Tropical Lake Ecology Assessment
With Emphasis on Changes in
Salinity of Lakes
Project No.SAA-140714
Technical Memorandum # 1
Research of Existing Salinity Standards

Prepared for:
Panama Canal Authority

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1.0 INTRODUCTION

The Panama Canal Authority (ACP) is currently performing a series of studies to assess the feasibility of a new set of locks, alternative systems to raise and lower vessels, and upgrading the navigation channel to prepare a Master Plan for the Modernization and Expansion of the Canal. Part of these studies includes the analysis of risks to increase the salinity of the freshwater lakes Gatún and Miraflores. This may occur as a consequence of increased traffic and anticipated structural modifications, which include an additional set of locks to accommodate larger Post-Panamax vessels. Lakes Gatún and Miraflores are adjacent to the locks on the Atlantic and Pacific extremes of the canal, respectively.

Within this context, URS Holdings, Inc. (URS) was retained by ACP for the execution of the contract for the Tropical Lake Ecology Assessment with Emphasis on Changes in Salinity of Lakes. More specifically, under this agreement, URS shall recommend the maximum salinity levels, which may be tollerated in the freshwater lakes mentioned above. The salinity standards must consider the current procedures for treatment of potable water in Panama and must also maintain the biological integrity of freshwater ecosystems.

The terms of reference specify several intermediate products in the form of technical memoranda. In this context this is the first technical memorandum, which deals with the revision of international standards regarding the control of salinity. Emphasis has been given to the potable water and biological integrity criteria as required by the terms of reference for this contract.

1.1 OBJECTIVE

Based on the previous paragraphs, the objective of this first technical memorandum is to present the results of the research and review of national and international salinity standards, as they relate to potable water and the protection of aquatic communities.

1.2 BACKGROUND

During the preparation of this Technical Memorandum, several water quality standards (both for potable purpose and for the protection of aquatic ecosystems) and relevant documentation was identified and reviewed, for tropical countries when possible, but also for temperate climate countries as well. The search was performed using various methods that included the Internet, telephone conversations and periodical review. The emphasis of the research was the recommended limits of salinity for potable water, aquatic organisms, and other uses. The most relevant sources of information consulted are listed below:

- World Health Organization (WHO) Water Pollution Control – A guide to the Use of Water Quality Management Principles
- Australian New Zeland Environment and Conservation Council (ANZECC) – Guidelines for Protection of Aquatic Ecosystems
- Interim National Water Quality Standards for Malaysia
- Comisión Panameña de Normas Industriales y Técnicas (COPANIT) – Dirección General de Normas y Tecnología Industrial (DGNTI) Reglamento Técnico 23-395-99 Agua Potable, Definiciones y Requisitos Generales

- CEPIS – Normas Internacionales para la Calidad del Agua de Bebida
- EPA – National Recommended Water Quality Criteria: 2002.
- Clasificación de los cuerpos de agua en México; and
- Reglamento en materia de contaminación hídrica (Decreto No. 24176), Bolivia. 1995.

In addition to the sources of information listed, URS contacted research centers in Latin America and requested via e-mail any available information on the subject matter at hand. However, no response has been received to date. The people contacted and their respective institutions are listed below:

- **Jorge Arturo Hidalgo.** Coordinator of Profesional Development for IMTA – Mexican Institute of Water Technology (Instituto Mexicano de Tecnología del Agua), jhidalgo@premia.imta.mx;
- **Luiz Augusto de Lima Pontes.** Executive Director of AIDIS -- Interamerican Sanitary and Environmental Engineering Association (Asociación Interamericana de Ingeniería Sanitaria y Ambiental), aidis@aidis.orgbr;
- **Mauricio Pardón.** Director of CEPIS – Panamerican Sanitary Engineering and Environmental Sciences Center (Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente), mpardon@cepis.ops-oms.org;
- **Aída Infante.** Venezuelan Limnologist that works for the University of Mobile in San Marcos, Carazo, Nicaragua, musica@ibw.com.ni.

Water quality standards for countries with temperate climates can serve as a guide. However, special conditions prevalent in tropical environments, such as the assimilation and depuration capacity of certain elements and compounds within a freshwater system, are different. Not withstanding the above, given that more research and standardization/regulation has been achieved in temperate climate countries, special cases were identified during the course of the research activity. These special cases are specific situation for which a salinity guideline was developed to address specific salinization concerns in a freshwater or estuarine system. These cases are listed below and are discussed in a later section of this Technical Memorandum:

- Water Quality Standards for surface waters from the Sacramento River, San Joaquin River and San Francisco Bay and Delta of the State of California. EPA. 1995;
- Colorado River Salinity Standard; and
- Florida Surface Water Standard.

