (95)
Brazil	2.78 (03)
Brazil, Sao Paulo	1.75 (03)
Canada	2.1 (97)
Chile	3.42 (99)
Colombia	2.30 (98)
Costa Rica	2.46 (99)
Cuba	1.62 (98)
Curacao	0.80 (01)
Cayman Islands	0.9 (99)
Dominica	2.0 (95)
Dominican Republic	4.31 (98)
Ecuador	2.95 (96)
El Salvador	1.36 (00)
Grenada	2.70 (00)
Guatemala	5.18 (02)
Guyana	1.33 (95)
Haiti	1.00 (00)
Honduras	4.00 (98)
Jamaica	1.1 (95)
Mexico	2.00 (01)
Nicaragua	2.8 (97)
Panama	3.61 (97)
Paraguay	3.83 (99)
Perú	2.9 (96)
St. Lucia	6.0 (04)
Suriname	1.9 (02)
Trinidad and Tobago	0.6 (04)
Turk and Caicos	0.92 (02)
Uruguay	2.50 (99)
USA	1.7 (00)
Venezuela	2.12 (97)

Source: PAHO Regional Oral Health Program 6/04

Fluoridation programs using salt as a vehicle are already implemented in Bolivia, Colombia, Cuba, Dominican Republic, Ecuador, El Salvador, Honduras, Nicaragua, Venezuela, Costa Rica, Jamaica, Mexico, Peru, and Uruguay. Projected programs are for Bahamas, Haiti, Guyana and Suriname. Water fluoridation systems continue to expand in Argentina, Chile and Puerto Rico. Already established water fluoridation programs are reaching more than 65% of the population in the United States, 40% in Canada and more than 80% in San Paulo, Brazil.

Altogether, over 350 million individuals have access to fluoridation programs in the Americas. It is projected that more than 430 million individuals will have access to fluoridation programs by the year 2010.

For the overall fluoridation plan, comprehensive oral health programs were developed and implemented throughout the Region. Although tailored to the specifics of each country adopting such plans, the major components include the following steps:

- Country baseline studies to assess oral diseases, DMFT and exposure to fluoride
- Cost-benefit analysis of various interventions
- Epidemiological surveillance systems for fluoridation, including biological and chemical monitoring of all fluorides, and quality control of fluoride supplementation
- Salt Industry assessments, where appropriate
- Evaluation and tracking systems to determine effectiveness of national fluoridation programs
- Country legislation and legal enforcement of fluoridation programs

PAHO´s technical cooperation is centered on providing technical expertise to countries to guide and carry out these program components. Taking a team approach, PAHO assembled various consultants who specialized in a particular component of the program. Local expertise in each country was identified and developed such that each country or sub-region would become self-sufficient.

Concrete results of the fluoridation plan included: 37 national oral health surveys, assessments and visits to 30 countries, and over 130 producers/processors of salt, and development and adoption of legislation and regulation on the use of fluorides in various countries.

The experience with salt fluoridation shows that it is effective in preventing caries. Data collected from the various national programs are showing high rates of prevention of caries. Despite potential methodological differences in the implementation of salt fluoridation programs as well as in the assessment of effectiveness outcomes, it is clear that salt fluoridation has achieved dramatic preventive results. Selected data collected in the Americas corroborate those findings. Table I.2 summarizes data related to the effectiveness of salt fluoridation. Effectiveness, in this context, is assessed by the reduction in caries between baseline and follow-up observations.

Table I. 2
DENTAL CARIES IN COUNTRIES WITH CONSOLIDATED NATIONAL SALT FLUORIDATION PROGRAMS

COUNTRY	BASELINE STUDIES		FOLLOW-UP ESTUDIES		CARIES
	YEAR	DMFT-12	YEAR	DMFT-12	REDUCTION (%)
COLOMBIA	1980	4.8	1998	2.3	52.1
COSTA RICA	1988	8.4	1999	2.5	70.6
JAMAICA	1984	6.7	1995	1.1	83.9
MEXICO	1987	4.6	1996	2.5	45.7
URUGUAY	1982	4.1	1999	2.4	41.5

Source: PAHO, 2004

For Example, in Jamaica, caries were reduced by 83% after eight years of program implementation. In 1987, a comprehensive salt fluoridation program was initiated. In 1995, a survey of Jamaican children was conducted to assess the effectiveness and risk of salt fluoridation. Dental examinations of 1,200 children ages 6 to 8, 12, and 15 showed a mean DMFT prevalence for 12-year-olds of 1.08, compared with the corresponding score of 6.7 DMFT for children of the same age at the baseline examinations in 1984. The percentage of sound permanent teeth in all age groups was 95%.[(3).]

Cost-Effectiveness of Salt Fluoridation [4]

The economics of salt fluoridation in the Americas is beginning to be understood. As more experience with the programs is accrued across countries, more information on this matter will become available. In any case, it is possible to indicate here that production costs of fluoridated salt are generally modest. In Switzerland, for example, production costs are between $ 0.02-$.04 per kilogram of salt to serve approximately 6 million people. In the Americas, most completed studies address the economic feasibility of programs using estimated costs.

Cost-benefit analyses conducted by PAHO in various countries use conservative assumptions: dental service coverage to approximately 50% of the population at an average of $10 per dental visit. A summary of result of these studies is shown in Table I.3.

[3] Estupiñán-Day, S., Baez, R., Horowitz, H., Warpeha, R., Sutherland, B., Thamer, M. Salt Fluoridation and Dental Caries in Jamaica. Community Dentistry and Oral Epidemiology, 2001; 29:247-252.

[4] Estupiñán-Day, D., "Overview of Salt Fluoridation in the Region of the Americas, Part I: Strategies, Cost-Benefit Analysis, and Legal Mechanisms utilized in the National Programs of Salt Fluoridation", Salt 2000, 8th World Salt Symposium, Volume 2, pg 983-988, 2000.

Table I. 3
Cost-Benefit Calculations for Selected Countries

Country	Program Cost U$ (000)	Caries Prevented (000)	Cost-Benefit Ratio
Belize	187	115	1:126
Bolivia	785	10,650	1:136
Dom. Rep.	520	12,500	1:203
Honduras	527	8,340	1:122
Panama	424	4,133	1:146
Paraguay	360	5,303	1:123
Total	2,803	41,041	

Estimates reveal that the cost-benefit ratio ranges from 1:122 to 1:203. This means that in the case of Bolivia at a cost-benefit ratio of 1: 136, for every dollar invested in salt fluoridation programs, the country will save $136 dollars in curative dental care that is avoided. Salt fluoridation is proving to be one of the most effective interventions in modern public health.

ORAL HEALTH STATUS DEVELOPMENT CONTINUUM

When the fluoridation plan was developed, a regional framework was proposed that will allow for recognition of individual country problems and develop targeted strategies. The first step adopted on the plan was a country classification. A first approximation, based on available data and a framework, indicated that DMFT-12 was the most important factor in grouping counties along an oral health development continuum. The DMFT-12 index was used extensively in the Region and three stages of oral health development were defined: first, emerging, defined as DMFT12- greater than 5; second, growth, defined by a DMFT-12 of 3 to 5; and third, consolidation, defined by a DMFT-12 lower than 3. Based on this criterion, the following tables I. 4, I. 5 and I. 6 group countries along an oral health status development continuum.

The overall oral health intervention strategy drafted in 1994 facilitated the progression along the development continuum, from the emerging category to the consolidation category. In other words, PAHO's strategy developed a series of activities and provided technical cooperation to the countries aimed at moving from high levels of disease and lacking appropriate preventive policies towards achieving improved status indicators and policies.

Table I. 4

TYPOLOGY TABLE (BEFORE 1990)	Emergent DMFT > 5 14 countries	Growth DMFT 3-5 10 countries	Consolidation DMFT < 5 6 countries
	Belize	Argentina	Bahamas
	Bolivia	Canada	Bermuda
	Brazil	Colombia	Cuba
	Chile	Ecuador	Guyana
	Costa Rica	Cayman/	Dominica
	Dominican/	Islands	USA
	Republic	Mexico	
	El Salvador	Panama	
	Guatemala	Peru	
	Haiti	Trinidad/	
	Honduras	Tobago	
	Jamaica	Venezuela	
	Nicaragua		
	Paraguay		
	Uruguay		

Table I. 5

TYPOLOGY TABLE (CIRCA 1996)	Emergent DMFT > 5 9 countries	Growth DMFT 3-5 15 countries	Consolidation DMFT < 3 8 countries
	Belize	Argentina	Bahamas
	Dominican/	Brazil	Bermuda
	Republic	Bolivia	Canada
	El Salvador	Chile	Cuba
	Guatemala	Colombia	Guyana
	Haiti	Costa Rica	Jamaica
	Honduras	Ecuador	Dominica
	Nicaragua	Mexico	USA
	Paraguay	Panama	
	Peru	Puerto Rico	
		Peru	
		Suriname	
		Trinidad/	
		Tobago	
		Uruguay	
		Venezuela	

Table I. 6

Typology Table (Circa 2004)	Emergin DMFT > 5 2 countries	Growth DMFT 3-5 7 countries	Consolidation DMFT < 3 29 countries
	Guatemala St. Lucia	Argentina Bolivia Chile Dominican/Republic Honduras Panama Paraguay	Anguila Aruba Bahamas Barbados Belize Bermuda Brazil Canada Cayman/ Islands Colombia Costa Rica Cuba Curacao Dominica Ecuador El Salvador Grenada Guyana Haiti Jamaica Mexico Nicaragua Peru Suriname Trinidad/ Tobago Turk and Caicos Uruguay USA Venezuela

Source: PAHO, 2004

II. PREVENTION OF DENTAL FLUOROSIS IN MEXICO

II.1. What is the Problem in Mexico?

In 1984, the National Health Program established the goal of reducing caries by 40%, and in 1985 the Department of Health Services [*Subsecretaría de Servicios de Salud*] gave priority to the launching of a nationwide salt fluoridation program as a preventive measure.

In 1985 the State of Mexico received authorization from the Ministry of Health, through the Department of Health Regulation, to offer fluoridated salt for consumption within that state, and at the end of 1986 it received assistance from the W.K. Kellogg Foundation to implement the program.

In 1991, Mexico became the seventh country in the world to use salt as a caries prevention vehicle. Fluoride was added to salt in a proportion of 250 ± 50 ppm per kg of salt. In 1993, the supply of fluoridated salt in the country was regularized.

On 13 March 1995, Mexican Official Standard NOM-040SSA1-1993, on goods and services, iodized salt, and fluoridated iodized salt, was published. This Standard contains the official regulations governing the salt industry with respect to the manufacture of salt for human consumption, giving the pertinent authority control over the end product, as provided by law. Moreover in 1996, a list was published detailing the states in which fluoridated iodized salt should not be marketed, since water for human consumption in those states has natural concentrations of fluorine equal to 0.7 mg per liter or more. These are:

- Aguascalientes
- Baja California
- Durango
- San Luis Potosí
- Sonora
- Zacatecas

Mexico's first National Survey of Caries and Dental Fluorosis was conducted in 1996.

Mexico's population in 1996 was over 92 million. Consequently, considering the geographical complexities involved, the size of the population in the different states, and the limited human resources available at that time, the survey was very difficult to carry out. In fact, to date only the preliminary data from the survey is available. The results and comparative analysis of three Mexican states were published in an article in the *Pan Health American Journal of Public Health*, entitled "Changes in the Prevalence of Dental Caries in Schoolchildren in Three Regions of Mexico: Surveys from 1987-1988 and 1997-1998." The results showed a reduction in the prevalence and severity of caries in the age groups ($P < 0.05$) examined. In the period 1997-1998, the States of Tabasco and Nuevo León both met the World Health Organization's goal of no more than three decayed, missing, and filled teeth [DMFT] among 12-year-olds, with DMFT indices of 2.67 and 1.72, respectively. However, the Federal District [*Distrito Federal*] exceeded this limit, with a DMFT index of 3.11. Conclusions drawn from this research show that several factors could have caused the reduction observed in the DMFT indices, such as the consumption of fluoridated salt, the use of fluoridated toothpastes and rinses, and greater access to dental services.

Preliminary data from the epidemiological survey showed indications of dental fluorosis in some of the 5 levels established by the Dean Index, which makes it possible to observe some differences since the start of the salt fluoridation program, given that, at the time, only six states limited distribution of fluoridated iodized salt due to the presence of endemic fluorosis.

Based on the states where dental fluorosis was found, the preliminary findings of the 1996-2001 survey, and the fact that studies of fluorine concentrations in water for human consumption reveal a high fluorine content in some areas, Mexico's states were divided into three regions: Region 1 (distribution and marketing of fluoridated salt prohibited); Region 2 (distribution and marketing of fluoridated salt partially permitted); and Region 3 (distribution, marketing, and consumption of fluoridated salt permitted).

