RECLAMATION
Managing Water in the West

Appendix E

Cienega de Santa Clara Literature Review

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado

Cienega de Santa Clara Literature Review

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Acronyms and Abbreviations

AF	acre-feet
Cienega	Cienega de Santa Clara
cfs	cubic feet per second
cm	centimeters
Delta	Colorado River Delta region
Demonstration Run	10 percent capacity test run of the YDP during 2007
Eh	reduction-oxidation potential
ET	evapotranspiration
Final EA	Yuma Desalting Plant Pilot Run Final Environmental Assessment
IBWC	International Boundary and Water Commission
Joint Report	Joint Report of the Principal Engineers Concerning U.S.-Mexico Joint Cooperative Actions Related to the Yuma Desalting Plant (YDP) Pilot Run and the Santa Clara Wetland
ha	hectares
m^3/s	cubic meters per second
mcm	million cubic meters
MGD	million gallons per day
mg/L	milligrams per liter
MODE	Main Outlet Drain Extension
mV	millivolts
ppm	parts per million
Reclamation	Bureau of Reclamation
ROE	residue on evaporation
SIB	Southerly International Border
TDS	total dissolved solids
TSC	Technical Service Center
Typha	*Typha domingensis* (cattail)
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
YCR	Yuma clapper rail
YDP	Yuma Desalting Plant
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
WMIDD	Wellton-Mohawk Irrigation and Drainage District

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Contents

Page

I. Background *1*

II . Introduction *3*

III . Purpose and scope *3*

IV . Technical data *4*

IV.A. Bypass Drain and Cienega inflows and water quality **4**

IV.B. Cienega inflows **6**

IV.C. Salinity and selenium concentrations **7**

Total dissolved solids 7

Selenium 10

IV.D. Relationship between Cienega inflows and wetland acreage (including open-water acreage) **12**

IV.E. Relationship between Cienega salinity and wetland vegetation (Typha) **13**

IV.F. Fauna habitats and populations review **15**

Selected fauna 15

Yuma clapper rail 15

Desert pupfish 17

Other bird species 18

Selenium effects 18

IV.G. Suggestions for data and information gathering **18**

V . Literature review *21*

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I. Background

This work summarizes a literature review process conducted during December 2008 and January 2009. The information was used to support bi-national consultations with Mexico that occurred between July 2008 and April 2009 through the International Boundary and Water Commission (IBWC). For further discussion of the consultation process with Mexico, see Appendix C of the Yuma Desalting Plant Pilot Run Environmental Assessment (Final EA).

An earlier version of this Literature Review was included as Appendix C of the Yuma Desalting Plant (YDP) Pilot Run Draft Environmental Assessment, dated May 2009. That version of the Literature Review included analysis of reductions in inflow and changes in water quality associated with the proposed Pilot Run. Subsequent to the issuance of the Draft EA, the U.S. and Mexico, through the IBWC, reached agreement on a program of joint cooperative actions related to the proposed Pilot Run of the YDP. These cooperative actions are described in the "Joint Report of the Principal Engineers Concerning U.S.-Mexico Joint Cooperative Actions Related to the Yuma Desalting Plant (YDP) Pilot Run and the Santa Clara Wetland" (Joint Report) provided in Appendix C of the Final EA. Particularly relevant to the Literature Review, the agreement states:

- The United States, Mexico, and a partnership of non-governmental organizations agree to each arrange for 10,000 acre-feet (12.3 million cubic meters [mcm]) of water, for a total of 30,000 acre-feet (37 mcm), in connection with the reduction in flow to the Santa Clara Wetland and the increase in salinity that would occur during the proposed YDP Pilot Run in the absence of the Joint Cooperative Actions identified in this agreement. These volumes shall be provided during the YDP Pilot Run period; however, each party may initiate conveyance of their respective volumes starting on the date a decision is made by the appropriate U.S. agency to proceed with the proposed YDP Pilot Run until the conclusion of the proposed Pilot Run.

The actions described in the Joint Report, taken voluntarily in the interest of international comity, address the reduction in flow and increase in salinity associated with the proposed YDP Pilot Run within the previously published Literature Review. Accordingly, the Literature Review has been updated and revised in the light of the joint cooperative actions identified in the Joint Report. This revised Literature Review no longer includes analyses of potential effects from the YDP Pilot Run on the Cienega de Santa Clara (Cienega).

Figure 1 provides a summary level water balance diagram for the proposed YDP Pilot Run. Figure 1 also includes a general depiction of how the cooperative actions identified in the Joint Report affect flows into the Bypass Drain.

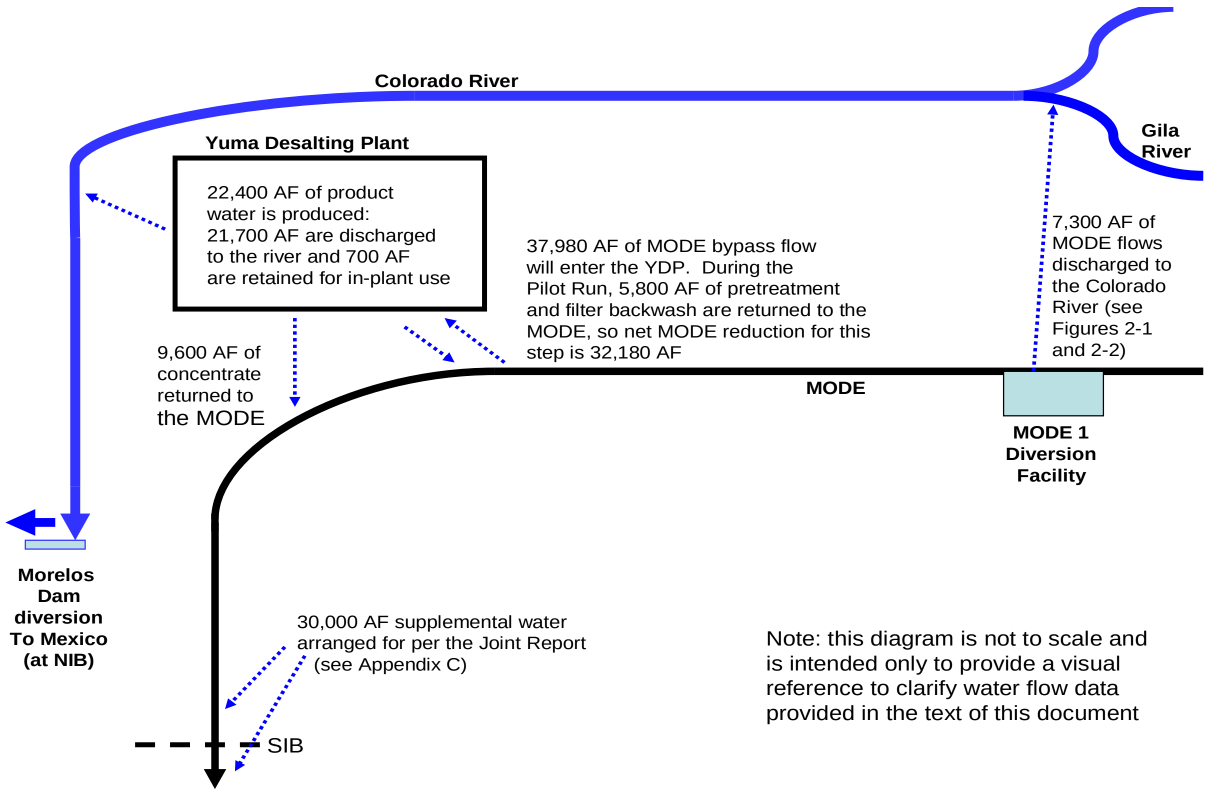

Figure 1. Summary level water balance (Reclamation 2008e).