1.3 STRUCTURE

This Technical Memorandum has been organized in a manner that is consistent with the objectives of the document and that will allow a clear and concise presentation of the standards researched, and their significance. The structure of the document is briefly discussed in the next paragraphs.

Introduction. This introductory section contains a general description of the work to be carried out by URS as well as the objective, and structure for the Technical Memorandum. In addition,

background information that explains the research activities performed to identify applicable standards is also presented.

Water Quality Standards. This section is the primary result of Task 1 of the project and presents the various standards that were identified and reviewed. The section has been organized into four sub-sections that contain general considerations as well as standards associated with potable water, aquatic organisms and special cases.

Conclusions. This section presents basic conclusions applicable to Task 1 of the project (Review of Existing Standards).

2.0 WATER QUALITY STANDARDS

This section of the Technical Memorandum presents the results of the research performed to identify applicable salinity standards to potable water and the protection of aquatic organisms. The following sub sections organize the standards into general considerations, those specific to potable water, aquatic organisms, and special cases.

2.1 GENERAL CONSIDERATIONS

Salinity is the correct chemical term for the sum concentration of all the ionic constituents dissolved in inland waters, both fresh and saline. Salinity is best expressed as total ion concentration in mg liter^{-1} or meq liter^{-1}, which are essentially equivalent as mass or volume in dilute solutions. In reservoirs and open lake systems, which have an outlet, the chemical composition of the water is governed largely by the composition of influents from the drainage basin and the atmosphere, while in closed systems salinity is normally increased by evaporation and modified by precipitation of salts.

Structural interventions in the natural hydrological cycle through canalization or damming of rivers, diversion of water within or among drainage basins, and the over-pumping of aquifers are usually undertaken with a beneficial objective in mind. Experience has shown, however, that the resulting long-term environmental degradation often outweighs these benefits. The most important anthropogenic impacts on water quality, on a global scale, are summarized in Table 2.1, which also distinguishes between the severities of the impairment of use in different types of water bodies.

Table 2.1
Major freshwater quality issues at the global scale[1]

Issue	**Water body**			
	Rivers	**Lakes**	**Reservoirs**	**Groundwaters**
Pathogens	xxx	x[2]	x[2]	X
Suspended solids	xx	na	x	Na
Decomposable organic matter[3]	xxx	x	xx	X
Eutrophication[4]	X	xx	xxx	Na
Nitrate as a pollutant	X	0	0	Xxx
Salinization	X	**0**	**x**	Xxx
Trace elements	xx	xx	xx	xx[5]
Organic micropollutants	xxx	xx	xx	xxx[5]
Acidification	X	xx	xx	0
Modification of hydrological regimes[6]	xx	x		X

A full discussion of the sources and effects of each of these pollution issues is available in the relevant chapters of Meybeck *et al.,* 1989.

xxx = Severe or global deterioration found

xx = Important deterioration
x = Occasional or regional deterioration
0 = Rare deterioration
na = Not applicable
[1] This is an estimate for the global scale. At a regional scale these ranks may vary greatly according to the stage of economic development and land-use. Radioactive and thermal wastes are not considered here.
[2] Mostly in small and shallow water bodies
[3] Other than resulting from aquatic primary production
[4] Algae and macrophytes
[5] From landfill, mine tailings
[6] Water diversion, damming, overpumping, etc.

From Table 1.1 it may be concluded that the negative effects of salinity on a global scale are severe for groundwater, due mostly to inadequate irrigation and pumping, occasional or regional for rivers and reservoirs, and very rare in lakes.

Pollution and water quality degradation interfere with vital and legitimate water uses at any scale, i.e. local, regional or international (Meybeck *et al.,* 1989). As shown in Table 2.2, some types of uses are more prone to be affected than others. Water quality criteria, standards and the related legislation are used as the main administrative means to manage water quality in order to achieve user requirements. The most common national requirement is for drinking water of suitable quality, and many countries base their own standards on the World Health Organization (WHO) guidelines for drinking water quality. In some instances, natural water quality (particularly conditions which occur very rarely) is inadequate for certain purposes as defined by recommended or guideline concentrations. However, other water bodies may still be perfectly usable for some activities even after their natural conditions have been altered by pollution.