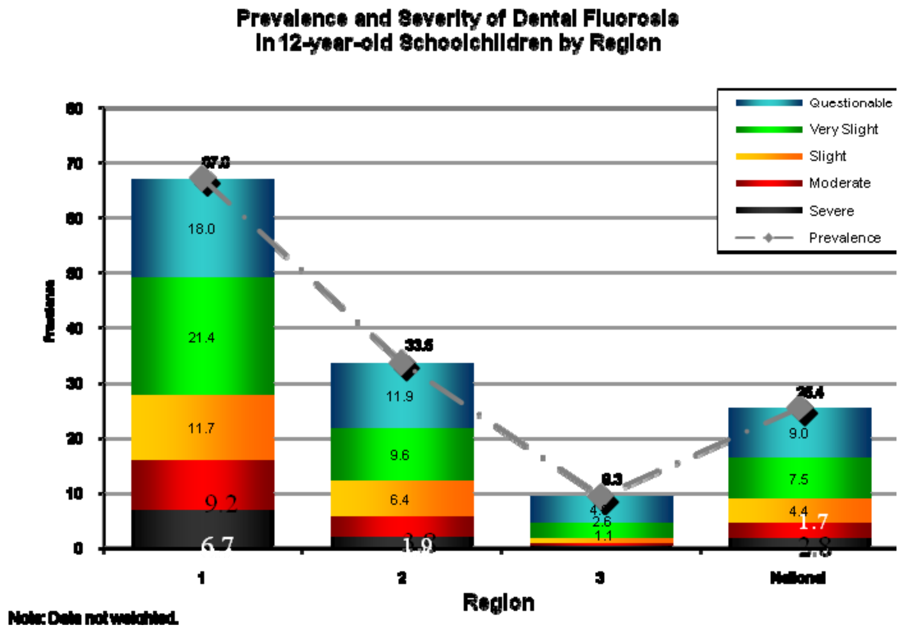
DISTRIBUTION OF FLUORIDATED IODIZED SALT BY STATE		
Distribution Prohibited	**Distribution Partially Permitted**	**Distribution Permitted**
AGUASCALIENTES BAJA CALIDORNIA DURANGO GUANAJUATO ZACATECAS	COAHUILA CHIHUAHUA HIDALGO JALISCO MEXICO MICHOACÁN NUEVO LEÓN PUEBLA QUERETARO SAN LUIS POTOSÍ SINALOA SONORA	BAJA CALIFORNIA SUR CAMPECHE COLIMA CHIAPAS DISTRITO FEDERAL GUERRERO MORELOS NAYARIT OAXACA QUINTANA ROO TABASCO TAMAULIPAS TLAXCALA VERACRUZ YUCATÁN

Source: Norma Oficial Mexicana. NOM-040-SSA1-1993 Productos y servicios. Sal yodada y sal yodada fluorurada Especificaciones sanitarias.
(Modificación Sept. 2003)

In Region 1 (yellow), where the distribution and marketing of fluoridated salt is prohibited, an area that includes the States of Aguascalientes, Baja California Norte, Durango, Guanajuato, and Zacatecas, preliminary data from the survey indicate that these five states represent 67% of the prevalence of the country's dental fluorosis. As seen in Figure 1, according to the Dean Index, 6.7 of the population fall into the severe category and 9.2 into the moderate category. Consequently, dental fluorosis constitutes a public health problem in the five states mentioned.

Overall dental fluorosis was 24.6%. In the State of Durango it was detected in 86.8% of the population studied, including 108 children with the severe type.

Figure 1
Prevalence and Severity of Dental Fluorosis in 12-year-old Schoolchildren by Region



Source: Encuesta Nacional de Caries y Fluorosis Dental, México 96/01.
Encuesta Nacional de Caries y Fluorosis. SSA. México 96-01

II. 2 Regulatory Criteria for Water and Salt Fluoridation

<u>Water</u>

The Amendment of Mexican Official Standard NOM-127-SSA1-1994, “Environmental Health, Water for Human Use and Consumption, Allowable Quality Limits and Treatments to Make Water Potable,” establishes the content of organisms from examining a simple water sample, which should be adjusted to the values in Table 1.

TABLE 1

CHARACTERISTIC	PERMISSIBLE LIMIT
Total hardness (as CaCO3)	500.00
Phenols or phenolic compounds	0.3
Iron	0.30
Fluorides (as F-)	1.50

Source: Norma Oficial Mexicana NOM–127–SSA1-1994, Salud ambiental. Agua para uso y consumo humano.

Water Treatments

To ensure effectiveness, the treatment of water from a given source should be justified by studies on quality and laboratory treatability tests to guarantee its effectiveness.

The following specific treatments, or those indicated by treatability tests, should be conducted out when the microbiological contaminants, physical characteristics, and chemical constituents, as listed in the preceding table, exceed permissible limits.

Microbiological Contamination

Bacteria, helminths, protozoa, and viruses should be treated with chlorine, chlorine compounds, iodine 1, ozone, ultraviolet light; ionic or colloidal silver; coagulation-sedimentation-filtration; or multiple-stage filtration.

Chemical Constituents

Elevated content of:
Chlorides: Ionic exchange, inverse osmosis, or evaporation
Fluorides: Activated aluminum, bone coal, or inverse osmosis

<u>Salt</u>

In 2003, Mexican Official Standard 040 on the production and marketing of salt in Mexico was amended. The fluoride concentration in salt was reduced from 250 ± 50 to 200 ppm minimum and 250 maximum—a 50 ppm reduction of the maximum limit.

Likewise, an annex was included with this Standard, showing a new list of the municipalities by state where fluoridated iodized salt should not be distributed because community fluorosis indices were greater than 6 for the population, with a level greater than or equal to 0.7 ppm of fluoride in water for human consumption. This list is not included here as it is too extensive.

To ensure compliance with these provisions, an agreement was signed with the Mexican salt industry, with a view to informing its distribution chains about areas where only iodized salt should be sold, and where fluoridated iodized salt should be sold.

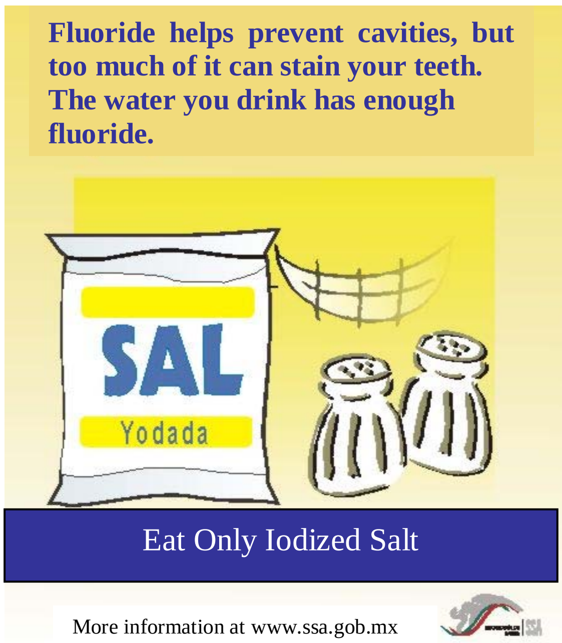
A new labeling system was developed to clearly distinguish between the two types:

a) Iodized salt: Includes two 1-cm wide yellow bands, located near the top and bottom of the label or container;

b) Fluoridated iodized salt: Includes two 1-cm wide red bands, located near the top and bottom of the label or container. The packaging and each individual unit of iodized fluoridated salt should display the following legend:

"THIS PRODUCT IS NOT TO BE SOLD IN MARKETS WHERE THE FLUORIDE CONTENT OF WATER FOR HUMAN CONSUMPTION IS GREATER THAN 0.7 MILLIGRAMS PER LITER."

This new identification system became mandatory in January 2005.



Posters have been created to help state health services inform small-scale vendors in areas at risk about the type of salt to sell. More detailed information is included in a brochure.

II. 3 Where is Fluorosis Occuring?

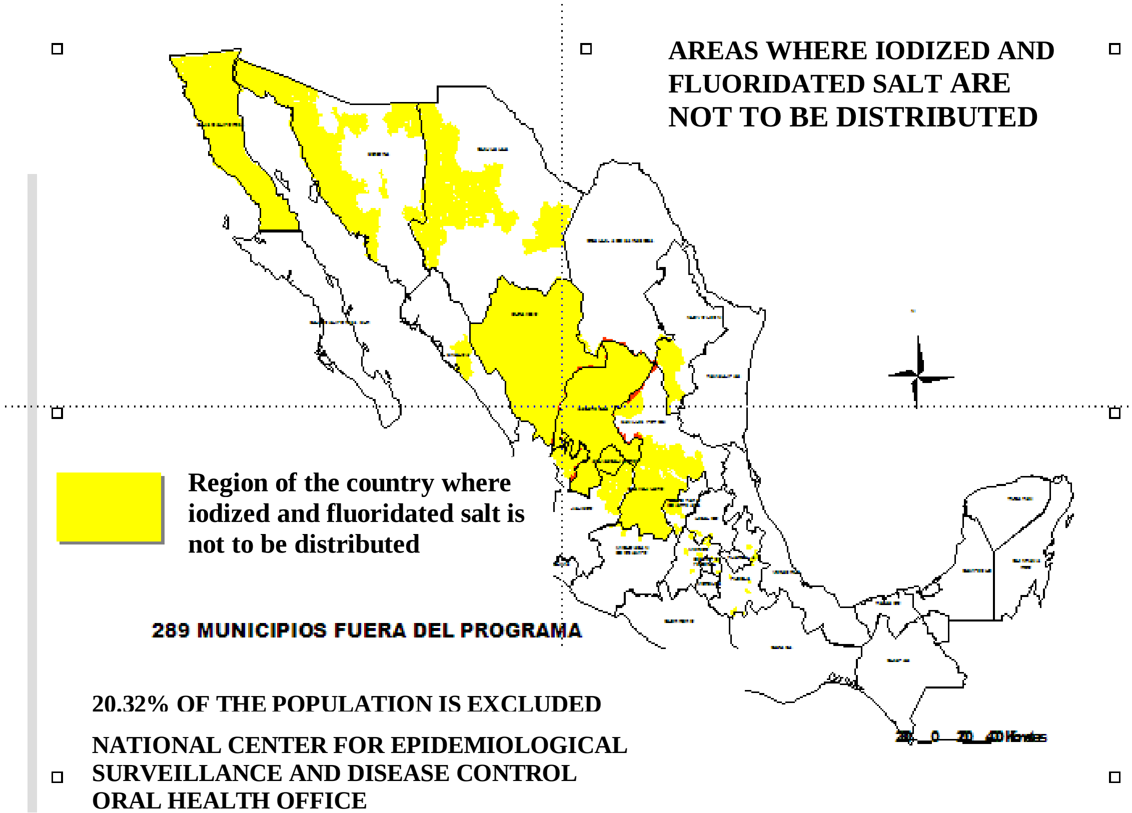
The states listed below reported ranges above maximum fluoride levels in the aquifers that supply water for various uses. Thus, water for human consumption in these areas should be monitored more closely than in other regions with lower ranges of fluorine concentrations. Consequently, these are considered areas at risk for dental fluorosis.

STATE	AQUIFER NAME	FLUORIDE CONCENTRATION RANGE (mg/l)	YEAR
AGUASCALIENTES			
	VALLE DE AGUASCALIENTES	0.73 - 9.26	1993
BAJA CALIFORNIA			
	SAN FELIPE - PUNTA ESTRELLA	1.31 - 7.48	1986
BAJA CALIFORNIA SUR			
	SANTO DOMINGO	0.05 - 1.00	1996
	SAN JOSÉ DEL CABO	0.34 - 2.42	2001
	LA PAZ	0.14 - 0.45	2001
	SAN JUÁN B. LONDÓ	0.41 - 1.12	2001
COAHUILA			
	MONCLOVA	0.22 - 1.35	1980
	PRINCIPAL - REGIÓN LAGUNERA	0.90 - 6.76	1990
CHIAPAS			
	ACAPETAHUA	0.05 - 0.94	1973
CHIHUAHUA			
	EL SAÚZ - ENCINILLAS	0.10 - 5.40	1996
	FLORES MAGÓN - VILLA AHUMADA	1.13 - 8.77	1998
	CONEJOS - MÉDANOS	1.77 - 5.50	1998
	CHIHUAHUA - SACRAMENTO	0.46 - 2.70	1972
	MEOQUI - DELICIAS	0.70 - 21.6	1996
	JIMÉNEZ - CAMARGO	0.45 - 4.30	1996
	VALLE DE JUÁREZ	0.47 - 3.40	1998
	PARRAL - VALLE DEL VERANO	0.6 - 2.20	1996
	TABALAOPA - ALDAMA	0.46 - 4.09	1972
	ALDAMA - SAN DIEGO	0.15 - 10.60	1972
DURANGO			
	VALLE DEL GUADIANA	0.42 - 21.77	1983
	VICENTE GUERRERO - POANAS	1.00 - 8.00	1993

Source: NATIONAL WATER COMMISSION GROUNDWATER DIVISION

As seen in Figure 1, the prevalence of dental fluorosis is found in the states that make up Region 1 (includes five states).