The Joint Report also discusses a comprehensive bi-national monitoring program. The information contained in this Literature Review provides a repository of information and historical perspective of the Cienega for future monitoring efforts. Additionally, this document can be used consistent with Minute No. 306 by the members of the Colorado River Joint Cooperative Process Work Groups and Core Groups to further develop long-term approaches to maintain the environmental values of the Cienega. As agreed in the Joint Report, such approaches should focus on identifying and quantifying the habitat values to be preserved and then on identifying the amount, timing, quality, and source of water associated with preservation of those values.

I. Introduction

The Cienega represents one of the few remaining wetlands in the Colorado River Delta (Delta) region. Located in Mexico, it forms part of the Upper Gulf of California, and the Colorado River Delta Biosphere Reserve, created in 1993 (part of Ramsar Site 804 "Colorado River Delta Wetlands"). In addition, it is an internationally recognized site within the Western Hemisphere Shorebird Reserve Network, and a significant site within the North American Waterfowl Management Plan.

The Cienega is regarded by many as one of the most important wetlands of the Delta due to its considerable size, condition, and biodiversity. Some consider this brackish wetland to contain the largest population of cattails in the Delta. The Cienega brings together an interconnected corridor of Delta wetlands and provides habitat for resident and migratory wildlife.

II. Purpose and scope

The purpose of this Literature Review is to provide information about the Cienega, in response to initial public comments received from a public scoping meeting Reclamation held on October 8, 2008 on the YDP proposed Pilot Run, and from comments received in response to the Draft EA. This Literature Review focuses on relevant data from available literature, including current discharges from the Main Outlet Drain Extension (MODE)[1] and the Bypass Drain to the Cienega in Mexico, as well as Cienega water quality, water quantity, wetland acreage, and habitat for selected fauna (desert pupfish [*Cyprinodon m. macularius, C. m. eremus*], Yuma clapper rail [*Rallus longirostris yumanesis*] [YCR], and migratory shorebirds/waterfowl).

This work reviewed existing scientific literature gathered from several consultations with individuals and groups familiar with the Cienega. No subsequent investigations or evaluations have been done to support the topics presented in this document. It should also be noted that data cited from specific sources needs to be taken in context; they are not intended to necessarily represent the current status in the Cienega.

Additionally, relationships and/or interactions of the Cienega with external ecosystems and biotic communities are not discussed. This is not intended to imply that such relationships are insignificant or do not exist. For example, the U.S. Fish and Wildlife Service (USFWS) considers that the stability of the Cienega population is important for the YCRs as a whole (USFWS 2006a).

[1] Note that this review uses "MODE" to refer to the Main Outlet Drain Extension above its endpoint at Morelos Dam, and Bypass Drain to refer to the drain from the end of the MODE to the Bypass Drain endpoint at the Cienega. The names of these drains vary in the literature.

Issues concerning the Cienega may also impact the Upper Gulf of California and associated marine species. These topics are not within the scope of this Literature Review but are recognized here as significant nonetheless and should be addressed appropriately in the course of sound analysis and research in the future.

This Literature Review is not intended to make conclusions or recommendations concerning the operation of the YDP and the Cienega; however, it does provide some information to consider for decision making, monitoring plans, and data analyses.

The Bureau of Reclamation's (Reclamation) Technical Service Center (TSC) identified over 180 published and unpublished reports, articles, and dissertations, pertaining to the Cienega. Over 150 of these were reviewed. This list of identified documents is in Section V.

It should be noted that this is not considered to represent the full extent of all documents in existence pertinent to these topics. However, the Literature Review was the result of a significant effort to identify all relevant information, including at least four data calls to organizations and individuals, domestic and international, most familiar with the Cienega. Additionally, some reports identified in this Review are not specifically related to the Cienega and were not explicitly consulted or analyzed in detail. Nevertheless, some ancillary material noted in several public comments has been added to the list in Section V.

The quality, thoroughness, comprehensiveness, and consistency of the existing literature were noted to be diverse. For this work, all data are presented without qualification of value. This work was not intended to credit or discredit individual documents or sources of information. Variation in information generally indicates differences in observations and conclusions based on assessments and interpretations of data.

III. Technical data

The Cienega is primarily comprised of *Typha domingensis* (common name "cattails" and referred to as "Typha"). Reports of the areal extent of Typha range from approximately 8,000 to more than 11,000 acres.

IV.A. Bypass Drain and Cienega inflows and water quality

The current flow stream of the Bypass Drain is indicated to be about 107,000 acre-feet (AF) per year (148 cubic feet per second [cfs]) at about 2,660 parts per million (ppm) total dissolved solids (TDS).[2] For the Pilot Run, estimated water quantity and water quality of the Bypass Drain flow stream would be about 77,000 AF per year (106 cfs) at about 3,200 ppm TDS without the addition of the supplemental flows provided by the Joint Report. Other indicated inflows[3] to the Cienega are estimated to range from about 22,800 AF per year (31.5 cfs) to about 35,100 AF per year (48.5 cfs). The corresponding salinity of these other inflows is estimated to be from about 3,680 ppm TDS to about 2,860 ppm TDS (Reclamation 2008e). Current water quality within this wetland ranges from about 3,000 ppm TDS at the inflow area near the terminus of the Bypass Drain to about 6,000 ppm TDS at the southern edge of the Cienega. Figure 1 depicts the intended Pilot Run flows and consequent water quality in the MODE and flows to the Cienega. Table 1 presents the estimated annual Bypass Drain flows at Southerly International Border (SIB) from 1978 to 2008, as provided by the IBWC and Reclamation (2008e). Data are sourced in cubic meters per second (m^3/sec) and converted to AF for this table. Values are approximate.

Table 1. Calendar year annual flows of the Bypass Drain at the SIB, from 1978 to 2008 in AF.