Table 2.2
Limits of water uses due to water quality degradation

Pollutant	**Use**						
	Drinking water	**Aquatic wildlife, fisheries**	**Recreation**	**Irrigation**	**Industrial uses**	**Power and cooling**	**Transport**
Pathogens	xx	0	xx	x	xx[1]	na	na
Suspended solids	xx	xx	xx	x	x	x[2]	xx[3]
Organic matter	xx	x	xx	+	xx[4]	x[5]	na
Algae	x[5,6]	x[7]	xx	+	xx[4]	x[5]	x[8]
Nitrate	xx	x	na	+	xx[1]	na	na
Salts[9]	**xx**	**xx**	**na**	**xx**	**xx[10]**	**na**	**na**
Trace elements	xx	xx	x	x	x	na	na
Organic micropollutants	xx	xx	x	x	?	na	na
Acidification	x	xx	x	?	x	x	na

xx = Marked impairment causing major treatment or excluding the desired use.

x = Minor impairment.
0 = No impairment.
na = Not applicable.
+ = Degraded water quality may be beneficial for this specific use.
? = Effects not yet fully realized.
[1] Food industries
[2] Abrasion.
[3] Sediment settling in channels.
[4] Electronic industries.
[5] Filter dogging.
[6] Odour, taste.
[7] In fish ponds higher algal biomass can be accepted.
[8] Development of water hyacinth (*Eichhomia crassipes*).
[9] Also includes boron, fluoride, etc.
[10] Ca, Fe, Mn in textile industries, etc.

Table 2.2 above illustrates that salinity affects water quality for Potable Purposes, as well as for agricultural and industrial use. Therefore, treatment prior to use would be required, which could be very costly. Generally speaking, salinity also affects aquatic organisms (including fish).

Due to the complexity of factors determining water quality, large variations are found between rivers or lakes on different continents or in different hydroclimatic zones. Similarly, the response to anthropogenic impacts is also highly variable. As a consequence, there is no universally applicable standard which can define the baseline chemical or biological quality of waters. At best, a general description of some types of rivers, lakes or aquifers can be given.

2.2 POTABLE WATER SUPPLY QUALITY STANDARDS

The water quality standards for potable in Panama, like in other countries in the region, have been proposed on the basis of the guideline values of the Pan American Health Organization (PAHO-WHO). The countries that have adopted the WHO guideline values as specific values for their National Standards are the following Caribbean countries: Antigua and Barbuda, the Bahamas, Barbados, Bermuda, Belize, the Dominican Republic, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Granadines, Surinam, and Trinidad and Tobago.

The water quality values for the physical, chemical, biochemical and bacteriological parameters have been enacted in Panama by COPANIT. The physical and chemical parameters related to salinity are conductivity, total dissolved solids, and chlorides. Tables 2.3 to 2.5 below show the values for these parameters adopted in different countries in Latin America as well as in North America, the European Union, and in other countries of the world respectively.

Table 2.3
Latin American Potable Water Standards

PARAMETER	UNIT.	WHO	ARG	BOL	BRA	COL	CR	CHI	ECU	ELS
Year		1995	1994	1997	1990	1998	1997	1984	1992	1997
Origin		Guideline values	Food Code	IBNORCA NB512	Porta-ria 36-GM	RAS-98	Dto. 25991-S	NCH 409/1	IEOS	NSO 130701
Substances which may lead to complaints by users										
Conductivity	uS/cm	-	-	-	-	1,000	400	-	-	1,600
Chloride	mg/L	250	350	250	250	250	250	250	250	250
Total dissolved solids	mg/L	1.000	1.500	1.000	1.000	-	1.000	-	1.000	600

Table 2.4
Latin American Potable Water Standards (cont.)

PARAMETER	UNIT.	WHO	GUT	MEX	NIC	PER	DOR	URU	VEN
Year		1995	1998	1988	1994	1999	1980	1996	1998
Origin		Guideline values	NGO 29001	NOM	CAPRE	DIGE-SA (proposal)	NOR-DOM	Dto. 27335	-
Substances which may lead to complaints by users									
Conductivity	uS/cm	-	-	-	400	1.500	-	-	-
Chloride	mg/L	250	600	-	250	400	600	300	300
Total dissolved solids	mg/L	1.000	1.500	-	1.000	-	1.500	1.000	1.000

