Water Resources Guide

Topock Marsh Unit, Havasu National Wildlife Refuge

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For Andrew Hautzinger, Region 2, USFWS

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Chapter 1 . INTRODUCTION

This guide is a water resource primer for decision-makers and operation mangers at the Havasu National Wildlife Refuge (HNWR). Its purpose is to concisely describe and quantify, using a water balance approach, the Refuge's entitlement, recent diversions, consumptive use, and water availability, all in the context of recent and significant infrastructure changes in 2011.

In addition, in 2014 the HNWR and the other Refuges on the Lower Colorado River (LCR) must plan their management goals and objectives for the next decade. The result will be a Comprehensive Conservation Plan (CCP) that identifies issues and opportunity to improve habitat for flora and fauna. In arid environments, restoration and enhancement nearly always involve water use. This manual provides a water compliance perspective for managers and planners who have the difficult task of balancing competing objectives.

1.1. Legal Framework

The Havasu National Wildlife Refuge is located in the Lower Colorado River Basin, in Mohave Valley, near Needles, CA (Figure 1). The legal history that led to establishment of HNWR and its water right is reviewed by Shoreline Engineering & Restoration (SE&R, 2006). The Arizona vs. California U.S. Supreme Court Decree of March 9, 1964, allocated certain water rights to the Havasu National Wildlife Refuge to fulfill the purposes of the refuge not to exceed 41,839 acre-feet (ac-ft) of water diverted from the mainstream or 37,339 ac-ft of consumptive use of mainstream water, whichever is less. Consumptive use is simplistically defined as diversions minus return flows . The phrase "whichever is less" is inferred by the United States Bureau of Reclamation (USBR) to also include "whichever occurs first" (pers. comm., Paul Matuska, USBR, 2011). Given these simple constraints, one baseline approach for Refuge managers to ensure water compliance is to divert the maximum 41,839 ac-ft and return 4,500 ac-ft by the last day of the calendar year.

For the Refuge, any surface water diverted into the marsh, and, any groundwater extracted from wells in the floodplain (see below), must be reported as a diversion. In practice, the USBR calculates the diversions from the mainstream by gathering flowmeter data from various Refuge measurement sites (most available online and are listed in this document's *References* section), while the Refuge staff also provide annual totalizer values from their two groundwater wells (Bermuda and Sacramento Wash).

The decree also requires USBR to formally tabulate and report all diversions and return flows from the mainstream annually (USBR, 2011). Previous years back to 2003 are summarized in this report below (see Table 2). SE&R (2006) has presented diversion and consumptive use data from 1966 through 2003; although these data have been used for water accounting, they did not include the Farm Ditch inflows until 2005, and the USGS inlet values have some significant uncertainty (see Guay, 2001; SE&R, 2006).

1.1.1. Groundwater

Groundwater extracted from wells located on the floodplain are presumed (by the USBR) to be recharged by the Colorado River and, therefore, are considered diversions from the mainstream (paraphrased from Owen-Joyce, 1996). For the Refuge, this means water pumped from either the Bermuda Field well or the new Sacramento Wash well (or any well on or near the floodplain) must be reported annually and counted against the entitlement as a diversion.

However, there is an important point to be made about groundwater in the floodplain. Water that is migrating through the floodplain as groundwater, even within Refuge property, is not specifically addressed in decree water accounting and is treated as a "system-wide" resource whether lost or gained. For example, groundwater consumed by phreatophyte vegetation on the HNWR is not considered a mainstream diversion but is clearly used by the Refuge for a beneficial use. The water might have originated as diverted mainstream water that seeped from an unlined canal (e.g., Topock Inlet or Farm Ditch), was irrigation water applied north of the Refuge boundary, or is river water that simply seeped unmeasured into the floodplain.

Chapter 2 . WATER INFLOWS

2.1. Lower Colorado River Flows in Mohave Valley

Water operations of the Lower Colorado River are thoroughly described by the USBR (USBR, 2011a). In Mohave Valley, the average annual discharge from Davis Dam for the period 1951–2010 was 13,679 ± 3,998 (1σ) cubic feet second (cfs), with an annual maximum and minimum of 29,830 cfs in 1984 and 10,060 cfs in 1993, respectively (USGS, 2011). Figure 2 shows more recent river discharge data for 1983–2010. Table 1 shows that in the past two decades peak monthly flows (≥ 16,300 cfs) occur in April through July, with low flows (≤ 10,200 cfs) occurring November through January. Summer releases correspond with peak demands for irrigation flows and power generation. The diurnal difference in river elevation (stage) between peak and low flow at the USGS structure on the Inlet Canal is about four to five feet in the summer (Guay, 2001). The daily oscillations are attenuated in the downstream direction to about three feet near Topock Gorge.

Refuge staff can view three-day projected releases from Davis Dam at the USBR website (USBR, 2011a). The releases are generally stepped in increments that roughly correspond to openings of individual penstocks for the five generator units they operate (~5,000 cfs/unit). The actual releases are measured by USGS at Davis Dam and can be found at the USGS website (USGS, 2011). The arrival times of Davis Dam releases at the Topock Inlet and the South Dike are discussed briefly in Section 3.1.1..