Year	Annual Flows
1978	182,036
1979	177,928
1980	154,630
1981	148,426
1982	149,698
1983	179,157
1984	125,615
1985	129,704
1986	110,052
1987	97,741
1988	128,176
1989	138,624
1990	155,630
1991	140,682
1992	101,109
1993	61,439
1994	124,435

[2] For the Colorado River, salinity and TDS can be considered synonymous. In this appendix, the terms are used interchangeably.

[3] Includes Riito Drain and groundwater to the Cienega.

Table 1. Calendar year annual flows of the Bypass Drain at the SIB, from 1978 to 2008 in AF.

Year	Annual Flows
1995	125,475
1996	112,390
1997	89,155
1998	113,769
1999	78,679
2000	107,443
2001	103,746
2002	121,749
2003	114,734
2004	98,812
2005	107,433
2006	107,514
2007	106,944 (provisional)
2008	115,449 (provisional)

IV.B. Cienega inflows

Pursuant to the IBWC Minute 242, drain-water discharges from the MODE to the Bypass Drain began in 1977. The terminal end of the Bypass Drain is at the head of the Cienega, immediately adjacent to the terminal end of the Riito Drain (as it is commonly termed in the literature). Over time, the marshland attendant to the inflow from the Riito Drain expanded from the additional Bypass Drain inflow. Together, these two sources of water have produced the large wetland known as the Cienega.

Located wholly in Mexico, the Riito Drain and its flows are not controlled by Reclamation. The documented history of the Riito Drain's inflows is very widely varied in volume, salinity, and selenium (Cohen and Henges-Jeck 2001, Burnett et al. 1993, Burnett et al. 1997, University of Arizona 2007, and Flessa and García-Hernández 2007).

Water provided by the Bypass Drain was somewhat less saline than the inflow from the Riito Drain. The initial quality of water from the Bypass Drain (beginning in 1978) averaged about 3,500 ppm TDS. With time, water quality improved to about 2,500 to 2,600 ppm TDS as the quality of pumped drainage from the Wellton-Mohawk Irrigation and Drainage District (WMIDD) improved. From 1995 to 2007, the quantity of water delivered to the Bypass Drain has generally averaged about 150 cfs—or about an average of 108,600 AF per year.

Annual flows from 1995 to 2007 ranged from a low of 78,667 AF in 1999 to a high of 125,341 AF in 1995. Flows before this time period had wider ranges (Table 1). Flows for the past 5 years (2004 – 2008) averaged approximately 106,897 AF. While inflow represented by the Bypass Drain is measured at the border, the terminus of the Bypass Drain is about 35 miles south in Mexico, and these flows are largely unmeasured.

IV.C. Salinity and selenium concentrations

Total dissolved solids

The TDS of the WMIDD drainage water (which constitutes the water conveyed by the Bypass Drain) has been monitored by either the U.S. Geological Survey (USGS) or Reclamation since 1961 (Reclamation 2008b, Reclamation 2008c, and USGS 2008). Between 1961 and 1982, the USGS monitored the water quality discharge in the Wellton-Mohawk Main Outlet Drain upstream from Morelos Dam. The USGS TDS data are shown on Figure 2 using specific conductance in microsiemens per centimeter (µS/cm). The USGS sampled the drainage variably on a weekly to monthly basis over that period.

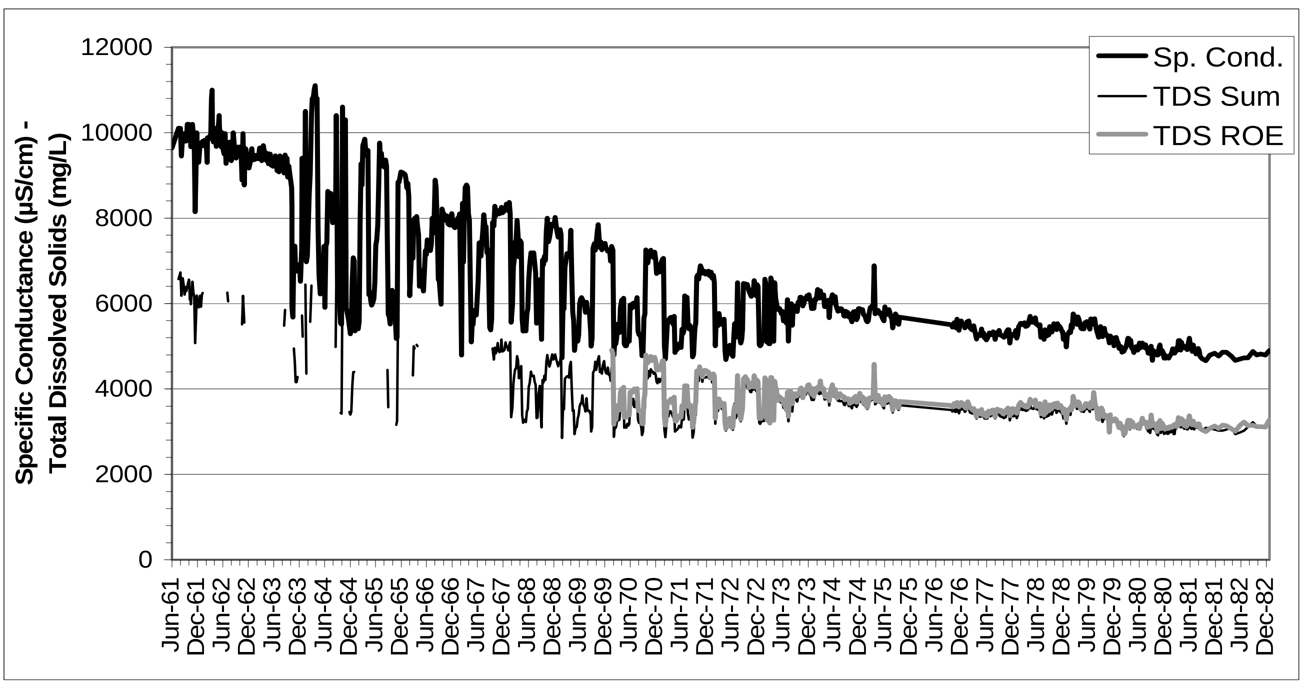

Figure 2. Specific conductance and TDS of the Wellton-Mohawk Main Outlet Drain near Yuma from June 1961 through December 1982 (data from USGS 2008).

Figure 2 shows two measures of TDS, the sum of the constituents (sum of the major ions) and the residue on evaporation (ROE).[4] The TDS data are somewhat spotty in the early record and consist of periodic calculations of the sum of constituents. There are no ROE data prior to water year 1970. To show the patterns of variation in TDS prior to their availability, specific conductance readings are also shown on Figure 2. The data collection began at the time of the initial discussion with Mexico over the TDS of the water delivered under the 1944 Water Treaty and associated implementing protocol, which entails the delivery of Colorado River water at Morelos Dam.