Table 2.5
European Union and North American Potable Water Standards

PARAMETER	UNIT.	WHO	CAN	USA	EEC	FRA	UNK	GER	ITA	SPN
Year		1995	1995	1998	1991	1989	1991	1990	1985	1990
Origin		Guideline values	HE EHD	NP DWR	-	Dto. 89-3	Reg. 1837	LF 66	Dto. PCM	Dto.1138
Substances which may lead to complaints by users										
Conductivity	uS/cm	-	-	-	400	-	1,500	2,000	400	400
Chloride	mg/L	250	250	250	250	250	400	250	200	200
Total dissolved solids	mg/L	1,000	500	500	1,500	-	1,500	-	1,500	1,500

Table 2.6
Potable Water Standards from Other Countries in the World

PARAMETER	UNIT.	WHO	RSA	AUS	TAW	CHN	THD	IDN	MLY	
Year		1995	1998	1987	1996	-	-	-	-	
Origin		Guideline values	UMGENI	AWRC	TDWR	-	MH	-	-	
Substances which may lead to complaints by users										
Conductivity	uS/cm	-	-	-	-	-	-	-	-	
Chloride	mg/L	250	250	400	250	-	250	600	200	
Total dissolved solids	mg/L	1,000	-	1,000	500	-	500	1,500	-	

Codes:

WHO	World Health Organization	**ARG**	Argentina
BOL	Bolivia	**BRA**	Brazil
COR	Costa Rica	**CHI**	Chile
ECU	Ecuador	**ELS**	El Salvador
GUT	Guatemala	**MEX**	México
NIC	Nicaragua	**PER**	Peru
DOR	Dominican Republic	**URU**	Uruguay
VEN	Venezuela	**CAN**	Canada
USA	United States of America	**EEC**	European Economic Union
FRA	France	**UNK**	United Kingdom
GER	Germany	**ITA**	Italy
SPN	Spain	**RSA**	South Africa
AUS	Australia	**TAW**	Taiwan
CHN	People's Republic of China	**THD**	Thailand
IDN	Indonesia	**MLY**	Malaysia

Source: CEPIS, Normas Internacionales para la calidad del agua de bebida, 2000

As shown in tables 2.3-2.5, the parameters directly related to salinity are deemed to be substances which may lead to complaint by users, specially due to the taste they give to water. The values of the parameters adopted by each one of the countries listed are compared to those proposed by the WHO, and, as it may be observed in the tables, in most cases they are the same. The WHO proposes as guideline values for chlorides 250 mg/l and for total dissolved solids 1,000 mg/l.

The Conductivity values in the Latin American countries surveyed range between 400 and 1,600 uS/cm, with Costa Rica and Nicaragua exhibiting the lowest limits, and El Salvador the highest. Additionally, only 5 out of the 15 Latin American countries include conductivity as a parameter to determine water quality. In the case of chlorides, the values range between 250 and 600 mg/l, with 250 mg/L being the most common value (9 out of the 15 countries), as proposed by the WHO. Guatemala and the Dominican Republic reported the highest value (600 mg/l), and the remaining 4 countries reported values of 300, 350 and 400 mg/l.

The total dissolved solids for Latin American countries range between 1,000 and 1,500 mg/l. Most countries (7 out of 11) reported a limit of 1,000 mg/l, as proposed by WHO. Three countries adopted as a limit for this parameter 1,500 mg/l, and El Salvador reported a value of 600 mg/l.

In the countries of North America, the European Union, and other countries of the world, the ranges for the conductivity, chloride and total dissolved solids parameters are similar to those listed for Latin American countries, with some exceptions, such as conductivity in Germany (2,000 uS/cm), and total dissolved solids in Taiwan and Thailand (500 mg/l).

Generally speaking, the standards evaluated for salinity-related parameters are similar throughout the world, and are consistent with guidelines set forth by the World Health Organization. In addition, the chloride limits established by the various countries listed in the tables above are driven mostly by a taste threshold rather than a health concern.

2.3 STANDARDS FOR CONSERVATION OF BIOLOGICAL INTEGRITY

As indicated in the introductory section, URS performed a wide search of standards around the world in order to identify recommended limits for those parameters associated with salinity in water. Specifically, standards were reviewed to identify proposed limits for the following parameters: conductivity, total dissolved solids, chlorides, and salinity.

Salinity or salinity-related parameters standards specifically drafted for conservation of biological integrity are very rare because different organisms respond differently to changes in salinity. It is more common, as will be presented in section 2.6, to have salinity standards for a specific body of water for which salinity intrusion is a concern.

It should be noted that although the issue of salinity is normally viewed along a gradient of concentrations from fresh waters, of relatively low salinity, to higher saline content in sea water, some inland waters show ionic concentrations in excess of those of sea water. It should also be pointed out that biological diversity and species richness is lowest in brackish waters. The number of species of species living in brackish water is very much smaller than the number living in marine regions with similar habitats and much smaller than the number of species in fresh water (see Figure 1). However, this decrease in the number of species in no way implies low productivity; productivity of adapted organisms can be exceedingly high.