An annex to Official Mexican Standard 040, “Iodized Salt and Fluoridated Iodized Salt,” provides a map by region, as well as a list by municipality for their regulation. It shows that 20% of the population lives in areas at risk for fluorosis, mainly children under age 6, meaning that action is needed to prevent it.



[Map is a picture and cannot be edited. Text in upper right of map:]
AREAS WHERE IODIZED AND FLUORIDATED SALT ARE NOT TO BE DISTRIBUTED

[Text in lower left of map:]
Region of the country where iodized and fluoridated salt is not to be distributed

20.32% OF THE POPULATION IS EXCLUDED

NATIONAL CENTER FOR EPIDEMIOLOGICAL SURVEILLANCE AND DISEASE CONTROL
ORAL HEALTH OFFICE

Testing for the fluoride ion should be conducted using the ion-selective electrode method.

II. 4 Activities in Epidemiological Surveillance of Fluorosis

An epidemiological surveillance system for oral health will be established. One of its purposes is to record cases of dental fluorosis. For this purpose, sentinel units are used to record cases. When any such unit observes that more than 25% of the individuals seen present some degree of dental fluorosis, it shall inform the authorities to conduct the necessary studies

The criterion to be followed is the Dean Index.

III. USE OF GROUNDWATER AND OCCURRENCE OF FLUORIDE IN MEXICO

III.1 Introduction

The National Water Commission (Comisión Nacional del Agua or CNA), is a Mexican governmental agency in the Ministry of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales). Its missions are the management and the preservation of nation's water resources to achieve their sustainable use involving the participation of society and other governmental agencies *(e.g.:* state and municipal).

CNA has a technical branch (Subdirección General Técnica, SGT) focused on water resources by determination of the components of the hydrological cycle *(i.e.:* rain, runoff, evaporation, aquifer recharge rates. etc.) and water quality monitoring and protection in order to establish water availability as a principal basis for administration of water resources. The Groundwater Division and the Water Quality and Sanitation Division of SGT are responsible for aquifer management and water quality affairs, respectively.

Mexico's basins and watersheds have been grouped into 37 hydrological regions for water management purposes (Figure III.1 and Table III.1). By contrast, water is managed by CNA on the basis of 13 administrative regions (Gerencias Regionales, Figure III.2). In general terms, their administrative boundaries correspond to those of the main hydrological regions. Although there are 19 CNA Sate Representations, Mexican State boundaries do not necessarily correspond with those of the administrative regions.

III.2 Public water supply in Mexico

Public water supply includes urban and domestic usages, along with industrial activities utilizing municipal potable water. Groundwater represents 65% of total use, whereas surface water contributes the remaining 35%. Percentages may vary according to each CNA Administrative Region (Figure III.3 and Table III.2) and, in some cases, groundwater use could be as high as 100% *(i.e.:* Yucatan Peninsula). In some areas where groundwater fluoride levels have been detected in excess of the 1.5 mg/l standard, aquifers may represent the unique source for public water supply.

III.3.1 Aquifers and groundwater use in Mexico

The Groundwater Division of CNA (Gerencia de Aguas Subterráneas) has identified a total of 650 aquifers in all over the country and their limits have been established based on both technical and administrative criteria. Aquifers subject to an intensive water withdrawal represent around 20% of this number, but they contribute 80% of the total volume of pumped groundwater. The total volume of abstracted groundwater is approximately 28 x 10^9 m^3 per year, with agriculture the most demanding activity (71% of this volume), followed by public water supply (20%). The remaining 9% of the pumped groundwater is used for industrial purposes and livestock (6% and 3%, respectively).

Figure III.1. Hydrological Regions of Mexico. See Table III.1 for details (source: National Water Commission. 2004).

Hydrological Region	***Area (km ^{2})***	***Hydrological Region***	***Area (km ^{2})***
I NW Baja California	28 492	20 Costa Chica de Guerrero	39 936
2 Central-W Baja California	44 314	21 Coast of Oaxaca	10 514
3 SW Baja California	29 722	22 Tehuantepec	16 363
4 NE Baja California	14 418	23 Chiapas COSAT	12 293
5 Central-E Baja California	13 626	24 Bravo-Conchos	229 740
6 SE Baja California	11 558	25 San Fernando-Soto La Marina	54 961
7 Colorado River	6 911	26 Pánuco	96 989
8 Northern Sonora	61 429	27 Nothern Veracruz (Tuxpan-Nautla)	26 592
9 Southern Sonora	139 370	28 Papaloapan	57 355
10 Sinaloa	103 483	29 Coatzacoalcos	30 217
11 Presido-San Pedro	51 717	30 Grijalva-Usumacinta	102 465
12 Lerma-Santiago	132 916	31 Western Yucatán	25 443
13 Huicicila River	5 225	32 Northern Yucatán	58 135

Hydrological Region	***Area (km ^{2})***	***Hydrological Region***	***Area (km ^{2})***
14 Ameca River	12 255	33 East Yucatán	38 308
15 Jalisco Coast	12 967	34 Northern Closed Basins	90 829
16 Armería-Coahuayana	17 628	35 Mapimí	62 639
17 Michoacan COSAT	9 205	36 Nazas-Aguanaval	93 032
18 Balsas	118 268	37 El Salado	87 801
19 Costa Grande de Guerrero	12 132		

Table III. 1. Description of hydrological regions of Mexico showed in Figure III.1 (source: National Water Commission, 2004).

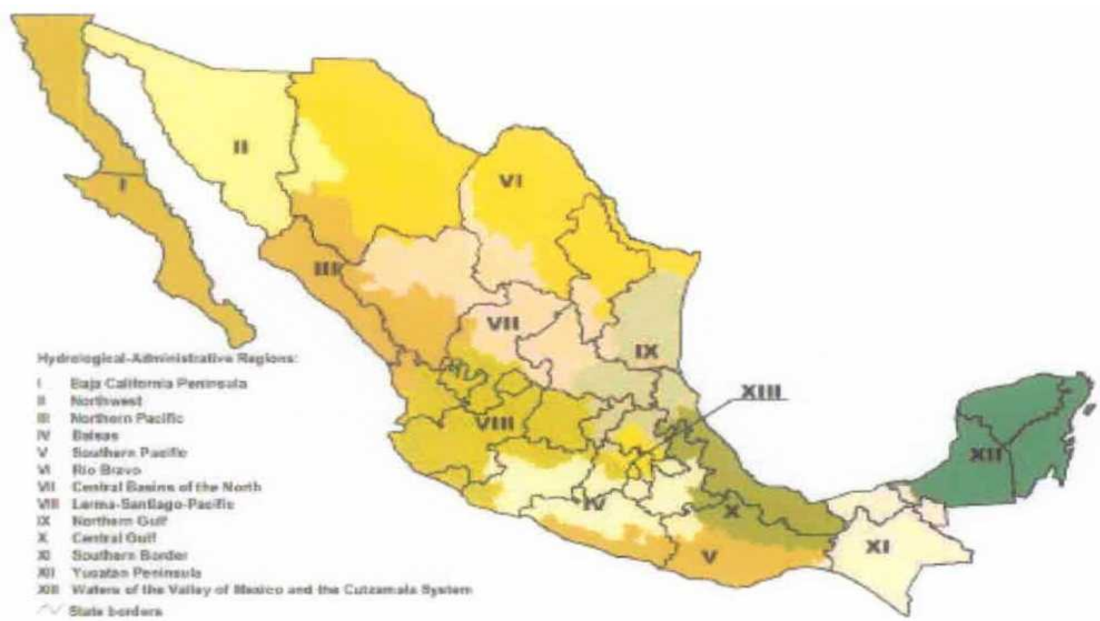


Figure III.2. Hydrological administrative regions of the National Water Commission. State limits are showed in black lines (source: National Water Commission, 2004).

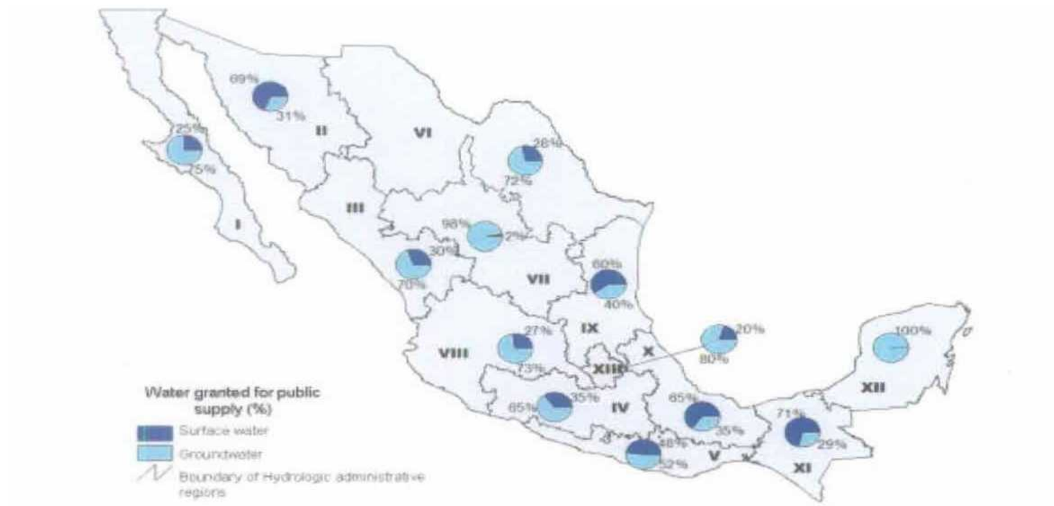


Figure III.3. Public water supply in Mexico: use of groundwater and surface water by administrative region (source: National Water Commission, 2004).

Administrative Region		*Surface water*	*Groundwater*	*Total*
I	Península de Baja California	103	313	416
II	Noroeste	607	267	874
III	Pacifico Norte	145	335	480
IV	Balsas	258	470	728
V	Pacifico Sur	125	137	262
VI	Río Bravo	185	486	671
VII	Cuencas Centrales del Norte	8	351	*359*
VIII	Lerma-Santiago-Pacifico	512	1383	1895
IX	Golfo Norte	238	158	396
X	Golfo Centro	472	258	730
XI	Frontera Sur	306	124	430
XII	Península de Yucatán	0	456	456
XIII	Aguas del Valle de México y Sistema Cutzamala	389	1547	1936
Total		3348	6285	9633

Table III.2. Volume of public water supply in Mexico: groundwater and surface water supplies by administrative region. Figures are in millions of cubic meters per year (source: National Water Commission, 2004).

III.3.2 Groundwater Salinity Map

The Groundwater Division of CNA has prepared several hydrogeological studies to characterize aquifers in Mexico. The preparation of a groundwater salinity map (scale 1:4'000,000) was prepared based on these studies presenting water quality variations among aquifers (Figure III. 4). Corresponding water salinity is expressed as total dissolved solids (TDS) in milligrams per liter (mg/l) and three groups were considered according to the potential of water to be used for potable purposes:

1) Fresh water (less than 1,000 mg/l as TDS)
2) Slightly brackish water (1,000 to 2,000 mg/l as TDS)
3) Brackish water, saline water and brines (above 2,000 mg/l as TDS)

The upper limit of the first group corresponds to the levels of TDS established by the Mexican Ministry of Health (Secretaría de Salud) for drinking water quality standards (Modificación a la Norma Oficial Mexicana NOM-127-SSA1).

Analysis of the salinity distribution identified that more than 80% of the aquifers displayed TDS concentrations below of 1,000 mg/l.

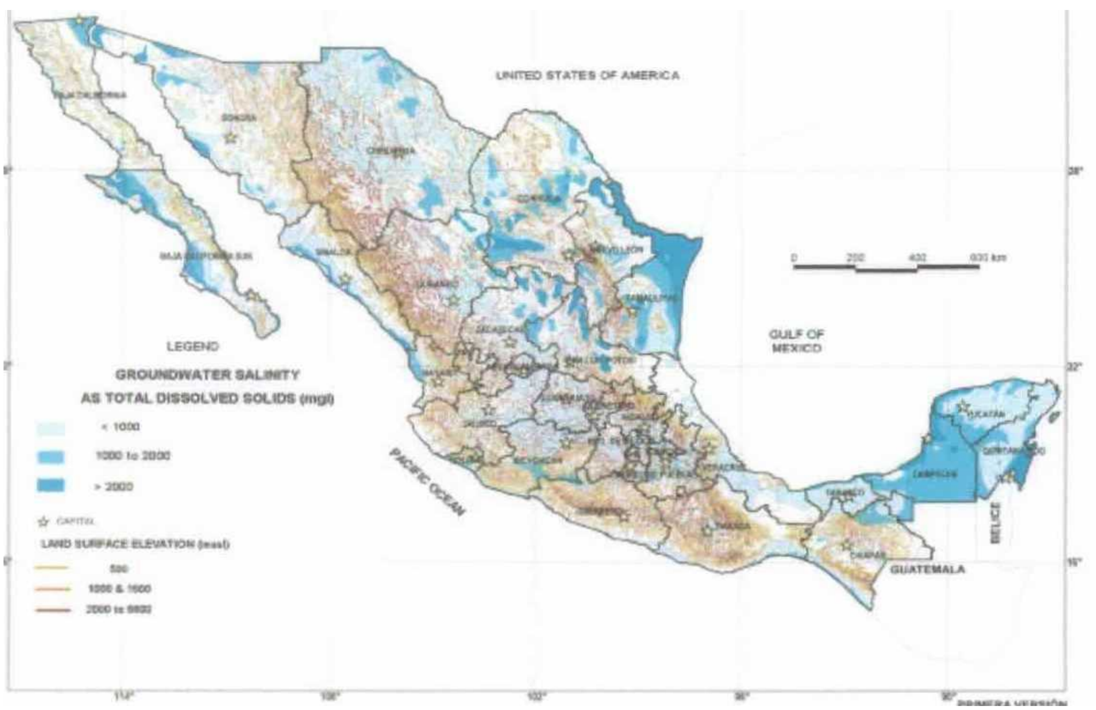


Figure III.4. Groundwater salinity map of Mexico (source: Comisión Nacional del Agua, Groundwater Division, 2002)

III.4 Fluorine Hydrogeochemical Cycle

Fluorine is the lightest member of the halogen group of elements and displays a different chemical behavior from other halogens. It is the most electronegative (relative tendency of an atom to acquire negative charge) of all the elements. Due to its highly reactive state, it is observed in nature in a reduced form as fluoride. Fluoride is fairly abundantly in the earth's crust, predominately in rock minerals, and only a small percentage of the total is contained in seawater. Its hydrogeochemical cycle is depicted in Figure III.5.