2.2. Diversions into Topock Marsh

Figure 1 shows the four locations where the Colorado River (surface water) can be diverted into Topock Marsh: (1) Inlet Canal, (2) Fire Break Canal (completed in 2011),

(3) Farm Ditch, and (4) South Dike Outlet (under special conditions). Each site has at least one water measurement gage that is capable of measuring bi-directional flow and whose data are available in near real-time at USBR and USGS websites (USBR, 2011a; USGS, 2011).

There are two locations along the South Dike where the marsh and river are in close proximity and could, with moderate effort, be connected to exchange water via mechanical pumping or gravity flow: these include (1) Beal Lake outlet and (2) a Topock Backwater channel and slough about 200 yards south of the former.

2.2.1. Topock Inlet Canal (USGS Diversion Structure)

Table 2 shows the diversions through the Topock Inlet Canal (TIC/Inlet Canal) into Topock Marsh from 2003–2010 (Line 1). The water measurement instrumentation was changed in about 2005 from a traditional two-float and chart recorder to a bi-directional acoustical flowmeter with telemetry. Today, near real-time flow data are found at USGS website (USGS, 2011). The 2003 and 2004 values seem unreliable given Davis Dam releases were near average those years -- 14,100 cfs and 13,660 cfs, respectively (Figure 2). The 2005–2010 inlet data appear more consistent. The uncertainty of the former USGS measurement system has been discussed previously by Guay (2001), where he points out that requisite conditions for measurement accuracy at the site are often unmet.

In the first mile of the Inlet Canal, three irrigation pumps extract water from the canal during the growing season to irrigate nearby farms. Two of three pumps, Fort Mohave Indian Tribe and Vanderslice, are metered and reported by USBR, but it is unclear how the Chesney pump (Pelican Farms), which irrigates about 60 acres, is accounted for. The two metered farmers annually withdraw about 13 percent of the inflows that pass through the USGS structure. Flows in the four-mile sand-lined Inlet Canal experience a transmission loss of about 12 percent before entering the north end of Topock Marsh (location of a second acoustical flowmeter). That means that the unlined canal lost on average ***3,826 ac-ft*** in four miles per year, or roughly 957 ac-ft/mile, or about three percent per mile.

During 2010-11, the USFWS contracted URS Inc., to design, and C3, LLC (Greenwood Village, CO), to construct a sheet pile structure one mile east of the USGS gates to impound flows in the Inlet Canal as a forebay for the three farmers and their irrigation pumps. The new structure has two 4'x 4' screw gates that can be opened/closed for special situations (e.g., fires, floods, circulation, etc). The design capacity of the inlet control gate structure is 200 cfs. The required differential head upstream and downstream of the control gate structure to pass 200 cfs is 1.5 feet (URS, 2010).

The top elevation of the initial structure was at 458.0 feet above mean sea level (ft amsl). After a washout episode on 3 March 2011, 1.5 feet of "C" channel was wielded on edge to raise the top of the structure to 459.5 ft amsl. However, the river elevation peak stage can be upwards of 461.5 ft amsl (see Guay 2001), so at static equilibrium, the structure may experience similar water elevations. At the time of this report, USFWS was investigating automated gates in the inlet canal to maintain water levels during the irrigation season (mid-March through early September).

It is recommended that seepage losses in that one-mile stretch be determined for several months if the Refuge plans to use the Inlet Canal and/or the USBR continues to consider the Inlet Canal a USFWS diversion. The simplest method may be to close the new sheet pile structure for extended periods of a few weeks to a month during irrigation season (allowing water in for farmers), then subtract pump withdrawals (the Chesney pump may need a meter but it can be reasonably estimated) from the USGS inlet flow measurements. The difference between the inflows and pump withdrawals is a reasonable estimate of seepage losses. If the seepage is substantial (>500 ac-ft/year) as predicted, the USFWS can make a case that the loss is not related to the operation of the marsh or consider lining the ditch. At a conservative estimate of $250 per ac-ft, 500 ac-ft is worth $125,000.

Alternatively, the Refuge may want to consider balancing water conservation against the habitat value that the Inlet Canal provides. There is relatively little incised, shaded, sand bottom, wooded “channel-like” habitat on the refuge (others areas include Beal Channel, Farm Ditch, and a few marsh backwaters). The Inlet Canal seems to provide good habitat for many animals and observers spot hunting raptors, a variety of water birds, spawning fishes, and beavers. In addition, the Inlet Canal is somewhat excluded from public access, but conversely the Refuge only owns a small portion of the canal and surrounding property.

2.2.2. Fire Break Canal

The USFWS awarded a construction contract on 29 March, 2010 to C3 LLC for the *Topock Marsh Infrastructure Improvement Phase I.* The first phase included three main infrastructure improvements: (1) a sheet pile gated control structure on the existing Inlet Canal (see above), (2) a polyethylene liner with a new slide gate on the Farm Ditch culvert, and (3) a ~2.8-mile concrete-lined inlet canal across the former Fire Break (so named because it was cleared to maintain a fire break and fence line east and west along the northern edge of the Refuge property). The Fire Break Canal (FBC) has a new gravity control structure on the western end at the point of diversion off of the Colorado River. The notice to proceed was issued on 16 August 2010, C3 LLC established a field presence in mid-September, and the on-site kick-off meeting was held 19 October 2010. The proposed completion date was initially mid-March 2011, in part, due to endangered species habitat concerns, but geotechnical and design challenges forced construction to continue through the summer of 2011 (author left site late June). The final inspection occurred on 20 September 2011.