The distribution of biota in fresh waters has been influenced by a long evolutionary history of physiological adaptations to a wide range of salinities. These mechanisms developed against a background of large differences between the salinity of the environment and that of the cytoplasm or body fluids. The lowest number of species occurs in salinities of about 5—7 ppt. The salinity gradient depicted here, with its associated osmotic and ionic properties, is the predominant factor influencing the distribution of biota in brackish waters. In these transitional waters, as in the spectrum of salinities of inland waters, the salinity range occupied by a species depends on the efficiency of the physiological mechanisms by which it is adapted to changes in salinity in the environment.

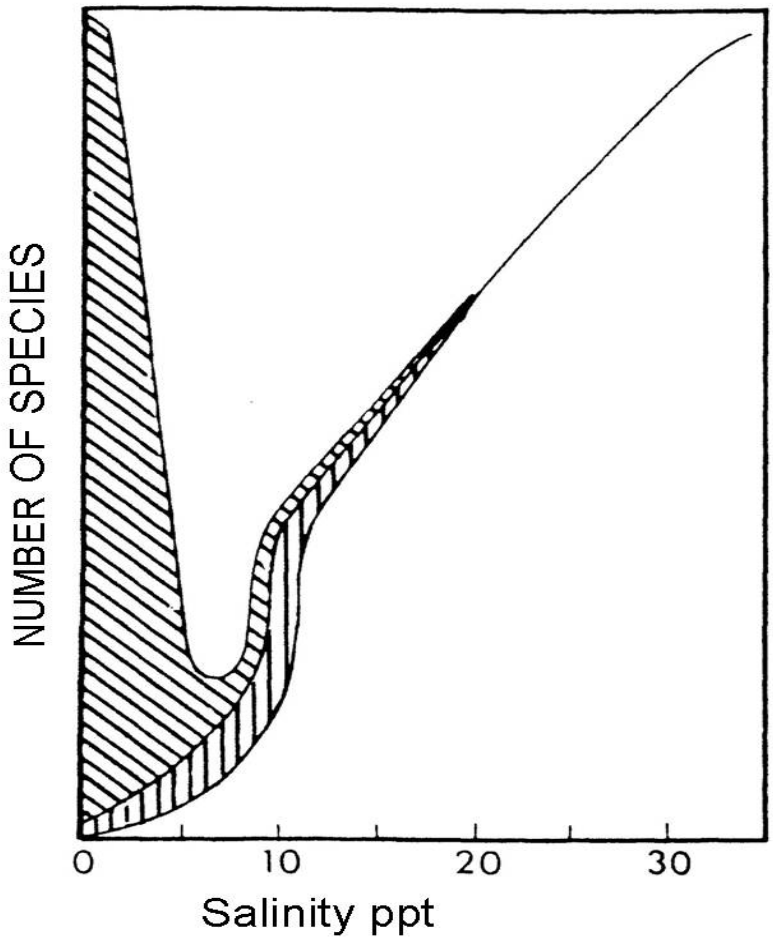

FIGURE 1: Number of species in relation to salinity. Diagonal hatching: proportion of freshwater species; vertical hatching: proportion of brackish-water species; lower open area: marines species. (Adpated from Wetzel, 2001.)

Osmotic regulation functions primarily in the maintenance of a difference in concentrations of ions inside and outside of the cells at appropriate operational physiological levels. Aquatic bacteria, monera and protista show high evolutionary adaptability to changes in Most freshwater bacteria are relatively homoiosmotic and tolerate only a narrow range of salinity but adapt to increasing salinity relatively rapidly by means of genetic change. Higher aquatic plants, which are of terrestrial origin, have developed adaptations to fresh water secondarily. Only a few major groups of angiosperms developed extensively in fresh waters, and very few groups extend into brackish waters or into hypersaline closed-basin lakes.

Nearly all of the higher freshwater animals originated from the sea, and had to face the challenge of osmoregulation for life in fresh water, and have developed diverse mechanisms to regulate salt and water content. Adaptation to low salinities by some marine animals has been achieved without osmoregulation. Such poikilosmotic animals adjust the osmotic pressure of their body fluids to become more or less isotonic with the salinity of the medium. In contrast, a homoiosmotic animal will tend to retain its initial internal osmotic concentration upon being ex posed to modest changes in the salinity of the medium.