In intrusive rocks (granitic/plutonic rocks) and alkaline volcanic rocks, fluorine is concentrated in minerals such as amphiboles (hornblende) and micas (biotite), where it has replaced part of their hydroxides. Important fluoride concentrations have been observed in geothermal water and hot springs associated with this chemical type of volcanism. There are two common fluoride minerals that may be present in sedimentary, igneous and metamorphic rocks: ***fluorite,*** CaF_2, and ***apatite,*** $Ca_5(C1, F, OH)(PO_4)_3$. Fluorite mineralization commonly results from the incursion of hydrothermal solutions into calcium-enriched host rocks. Fluorite and apatite solubility may control the presence of fluoride in groundwater especially in carbonate rocks. The stoichiometry of fluorite dissolution shows that low calcium concentrations are related to high levels of fluoride in groundwater and vice-versa. In these cases, ion exchange along groundwater flow lines may play an important role, since the resulting increase of Na and decrease of Ca may contribute to the rise of fluoride levels in groundwater. In general terms, depth and age concentrate fluoride in groundwater, but also evaporative processes in alkaline lakes (associated with rift valleys) and arid regions may increase fluoride levels up to ten times.

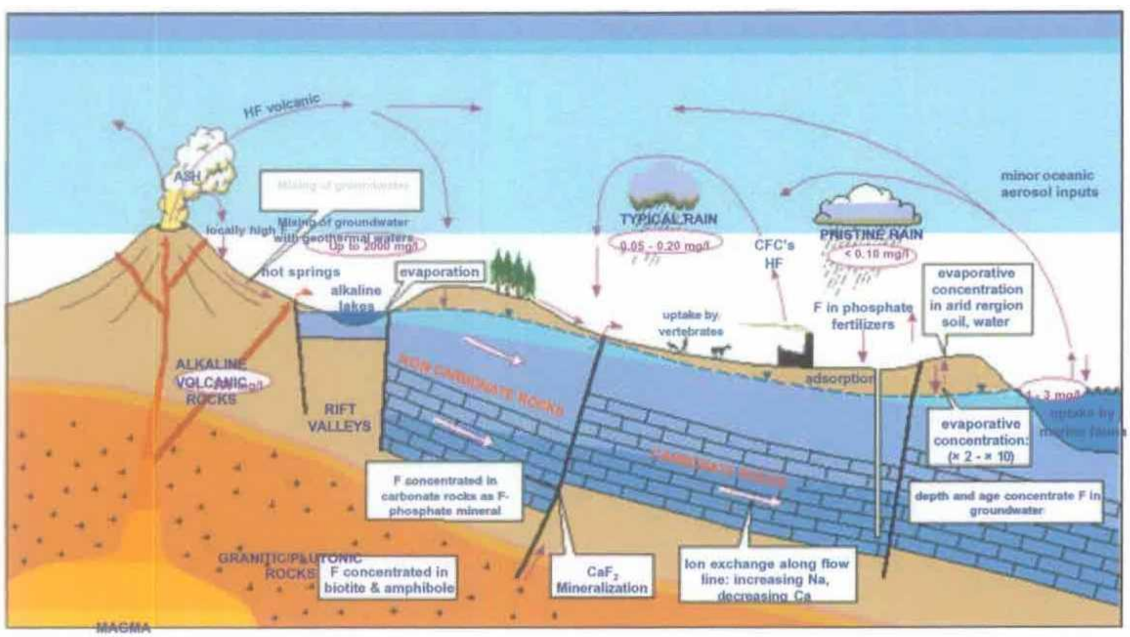


Figure III.5. The hydrogeochemical cycle of fluoride (source: The British Geological Survey, 2003).

Fluoride in seawater results from erosion, aquifer and river discharges into the ocean, rain, and submarine volcanic activity. Atmospheric fluoride results from volcanic emissions, minor oceanic aerosols inputs and anthropogenic activities. In urban areas HF and CFC's (chlorofluorocarbons) may incorporate fluoride in local rains in concentrations as high as 0.2 mg/l.

Other important anthropogenic release of fluoride results from the application of phosphate fertilizers during agricultural practices on which adsorption phenomena is critical for fluoride retention in soils.

Terrestrial vertebrates incorporate fluoride in their skeletons and teeth mainly through water consumption. Fluoride bio-accumulation by marina fauna is another important process integrating this chemical element into the life cycle ending by the deposition and consolidation of skeletons.

III.5 Fluoride Occurrence in Groundwater

Hydrogeological studies performed by CNA have showed the presence of fluoride levels in 80 aquifers comprising 20 Mexican States. A partial list is given in Table III.3 showing state, aquifer name and concentration range in mg/l. In some aquifers, fluoride levels exceed Mexican drinking-water quality standards (i.e. :> 1.5 mg/l) and their spatial distribution is presented in Figure III.6.

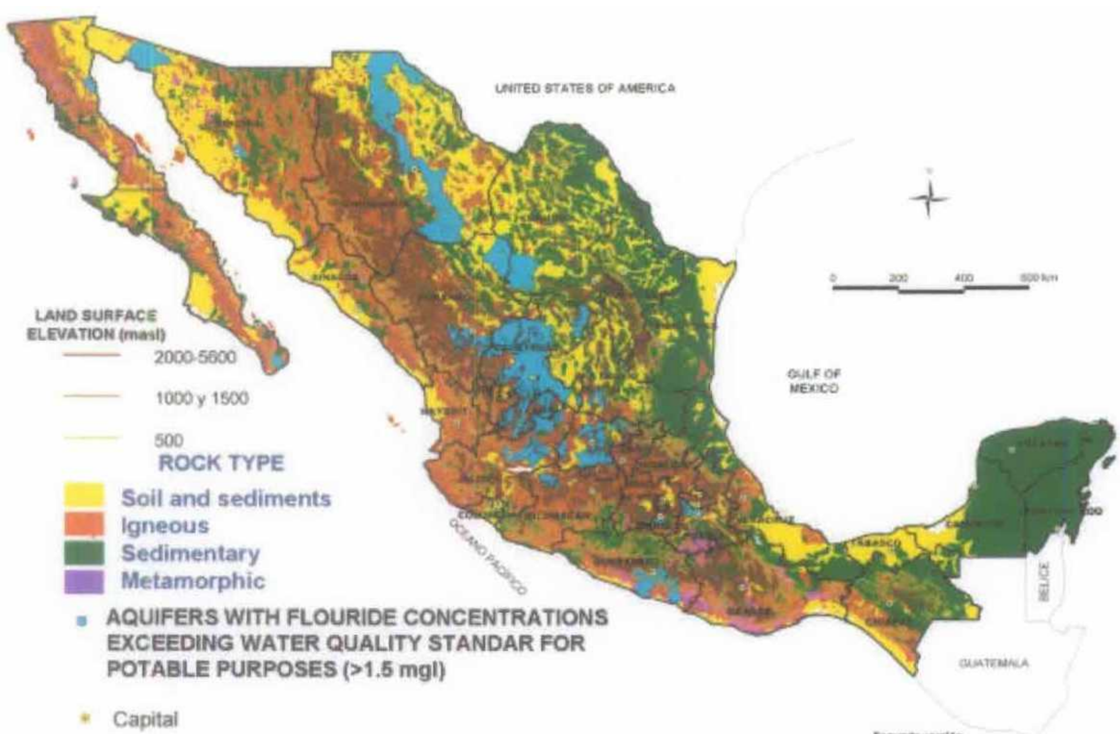


Figure III.6. Mexican aquifers in which the presence of fluoride has been detected in levels exceeding drinking-water quality standards. Note the complexity of the different hydrogeological environments. (Source: Comisión Nacional del Agua, Groundwater Division, 2003).

State	Aquifer name	Fluoride concentration range (mg/l)
Aguascalientes	Valle de Aguas Calientes	0.73-9.26
Baja California	San Felipe - Punta Estrella	1.31 – 7.48
Coahuila	Monclava	0.22 – 1.35
	Principal – Región Lagunera	0.9 – 6.76
Chiapas	Acapetahua	0.05 – 0.94
Durango	Valle de Guadiana	0.42 – 21.77
	Vicente Guerrero - Poanas	1.00 – 8.00

Table III.3. Hydrogeological studies performed by the National Water Commission have detected the presence of fluoride in groundwater. A partial list by Mexican states is given showing aquifer names and concentration ranges found in wells supplying water for different uses: agricultural, industrial, public and livestock. (Source: Comisión Nacional del Agua, Groundwater Division, 2003).

Concentration ranges are based on chemical analysis of groundwater samples taken from a wide variety of wells used for agriculture, public supply, industry, and livestock. Therefore they are not representative of the water being consumed by the population, so testing on public water supply samples withdrawn from faucets, storage tanks, etc. will need to be conducted to assess reliable health risk analysis.

Occurrence of fluoride in groundwater can not be generalized to a specific hydrogeological environment due to the complex geology and climate diversity in Mexico. Relatively high levels of fluoride in groundwater have been found in deep rhyolitic aquifers in central Mexico (*e.g.:* Aguascalientes State) and also in mine- influenced environments in both alkaline igneous rocks and carbonate rocks (*e.g.:* Durango and Zacatecas States and Hidalgo State, respectively). Flouride has been also concentrated due to evaporative processes in dry alkaline valleys in north central Mexico (*e.g.:* Coahuila and Chihuahua States). Influence of geothermal activity is also important in aquifers located in west-central Mexico (e.g.: Jalisco and Michoacan States).

III.6 Mitigation Options Currently Implemented in Mexico

Some mitigation options are currently practiced in places where excessive levels of fluoride have been detected in groundwater to supply safe public water. Some of them are briefly described below. It is important to note that there is no unique solution and that a combination of mitigation options is a common practice.

1) Field testing. Identification of wells where fluoride levels are suitable for potable purposes.

2) Groundwater mixing and dilution. An example is given below.

Well # 1	Well # 2
Yield = (10 1/s)	Yield = (15 l/s)
Fluoride concentration = 1.5 mg/l	Fluoride concentration 1.0 mg/l

If water from both wells is blended, the composite fluoride concentration is derived by a mass balance equation:

Final fluoride concentration $(Q_1C_1 + Q_2C_2)/ (Q_1+Q_2)$

Therefore the final fluoride concentration is 1.2 mg/l

3) Treated surface water

When available surface water with lower fluoride concentrations is available, it is possible to blend surface water to achieve acceptable fluoride levels.

4) Treatment of groundwater. The final option when aquifers are the only water source. Modern technologies include reverse osmosis and alumina treatment. This option can be combined with groundwater blending.

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III.7 Use of Reverse Osmosis in Mexico, 1980’s

Mexico has reported that approximately 14 reverse osmosis systems have been in production with varying success for several years. The engineering, operating, and maintenance history of those systems should be documented. A program should be implemented to visit each facility, collect historical information on design basis, membrane type, operating records, when/if the membranes have been replaced, interferences encountered in the operation of the facility, and in cases where the operations have been terminated, the reasons for that action. In addition to visiting the historical facilities in Mexico, it would important to assess if recent membrane technology can provide more reliable and sustainable treatment practices. This can be accomplished by contacting the manufacturers of membranes for recommended locations of modern facilities that could be visited by the evaluation team to observe differences in the facilities and ascertain if the current design approaches addresses the experienced historical problems with membrane systems in Mexico. Section V has a proposed work scope for further evaluation of membrane technology.