The TDS was between 6,000 and 7,000 milligrams per liter (mg/L) at the time that Mexico began to discuss the salinity of the Colorado River (Figure 2). The TDS was highly variable. Over the years, both the TDS and its variability have decreased, reflecting a combination of management actions and a decrease in the TDS of the WMIDD drainage. At the end of the USGS water quality monitoring record, the TDS of the drainage was around 3,000 mg/L (Figure 2).

Reclamation began monitoring the TDS of the Bypass Drain at the SIB in 1978. The Reclamation data (plotted on Figure 3) indicate that the decline in TDS of the WMIDD drain water (shown between 1961 and 1982 on Figure 2) has continued and appears to have leveled off in the mid -1990s (Figure 3).

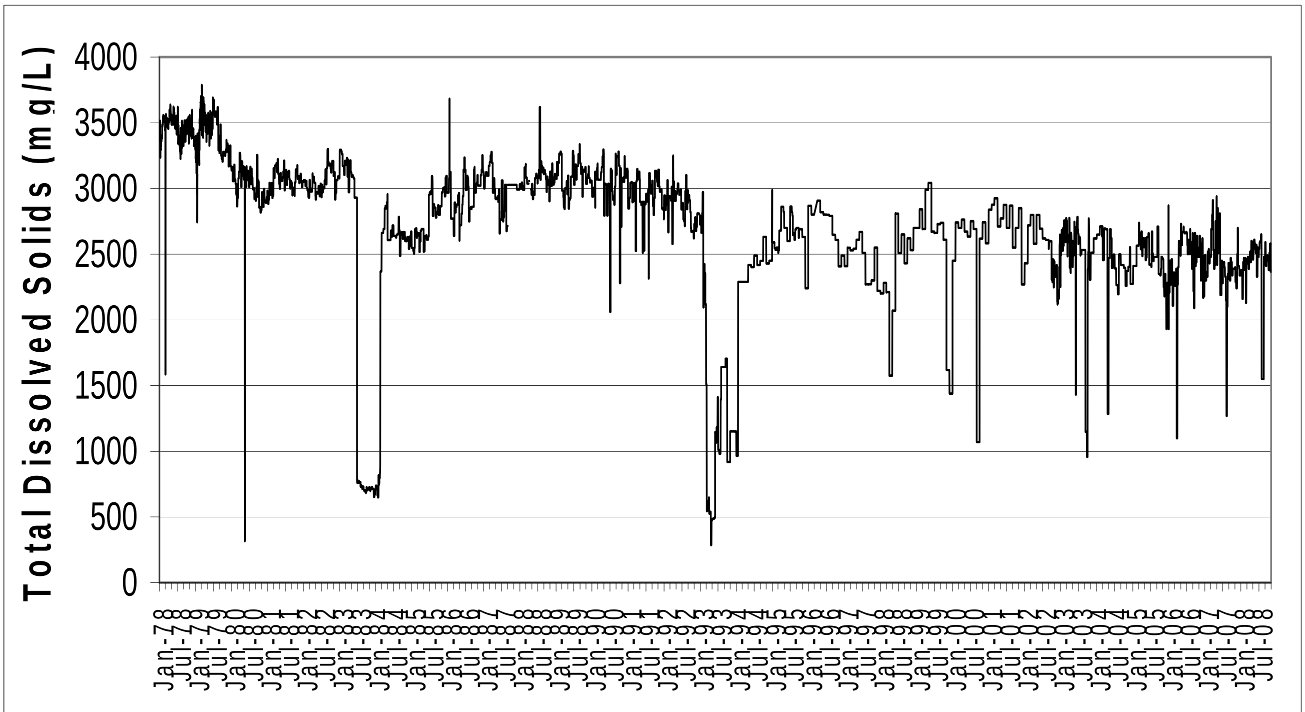

Figure 3. TDS concentrations in the Yuma Bypass Drain from January 1978 through October 2008. (Data from Reclamation 2008b and Reclamation 2008c).

4 ROE = weight of residual salts.

The TDS of the water in the Bypass Drain decreased from about 3,500 mg/L to about 3,000 mg/L between 1978 and 1983 (Figure 3). There was a decrease in TDS to around 700 mg/L during much of 1983 and 1984 after large-scale flooding of the lower Colorado River. The TDS gradually increased in the following years back to around 3,000 mg/L. There was another large-scale decrease in TDS during 1993 and 1994, to between 500 and 1,500 mg/L, following flooding on the Gila River. After that flood, TDS of the Bypass Drain increased, but TDS has since stabilized at around 2,500 mg/L (Figure 3).

The chemical composition of the WMIDD drainage has also changed. The ionic composition of the TDS from the USGS data set is shown on Figure 4.