Final Phase II negotiations were underway in July 2011; up to an additional $2.5M will be used to install four line shaft driven vertical axial flow pumps mounted on a barge pump station that will be anchored in the Fire Break inlet between the river and the levee road. Water is routed via flexible hosing to a junction box that discharges into the lined canal. The barge pumping station will provide a total capacity of 40 cfs, or 79.2 ac-ft/day. Since the pump shafts extend below the base of the barge (which has support legs), the pumps will operate to a minimum river elevation of 451.0 ft amsl. The barge pumps will augment the gravity feed system.

The new ~14,726 foot-long, concrete lined (lined portion ~13,800 ft), Fire Break Canal (FBC) will replace the four-mile, sand-lined, Topock Inlet Canal. Unlike the TIC, the FBC will conserve water (minimal seepage loss) and be entirely located on USFWS property. The features of the structure are described in the *Design Summary Report* (USR, 2010), *Technical Specifications* (URS, 2010a), and depicted in *Topock Design Drawings* (URS, 2010b).

The design capacity of the FBC inlet control gate structure is 200 cfs, equivalent to 397 ac-ft/day. This typically includes maintaining one (1) foot of freeboard on the 7.5 foot deep trapezoidal canal. The bottom sill of the reinforced concrete pipe (RCP) leading to the lined canal (the river side) has an elevation of 453.0 ft amsl. The RCP passes under the levee road and discharges into the west end of the canal. The lined canal section appears nearly flat but has a grade of 0.0107% or 0.000107 ft/ft. Technical drawings indicate the canal bottom elevation is about 452.5 ft amsl (west end) and the marsh end is 451.04 ft amsl (URS, 2010b), a drop of about 1.5 ft. As a check, the lined canal is approximately 13,800 ft long (estimate of lined length), therefore the canal would drop 0.000107 x 13,800, or 1.476 ft – consistent with drawings. That means, for example, that if the marsh elevation was at 454.0 ft amsl, then the water depths within the canal would back up with about three (3) ft on the east end and about 1.5 ft on the west end. There is an emergency spillway on the east end on southern canal bank with design capacity of approximately 150 cfs. The spillway is a low-head broad crested weir, approximately 200 feet in length, with a design depth of a minimum of 6 inches deep.

The Colorado River rarely has idealized unvarying flows. Instead, the river has seasonal high flows in the summer, with diurnal fluctuations of about four (4) feet in Mohave Valley (Guay, 2001). The flow peaks are often short-lived. URS (2010) recognized that maximum flows would be short in duration and provided some estimates of minimum, mean, and maximum flows (Table 3). They looked at four years (1999–2002 & 2009) of river elevation data for the month of June and adjusted the elevations from the Needles Bridge gage to other sites.

They found the minimum river elevation was 453.18 ft amsl, the maximum elevation was 461.2 ft amsl, and the unweighted mean value was approximately 457.8 ft amsl. They noted a significance difference in the low values between the two datasets (2009 value is 6.6 ft lower); Figure 2 does suggest river flows were lower in 2009, but channel down cutting (degradation) cannot be ruled out.

Figure 3 shows the canal gravity flow discharge for various river and marsh elevations. The capacity of the concrete lined canal with 1-foot of freeboard will convey 200 cfs at a Colorado River elevation of 462.2 ft amsl and a mid-marsh elevation of 455.28 ft amsl. Considering a typical high marsh elevation of 456.7 ft amsl and high Colorado River elevation of 462.8 ft amsl, the canal's flow of 200 cfs will reduce the freeboard to less than 1 foot but will remain within the banks of the canal (URS, 2010).

URS used hourly stream gage data for the "wet" months for the period from June 2006 thru September 2009 to determine the percentage of time the Colorado River elevation is sufficient to produce specified discharges in the FBC. Table 4 shows that the FBC can gravity flow about 50 and 100 cubic feet per second 63 and 34 percent of the time, respectively (URS, 2010).

Given these values, how long to fill the marsh? Guay (2001) shows the typical winter marsh elevation (~454.0 ft amsl) has a volume of about 5,573 ac-ft and a typical summer elevation (~456.5 ft amsl) has a volume of 14,495 ac-ft, a difference of 8,922 ac-ft (Table 5). The URS data suggests the average flow will be about 65.5 cfs or 130 ac-ft/day, so it would take 69 days to fill using only the FBC. For comparison, the Inlet Canal in 2010 (June – Sept) averaged 50.3 cfs at the north dike. If these inflows were augmented by the Farm Ditch, say another 11 cfs, then the typical inflows would be approximately 122 ac-ft day, with infill taking about 73 days. Guay (2001) showed average river stage at the Topock Inlet Canal was in the range of about 461.0 ft amsl for the months of April and May in 1997. URS (2010) data suggests this would yield an adjusted river stage at the FBC of approximately 460.5 ft amsl. River flows in the spring can be more uniform, thus the peak inflows may be approximately 160 cfs (Figure 3). If this was augmented with Farm Ditch peak flows of 50 to 80 cfs, the total combined average inflows could be in the range of 225 cfs or 446 ac-ft/day. So in an idealized case (steady high flows), the marsh would receive about 13,385 ac-ft/month and could be filled in under a month (20 days). As a reality check, Figure 4 shows a partial record of surface water elevations at Topock Marsh from 1997 through 2011. The infill rate after 2005 is typically three (~90 days) to five months (~150 days). The actual infill rate will vary with river flows and marsh elevation and is probably somewhere between these estimates of 20 and 150 days. In general, the projected flow rates in the FBC seem fairly consistent with previous operations at the Refuge, but under certain conditions, the infrastructure improvements will significantly increase the Refuge's infill capability. The second phase's pump station would further improve year-round infill capacities.