The few salinity related standards applicable to aquatic organisms and the conservation of biological integrity, URS was able to find are shown below. The freshwater quality standards identified are similar in that they intend to classify water bodies according to their aptitude and based on their water quality. In other words, the acceptable range for a specific parameter for a specific use is provided by the standards reviewed. For instance, in the case of Florida, all surface waters of the State have been classified according to designated uses as follows. Water quality classifications are arranged in order of the degree of protection required, with Class I water having generally the most stringent water quality criteria, and Class V the least:

Class I	Potable water supplies;
Class II	Shellfish propagation and harvesting;
Class III	Recreation, Propagation and Maintain of a Healthy, Well-Balanced Population of Fish and Wildlife;
Class IV	Agricultural Water Supplies;
Class V	Navigation, Utility and Industrial Use

The information used during this investigation in the case of Florida was that for Class III surface water.

Table 2.7
Recommended Standards for the Protection of Aquatic Life

Deleted: 3

Parameters	Recommended Standards			
	ANZECC	Malaysia	EPA	Florida
Conductivity (umhos/cm)	-	1000	-	1275
Total Dissolved Solids (mg/L)	-	-	-	-
Salinity (per thousand)	< 1	1	-	-
Chlorides (mg/L)	-	-	230	-

As may be seen from the table above, general aquatic organisms protection standards associated with salinity and/or related salinity components are few around the world. However, from these limited values certain similarities may be observed. For instance, conductivity standards for Florida and Malaysia, and salinity standards for ANZECC and Malaysia are similar. This simple fact may have significance when proceeding with other Tasks of the project, for instance the recommendation of Standards (Task 3). While the exact justification for drafting these standards in various countries may reveal a more complex evaluation of indicator organisms and their tolerance to salinity and salinity-related components, for the purposes of this Technical Memorandum, a simple comparison will suffice.

Although the investigation did not yield a great quantity of general salinity-specific standards for the protection of aquatic organisms, it did however yield several case-specific salinity regulation / control efforts. These are discussed in more detail in section 2.4.

2.4 STANDARDS DEVELOPED FOR SPECIAL CASES

As has been indicated previously, standards associated with salinity and salinity-related parameters are available for special cases where salinity intrusion is a concern. Some of these cases, which are relevant to the work at hand, are analyzed in this section. The various cases analyzed are listed below and discussed in the remainder of this section.

- Sacramento and San Joaquin Rivers in the San Francisco Bay
- Colorado River Basin Salinity Control Forum
- Washington Lake Shipping Canal

2.4.1 Sacramento and San Joaquin Rivers in the San Francisco Bay

Under Section 303 of the Clean Water Act (CWA), this case is part of an interagency effort designed to ensure that the fish and wildlife resources of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay/Delta) are protected and to minimize the likelihood of future listings of Bay/Delta species under the Endangered Species Act. The Bay/Delta is the West Coast's largest estuary, supplying habitat for over 120 fish species and large populations of waterfowl. Over the past years, the U.S. Environmental Protection Agency (EPA) has worked closely with the Departments of the Interior and Commerce, as well as the State of California, to address the severe and continuing decline of Bay/Delta fish and wildlife resources. This decline has been so severe that a number of fish species, including the winter-run chinook salmon are considered

threatened or endangered under the Endangered Species Act. In coordinating their respective actions in the Bay/Delta, the Federal agencies endorsed an ecosystem (as opposed to a species-by-species) approach. EPA's final rule establishes four sets of water quality criteria protecting habitat conditions in the estuary.

Most of the State's developed water--75 to 85 percent—is used for irrigation purposes by agriculture, irrigating over 4.5 million acres throughout the State. The Bay/Delta watershed also provides part or all of the drinking water supply for over 18 million people. In large part due to the effects of these water diversions, the fish and wildlife resources in the Bay/Delta estuary have deteriorated drastically over the past twenty years.

Under section 303(c) of the Clean Water Act, states review their water quality standards every three years and submit any new or revised standards to EPA for approval or disapproval (the ``triennial review"). A water quality standard for a waterbody consists of two components: (1) Designated uses for the waterbody and (2) water quality criteria which support such designated uses. The designated uses for waters of the Bay/Delta included the following: Agricultural Supply, Cold and Warm Fresh-Water Habitat, Estuarine Habitat, Fish Migration, Fish Spawning, Groundwater Recharge, Industrial Process Supply, Industrial Service Supply, Municipal and Domestic Supply, Navigation, Contact and NonContact Water Recreation, Ocean Commercial and Sport Fishing, Preservation of Rare and Endangered Species, Shellfish Harvesting, and Wildlife Habitat.