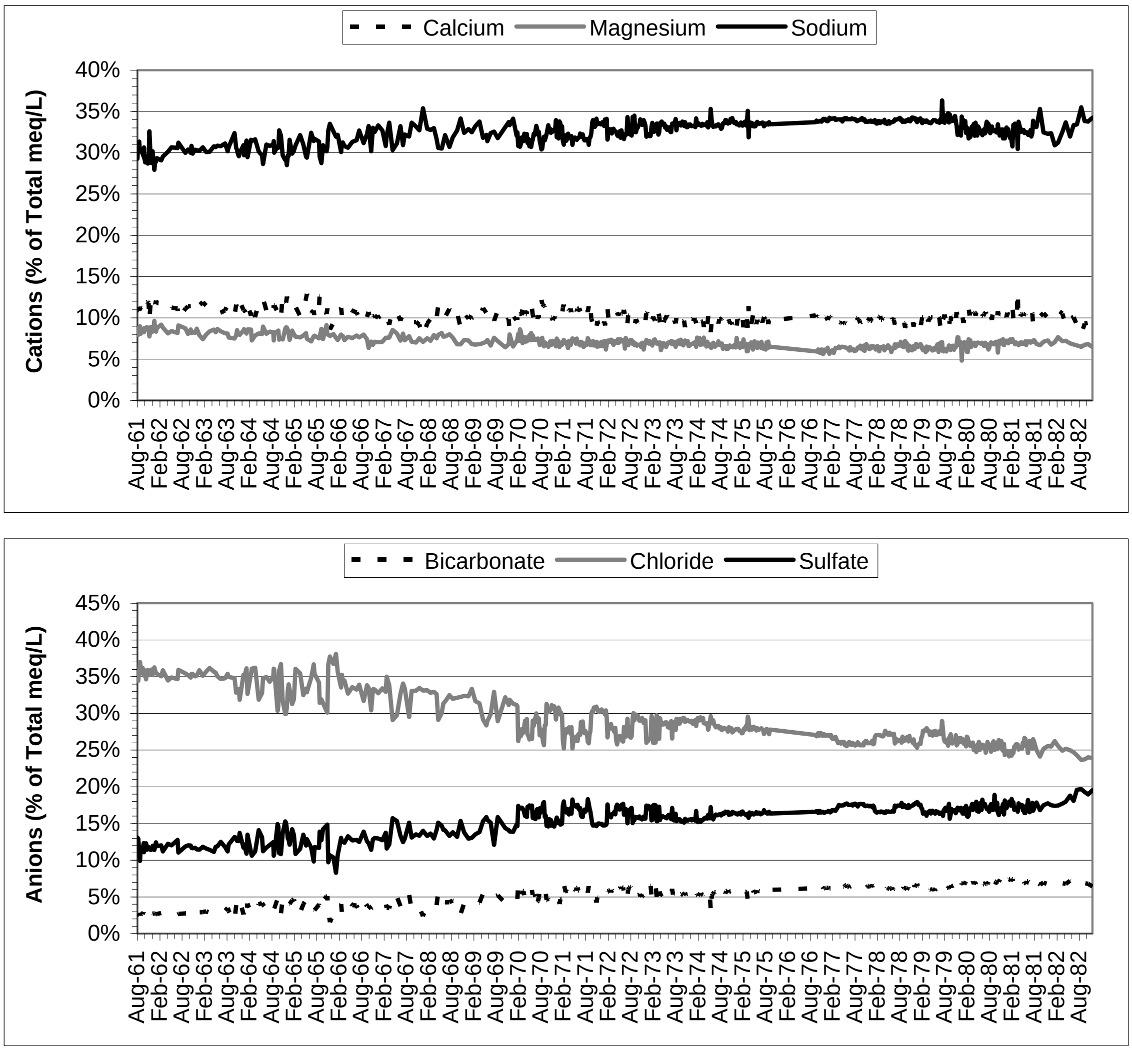

Figure 4. Percent composition of the TDS between 1961 and 1982.

The plots, which are intended to show the general trends in the percent composition of the major ions, indicate that there was an increase in sodium at the expense of calcium and magnesium among the cations, accompanied by a large-scale decrease in chloride and increases in sulfate and bicarbonate from1961 through 1982. As a result, what was a sodium-chloride-type water in 1961 became more of a sodium-chloride-sulfate-type water by 1982. There are no ionic data available after 1982 to evaluate whether the composition has changed further.

Selenium

The U.S. Environmental Protection Agency (USEPA) criterion for selenium for freshwater aquatic life is 5 micrograms per liter (µg/L) (USEPA 2006b) and the criterion for drinking water standards is 50 µg/L (USEPA 2006a). The Mexican selenium standard for the protection of fresh water aquatic life, including wetlands, is 8 µg/L and 5 µg/L for aquatic life in coastal and estuarine waters (Translated from: Mexico, ConAgua [National Commission of Water], 2007).

Selenium data from the Bypass Drain are limited to eight samples collected at the SIB at the time of the 10 percent capacity test run (Demonstration Run) of the YDP during 2007. The samples consisted of three prior to the Demonstration Run, four during the Demonstration Run, and one following the Demonstration Run. The selenium concentration was slightly lower (average 1.9 µg/L) during the test, compared to an average of 2.1 µg/L in the non-test samples. The difference could reflect removal of selenium during pre-treatment at the YDP, seasonal differences, adsorption, or other factors during the two periods.

Flessa and García-Hernández (2007) monitored “water quality at 16 stations, including the Cienega inflows (MODE and Riito), the marsh rim, and the vegetated core of the wetland. The Riito Drain was measured at points close to its entrance into the Cienega. The MODE was sampled under the last bridge before entering the Cienega.” (Note that these locations were in Mexico.) Flessa and García-Hernández (2007) also collected samples at five sites at the very beginning of the Demonstration Run. Those data showed selenium concentrations of 2.3 µg/L in the Bypass Drain and 2.1 µg/L in the Riito Drain. Selenium concentrations decreased within the Cienega – to 1.4 µg/L and then to 0.86 µg/L at the lower end of the vegetated zone. These results indicate that the selenium is being lost to either the sediments or the biota within the Cienega.

Data from García-Hernández et al. (2001a) indicate that selenium is being sequestered in the sediments within the Cienega. Other data show that there is some degree of biotic accumulation in the Cienega as well. Sediment selenium is very sensitive to the reduction-oxidation potential (Eh). Selenium solubility decreases with decreases in Eh. García-Hernández et al. (2001a) investigated selenium concentrations in sediments and biota at 12 sites within the Colorado River delta, including the Cienega. The study was designed to “determine the distribution of selenium in bottom materials and ecosystems in the delta.” The sediments in the Cienega were highly reducing (-90 millivolts [mV]). At that Eh and the pH (8.4) of the Cienega sediments, the selenium would be in the center of the stability field for elemental selenium in the selenium phase diagrams (Herring 1991 and Reddy and DeLaune 2008). In other words, the elemental selenium would be inert unless the Eh is raised significantly (something that is unlikely in wetlands soils).

The USGS collected two samples from the MODE upstream from the Bypass Drain in 1995 that included analyses for selenium. Those results showed selenium concentrations of 2 μg/L in March and <1 μg/L in June. These results indicate that lower selenium concentrations than those observed during the Demonstration Run are possible. However, there are no data on selenium removal by the YDP. If there is significant removal to the concentrate stream, then an increased concentration is possible. Alternatively, the data from the Demonstration Run indicate that lower selenium concentrations in the concentrate stream are also possible. The data collected during the Demonstration Run indicate that most of the selenium is lost in transit in the Cienega.

García-Hernández et al. (2001a) also investigated selenium concentrations in biota in a number of areas within the Colorado River delta. Selenium was elevated in some species but not in others. This would indicate that selenium is being lost to biota. However, species with reported elevated selenium are either not edible or are on a low trophic level (e.g., sailfin molly and brine shrimp). This suggests that there is a low probability of selenium bioaccumulation. More study would be required to accurately assess the impact of elevated selenium levels on the ecosystem's food chain.

Waterbirds exhibit some degree of species-specific variability in their sensitivity to reproductive effects of selenium. Three parts per million (ppm) is generally used as a baseline for selenium concentrations in various species of waterbird eggs from selenium-normal sampling sites. The EC_{50} (concentration where 50 percent of the population exhibits a response) for overt teratogenesis (birth defects) has been reported as 30 ppm for dabbling ducks (*Anatinae* ssp.), 58 ppm for black-necked stilts (*Himantopus mexicanus*), and 105 ppm for American avocets (*Recurvirostra Americana)* (Skorupa and Ohlendorf 1991). Rusk (1991) examined selenium concentrations in YCR from the lower Colorado River and indicated that they are at low risk of adult mortality from selenium but are highly susceptible to teratogenicity (risks of birth defects).