2.2.3. Farm Ditch

The two-mile long Farm Ditch, constructed in 1959 and extended in 1968, is a surface inflow and diversion point for water accounting purposes (Figure 1). It has been instrumented with bidirectional acoustic flowmeters since 2005, which is also the first year that the Farm Ditch was officially listed as a diversion for HNWR in the Decree Accounting reports (USBR, 2011). The instrument is located about one mile (1.02 miles) east of the river at the impounded site where former propeller meters were installed by Guay (2001) during a 1995-98 hydrologic study.

In 2011, as part of infrastructure improvements (Section 2.2.2), the aging Farm Ditch had three modifications done to it. First, Insituform Inc., installed a 600-foot curedin-place pipe (CIPP) polyethylene liner to the 42-inch corrugated metal pipe that underlies the levee road connecting the river to the open ditch near the maintenance shop. In addition, a new stainless steel slide gate was mounted at the river to replace the existing corroded structure. At the time of writing, USFWS plans to relocate the USBR gage into or near the culvert adjacent the maintenance facility. Flap gates installed on the existing culvert may need to be modified or relocated (at marsh culvert). Vegetation that impedes inflow has not been cleared for nearly a decade. In addition, the culvert at the discharge end of the Farm Ditch at Glory Hole appears to be undersized and flow could be enhanced by adding a second culvert or enlarging the existing one.

During 2005–2010, an average of 5,992 ac-ft was annually diverted through the Farm Ditch (Table 2). This accounts for about 16 percent of the combined decree accounting diversions -- Inlet Canal plus Farm Ditch. Assuming a six (6) percent transmission loss across the two mile stretch, the Refuge could conserve approximately 370 ac-ft if the Farm Ditch was no longer used or was lined. Not using the conveyance may have some ecological downsides and adversely affect water circulation in the dredged channel in and around the Glory Hole.

2.3. Bermuda Field Well

The Bermuda Field well is located on the north central edge of the Bermuda grass pasture northeast of the maintenance shop (Figure 1). The recharge source for the approximately 96-foot deep well is certainly Colorado River water since the well is located in the active floodplain only 0.6 miles from the river and 970 feet from the Farm Ditch (river water conveyance). Originally drilled in 1962, then redrilled twice (1965, 1995), the current well is equipped with a 75-horsepower turbine pump (electric), that can produce about 1,800 gallons per minute (gpm). The surficial material is fluvial fine sand characterized by Malmon et al. (2009) as channel and floodplain deposits, but is locally described as “sugar sand.”

The well water currently supplies a pivot irrigation system for the production of approximately 53 acres of grasses in the fall and winter months. The irrigation cycle generally begins in mid-August and continues as needed throughout the winter. Bermuda grass is no longer planted, but it germinates on its own with irrigation in late summer. The bermuda grass is an erosion control tool and provides a green browse for geese in the early fall and rhizomes for snow geese in the winter. Annual ryegrass is sown within the bermuda grass shoots; when the bermuda grass goes dormant in the late fall, the ryegrass is available as a green browse for geese (USFWS, 2010).

The well has/had a functioning flowmeter and totalizer that should be provided to the USBR annually for water accounting purposes, but it appears the value has been estimated for several years (Table 2). On an average year, the ET loss is about 2.4 ft (using 2010 data) from August through December, so it’s reasonable to assume that USFWS is applying three feet of water per year over 53 acres for an annual use of 212 ac-ft.

An adjacent area merits discussion. Along the south end of the Bermuda Field are 20 acres of unmanaged maturing native trees (cottonwood, willows, and mesquite) that were first planted in or about 1998. The former restoration site is still equipped with an irrigation system whose source is the Bermuda well. The water feeds into a network of furrows and drainage ditches that were used during the establishment of the trees. Although the soils are quite sandy, the site has tremendous potential for enhancement in part because of existing water infrastructure (i.e., Farm Ditch and well), source of nursery trees, shallow groundwater, and workable soils.

2.4. Sacramento Wash Well

In 2008, the Sacramento Wash Fire burned 306 acres including approximately 240 acres of dense tamarisk (Tamarisk ramosissima and T. aphylla) growing on the alluvial fan deposits where the Sacramento Wash terminates at the southern end of Topock Marsh. In late 2011, Parametrix had completed a revegetation pilot project to investigate regrowth potential of native species across a 22-acre portion of the burned site (Parametrix, 2011). The plan required an extensive irrigation system and the USFWS opted to install a pumping well, the Sacramento Wash well.