The Estuarine Habitat designated use is intended to provide ``an essential and unique habitat that serves to acclimate anadromous fishes (salmon, striped bass) migrating into fresh or marine conditions. This habitat also provides for the propagation and sustenance of a variety of fish and shellfish, numerous waterfowl and shore birds, and marine mammals." EPA considers protection of the Estuarine Habitat designated use to be important for a number of important reasons, as provide a unique food source, spawning habitat or nursery habitat for a whole range of aquatic and aquatic-dependent species.

As stated in the Proposed Rule, the Estuarine Habitat criteria consisted of three interrelated components:

(i) A salinity requirement of 2 parts per thousand (2 ppt); define in terms of micromhos per centimeter specific conductance at 25 degree C, instead of parts per thousand salinity. Accordingly, the final rule will state the criteria value as ``2,640 micromhos/cm," which is equivalent to 2 ppt salinity.

(ii) Maintained at one or more of three monitoring locations in the Suisun Bay; and

(iii) For a specified number of days during the critical spring months.

In order to approve a state's water quality criteria, EPA must determine that the state has adopted ``water quality criteria that are sufficient to protect the designated uses."

Salinity was selected for several reasons: it is closely associated with the abundance and distribution of species at all trophic levels, it can be measured accurately and easily, and it integrates a number of important estuarine properties and processes. EPA proposed maintaining the low salinity 2 ppt isohaline (an isohaline is simply a line joining all points of equal salinity) in Suisun Bay during the critical wet season months of February to June. This particular time period is important because many different species use the low salinity habitat in the spring for spawning, as nursery habitat, for transportation through the Delta, or for a combination of these three purposes. To take account of the variation in natural hydrological conditions, EPA proposed criteria that varied according to the water year type. In all water years, the 2 ppt salinity criteria would be met at the furthest upstream monitoring site. In wetter years, the 2 ppt salinity criteria would also be met.

Low salinity in the 2 ppt range is being used to describe salinity conditions in the “mixing zone" between freshwater coming downstream and marine water moving inland from the ocean in response to tidal influences and fluctuations in freshwater outflow. This mixing zone generally contains low surface salinity of 1 to 6 ppt, whereas ocean salinity is over 30 ppt and freshwater salinity is generally less than 1 ppt (Arthur and Ball 1979).

EPA believes that attainment could be measured at the Roe Island and Chipps Island monitoring sites by any of (1) the daily salinity value, (2) the 14-day average salinity, or (3) the ``flow equivalence" of the salinity value, as predicted in the recent Contra Costa Water District (CCWD) model.

2.4.2 Colorado River System

This section provides a review of the water quality standards for salinity for the Colorado River. It summarizes the Colorado River salinity control program and its proposed Plan of Implementation for continued salinity control.

Background information and activities regarding historical actions relative to the development and adoption of salinity standards in Colorado River Basin (157 million acres) began since early 70’s. In a 1971 study, the EPA concluded that 47% of the salinity concentration measured in water arriving at Hoover Sam is from natural causes (saline springs) and 53% from various human activities (37% from irrigation); 75% of the land is owned and administered by the Federal Government or held in trust for Indian tribes. Its waters serve some 7.8 million people; about 3.5 million acres are irrigated; and 12 billion kilowatt-hours annually are generated in the United States portions, and 2.3 million people and 0.5 million acres are irrigated in Mexico.

Economic damages due to elevated salinity levels in the Colorado River System have been significantly reduced through a Control Program at very modest costs. In Arizona, California and Nevada economic damages have been reduced by $300 million per year, accomplished at a Federal funding level of less than $20 million per year. The Salinity Control Program is a cooperative watershed effort between several federal agencies and seven states designed to meet national, international and state water quality objectives.

Section 303 of the Clean Water Act (CWA) requires that water quality standards be reviewed al least once during each three-year period. Accordingly, the seven-sate Colorado River Basin

Salinity Control Forum (Forum) reviewed in 2002 the 1999 existing state-adopted and Environmental Protection Agency (EPA)-approved water quality standards for salinity and recommended no change in the numeric criteria at the three stations located on the lower mainstream of the Colorado River.

Station	Salinity (mg/l)/1
Below Hoover Dam	723
Below Parker Dam	747
At Imperial Dam/2	879

/1 Flow-weighted average annual salinity.
/2 Below Imperial Dam, salinity is controlled as a federal responsibility to meet the terms of the agreement with Mexico.