Selenium concentrations in waterbirds can vary even under relatively stable selenium levels in the environment, due to variable feeding habits and nesting conditions. Therefore, it is difficult to determine specific effects of selenium on nesting success directly from field studies (Henny et al. 2000).

IV.D. Relationship between Cienega inflows and wetland acreage (including open-water acreage)

Sykes (1937) described the Santa Clara Slough, the upper part of which was in approximately the same location as the present day Cienega. Prior to control of the Colorado River, Sykes observed that over-bank flood flows from the Colorado into the Rillito Salado (a side distributary channel of the Colorado delta) provided fresh-water inflow to the head of the Santa Clara Slough. Sykes observed that by 1930, after the cessation of flow from the Colorado River, the Santa Clara Slough had become a vestigial, estuarine stream course within an expansive salt flat on the eastern edge of the Colorado delta. The geomorphic expression of the Santa Clara Slough was similar to a shallow, terminal basin with an overflow to the sea. Fresh-water inflows to fill this basin were essentially non-existent. A broad shoal blocked the outlet of this basin at low tide (Sykes, 1937). Occasional tidal inflow, however, would flood the slough to produce a shallow estuarine lake within this basin. Some of this water would drain back to the sea as tidal outflow, while evaporation consumed much of the water that remained—producing a vast salt-flat within the southernmost part of the Colorado River delta.

Irrigated agricultural development adjacent to the Limitrophe along the east side of the Colorado River in Mexico required drainage. The Limitrophe is the 23-mile segment of the lower Colorado River that serves as the international boundary between the U.S. and Mexico. The Riito Drain, which provides the conveyance channel for this drainage and flows through the then-abandoned Rillito Salado stream course, met this need. The Rillito Salado once carried over-bank flood flows from the Colorado River as inflow to the head of the Santa Clara Slough. This drain discharged directly into the head of the Santa Clara Slough, having an estimated flow of 15 to 20 cfs with an average salinity of 5,200 ppm TDS (Reclamation 1975). By the early 1970s, effluent from the Riito Drain supported a small yet viable marsh about 150 feet wide and 3.5 miles long, with an area of about 75 acres. This marsh was completely isolated from the Colorado River, the Gulf of California, and seep-spring water along the base of the Desierto del Altar mesa escarpment to the east. At the terminus of this marsh in the salt flats, the salinity of the water was noted to be as high as 82,800 ppm TDS (Reclamation 1975).

Variations in water quality and water quantity have been postulated to have a direct relationship to the area covered by viable marsh and the growth of that marsh within the wetland area of the Cienega (Burnett et al. 1993, Flessa and García-Hernández 2007, Garcia et al. 1999, Glenn et al. 1995, Tanner et al. 1997a, and Zengel et al. 1994). These studies have discussed the effect of increased salinity on the growth of Typha, with some discussion regarding the water requirements of this cattail species and the consequences of a decline in water supply. Burnett et al. (1993) presented a water budget and salt balance analysis regarding changes in marsh area due to YDP operations. Glenn et al.

(1995) presented the results of greenhouse experiments with Typha that incorporated variations in salinity and observed changes in growth.

Various published study objectives and data considered a range of conditions in the Cienega. For instance, a greenhouse study by Glenn et al. (1995) provided direct evidence of the effect of increased in salinity on Typha and the relative resilience of Typha specimens taken from the Cienega. Another study by Zengel et al. (1995) documented the effect of a substantial loss of inflow to the Cienega and relative resilience of the marsh to a return of the inflow. Several models are available that are based upon the hydrology and water chemistry of the marsh (e.g., Hucklebridge 2008, Burnett et al. 1993, and Tanner et al. 1997a). Although these models may have similar conceptual bases, they differ in approach and in detail regarding their methodology in portraying the effect of changes in salinity and volumetric inflow to the marsh. For example, the model developed by Hucklebridge is presently the most comprehensive and temporally based. As Hucklebridge noted, the model "is designed primarily as a management tool to predict large-scale changes over relatively long time scales [yet] is not precise enough to evaluate small-scale wetlands dynamics and should not be used in these types of applications." The models by Burnett et al. (1993) and Tanner et al. (1997a) are concise calculation procedures that predict the total changes in wetland area based upon the changes in the salinity and quantity of water coming into the Cienega. But these models do not consider the temporal aspect of these changes.

IV.E. Relationship between Cienega salinity and wetland vegetation (Typha)

The relationship between Typha and salinity levels has been studied in both laboratory settings and through field observations directly on the Cienega. Zengel et al. (1995) reported that Typha is the dominant plant in the Cienega, densely covering the uppermost 10,300 acres of the wetland.

Although Typha is the predominant plant species, there are many other plant species in the Cienega that may contribute to wildlife habitat. A total of 24 wetland emergent plant species have been cataloged within the Cienega (Zengel et al. 1995). In addition to wetland species, many mesic[5] and upland species are known to provide habitat for a number of wildlife species. Other plant species of potential interest include rushes (*Juncus* spp.), saltgrass (*Distichlis spicata*), iodinebush (*Allenrolfea occidentalis*), saltcedar (*Tamarix*. spp.), phragmites (*Phragmites communis*), creosotebush (*Larrea tridentata),* white bursage (*Franseria dumosa*), and saltbush (*Atriplex polycarpa*).

[5] Habitat with a moderate or well-balanced supply of moisture.

Some of the studies have provided valuable information regarding the assessment of changes in the growth of Typha and changes in the vegetated area due to changes in water quality and water quantity. Changes in water levels and correlating changes in salinity may affect where Typha is able to grow. Davis (1994) reported the optimal depth for Typha was 58-105 centimeters (cm) (1.9 to 3.4 feet).

Lab studies were conducted by the University of Arizona with root-stock of Typha taken from Cienega and treated with water of varying salinity levels (Glenn et al. 1995). The response of Typha to increasing salinities was somewhat variable, but generally there were reductions in growth and plant vigor starting at salinities above 3,000 ppm. At 5,800 ppm, total dry matter production was reduced by 50 percent, at 8,000 ppm, new shoot initiation was reduced by 50 percent, and plant height was reduced by 50 percent at 9,500 ppm. Plants would not grow when treated with water above 10,000 to 11,000 ppm and appeared dead; only 1 out of the 4 plants recovered when treated with fresh water. These findings generally coincide with Burnett et al. (1997), who reported the salt tolerance of Typha to be 5,000 – 6,000 ppm.

Field observations of Typha and water salinity levels at the Cienega by Glenn et al. (1995) indicated that the plants were predominantly found in areas with salinities less than 6,000 ppm, although it was noted that stands in salinities higher than 3,000 ppm were of reduced stature and vigor. Typha was not found in areas with salinities higher than 8,000 ppm (Glenn et al. 1995).