III.8 Criteria for Establishing Risk Factors of Fluoride Exposure Related with the Quality of Drinking Water in Mexico

In 1999, the Water Quality and Sanitation Division of CNA performed a study to define the extent of sanitary-environmental risk caused by the presence of fluoride in groundwater (CNA, 1999, 2002). According to this study, the presence of fluoride in drinking water has been mainly documented in the following Mexican states: Aguascalientes, Chihuahua, Coahuila, Baja California, Durango, Estado de Mexico, Guanajuato, Jalisco, San Luis Potosí, Sonora, and Zacatecas. Figure III.7 shows those states either in red or yellow color depending on fluoride levels and sampling frequency. There are three additional Mexican states, Michoacán, Puebla and Queretaro (not shown in Figure III.7), where fluoride have been detected in drinking water in some communities. Also, there is background information from governmental agencies and universities showing the presence of dental fluorosis in people from certain localities within those states.

Figure III.7. Mexican states where relatively high fluoride concentrations have been detected in wells supplying drinking water. States in red represent higher possible health risk compared to those in yellow.

III.8.1 Methodology to Identify Risk Zones Due to the Presence of Fluoride in Groundwater

Risk resulting from fluoride exposure through drinking water was defined gathering information on fluoride levels from: 1) regions where fluoride have been detected in groundwater (see 111.5), 2) water distributions systems (e.g.: faucets and water storage tanks), 3) wells supplying a particular water distribution system, and 4) individual wells as a single source of drinking water.

Information on fluoride concentrations in water distribution systems was not always sufficient and, because of water blending practices, the available information was from individual wells. Therefore, a clear correlation between fluoride levels in individual wells and water supply systems was not established for most localities. It was then decided to study the likely of exposure at a county level.

Ecological techniques applied in epidemiological studies were used to establish a relationship between an environmental causal exposure and a probable effect. In this case, groups rather than individuals are considered and field observations correspond to average exposures and effects. The exposure and the average risk for groups of inhabitants was then investigated. The total county population was considered as exposed if water quality data came from more than a half of the total amount of wells or potable water systems in that county, or if they corresponded to the wells supplying >50% of the county's communities, It is important to note that information on the prevalence of fluorosis in Mexico was not obtained during this study.

III. 8.1.1 Exposure Doses

The probable exposure dose for fluoride in drinking water was determined in each county for two age groups with no sex distinction: children and adolescents, and adults. A methodology to determine the reference dose to toxic substances for non-carcinogenic effects was used. The reference (RfD) considered was the dose above which adverse effects are observed, and it relates the exposure to the Lowest Observed Adverse Effects Limit (LOAEL), according to the Integrated Risk Information System, IRIS (1999) USEPA.

A LOAEL oral reference dose for fluoride of 0.11 mg/kg-day was used for a minimum concentration producing observable dental effects: 2 mg/l fluoride in water, according to the study conducted on 12 to 14 year-old children, weighing 20 kg in average, and drinking one liter of water daily (Hodge, 1950; Underwood, 1977). A fluoride diet ingestion of 0.01 mg F/kg body weight/day was assumed (50 FR 20164). Exposure doses for each population county were then determined substituting reference doses with corresponding maximum and minimum reported concentrations. Results were used to determine the hazard coefficient in order to compare exposure doses of studied populations with the reference dose. If the exposure dosage divided by the RfD is greater than one, then the exposed population is at risk.

III.8.2 Results

III.8.2.1 Exposed Population

The total population living in Mexican States having systematic information on the presence of fluoride in drinking water is around 9 million people, distributed in 51 counties. Population can be classified into four main groups of ages: 0-19 year-old children and teenagers (45.6%), 20-39 year-old young adults (33%), 4 1-59 year-old mature adults (14.4%), and >60 year-old elderly people (7%). According to the criteria specified in III.7.2, only 26 counties showed to have enough fluoride information and they represent 2,073,752 inhabitants likely exposed. Most people live in small towns having less than 2,500 inhabitants, considered in Mexico as rural communities. Rural population in four Mexican States having the most representative fluoride information is distributed as follows: Aguascalientes 22%, Chihuahua 20%, Durango 59%, and Jalisco 17%.

Important information is presented in a pair of tables for each of these Mexican States. The first table shows for each county, its population, the number of communities, and the number of drinking- water wells and/or other types of potable water sources monitored at least once a year, mean volume of pumped water and percentage of homes receiving water through pipes.

III.8.2.2 Aguascalientes

Data on population and drinking water supply data for specific Aguascalientes State counties are shown in Table III.4. Total state population is 862,720, from which 759,363 inhabitants could be at risk for a chronic oral exposure due to ingestion of fluoride- bearing water.

Table III.4 Data on population and drinking water supply for Aguascalientes State counties where presence of fluoride have been detected.

county	***Inhabitants***	***communities***	***Drinking*** *Water* ***Wells***	***Extraction Volume*** ***x 1O ^{3} m ^{3} /day***	*Other* ***sources of Drinking*** *Water*	***Houses with Piped water*** *(%)*
Aguascalientes	582,827	71	185	247.02		98
Calvillo	51,658	40	38	***19.35***	2	91
Jesús Maria	54,476	38	33	14.95		92
Pabellón de Arteaga	31,650	13	17	12.22		94
Rincón de Romos	38,752	20	20	12.87		87

For the same Aguascalientes State counties, Table III.5 shows values of average fluoride concentration in drinking water, the range of exposure dose in mg/kg/day, and the hazard coefficient ratio (HCR). Average fluoride concentrations correspond to annual mean fluoride levels from wells and/or drinking water distribution systems being monitored during a minimum period of three years. The range of exposure shows the minimum and maximum possible dosage for the population group of children and teenagers. The HCR relates the exposure with the reference dose, representing how many times exposure is greater than reference doses. It indirectly indicates the likely of the presence of adverse effects in the studied population.

Table III.5 Average fluoride concentration in drinking well water, exposure dose range, and hazard coefficient ratio for Aguascalientes State counties where presence of fluoride have been detected.

County	***Inhabitants***	***Average Fluoride concentration (mg/i)***	***Exposure Dose Range** mg/kg/day **Minimum-Maximum***	***Hazard Coefficient** Ratio **HCR***
Aguascalientes	582,827	2.12	0.32—0.34	2.9—3.09
Calvillo	51,658	1.95	0.095 —0.16	0.86— 1.45
Jesús Maria	54,476	2.80	0.20—0.37	1.8— 3.36
Pabellón de Arteaga	31,650	1.95	0.12—0.18	1.09— 1.6
Rincón de Romos	38,752	2.20	0.18—0.29	1.6—2.68

III.8.2.3 Chihuahua

Data on population and drinking water supply data for specific Chihuahua State counties are shown in Table III.6. Total state population is 2,793,537, from which 282,137 inhabitants could be at risk for a chronic oral exposure due to ingestion of fluoride- bearing water. Corresponding values of average fluoride concentration in drinking water, the range of exposure dose in mg/kg/day, and the HCR are shown in Table III.7.

Table III.6 Data on population and drinking water supply for Chihuahua State counties where presence of fluoride have been detected.

County	***Inhabitants***	***Communities***	***Drinking Water Wells***	***Extraction Volume x*** 10^3 m^3 ***/day***	***Other sources of Drinking** Water*	***Houses with piped water*** (%)
Camargo	46,386	20	1	19.537	3	95
Jiménez	39,746	21	10	24.883		96
San Francisco de Conchos	2.991	10	1	0.138		93
Aldarna	19,998	21	3	6.190		94
Delicias	110,876	15	21	56.915		97
Julimes La Cruz	5,335 3,844	10 7	1 1	0.563 0.567		95 94
Meoqui	38,152	18	4	11.820		93
Rosales	14,809	12	3	5.069		91

Table III.7 Average fluoride concentration in drinking well water, exposure dose range, and hazard coefficient ratio for Chihuahua State counties where presence of fluoride have been detected.

County	***Inhabitants***	***Average Fluoride*** *concentration Mg/l*	***Exposure Dose Range*** *mg/kg/day* ***Minimum-Maximum***	***Hazard Coefficient*** *Ratio* ***11CR***
Camargo	46,386	1.50	0.10—036	0.95—3.2
Jiménez	39,746	1.70	0.07— 0.49	0.6—4.45
San Francisco de Conchos	2,991	3.72	0.32—0.44	2.9—4.4
Aldama	19,998	2.40	0.16— 0.35	1.45 - 3.18
Delicias	110,876	1.70	0.012—0.31	0.1 —2.8
Julimes	5,335	5.90	0.33—0.92	3—8.36
La Cruz	3,844	2.70	0.10—0.90	0.9—8.18
Meoqui	38,152	5.30	0.012— 1.34	0.109—12.2
Rosales	14,809 2.50		0.07—0.80	0.6—7.3

III.8.2.4 Durango

Data on population and drinking water supply data for specific Durango State counties are shown in Table III.8. Total state population is 1,431,748, from which 497,206 inhabitants could be at risk for a chronic oral exposure due to ingestion of fluoride- bearing water. Corresponding values of average fluoride concentration in drinking water, the range of exposure dose in mg/kg/day, and the HCR are shown in Table III.9.

Table III. 8 Data on population and drinking water supply for Durango State counties where presence of fluoride have been detected.

County	***Inhabitants***	***Communities***	***Drinking*** *Water* ***Wells***	***Extraction Volume*** *$x10^3$ m^3 /day*	***Other sources of Drinking*** *Water*	***Houses with piped water (%)***
Valle del Guadiana	74,954	……….	23			97
Ciudad de Durango	389,612	………..	123	148.97	34	97
Guadalupe Victoria	32,640	18	14	9.03	29	97

Table III.9 Average fluoride concentration in drinking well water, exposure dose range, and hazard coefficient ratio for Durango State counties where presence of fluoride have been detected.

County	*Inhabitants*	*Average Fluoride concentration mg/l*	*Exposure Dose Range mg/kg/day Minimum – Maximum*	*Hazard Coefficient Ratio HCR*
Valle del Guadiana	74,954	3.23	0.013—1.3	0.12- 11.8
Ciudad. de Durango	389,612	5.37	0.55	*5*
Guadalupe Victoria	32,640	1.86	0.20	1.8

III.8.2.5 Jalisco

Data on population and drinking water supply data for specific Jalisco State counties are shown in Table III.10. Total state population is 3,99.l,176, from which 215,502 inhabitants could be at risk for a chronic oral exposure due to ingestion of fluoride- bearing water. Corresponding values of average fluoride concentration in drinking water, the range of exposure dose in mg/kg/day, and the HCR are shown in Table III.11.

Table III.10 Data on population and drinking water supply for Jalisco State counties where presence of fluoride have been detected.

County	*Inhabitants*	*Communities*	*Drinking Water Wells*	*Extraction Volume X10^3 m^3/day*	*Other sources of Drinking Water*	*Houses with piped water (%)*
Lagos de Moreno	124,972		16	447.0	2	81.5
San Juan de los Lagos	53.366		12	181.8	1	82
Teocaltiche	37,164		6	57.0	3	78

Table III.11 Average fluoride concentration in drinking well water, exposure dose range, and hazard coefficient ratio for Jalisco State counties where presence of fluoride have been detected.

County	*Inhabitants*	*Average Fluoride concentration mg/l*	*Exposure Dose Range mg/kg/day Minimum – Maximum*	*Hazard Coefficient Ratio HCR*
Lagos de Moreno	124,972	2.40	0.08—0.38	0.7 —3.45
San Juan de los Lagos	53,366	1.89	0.11—0.29	1 —2.6
Teocaltiche	37,164	4.40	0.13— *1.5*	1.18—13.6

III.8.3 Conclusions

Results from this study show that population groups are exposed to unacceptably high levels of fluoride, representing a potential health problem. The number of people being (or that they have been) at risk of developing dental fluorosis with high HCR, considering the group of children and teenagers, totalizes 1,754,208 inhabitants from counties of Aguascalientes, Chihuahua, Durango, and Jalisco States.

Information analysis from ecological data should be carefully interpreted due to the uncertainty of the exposure evaluation method. The lack of precise individual exposure data may increase the amount of erroneous measures affecting data interpretation.

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IV. STRATEGIES FOR ANALYSIS OF FLUORIDE EXPOSURE

IV. 1 PAHO's Current Recommendations for Surveillance of Fluoridation Programs

The experiences of the countries that have implemented national salt and water fluoridation programs allow us to identify three phases of development that these programs comprise to reach their objective: Phase I, feasibility or initiation; Phase II, first evaluation; and Phase III, consolidation and maintenance. Sound execution of an effective salt fluoridation program requires that the surveillance of fluoride is a critical component of the programs.

Epidemiological surveillance is the central axis of a natural fluoridation program. It provides information with regard to the prevalence of caries and its trends, the potential problems, and the operation and effectiveness of salt and water fluoridation. Baseline studies and, subsequently, biological and chemical monitoring will make it possible for us to monitor each one of the actions required to determine the proper dosage of fluoride concentration in salt required to achieve the greatest protection against caries with the least risk of producing dental fluorosis.

Additional baseline studies or monitoring activities should be considered, taking into account the needs or special features of each country and the results of evaluations that are being carried out.

The sustainability and long term survival of a program relies on the local authorities and country salt industry. The PAHO Regional Oral Health Program recommends that for each country program, an individual country technical officer (CTO) be designated to act as liaison and project coordinator, between health authorities and salt industry. In addition, this individual provides assistance on funds disbursements and coordinates consultant activities within the country on the various tasks or missions being developed for each of the project components.