The Plan of Implementation as set forth in 2002 Review is designed to meet the objective of maintaining the salinity concentrations at or below the numeric criteria. The Plan of Implementation is designated for 15 million acre-feet per year and includes:

i) Completion of salinity control measures to the extend that each unit remains viable and appropriately cost-effective;

ii) Implementation of the Forum´s recommended and adopted policies for effluent limitations, principally under the National Pollutant Discharge Elimination Systems (NPDES) permit program established by Section 402 of the CWA as amended. The implemented policies are the following:
-"Policy for implementation of Colorado River Salinity Standards through the NPDES Permit Program";
-"Policy for use of brackish and or saline waters for industrial purposes";
--"Policy for implementation of Colorado River Salinity Standards through the NPDES Permit Program for intercepted ground water"; and
-"Policy for implementation of Colorado River Salinity Standards through the NPDES Permit Program for fish hatcheries".

iii) Implementation of nonpoint source management plans developed by the states and approved by EPA.

The salinity control measures remove 800,000 tons and an additional 1,000,000 tons per year of salt must be implemented y 2020. The adopted Plan of Implementation requires al least $24.3 million annually.

2.4.3 Lake Washington Ship Canal

Lake Union, Portage Bay, and Lake Washington were historically unconnected to Salmon Bay and Puget Sound. These bodies of water, collectively called the Lake Washington Ship Canal, were connected with the construction of the Hiram Chittenden (Ballard) Locks and the dredging of two canals (Fremont Cut and Montlake Cut) to Lake Washington in 1914. These changes have had a great impact on Lake Washington and connecting waters. The water level in Lake Washington was lowered, and Salmon Bay was converted from a tidal saltwater inlet into a

freshwater bay. As a result of the locks and their operation, saltwater seasonally intrudes into Salmon Bay and Lake Union.

The USACOE is responsible for the operation and maintenance of the locks. They are also responsible for keeping saltwater intrusion to a minimum. To minimize salt-water intrusion, the USACOE instituted the following measures.

- A basin was dredged and a drain was installed just above the large lock to collect saltwater. The heavier saltwater settles in this basin and is siphoned out through the drain using a mechanical pump.
- In 1966 a saltwater barrier was installed just downstream of the saltwater basin.

Despite these efforts, a saltwater wedge still intrudes into Salmon Bay. The USACOE monitors salinity at various points along the Ship Canal (Lower Locks, Ballard Bridge, Fremont Bridge, Gas Works Park, and UW Bridge). Salinity is continuously monitored at depth and near the surface. Washington State Water Quality Standards (**WAC 173–201A–130. Specific classifications-Freshwater)** state that "*(58) Lake Washington Ship Canal from Government Locks (river mile 1.0) to Lake Washington (river mile 8.6). Special condition - salinity shall not exceed one part per thousand (1.0 ppt) at any point or depth along a line that transects the ship canal at the University Bridge (rivermile 6.1)".* The primary goal of this requirement is to prevent saline water from passing east through the Montlake Cut into Lake Washington.

3.0 CONCLUSIONS

After reviewing the various international standards available for salinity and salinity-related parameters in the context of potable water and the protection of biological resources, the following conclusion may be made:

- Salinity-related parameters standards for potable water are very well established throughout the world and generally follow the guidelines of the WHO. The primary reason for this is that limits are established for aesthetic reasons (taste) and not for the protection of human health or the environment. It is widely accepted that a limit of 250 ppm (or 0.250 parts per thousand) for chlorides is adequate to prevent a potable water source from presenting an undesirable taste.
- General salinity standards established for the protection of biological resources are not very common because of the great variability of tolerance by organisms to the effect of changes in salinity. In addition, a general standard would cover a wide geographic area, and therefore may not be applicable to all situations encountered within a countries territory.
- In those countries where such general salinity and salinity-related parameter standards were identified the values were similar, typically 1 part per thousand for salinity and in the range of 1,000 umhos/cm for conductivity.
- Salinity and salinity-related parameter standards are more common for specific situations where salinity intrusion is a concern. This is the case of the San Francisco Bay, the Colorado River, and Lake Washington, to mention a few. Salinity standards in these bodies of water range from 0.723 parts per thousand to 2 parts per thousand.
- It is possible that the potable water limit for the salinity and salinity-related parameters standards for the Panama Canal lake system, may be the limiting factor when considering a standard for the protection of biologic organisms. The limit of 0.250 parts per thousand for potable water is lower than all standards reviewed for the protection of biologic organisms.

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