The well was drilled between 25 October and 4 November 2010 using a dual rotary drill rig. A rudimentary 24-hr pump test was completed 11 November 2010. Figure 5 summarizes the borehole and well construction details. The borehole was drilled to approximately 156.5' below ground surface (bgs). There were two dominant water bearing zones between 35' to 74' bgs and 83' to 156.5' bgs. These strata consisted of varying proportions of sand and gravel (fluvial and/or alluvial). Clay-rich zones were present 0' to 34' bgs and, to a lesser degree, at 75' to 82' bgs. Static water level in the well is typically seven feet bgs.

The borehole was cased from 2.8 feet above ground to 116.5' bgs with 10-inch solid steel well casing. Below the solid casing was 40 feet of similar diameter stainless steel slotted (0.03" slots) well screen emplaced from 116.5' to 156.5' bgs. The steel casing above the well screen was later mechanically perforated to about 92' bgs.

A simple (e.g., no observation wells) drawdown test was performed on the well using a variable speed submersible pump. The aim was to find the maximum sustained yield during a 24-hour period that would result in no further drawdown. With temporary pump intake at about 88' bgs, it was determined that the well could yield approximately 1,100 gpm with a steady state drawdown at about 82' bgs. Based on the pump test results and irrigation requirements, a 75-horsepower, electrical (440 volt), fixed speed submersible, Grundfos pump was installed on 19 December 2010. The pump was comparatively over-sized, in part, to accommodate future water operations. To meet the power requirements, USFWS hired Mohave Cooperative Electric to install a third transformer on the nearby power pole, and extended the line over the road to a power box mounted on a new pole on USFWS property. From the box, Bay Star Electric installed underground conduit to the main fuse box at the wellhead.

An In-Situ Level TROLL 300 pressure transducer was installed in the finished well to record drawdown when needed. The transducer is inserted into one-inch PVC conduit (perforated near end) that is affixed to the pump assembly and riser and cabled to the surface where it is fed underground through conduit to the main junction box. The bottom of the PVC conduit is positioned a few feet above the pump intake at about 84' bgs. Transducer readings can be viewed and recorded on a laptop using Win-Situ 5. In general, the pump draws water inside the casing down about 82 feet bgs to about two to three feet above the pressure transducer, or about five to six feet above the pump intake.

The well water was sampled and analyzed shortly after construction. Table 6 shows the water quality results, which represents relatively good water quality for the arid Southwest. The environmental isotopes indicate, at least at the time of sampling, the water source was predominantly locally recharge and not Colorado River water (see Guay et al., 2006). Despite its apparent source, the withdrawal from this well is considered by USBR to be river water and must be reported annually as a diversion.

An irrigation system was connected to the well by Rain-for-Rent (Las Vegas) in December 2010. The system included a pressure gage, a spring valve to maintain pressure below 60 pounds per square inch (psi), and a flowmeter (with totalizer). Overall details of the irrigation system and the 22-acre ecological restoration project can be found in Parametrix's restoration report (Parametrix, 2011), and daily output from the well are recorded in a USFWS logbook for the site. The total water extracted from late-January through mid-June of 2011 was approximately 114 ac-ft. The irrigation system is scheduled to operate through mid-August 2011.

2.5. Direct Rainfall and Surface Runoff

Mohave Valley climate and current weather data can be found or linked to several nearby meteorological stations in the Mohave Valley: these include (1) two AZMET Stations (AZMET, 2011), (2) Needles Airport (WRCC, 2011); and (3) a RAWs station (RAWS, 2011). The average precipitation for the valley is 4.54 inches per year recorded at the Needles Airport (WRCC, 2011). Precipitation in Mohave Valley is bimodal with a winter and a summer season (Guay, 2001). Isotope data suggests that winter rain tends to be the dominant source for local recharge (Guay et al., 2006).

Table 2 (Line 8) estimates the direct rainfall into the marsh by multiplying annual rainfall times the approximate surface area of the marsh (≈ 4,200 acres). The values range from between 595 and 3,192 ac-ft per year for 2003–2010. Indirect runoff volumes from the eight modest-sized eastern washes that discharge into the marsh are much less certain (Guay, 2001). Casual field observations suggest that about five to ten times a year, runoff actually makes it into the marsh. The observable evidence is usually fresh down cutting, road over wash, and localized turbid condition in a section of the marsh. For this report, we assume its contribution is negligible. Anecdotally, locals do talk about car-sized boulders flowing down Sacramento Wash on a frequency of about once every 25 or more years.

Chapter 3 . WATER OUTFLOWS

3.1 Return Flows

Table 2 indicates the marsh annually loses almost twice its volume through the process of evapotranspiration, or ET. A much smaller proportion, especially in the past six years, is released through the South Dike control structure as measured return flows. Unmeasured return flows are not quantified by physical measurement in this stretch of the river but are instead primarily an accounting adjustment first reported in 2003 by USBR (discussed below). Of course actual seepage leaving the marsh as groundwater below the South Dike could be estimated, but it would require significant groundwater monitoring and modeling. Recall, for much of the year the marsh surface is at a higher elevation than the adjacent river along the South Dike (Guay, 2001). Since 2003, the USBR Annual Decree Accounting Reports include "line items" for Havasu NWR for both the measured and unmeasured flows (USBR, 2011).