The CTO would also assists on the periodic meeting of the Salt Fluoridation Commission in each country and expedites development of legal documentation to enforce salt fluoridation. The CTO can also coordinate and assist the program to identify funding sources to aid program development that might not be directly funded by external or internal donors.

At the International level, the Regional Oral Health Program through the PAHO Advisory Board on Oral Health Programs had made recommendations for project improvement and set protocol guidelines and specific requirements based on scientific evidence. Research experiences and specific country studies are discussed and a consensus presented to the in country project directors for implementation. In February 1998 a group of scientific experts was called together by the Regional Oral Health Program of PAHO in Washington, D.C., to evaluate the technical aspects of the salt fluoridation programs, using existing scientific evidence as reference. Those experts submitted recommendations to PAHO which were approved by the representatives of the fluoridation programs in 19 countries at the First Regional Workshop on Salt and water Fluoridation held in Quito in July of the same year.[1] The 10 recommendations included items related to the type of fluoridation programs to be maintained in each participating country, those that need to be faced out, and the instruments for data collection to monitor program implementation. The latter group was an extension of the monitoring sections included in the grand proposal and the country results has been presented and discussed before in this report. Two qualifiers were introduced in the recommendations. "Essential" items are those that need to be implemented because they are vital for the success of the program. "Non-essential" recommendations are important but not vital and also include alternative options for essential items; non-essential recommendations could be opted by countries if necessary. At the workshop held in Quito, Ecuador, a consensus was reach with all participants on the recommendations for countries engaged or considering development of salt fluoridation programs. These recommendations are current.

1. Only one systemic source of fluoride is recommended in each country. This should be either salt or water, but not both.

2. Dental caries should be monitored to evaluate the effectiveness of the preventive program. Both, baseline and follow-up studies were recommended; however, only the baseline study was within the scope of the Grant Proposal). The baseline survey of dental caries is essential and should target 6 to 8, 12 and 15-year-old children. The recommended survey uses a tooth-based index (DMFT) and the diagnostic criteria and coding recommended by WHO. A surface-based index (DMFS) is not essential but could be utilized by the countries.

3. Dental fluorosis monitors past exposure to fluoride and should be monitored to assess unacceptable cosmetic effects of systemic fluoride overuse during the permanent teeth formative years. Dental fluorosis was measured by a modified version of Dean's Index that included only the upper anterior teeth (cuspid to cuspid). Only the facial surfaces were evaluated using the six categories described by Dean. Other teeth could be included but their inclusion is non-essential.

4. Urinary fluoride excretion should be monitored to evaluate the current exposure to fluoride. Therefore, the target population for these studies included 3 to 5-year-old children. This study was highly recommended but considered non-essential. According to the WHO recommendations these studies should be implemented immediately before the introduction of the systemic fluoride and thereafter at 6-months and 12-months. PAHO recommendations were modified to include only one evaluation 24 months after the program was initiated, but indicated that a baseline study could be included if the country considers it necessary. A 14 to 18 hours collection period was considered an acceptable protocol for urine collection. In addition, this study should be conducted in clusters of 30-35 children in communities with sub-optimal, optimal and above optimal concentration of fluoride in the drinking water and, during follow-up studies, in communities were the salt is distributed.

5. The baseline study of fluoride concentration in the water supplies for human consumption is essential. In all participating countries fluoride occurs naturally and its concentration may experience variations by season of the year and other geological activities. As a consequence, all water sources with concentrations higher than 0.5 parts per million of F should be monitored on a permanent basis to avoid overexposure if the fluoride content of the water increases after the introduction of salt fluoridation.

6. A nutritional survey to determine the consumption and ingestion of salt is non-essential. Data from previous nutritional studies could be used and/or extrapolated.

7. Regarding other sources of fluoride:

    a. Systemic fluoride, i.e., dietary fluoride supplements (drops, tablets, and in multi-vitamin combinations) should be eliminated. Monitoring of this recommendation could be used through market presence of these products and surveys of health practitioners or parents.

b. In a country with a national systemic fluoride program, fluoride mouthrinse programs provide additional topical preventive effect and should not be used if the DMFT at age 12 falls below 3. In countries without national fluoridation program, these programs should be continued if the DMFT index is greater than 3. If the index is less than three, these programs could continue if shown to be cost-effective. When used, fluoride mouth rinses should only be provided to children older than 6 years when the swallowing reflex is developed enough to avoid accidental ingestion of the product. When used in older children and swallowed, the effect on dental fluorosis is negligible because most anterior teeth are completely formed at that age.

c. The use of fluoridated toothpaste is highly recommended. In younger children, less than 6 years, only a "pea" size of toothpaste should be delivered by the parent/guardian. In addition, tooth brushing with fluoride toothpaste among children less than 3 years of age should be supervised directly by the mother or guardian. It is recommended that children under 6 years should use toothpaste with a fluoride concentration between 400 and 550 ppm. Children over 6 years or age should use the standard formulated fluoride toothpaste (between 1000 and 1500 ppm). A baseline and periodic survey of toothpaste use is part of the ongoing monitoring recommendation. Periodic evaluations could be performed thorough sales and import data.

d. Oral health promotion and toothbrushing training should continue after the implementation of national programs using systemic fluoride.

8. The recommended range of fluoride concentration in the salt for human consumption is 200-250 mg per kilo (equivalent to 250 ppm F). The actual concentration should be adjusted based on the level of urinary fluoride excretion, the level of fluoride in the drinking water and the prevalence and severity of fluorosis, accounting for the time-lapse between the fluorosis observed and the time when exposure occurred.

9. Countries should assess the existing and regulatory framework that supports or hampers the introduction and sustainability of fluoridation programs. This requires the review of existing laws, regulations, and the promotion of new or supplementary ones. Also, a regulatory mechanism for quality control should be part of the regulations concerning dosage.

10. Continuing education to the public and to health professionals is essential.

IV. 2 International Standard Regulatory Criteria for Fluoride in Drinking Water

The World Health Organization (WHO) considers health effects resulting from the presence of contaminants in drinking water and establishes a guideline value for consideration by countries on setting a regulatory limit by that country. WHO established a guideline value for fluoride in drinking water of 1.5 mg/l in 1984, and reconsidered that value in 1996 concluding that there was no new information that would warrant a change in the guideline value. The Mexico Ministry of Health, Subministry of Health Prevention and Protection, is the regulatory agency for establishing drinking water quality and the Maximum Acceptable Level (MAL) for contaminants. The Ministry has set a fluoride MAL to be 1.5 mg/l consistent with the WHO guideline. The United States of America Environmental Protection Agency (EPA) has set a Maximum

Contaminant Level (MCL) for fluoride, comparable to the Mexico MAL, of 4 mg/l based on health effects. The EPA has further identified a Secondary Maximum Contaminant Level (SMCL) for cosmetic dental fluorosis of 2 mg/l. The EPA SMCL is not a regulatory limitation, but is established as an advisory concentration. When a community water supply has water that has naturally occuring fluoride that exceeds 2 mg/l, but does not exceed the MCL of 4 mg/l, then the water utility has the responsibility to inform its customers that the fluoride exceeds the SMCL and that the potential exists for increased succeptability to dental fluorosis, a cosmetic result.

The WHO recommendations for fluoride level in drinking water for achieving optimal fluoridation for oral health benefits would be approximately 0.5 to 0.7 mg/l in Mexico based on annual average temperatures. However, the optimal benefical concentration presumes that there are minimal other sources of fluoride for humans. Mexico has operated a salt fluoridation program since 1994, with a carefully managed program of providing fluoridated salt to states with low naturally occuring fluoride in the drinking water, and providing unfluoridated salt to states that have higher levels of naturally occuring fluoride in the water. Consequently, approximately 80 percent of the population consume fluoridated salt, and the remainder, living in areas identified as having high naturally occuring fluoride in drinking water, have access to unfluoridated salt.

The consensus of the participants of the Task-Force was that Mexico should reconsider contaminant limitations for water, and identify different water fluoride regulatory levels for different areas of the country for guidance in management of fluoride in drinking water. The consensus of the Task-Force was that cosmetic mild dental fluorosis was tolerable, but that severe dental fluorosis should be minimized, and the combined salt and water fluoride exposure should be evaluated with that objective. The basis for establishing the allowable concentrations should include cosmetic and appearance considerations, health effects concerns, and ecomonic hardship on communities that result when fluoride must be removed from the water. The various limitations that could be established could include the following conditions.

- Secondary MAL for areas identified as having low natural fluoride in the drinking water where salt fluoridation is practiced to identify the desirable water fluoride level to minimize the occurance of mild dental fluorosis when water consumption and salt consumption are considered jointly.
- MAL for areas identified as having low natural fluoride in drinking water where salt fluoridation is practiced to account for the combined environmental exposure to avoid undesireable health effects.
- Secondary MAL for areas identified as having high natural fluoride in drinking water where salt fluoridation is not practiced to identify the desirable fluoride level minimize the occurance of moderate dental fluorosis.
- MAL for areas indentified as having high natural fluoride in drinking water where salt fluoridation is not practiced to avoid undesireable health effects.

IV. 3 International Management Strategies for Achieving Acceptable Fluoride Exposure /CDC

As has been discussed elsewhere in this document, the sources of water with elevated fluoride content in excess of the MAL are predominately groundwater wells. The production yield of most wells is insufficient to satisfy the demand of an entire community. In order to provide satisfactory water supply for an entire community, the typical community water system will have multiple wells supplying water to the water distribution system in a distributed source feed at different locations within that community. As a result, the water that a community will consume may have inconsistent quality characteristics depending on which well is supplying water to each portion of the community water system. Having different qualities of water within a single community water system presents opportunities for management of overall water quality, but also poses technical challenges when water qualities must be manipulated by treatment.

Mexico has actively worked to address high naturally occuring fluoride levels in drinking water for many years, and has developed some strategies. The strategies typically take advantage of the opportunities presented by distributed sources from groundwater wells with different water quality. The major management strategies include the following practices.

- When a drinking water well is drilled, careful testing of the water quality at different datum are measured. This allows an assessment as to if certain datum contribute disportionate quantities of the fluoride. If certain datum can be identified as contributing disportionate quantities of fluoride, the well can be sealed at those datum to minimize the fluoride content of the finished well.
- If a drinking water well has a higher natural fluoride level than is desireable, then an investigation should be considered to identify a replacement well which may potentially have lower fluoride content.
- If a drinking water well has a higher natural fluoride level than is desireable but must continue to remain in service, then well-blending should be considered. Many communities have multiple wells and some of the wells may have lower fluoride content than other wells. The blended water may have a fluoride content that is below the proscribed MAL. However, the current practice is to connect wells to the nearest location in the water distribution system which may result in different water fluoride content at different locations within a community. Consequently, some households may be exposed to elevated fluoride levels while other households may have fluoride levels below the MAL. A better practice would be to have a dedicated pipe conveyance of the water with elevated fluoride content to another well location with lower fluoride content so that the blending can occur at the point of entry to a water system thereby minimizing the exposure to high fluoride content water.
- There may be a potential for using wells on a seasonal basis for managing fluoride levels. The water quality from individual wells may vary seasonally depending on surface influences and hydrogeological influences on water quality. Some wells may have higher fluoride content during the dry season and lower fluoride content in the wet season, or visa-vesa. It may be possible that one well would have elevated fluoride content when another well has lower fluoride content. If so, seasonally placing wells into production or withdrawing them from production might allow the community water system to achieve the desirable MAL by choosing which well to use according to the season.
- Another approach is to consider adding large storage tanks to maximize storage of lower fluoride content waters. Typically, groundwater wells supplying water to a community water system do not pump continuously, but rather will operate for only a portion of the day, with demand varying diurnally. It is not uncommon for wells to only produce one-third of the time. Since there is some unused delivery capacity, addition of storage tanks could provide a system to maximum the supply of the lower fluoride content water. The storage tanks could fill using the lower fluoride content water in low-use periods such as night periods, while at the same time terminating the use of the high fluoride content wells during those low use periods. Then when high-use periods such as peak-day events occur, the high fluoride content wells could be added back into production. The result is that instead of all the production wells being used equally, the lower fluoride content wells could provide a higher portion of the supply to the community, and the higher-fluoride content wells would provide a loer portion of the supply to the community. This would result in a net reduction of fluoride exposure to a community, and may allow a community to achieve the desired MAL.

- There may be limited communities where bottled water imported from communities with acceptable fluoride content is less expensive than treating the water to remove the high fluoride content. This would have applicability for small rural communities where the economic hardship of constructing and operating a fluoride removal facility would be greater than the cost to import bottled water. In this case, the community would continue to use the community water for washing and other sanitary practices, but would use bottled water for human consumption, or for consumption by children. Each household could be given a bottled water dispenser and then the bottled water could be distributed to the households at scheduled periods. It would be important that the bottled water would have sufficient fluoride content for optimal oral health benefits.
- When other management approaches are not feasible, then fluoride removal from the drinking water should be considered to achieve a fluoride content less than the MAL. It would not be likely that all of the water in a community would require defluoridation. Rather, one or more wells might be treated to remove fluoride and then blended with water from other wells in the community to achieve a blended fluoride content that meets the MAL.