Lab studies by Glenn et al. (1995) reported transpiration rates of Typha from 1.65 cm/day in fresh water to 0.42 cm/day at 15,000 ppm (above mortality level). Evapotranspiration (ET) was cut in half at salinities of 7,900 ppm, and water-use efficiency is reduced by 50 percent at 6,200 – 7,400 ppm. Glenn et al. (1995) extrapolated the lab-generated ET rates to the Cienega summer ET rates to 1.65 cm per day – 0.42 cm/day, which is the same as the 0 – 15,000 ppm range.

Several models of the relationship between salinity and Typha ET have been generated. Tanner et al. (1997b) explored models in which ET is a function of salinity levels alone, and in which ET is a both a function of—and contributes to—salinity levels by evaporative concentration. The output of these models is a graph of the relative value of inflow water versus salinity. Both models assumed 6,000 ppm as threshold for Typha growth, based on Glenn et al. (1995).

Typha generally shows tolerance to relatively high salinities, but as levels increase they exhibit lower vigor, growth, germination, and ET rate. As salinity levels increase, the osmotic potential for water uptake through the root system declines and subsequent transpiration is thus reduced. This is the primary way that increasing salinity levels deter growth and shoot germination as well as reduce the vigor of plants.

IV.F. Fauna habitats and populations review

Selected fauna

Numerous fauna use the Cienega for breeding, feeding, and as a migration stopover. Of the most concern are the federally endangered YCR and desert pupfish. Although most studies have focused on these two species, it should be noted that other "species of concern"[6] (as classified by USFWS) have been observed at the Cienega.[7] Species of concern include the California black rail (*Laterallus jamaicensis corurniculus*) and the gull-billed tern (*Sterna nilotica vanrossemi*).

Yuma clapper rail

The YCR was listed as an endangered subspecies in the U.S. in 1967 (32 FR 4001, 11 March 1967). The Yuma clapper rail recovery plan was signed in 1983 (USFWS 1983). Regarding populations of YCR in Mexico, USFWS stated: "There are significant differences in the level of protection and management afforded to the clapper rail in the United States and Mexico. United States populations are considered endangered under the Endangered Species Act and the United States' population is significant because its loss would significantly reduce the range and numbers of the subspecies" (USFWS 2006a). The Mexican population is included in NOM-059-SEMARNAT-2001 as a threatened species. The species is also one of the conservation priorities for the Upper Gulf of California Biosphere Reserve and the Delta.

The YCR inhabit vegetated wetland areas with relatively stable water levels and are found primarily in Typha and cattail/bulrush stands and occasionally in common reed (*Phragmites australis)*, saltcedar, arrowweed (*Pluchea sericea*), and iodinebush. It is relatively consistently reported that water and vegetation are significant factors in determining the quality of YCR habitat. The limiting factors for the YCR have been reported as availability of suitable habitat and food (USFWS 1983). YCRs were not discovered in zones with salinities higher than 8,000 ppm (Garcia et al. 1999 and Hinojosa-Huerta et al. 2008).

Surveys have been conducted at the Cienega to estimate population size and/or distribution for YCR using various sampling methodologies and extrapolation techniques (e.g. Piest and Campoy 1998, Eddleman 1989, Abarca et al. 1993, and Hinojosa-Huerta et al. 2001a). It is not within the scope of this document to assess these estimates to provide a conclusion on the status of the current

[6] "Species of concern" is an informal term that refers to species which the USFWS believes might be in need of concentrated conservation actions. Species of concern receive no legal protection and the use of the term does not necessarily mean that the species will eventually be proposed for listing as a threatened or endangered species.

[7] This work does not summarize the sightings of these species.

population of YCR at the Cienega. Researchers should analyze the methods and results of these and other pertinent literature sources to guide future studies.

Observed relationships between multiple habitat variables and YCR populations from the existing literature are summarized here. There is some variation in the literature as to the nature of preferences to specific habitat characteristics such as shorelines, vegetation densities, and proximity to open water. Several studies report a bias of YCRs toward margin habitats (interface between land and water) such as shorelines or hummocks, attributing the preference to lower stem densities and heights in shallower areas and the presence of loafing areas for adults and rearing areas for young. Piest and Campoy (1998) observed more YCR per ha of cattails along shorelines (1.09, 0.44 per acre) than the interior (0.79, 0.32 per acre). Todd (1986) also concluded that YCR had an affinity for shorelines. Conway et al. (1993) reported an avoidance of shorelines during the late breeding season through early winter.

There are also diverse reports of YCR inclination for cattail stem densities and habitat adjacent to open water. Conway and Nadeau (2005) state that cattails can become too dense and senescent to support high densities of YCR. In contrast, Tomlinson and Todd (1973) stated that the YCR commonly inhabit dense cattail and bulrush stands, and Rosenberg et al. (1991) reported that they prefer the tallest and densest cattail marshes. Piest and Campoy (1998) observed no preference by YCR either for or against habitat next to open water. However, Tomlinson and Todd (1973) reported that the YCR selected areas with shallow water where mud flats were prevalent for feeding grounds and that the densest populations were found in stands of vegetation divided by narrow channels of open water.

The quality of YCR habitat has been correlated with the successional stages of a wetland, which is primarily a product of hydrologic regimes and disturbances (such as fire and grazing). Hinojosa-Huerta et al. 2008 reported two examples: 1) changes in flow direction at the Cienega in 2003 promoted Typha growth at new sites that resulted in a population increase and shift in distribution towards these younger Typha stands and 2) a wildfire that burned 4,940 acres (2,000 hectares [ha]) in the central portion of the Cienega in the early part of 2006. In the latter case, Typha was observed growing back by late spring of the same year. YCR populations subsequently increased throughout the re-sprouted burned area. Other studies have shown similar Typha responses to burning and successive YCR usage of these areas (Piest and Campoy 1998 and Todd 1980). Ideally, YCR habitat would consist of a dynamic mosaic of age classes from regular disturbances such as fire to prevent senescence and overly dense vegetation (Hinojosa-Huerta et al. 2008 and Conway et al. 1993).

Both intentional and unintentional fires have been reported at the Cienega. Conway et al. (1993) theorized that the burning of marshes may benefit YCR by reducing stem densities and litter. Piest and Campoy (1998) did surveys just after a fire where an estimated 70-80 percent of cattail habitat had burned. They found that YCR use of burned and unburned habitat differed little. They reasoned that this was likely due to dramatic regrowth of the vegetation, as burned areas were visually similar to unburned areas at the time of the surveys. Todd (1980) also noted vigorous regrowth of Typha after burning, with no apparent affect on YCR densities the following season.