3.1.1. Measured Returns -- South Dike Outlet Control Structure

The South Dike (SD) was constructed from dredge spoils in 1965 to impound the waters of Topock Marsh. It is the nominal outlet for Topock Marsh in part to promote southerly circulation of inflows, and, because it has the greatest elevation difference with the river. The SD outlet control structure was leaking in the late 1990's and the submerged orifice slide gate structure was replaced by a Langemann bi-fold gate (Aqua Systems 2000, Inc.) in early 2006. The latter is similar in concept to an electric scissor-lift used at construction sites, i.e., it is a folding barrier can be raised and lowered to a desired elevation. Setting the top elevation of the gate sets the water elevation in the marsh, and any additional water (e.g., waves) will simply flow over the structure in either direction. Battery operated and chain driven by an electric motor, the gate is maneuvered from the adjacent control panel. Pressure sensors on either side of the structure provide real-time elevation measurements of the marsh and river (slough) that can also be seen in the panel. The device has a factory rating for outgoing discharge and is monitored by the USBR. Data from the structure (marsh elevation, river elevation, and gate opening) is sent via telemetry and posted online (USBR, 2011a).

During 2005–2010, there were relatively few or no releases from the SD outlet (Table 2, Line 11). With extensive evaporation and no outflow, the expectation is that the marsh should get progressively saltier unless offset by significant rainfall or seepage (see below).

Although the SD outlet is primarily designed for outgoing flow, it was used in 2011 as an inlet. The embayment area downstream of the South Dike, Topock Bay, has for a long time exhibited tidal-like behavior. Prior to 2001, the water entered the Bay through a relatively constricted channel passing by Topock Marina before expanding into a large backwater storage area below both south dikes. To shorten the residence time of water in this backwater (refresh), the USFWS in 2000 connected the slough (Figure 1) that parallels the South Dike to the river with three (approximately) 24" culverts that actually flow 3.4 miles to the southeast, but this is equivalent connecting to the river about two miles (1.9 miles) upriver of the geographic position of the SD structure. This means that relatively fresh river water can get behind the SD and enter the marsh if the SD outlet gate is lowered and the river is at a higher elevation than the marsh.

This is precisely what happened during most of 2011, where the SD outlet out of necessity became a primary inlet structure as construction on the inlets reduced typical inflows into the marsh. Not designed for reverse flow, the USBR had to develop new inflow calibration curve(s) for the structure. This capability could be enhanced by installing stop-logs (actually concrete slab sections) in the New South Dike (a dike located 0.3 miles south of older South Dike), but several other factors should be considered if this approach is taken.

The rise and fall of the river has a complex delayed and lagged response that varies mostly with the rate and timing of Davis Dam releases. For example, from 15–22 September 2011, the river flows fluctuated daily from about a minimum of 4,830 cfs to a maximum of 19,000 cfs. On the rising limb of the hydrograph, the lag from Davis Dam to Topock Inlet Canal and the South Dike (river side) was 10 and 14 hours, respectively. The amplitude of the typical fluctuations of hydrograph were about five (5.2), four (3.7) and one (1.0) feet at Davis Dam, Topock Inlet Canal, and the South Dike (river side), respectively. On the falling limb, the lag was a corresponding six (6) and nine (9) hours.

Depending on the releases from Davis Dam, the USFWS was able to lower the Langeman Gate, sometimes four to five feet, to allow inflows that typically had a daily average between 25 and 75 cfs. In general, Davis Dam releases greater than about 18,000 cfs seemed to produce river elevations behind the SD of between 454.5 and 455.5 ft amsl. Topock Marsh is normally operated between 454.0 and 457.0 ft amsl, but in 2011 it was generally below 454.2 ft amsl for the first 10 months of the year because of construction related activities.

3.1.2. Unmeasured Return Flows

Not all the water used or applied to a field/crop is lost to ET, and some portion of the diversion reaches the water table and eventually returns to the river (usually with increased dissolved salt). Since the late 1960's, states and individual users along the LCR wanted credit for this "unmeasured return flow." The USBR tried an approach in the 1990's with the Lower Colorado River Accounting System (LCRAS). However, LCRAS had several challenges to overcome, so beginning with the decree accounting report for calendar year 2003, the USBR opted to estimate return flow factors for major diverters. Uniquely, the Havasu Refuge was initially given an 88% return flow factor (SE&R, 2006) that was being considered for reduction. Table 2 suggests the factor may still be about the same (Line 12 ÷ Line 10). Regardless, there is limited benefit to individual users since the unmeasured return flow is aggregated and credited to the states of Arizona, California, and Nevada. From an accounting perspective, however, this approach virtually eliminates concern for exceeding the Refuge's consumptive use target of 37,339 ac-ft. That is, consumptive use is diversion minus return flow, thus with large return flows (measured + unmeasured), the Refuge will almost always have a small consumptive use and be well below its consumptive use entitlement.

3.1.3. Evapotranspiration

In arid environments with ample water, like Topock Marsh, the largest portion of the water budget "outflows" usually come from direct evaporation and plant transpiration, or evapotranspiration (ET). The University of Arizona operates a Meteorological Network, AZMET, which estimates a reference crop evapotranspiration ETo for various agricultural areas across the state, including two stations in Mohave Valley (see documentation at AZMET, 2011). The AZMET ETo values can be used to estimate open water evaporation and cattail evapotranspiration using a correction factor (see Guay, 2001).