IV. 4 Alternative Defluoridation Processes

Removal of fluoride ion from water is difficult. Fluoride is a stable ion which is not conducive to removal by many processes commonly used in water treatment. The selection of a process for fluoride removal may be a function of whether the source is an individual well for one residence, a community well for a neighborhood with a common faucet that is used by several households to fill containers that are carried to the household for use, or an inter-connected well system with a distributed feed to the distribution system with individual service connections to each household.

This analysis has considered various fluoride removal processes that could be considered. In general, the major categories of defluoridation processes can be summarized as:

- Precipitation Methods
- Adsorption Methods
- Ion Exchange Methods
- Other Methods

All of these processes offer advantages and disadvantages. In each case, the methods available suffer from one or more of the following drawbacks.

- High initial cost
- Lack of selectivity for fluorides
- Poor fluoride removal capacity
- Separation problems
- Complicated operator intervention or training
- Expensive regeneration.

Conventional Water Treatment Processes

Conventional surface water treatment processes can remove some fluoride. Use of aluminum sulfate (alum), a common water treatment coagulant, and lime addition, can both result in removal of some portion of the fluoride. In a typical surface water treatment facility, 10 to 30 percent of the fluoride can be removed by these common treatment processes, and potentially higher levels if the process is carefully monitored. Use of alum for removal of fluoride is dependent on precise dosage in relation to fluoride content, and requires a careful operator attention to the process. If convention surface water treatment processes were being employed, it is possible that sufficient fluoride removal could be accomplished in some instances by chelation or precipitation through higher alum dosages within the existing treatment facilities. If there are facilities within the subject area utilizing this technology, then the incremental cost to remove fluoride ion might be minimal and would be the most cost-effective approach. However, much of the water being considered for treatment in Mexico has a groundwater origin so it may not be currently treated using conventional surface water treatment systems. If waters have a high hardness in addition to fluoride, then a lime-softening treatment facility would be the cost-effective approach to accomplishing both hardness and fluoride reduction. Adding a conventional surface water coagulation-flocculation-sedimentation process or lime-softening process, if it was not otherwise needed, would be very expensive and add significant operator complexity.

Bone char and Activated Carbon

Carbon-based adsorbents have been found to remove some fluoride. Bone char is a carbon-based adsorbent designed to remove inorganic as well as organic constituents from solution, and has had success in reducing the fluoride content in some community water systems. It can also have minor reduction of metal cations such as aluminum, arsenic, cadmium, chromium, iron, lead and zinc from waste water. It is commercially available and is commonly used in the sugar processing industry for color removal. Eventually, the bone char is saturated with fluoride (and other adsorbables) and must be regenerated using a 1 percent solution of caustic soda. The bed is then washed with water to purge the caustic soda and returned to service. There is limited operational history using bone char, but the data that exists suggests that the bone char would achieve a fluoride reduction to approximately 1.5 mg/l or below, which would satisfy the WHO limitation of 1.5 mg/l. Since this process has only had limited operating experience in a few select locations, the design basis is not well established. There would need to be some pilot studies conducted to verify the design basis.

Activated carbon is another carbon-based adsorbent normally derived from coal or lignite. Activated carbon would be comparable to the operating performance of bone char, but would likely be slightly more expensive. Some literature has also suggested that the use of activated carbon might be more effective at acidic pH conditions achieving higher rates of removal, which might result in the need to have chemical adjustment before and after treatment.

Use of carbon-based adsorbents would have the advantages of operator simplicity and removal of organic contaminates or hydrogen sulfide if they are present. Hydrogen sulfide is often present in groundwaters and although it does not have an epidemiological concern, it does result in an aesthetic concern due to unfavorable odor. The operating requirements would include charging the contact vessel with adsorbent, then monitoring the product water for fluoride content. When a desired level of fluoride in the product water was exceeded, the bed would be removed from service and regenerated. Regeneration of activated carbon for fluoride removal would entail the same caustic solution backwashing as required for bone char. Some studies have found that using a sequence of caustic solution backwashing followed by an alum solution impregnation can increase the fluoride removal effectiveness of the carbon. Periodically, the entire contents of the contact vessel would need to be replaced with fresh adsorbent as the media would ultimately experience saturation. Experience at other locations suggest that the carbon media would need to be replaced after approximately 40 cycles.

It is possible that point-of-use carbon filters that are commercially available could be used in individual residences and pilot evaluations could verify if they would perform in a satisfactory manner. However, the commercially available point-of-use carbon filters are ineffectual in adsorption at the flow rates that they commonly experience in household plumbing. As commonly experienced, these units typically have less than 5 seconds of contact, while they would need to be designed to provide up to 20 minutes of contact on an empty-bed basis. This would require that the filters be on a flow restricted line so that the longer necessary retention was provided. Use of these household filters would only be economical if they were regenerated. A program could be considered on training the population on the care and attention of these devices with an exchange program so that the media could be regenerated at a central location. Regeneration could be accomplished using a standard caustic solution.

Activated alumina

Activated alumina is a porous granular media that is a residual of the manufacture of aluminum. It is primarily aluminum oxide that has been exposed to a high temperature and caustic soda. Fluoride ions in the source water are attracted to the surface where they are retained. The process is very pH sensitive with optimum adsorption of fluoride at pH 5.5. At this optimum pH, the fluoride content of the finished water will be 0.5 mg/l, and will be higher when the pH varies from the optimum. Approximately 500 to 800 mg of fluoride can be adsorbed by one liter of media. When the media reaches saturation, then it must be regenerated by flushing with a caustic solution. Regeneration can also be accomplished using Hydrochloric acid, Sulfuric acid, or alum. The use of activated alumina for groundwater wells is considered a good application if the water does not have other contaminants that require removal. The process can be automated and can operate with low operator supervision. The primary requirements are attention to adjusting the source water pH and neutralizing the product water pH, monitoring the product water fluoride content, backwashing the media when it reaches saturation, and disposing the backwash/regeneration flow.

Activated alumina loses effectiveness as the alkalinity of the source waters increase. If the source waters are highly alkaline, then the use of high-lime softening might be a more appropriate method for fluoride reduction. The fluoride capacity is also reduced if there is high arsenic content of the water as arsenic is preferentially adsorbed. Other interferences include silica and boron. Additionally, the effectiveness of activated alumina decreases as the number of regeneration cycles increase. Some technical literature has reported losses of 50 percent of the original capacity after 40 cycles of regeneration, leading to a need to replenish the media periodically. The longevity of the media will depend on the fluoride content and other absorbable ions in the source water.

Ion exchange

Ion exchange is a process where a media is used to exchange one ion for another similarly charged ion. Water softening is an example of ion exchange where sodium from table salt is exchanged for calcium to reduce hardness. Ion exchange resins can either be general or specific in their exchange capabilities. Ion exchange can be an effective means of anion and cation removal, but will have a higher relative cost than some other fluoride removal methods. It could have applicability for home point-of-use devices. Ion exchange does have disadvantages of brine disposal, and the need to monitor the effluent fluoride content to determine when the bed is approaching exhaustion and requires regeneration. Fluoride is one of the few ions that is not favorably removed by many ion exchange resins commonly used. If ion exchange is used for fluoride removal, it may require separate strong cation and strong ion beds in sequence. Such a process will also require stronger acids and bases for regeneration leading to the need to handle more hazardous chemicals, or expensive throw-away media cartridges. Polystyrene anionic exchange resins and strongly basic quaternary ammonium type resins have shown some success, as have the speciality resins recently developed that are fluoride specific. These often have a high incremental cost.

Electrodialysis

Electrodialysis uses an alum solution in an electrochemical cell. The fluoride will be removed via precipitation. The process requires a large electrical demand of 0.3 to 0.6 Kilowatt-hours per 1,000 liters of water processed. The process is one of the easiest methods to use and does not require the complex chemical adjustments that some other processes require, but uses a lot of electricity, continuously exhausts the anode which must be periodically replaced, and generates a sludge for disposal. For rural areas with limited electricity service, it may not be appropriate.

Reverse Osmosis

Reverse osmosis is a proven method for removal of fluoride, but is a comparably expensive means. There are two types of reverse osmosis systems available: large-scale production units using medium pressure membranes to provide treatment for larger flows, and small-scale individual household units using low pressure membranes for very small flows.

The large-scale reverse osmosis systems requires a specialty membrane from a manufacturer, high-pressure pumps, an electrical source, and a means to dispose of the reject water. Reverse osmosis works by pressurizing a water flow on one side of a semi-permeable membrane so that the ionic osmosis forces are reversed resulting in pure water to pass to the product water side of the membrane while the ions are retained on the pressured (reverse) side. This can result in very pure product water. In large community production facilities, they would normally only be used for a portion of the flow and then blended with some untreated water to achieve a blended aggregate concentration of less than 1.5 mg/l. A common approach in a community with multiple wells might be to treat the higher fluoride content wells with reverse osmosis and then blend the product water with the output from other wells to achieve a fluoride content that is less than the MAL.

Individual household low-pressure reverse osmosis units are available, but they are quite expensive, with a purchase cost for a house-hold sized unit on the order of $400 when purchased in bulk quantities of several hundreds at a time. They also require a trained operator to evaluate if the membranes are working effectively, or if they need regeneration or replacement, and the cartridges must be replaced approximately annually with a cost of approximately $200. The household units are not true reverse osmosis, but are based on a low pressure membrane system. They will provide a reduction in fluoride content and could be suitable for small rural communities where the expense of operating and maintaining a production sized reverse osmosis system might be difficult, as the use of replaceable cartridges could offer a lower operator skill.

Mexico has the experience of investigating the use of community production reverse osmosis systems in approximately 14 locations. The experience with these systems has been mixed with reported difficulties with some locations. All of these systems are older systems that do not reflect the modern developments of reverse osmosis products on the market currrently. It would be appropriate for Mexico to conduct a detailed assessment of the systems that have been implemented to develop documentation on “lessons learned” so that future installations can address those deficiencies and avoid past mistakes.

Nalgonda

The Nalgonda process is an point-of-use system using an aluminum sulfate (alum) based coagulation-flocculation-sedimentation sequence that has been used in some locations in India and Tanzania. It is suitable only for waters having a fluoride content less than 10 mg/l. The essential process is a two-bucket apparatus, featuring a raw water bucket and a finished water bucket. The raw water is mixed with a measured dose of alum and lime in the first bucket, and the user is trained to stir the raw water bucket for 1 minute at a faster designated rate, followed by 5 minutes of stirring at a less vigorous pace. Then the raw water bucket is allowed to settle for one hour before being slowly filtered through a sieve with a cotton cloth as the contents are transferred to the second finished water bucket. This process has been used principally by rural populations, who are often poorly educated or hard to educate on the complexities of the process. It involves an exact alum dosage, which is specific for the actual fluoride concentration of the water. If the alum dosage is not carefully balanced with the actual fluoride level of the water, then the resulting product water may have high residual aluminum content easily exceeding the desirable maximum concentration. Consequently, the product water may have a "metallic" flavor which can discourage the population from continuing the process.

"KRASS" system

KRASS (Krishna Ram Ayurvigyan Shodh Sanstan) is a system devised as point-of-use application. The KRASS process utilizes a specialty media that is less influenced by alkalinity and pH than some of the other processes. It can be used as a point-of-use system in residences. An advantage is the low aluminum content of the product water in comparison to the Nalgonda method, and the easier operating instructions than the Nalgonda method. The media will be exhausted and the fluoride content needs to be evaluated periodically to ascertain if regeneration is required. Regeneration is accomplished by backwashing the media with alum. Initial studies have suggested that the media would need to replaced after 40-plus regeneration cycles.

A technology-transfer request has been submitted to the developers in India. However, this is process that is still under development and has only been verified in the laboratory for one location. It will need to be pilot tested for various waters in Mexico to assess if it is suitable for use with the water chemistry that is experienced in Mexico. The commercial licensing arrangements are undefined at this time, so there will need to be negotiations on a reasonable fee for intellectual property rights associated with the use of the propriety media. It cannot be considered at this time as a strong candidate for use in Mexico, but it might have longer-term implications for possible use if these issues can be satisfactorily resolved.

Bottled Water

For some areas, it may be particularly expensive to process water to remove fluoride, particularly in rural areas with no community systems. It may be feasible to provide bottled water for the residents with low-fluoride water. The residents could then continue to use the high-fluoride waters for non-consumption use, but use bottled water for drinking and food preparation. If the residents are principally consuming low-fluoride waters, occasional consumption as can happen as part of food preparation of the other high-fluoride water may be acceptable.