The literature describes nesting habitats of the YCR in various ways. Most sources report that YCR nests are found in dense vegetation along shorelines or small high sites within marshlands (Arizona Game and Fish nd). YCRs have been noted to adapt to changes in nesting areas: Arizona Game and Fish (nd) reports that the YCR will renest if eggs are lost. Conway and Eddleman (2000) report that males may build multiple nests that "can be used for incubation if predators or high water disturb the primary nest." They noted that "adults have the extraordinary ability to carry eggs in their bills to a new nest." Eddleman and Conway (1998) reported that for clappers in general, "Nest success is typically high in high-quality habitats; flooding and predation are the principal causes of nest failure. Pairs may renest up to 5 times after failure of previous nests, allowing populations to withstand significant losses of nests."

YCRs are known to have a diet consisting mainly of crayfish, insects, and fish. Other preferred food items include clams, frogs, isopods, spiders, snails, small seeds, and some plant species (Arizona Game and Fish Department nd). They forage on mud flats, sandbars, and within stands of vegetation (Todd 1986).

Movement patterns of YCR (including migration and dispersal) between the U.S. and Mexico are not well understood. Some evidence suggests that YCR can travel significant distances and successfully disperse to new habitats (USFWS 2006a). However, some localized YCR populations may be resident (Eddleman 1989 in USFWS 2006a). USFWS reports that "habitat that can be used by migrating, dispersing or transient individuals connects the [lower Colorado River], Gila River, and Mexican populations, so movement of individuals is not precluded." As migration is not precluded, Mexican populations of the YCR may be significant to U.S. populations (USFWS 2006a).

As discussed above, field observations and laboratory studies have demonstrated a negative correlation between increasing water salinities and Typha height, density, and vigor. Studies from the Cienega have found a positive association with YCR abundance and Typha and thus have correlated YCR densities indirectly with water salinity.

Desert pupfish

An Environmental Statement from Reclamation (1975) reported numerous fish species at the Cienega, including carp (*Cyprinus carpio*), mosquito fish (*Gambusia affinis)*, red shiner (*Cyprinella lutrensis*), mollies (*Poecilia* ssp.*)*, and desert pupfish, with the desert pupfish noted as by far the most numerous species—comprising about 80 to 90 percent of the fish fauna in the marsh in the early 1970s.

The desert pupfish was listed as an endangered species in 1986 (50 CFR Part 17, Mar 31, 1986). The reasons for listing included: habitat loss and modification due to dewatering of streams and marshlands, stream impoundments, channelization, diversion, livestock grazing, mining, pollution, and interactions with predatory and competitive non-native fishes (USFWS 1992). Desert pupfish inhabit primarily shallow (<30 to 40 cm) water with little or no emergent vegetation and soft bottoms (mud or grass) (Abarca et al. 1993). These areas are often shallow pockets of water with little or no connectivity to the main water body, where predator fish can not penetrate (Zengel and Glenn 1996). Desert pupfish are known to tolerate extreme environmental conditions, including extremes in water temperature (up to 45º C), oxygen levels (as low as 0.1-0.4 mg/L), and salinity (as high as 68,000 ppm) (Marsh and Sada 1993, Lowe et al. 1967, and Barlow 1958).

Various piscivorous birds along with the Virginia rail and the endangered YCR inhabit the Cienega (Reclamation 1975). The threat of exotic fishes to the desert pupfish in Mexico has been noted (Hendrickson and Varela-Romero 1989) as desert pupfish are susceptible to predation and interruptions in breeding (Marsh and Sada 1993 and Hendrickson and Varela-Romero 1989). Marsh and Sada (1993) identified control of non-native aquatic species as a primary requirement for recovery of the desert pupfish throughout its range.

Other bird species

The Cienega is used by many bird species, including shorebirds, wading birds, marsh birds, and migratory waterfowl. These birds depend heavily on benthic (bottom-dwelling) macroinvertebrates as a food source. Few sources of detailed information on population dynamics of the numerous bird communities at the Cienega were found in the course of this literature review. Further efforts should be made to locate such information as a foundation to guide future studies.

Selenium effects

See previous section, "IV.C. Salinity and selenium concentrations" for a discussion of selenium effects to wildlife.

IV.G. Suggestions for data and information gathering

The Joint Report offers a mechanism to provide $250,000 to fund a comprehensive, bi-national monitoring program. This funding, in conjunction with this Literature Review, is an excellent opportunity for monitoring and study efforts at the Cienega. These efforts could shed light on many aspects of the complex of hydrologic, biotic, and ecologic dynamics present, particularly if this information is widely distributed among interested parties. Studies incorporating rigorous scientific processes will provide a substantial foundation to clarify areas of uncertainty, supporting the need for furthering a robust monitoring plan and subsequent research. Considerations should be given to conducting simple data analyses and causal hypothesis tests that support, or refute, a central hypothesis regarding aspects of the Cienega.

Other factors to consider are the temporal and spatial resolution of the activities to be conducted. Assessment of long and/or short-term, localized and/or dispersed effects should be integrated into projects when and where applicable. For example, species such as microorganisms and insects can be used as indicator species for short-term effects of changes to the Cienega, due to their rapid development, while mature Typha stands may be better indicators of long-term effects due to their ability to recover from shorter-term changes.

At present, a clear, central hypothesis cannot be unambiguously evaluated regarding the impact to the Cienega from various changes in present conditions. Many observations and studies are available regarding the relationship between the quantity and quality of inflows to the Cienega, and vegetative status of the marsh. However, this body of presently available evidence is insufficient to understand the time-related aspect of the impact to the marsh, or permanence in changes to the growth, stature, and vigor of the marsh, consequent to various changes that may occur in water quantity and salinity. In other words, the relationship of the changes to the consequent temporal impacts poses questions that cannot be answered directly.

Evaluating a clear, central hypothesis will require a model that sufficiently integrates known information about various factors within the Cienega so that the response of the marsh to known temporal changes may be confirmed. With such a model, the posed questions about changes in present conditions may be evaluated. At present we do not have sufficient data to formulate such a model. Nevertheless, the operations presented in the bi-national agreement provide an opportunity to implement a comprehensive monitoring program at the Cienega during a period of what may be termed baseline conditions. Such a program would provide the necessary data about many interactive factors at the marsh, including ET, changes in ground water, changes in water inflow quantity and quality, as well as a comprehensive on-the-ground assessment of the marsh as an ecosystem. This information, in addition to other data gathered as part of the monitoring program, would then be available to support a modeling effort to evaluate potential changes in the marsh environment.

Emphasis should be placed on discussions with all interested parties to assist in creating joint monitoring and research efforts. Collaborative endeavors could facilitate defining priority parameters to be examined as well as potential mitigation, recovery, and/or compensation measures to be taken. Joint planning processes should focus on identifying and quantifying the habitat values to be preserved. The amount, timing, quality and source of water associated with preservation of those habitat values should then be identified. This process would assist in the validation of specific steps to be taken in order to support future decisions regarding management of the Cienega.

IV. Literature review

This list shows the articles, publications, and data identified during the literature search as a part of this research. Not all documents were cited in this report; some were unavailable.

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