AZMET data for 2003–2010 shows the average annual evapotranspiration (ETo) rate, using the original method, is 80.6 inches or 6.7 feet per year (AZMET, 2011). Table 2 shows the annual average ET is about 28,720 ac-ft for the past six years for the 4,200 acre marsh (surface area, see Table 5). To simply make up for the ET losses, the marsh inflows during nine months of sustained gravity flow would need to average 52.9 cfs/day. More specifically, during the hot season of June through August (using 2010 data), the average ET is about 0.34 inches/day, thus the daily inflows needed to simply maintain the marsh (ignoring seepage) would have to be 59.8 cfs or 119 ac-ft/day. In June 2011, this reality was crudely demonstrated when the Refuge was unable to sustain inflows (due to construction on the inlets) rates above this rate and the marsh elevation fluctuated around an atypically low level of 454.0 amsl (Figure 4).

3.1.4. Internal Diversions/Outflows

After mainstream water is diverted and measured, the Refuge redirects flows internally to support various management objectives such as producing forage crops for migratory waterfowl, creating moist soil units, and supporting habitat restoration for targeted species of fish and birds. While these intensive projects have many wildlife benefits, from a water management perspective, they generally reduce the water destined for or already in the marsh and increase overall consumptive use. As will be shown, the internal diversions described here account for approximately 3,736 ac-ft per year. This section briefly describes the major internal project sites in 2011, but for additional historical information see SE&R (2006) and Guay (2001).

3.1.4.1. Agricultural Units -- Pintail Slough Management (PSM) Unit

The Refuge has five agricultural units (fields), and adjoining moist soil units, that comprise the PSM Unit, located north of the North Dike (Figure 1). The farming method and crop types have changed over the years (see SE&R, 2006; USFWS, 2010). The agricultural units include about 100 acres that has been planted with crops such as wheat, barley, oats, forage mix, ryegrass, and, occasionally, a sorghum crop such as milo (USFWS, 2010). The agricultural units provide green browse for wintering geese as well as a seed source for resident and migratory granivorous birds. Comingled in the agricultural fields are roughly 32 acres of riparian areas that also receive water during irrigation operations.

Irrigation typically begins in early to mid-October and continues through late winter and early spring until the crops go to seed. If a sorghum crop is planned, seeding would be in late June or July with irrigation starting at that time and continuing until the crop goes to seed in October or November. Water is delivered to the fields by using a diesel powered platform pump (“red pump”) that draws water from the Inlet Canal about 1,400 feet upstream of the last control structure before Topock Marsh. The pump does not have a flowmeter. If the inlet can be filled near capacity, there is also a gravity feed system. Both methods discharge into a ~5,000 foot concrete lined ditch that has slide gate turnouts for gravity flow into the fields. Excess water can be drained off the fields into the moist soil units.

Based on correspondence with staff and the recent Environmental Assessment of the Farming Program (USFWS, 2010), it is estimated that USFWS applies about four feet of irrigation water annually to the agricultural fields, or roughly 528 ac-ft. No doubt, some small portion of this water returns to the marsh as drainage water or seepage, but in general, intensive cultivation and some native vegetation is expected to make full consumptive use of the applied waters.

3.1.4.2. Moist Soil Units - PSM Unit

Pintail Slough is a highly productive moist soil unit that is a well known site for the popular fall/winter duck hunting season. Renovated in 2000–2005, the 75 or so acres of moist-soil units are seasonally flooded to provide feeding, loafing, and escape habitat for wintering waterfowl, migrating shorebirds, sandhill cranes, and waterbirds.

The irrigation season begins in mid-July for the planted crops grown in the moist-soil units. The moist-soil units are flooded up and drained or pumped dry again several times until they are seasonally flooded in mid-October. Then the water stays on the moist-soil units until late winter or early spring when it is drawn down, pumped out, or allowed to evaporate (USFWS, 2010).

It is estimated that USFWS applies between three and five feet of irrigation water per year to the moist soil units, or ~375 ac-ft. Again, some small portion of this water likely returns to the marsh as drainage water or seepage.

3.1.4.3. Beal Lake

The restoration of Beal Lake was originally prompted under the 1997 Biological Opinion (BO) and required Reclamation to complete and maintain native fish impoundments (USBR, 2011b). In the mid-1990's Beal Lake was managed as an open water habitat for avian species (cattail suppression was the primary management issue). To meet these new conditions of compliance, rooms and channels were dredged out of the shallow 260 acre wetland (using approximate high water mark) in 2001 to allow for areas of deeper water where fish, primarily the razorback sucker (Xyrauchen texanus) and bonytail chub (Gila elegans), would be able to survive during the summer months when temperature and evaporation rates peak.

Beal Lake is recharged from both groundwater (seepage) and surface water that is diverted from Topock Marsh through the Beal Ditch (earthen canal) – neither is measured. The seepage probably contributes to both recharge and discharge depending on surrounding water elevations in the slough, river, Topock Marsh, and proximal groundwater. Surface water entering Beal Ditch passes through three control structures that were installed as part of an experimental fish barrier (Normandeau, 2005). The middle section now consists of four submerged culverts fitted with slotted wire screen end-caps that tend to biofoul, thus restricting flow to the lake – i.e., water elevations in Topock Marsh are generally above those in Beal Lake.