Treatment Options for Defluoridation

Method	Working pH	Interference	Advantages	Disadvantages
Aluminum Sulfate	Ambient	--	Conventional water treatment process used for precipitation of surface water turbidity producing contaminants.	1. Sludge produced. 2. Alum addition results in low pH of product water. 3. Requires trained operator and moderately expensive facilities.
Lime Softening	Alkaline	--	Conventional water treatment process used for softening of hard groundwaters.	1. Sludge produced. 2. Lime addition produces water of high pH.
Bone char	Ambient		Simple operation with filtering of water until media is saturated, then regeneration using caustic soda.	1. Requires handling caustic solution for regeneration. 2. Creates a regeneration waste flow for disposal. 3. Bone char will eventually be exhausted and must be replaced.
Activated Carbon	Acidic	Arsenic	1. Simple operation with filtering of water until media is saturated, then regeneration using caustic soda. 2. Higher capacity than bone char.	1. Requires handling caustic solution for regeneration. 2. Creates a regeneration waste flow for disposal. 3. Activated Carbon will eventually be exhausted and must be replaced. 4. Reduces other water contaminants; improves taste and odor resulting from organic compounds..
Ion Exchange	Acidic	Other ions in source water	Relatively simple operation	1. Expensive operation 2. Requires acid and caustic solutions for regeneration 3. Creates a regeneration waste flow. 4. Media may ultimately foul and require replacement. 5. May require acid-base adjustments to pH.
Defluoron-2 Or Other specialty ionic exchange resins	Ambient	Alkalinity	Relatively simple operation	1. Expensive operation 2. Requires acid and caustic solutions for regeneration 3. Creates a regeneration waste flow. 4. Media may ultimately foul and require replacement.
Electro dialysis	Ambient	Turbidity	Can remove other ions	1. Expensive operation. 2. Requires skilled operators 3. Consumes electricity
Activated Alumina	5.5	Alkalinity	Effective, simple in application	1. May require acid-base adjustments to pH. 2. Creates a regeneration waste flow for disposal.

Method	Working pH	Interference	Advantages	Disadvantages
Reverse Osmosis	Ambient	Turbidity	Can remove other contaminants	1. Expensive process. 2. Requires highly skilled operators. 3. Produces brine for disposal. 4. Consumes electricity.
Alum and lime (Nalgonda Technique)	Ambient	--	Low technology	1. High chemical dose. 2. Difficult to control effectively; may expose users to high alum dosage. 3. Residual disposal required.
KRASS	Ambient	--	Low technology	1. Requires support to local population for regeneration.
Bottled Water	Ambient	--	Low technology	Requires an educational program and ability to distribute the bottled water.

Source: CDC, 2004

V. TASK FORCE TECHNICAL RECOMMENDATION FOR MANAGEMENT OF FLUORIDES IN MEXICO

V. 1 Technical Approach for Management of Acceptable Fluoride Exposure in Ground Water

Establishing guidelines in conducting and implementing specific studies in a community where there is risk exposure.

Documentation of water fluoride levels needs to be conducted on two levels: the water quality of the source groundwater wells supplying water to the system, and the water quality that consumers experience at their taps. Both of these fluoride levels are important for analysis.

Source Water Fluoride Levels: Data collected on source water quality at the well-head has been irregular, with some wells having only a single measurement, and other wells having multiple measurements. It is important to institute a program of systematic measurement of source water quality at least twice each year for each source. The minimum two samples need to include one sample collected in the dry season and the other sample collected in the rainy season. This will assist in characterization of the water source with respect to surface influences and hydrogeologic influences on water quality. Since many wells have been extended to deeper datum to continue production as groundwater levels have decreased, there may be less seasonal variability. However, some shallower wells and wells in areas with extensive faulting may continue to display seasonal variability.

Water Fluoride Levels at Consumer Taps: Since most of the water systems with high fluoride content have groundwater supply from multiple wells, the water quality within the water distribution system may be different at different locations within the distribution system depending on the water quality that is derived from the nearest supply well. Consequently, it is necessary to measure the water quality at various locations within the water distribution system. The fluoride level of the delivered blended water should be collected at household taps at the same time that the fluoride level is measured at the well locations. It is recommended that at least three household taps be measured for fluoride content for each well supplying water to a community, and that samples be collected concurrently to the well samples. The household tap samples should be geographically distributed within a community water system service area.

Proposed Technical Approach to Evaluation of Reverse Osmosis

Reverse osmosis has been identified as a potential method of fluoride reduction in the water supply of some communities. Approximately 14 facilities have been constructed in Mexico in the past for fluoride removal, and antidotal reports suggest that these facilities have had varying success, and that some have terminated operations. It is therefore important that a more detailed assessment of the use of reverse osmosis be conducted to ensure that the technology will be appropriate for the communities and will be a reliable means of fluoride reduction.

Based on verbal reports, it is believed that the 14 reverse osmosis facilities in Mexico were installed more than 10 year ago. Reverse osmosis technology has progressed significantly in the past 10 to 20 years, and the technology is less expensive and more reliable than historical installations. However, it is important that the problems with the earlier facilities be fully understood so that the same issues can be avoided in future installations. It may also be possible that existing facilities could be candidates for potential retrofits with new equipment that would yield satisfactory results. Therefore, it is important to conduct an assessment of the legacy facilities.

Collecting information on older facilities can sometimes be problematic for knowledgeable people and records may be difficult to locate. It is therefore recommended that a sequential assessment be conducted. The recommended scope and approach of this assessment would be as follows.

Step 1: Prepare Evaluation Tool: Three questionnaires would be prepared for the initial survey. One questionnaire will be directed to the community (or water utility) that owned and operated the facility, a second would be directed to the design engineer of record, and the third would be directed to the manufacturer of the reverse osmosis system installed. Each questionnaire would request contact information (names, phone, address) historical information on operation, design basis, operating documentation, and problems encountered. For some facilities, these questionnaires may need to be mailed in sequence as contact information is obtained. Some facilities may not respond to the Step 1 Questionnaire. Those facilities should be contacted by phone or other means.

Step 2: Verification of Evaluation Tool Information: The information from the questionnaires will be compiled and compared to determine if trends or conclusions can be derived. Based on these trends and conclusions, facilities will be chosen for site visitation.

Step 3: Site Visits: Up to eight facilities will be visited for inspection and evaluation. four will be successfully operating facilities, and four will be installations not successful or with terminated operations. Additionally, two manufacturers of current membrane technology with successful reverse osmosis operations treating for defluoridation of water implemented in the past five years will be chosen and two facilities from each manufacture will be visited and evaluated.

Step 4: Implementation Recommendations: Based on the information and conclusions of the study evaluation, recommendations for implementation of new reverse osmosis projects in Mexico will be developed.

V. 2 Establishing Guidelines in Conducting and Implementing Specific Studies in a Community Where There is Risk Exposure

Documentation of water fluoride levels needs to be conducted on two levels: the water quality of the source groundwater wells supplying water to the system, and the water quality that consumers experience at their taps. Both of these fluoride levels are important for analysis. Source Water Fluoride Levels: Data collected on source water quality at the well-head has been irregular, with some wells having only a single measurement, and other wells having multiple measurements. It is important to institute a program of systematic measurement of source water quality at least twice each year for each source. The minimum two samples need to include one sample collected in the dry season and the other sample collected in the rainy season. This will assist in characterization of the water source with respect to surface influences and hydrogeologic influences on water quality. Since many wells have been extended to deeper datum to continue production as groundwater levels have decreased, there may be less seasonal variability. However, some shallower wells and wells in areas with extensive faulting may continue to display seasonal variability.

Water Fluoride Levels at Consumer Taps: Since most of the water systems with high fluoride content have groundwater supply from multiple wells, the water quality within the water distribution system may be different at different locations within the distribution system. Consequently, it is necessary to measure the water quality at various locations within the water distribution system.

V. 3 Preliminary Design for Research

With the information currently available and from the technical discussions during the Task Force Meeting on Defluoridation Systems, the experts recommended need to conduct a case control study alongside and based on *community assessment on the use of fluoride and relative risk factors associated to dental fluorosis, involving an case control sample and a fluorosis risk group.* Given a significant amount of documented evidence on fluorosis and epidemiological oral health survey conducted in Mexico and presented in this report, the study will identify populations that have potential risk factors and relative risk factors associated to dental fluorosis. Children under six years of age will be the subject of the study, who is free of fluorosis and children with fluorosis above acceptable levels and population tolerance. A second group will be broken down from the fluorosis group to look at attributable risk and cumulative factors effects.

The study design, will aim to understand what are the risk factors and relative risk factors associated to dental fluorosis and when the fluorosis occurred. Additional environmental exposure will be assessed, including exposure to volatile vectors and aerosol, bottle water, toothpaste consumption, brushing frequency, sods, informant formula and others. A market basket questionnaire can be used to obtain data on fluoride exposure.

Concurrent with the definition of the study as a case controlled study, the control sample will consist of children free of fluorosis and fluorosis group two sub-samples: children with fluorosis above acceptable levels and population tolerance and children with severe fluorosis. Children will undergo dental examinations and will receive a questionnaire based on the exposure to fluorides.

Both the control and fluorosis samples will be comprised of a similar number of children and will be drawn from the same community populations in order to control for the background variables of fluorosis and non fluorosis Mean DMFT score and fluorosis must also be close in both groups at the start of the project. The sample size will be determined in by means of statistical sampling. Eventually, the outputs from both approaches would be reconciled in order to make the sample both accurate and affordable.

Based on the above, the proposed study will make a significant contribution to *Mexico-specific* knowledge in the following areas:

(1) The potential of abating progression of dental fluorosis in high risk populations in Mexico.
(2) To provide alternatives for achieving optimal levels of fluoride in high risk population.
(3) The outlined research can be used to lead to the statement of alternatives methods for achieving optimum levels of fluoride in high risk population where fluorosis is above optimum levels.
(4) The concluding stage in the case control study will assist Mexico in the decision process on which the final recommendation of the most effective alternatives to provide optimal levels of fluoride to communities where there is excess of fluoride, will be submitted to policy-makers, researchers and communities to take action and reduce the risks of fluorosis.

Technical design and protocol

The structure of the design research protocol will offer pieces of evidence, assumptions, and other input information in execution of the protocol. These inputs are considered tentative and are open for verification, refinement, and revision in the course of the proposed study.

Consistent with the above, the description of research protocol steps will include several or all of the following:

- Rationale,
- Suggested approach,
- Methods,
- Activities, required data, worksheets.
- Statement of Problem, Need and Opportunity
- Description of Alternatives and Expected Benefits
- Tools, Materials and Supplies
- Sampling Based on Statistical Methods
- Analysis
- Final Recommendations
- Estimated Staffing and Level of Effort of Team, in Person-Months
- Final report and recommendations for action

APPENDIXES

Appendix No. 1 Agenda and List of Participants
Appendix No.2 Presentations

PAN AMERICAN HEALTH ORGANIZATION PAHO/WHO
TASK-FORCE MEETING
DEFLUORIDATION SYSTEMS FOR LATIN AMERICA AND THE CARIBBEAN

18 - 22 de October 2004
Washington, DC

Agenda

<u>Monday</u>

- Welcome. Objectives of the meeting
  Dr. Saskia Estupiñán-Day, Regional Advisor for Oral Health

- Fluoridation Programs in Latin America and the Caribbean countries, and
- PAHO's recommendations for surveillance and monitoring of fluoridation programs.
- Dr. Saskia Estupiñán-Day, Regional Advisor for Oral Health, PAHO/WHO

- Break

- Fluorosis prevalence in the Americas and identify risk populations.
- Dr. Heriberto Vera, Director Tecnico de Salud Bucal, Ministry of Health, Mexico

- Recent developments in point of-use defluoridation technology, and the published literature on defluoridation systems around the world and details of defluoridation process.
  Dr. Kip Duchon, National Fluoridation Engineer, NCCDPHP

- Noon - Lunch – Dr. Christopher Fox, DMD, DMSc, IADR

- Krass Process
  Dr. Kip Duchon, National Fluoridation Engineer, NCCDPHP

- Analysis of critical areas with fluorosis in Mexico
  Information of water sources in Mexico versus percent on groundwater
    - Number of water treatment plants greater than 40,000 cubic meters per day
    - Number of water treatment plants between 10,000 to 40,000 cubic meters per day
    - Number of water treatment plants between 2,500 to 10,000 cubic meters per day
    - Number of water treatment plants less than 2,500 cubic meters per day

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Treatment plants with fluoride less than 0.6 mg/l. If the "optimum fluoridation" level is 0.8 mg/l, the operating range would likely be 0.7 to 1.2 mg/l. If the naturally occurring fluoride is 0.6 mg/l. is not worth the effort to adjust the fluoride to 0.7 mg/l.
Dr. Heriberto Vera, Director Tecnico de Salud Bucal, Ministry of Health, Mexico

- Availability of base material for the design of defluoridation systems
  Dr. Kip Duchon, National Fluoridation Engineer, NCCDPHP

Tuesday

Design of defluoridation systems and alternatives- Working group

Wednesday

Recommendations for Latin America and the Caribbean Region – Working group

Thursday

Traveling date

“TASK-FORCE MEETING, DEFLUORIDATION SYSTEMS FOR LATIN AMERICA AND THE CARIBBEAN”
Regional Oral Health Program

Washington, D.C., 18-22 September 2004

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