To simply overcome ET losses, it is estimated that the lake needs annual inflows of 1,742 ac-ft (260 ac x 6.7 ft). It might be interesting to measure Beal Ditch inflows (and water levels) for a year to assess the relative contributions from the marsh versus seepage to Beal Lake. If net seepage is minimal, then the Refuge may want to evaluate whether the project's limited success (survival rates are quite low) is worth 4.2 percent of its diversion entitlement. If alternative approaches are needed, Beal Lake may be able to sustain suitable water quality from seepage alone, enhanced seepage, or by raising the slough water levels during the summer.

3.1.4.4. Beal Lake Riparian Restoration

Beal Lake Riparian Restoration research project was initiated to attempt blending the dredge material from Beal Lake with existing soils and replanting the mixed soils with native vegetation (Figure 1). The riparian project underwent two phases of planting in 2002 and 2004 (USBR, 2008). The 107 acre habitat of cottonwood, willow, and mesquite gradually attracted LCR MSCP covered species that in 2010 included nesting pairs of Sonoran Yellow Warbler, Arizona Bell's Vireo, Summer Tanager, and Yellow Billed Cuckoo (USBR, 2011c).

The dredged and native soils at the site are largely fine "sugar" sand. The site is irrigated using a platform-mounted diesel pump capable of delivering more than 10,000 gpm. The restoration site is subdivided into approximately 30 shallow cells, each with slightly different irrigation frequency and duration (USBR, 2008). In 2011, the intensive and daily irrigation was performed by USFWS staff but was subsequently contracted by USBR to a private vendor. The irrigation schedule runs between March and October.

Regarding water use, during FY-08, for example, an average 10.2 feet (two early reports site estimates of approximately 16 feet) of water was applied to 107 acres (USBR, 2009). This equates to 107 ac x 10.2 ft, or 1,091 ac-ft, or 2.6% of the annual entitlement. On a typical 2011 summer day, USFWS staff applied between five and eight ac-ft to produce ponded water in two cells. Trees of this type usually require about three to four feet of water applied annually to meet ET (Westenburg et al., 2006; Leenhouts et al., 2006; Dahm et al., 2002). It is presumed that these trees have already extended their root systems into the groundwater which is typically less than seven feet below ground surface (USBR, 2008).

In April 2010 the Riparian Area (107 acres) was confirmed as a LCR MSCP Conservation Area by the program's Steering Committee (LCR MSCP 2010). Nonetheless, the Refuge should consider measures to reduce energy and water consumption at this site.

Chapter 4 . CONSUMPTIVE USE

4.1 General

Starting in 1964, the method that USBR used to calculate consumptive use was *measured* diversions from the river minus *measured return* flows to the river (SE&R, 2006). In 1969, Arizona, California, and Nevada asked USBR to develop a method of water accounting that includes an unmeasured return flow component. This is important for the Refuge, for example, when the elevation of Topock Marsh (e.g., 456.5 ft amsl) is greater than the slough elevation (e.g., 454.0 ft amsl) below the South Dike, significant groundwater can seep back into the river system unaccounted for. USBR has been for decades experimenting with various approaches to quantify these unmeasured return flows (e.g., LCRAS).

Prior to 2003, when only measured quantities for diversion and return flows were used in decree accounting reports, the Refuge could maximize diversion/consumptive use by annually diverting 41,839 ac-ft, return 4,500 ac-ft (through South Dike), which yielded a consumptive use of 37,339 ac-ft.

After 2003, USBR made a policy shift in accounting practice where unmeasured return flows were listed in the reports (at the level of the individual diverter). As a result, the Havasu NWR received an unmeasured return flow credit of 88 percent of its diversions (minus measured return). While this percentage was considered for reduction in 2005 (SE&R, 2006), the approach has continued into 2010.

4.1.1. Current Decree Accounting Consumptive Use

Table 2 (Line 14) shows consumptive use computed by subtracting all return flows (Lines 11 + 12) from diversions (Line 10). From a USBR water accounting perspective, the Havasu NWR does not exceed its 37,339 ac-ft of consumptive use of mainstream water. In fact, exceedance is quite unlikely given that the reporting shows the Refuge has averaged 4,541 ac-ft of consumptive use in the past six years. So long as the USBR continues to credit Havasu NWR with large unmeasured return flows, the Refuge's does not "need" to be focused on decree accounting consumptive use nor releasing 4,500 ac-ft through the South Dike. Furthermore, the Refuge has additional capacity to increase its consumptive use so long as total diversions are not exceeded.

4.1.2. Traditional Consumptive Use

Table 2 (Line 15) shows the computed (Line 10 – Line 11) "traditional" consumptive use values for the Refuge. Clearly, if the USBR returns to the previous approach or greatly reduces the unmeasured return flow credit for the Refuge, water managers could quite easily exceed their consumptive use allotment.

4.1.3. Water Balance

This manual is not intended as a rigorous water balance of Topock Marsh, but recent advances in water measurement technology and better coverage present some interesting perspectives on the current water balance. First, Table 2 shows the inflow data from the 2005–2010, i.e., the year-to-year values for the Inlet Canal and Farm Ditch are remarkably steady and consistent (c.f., Guay, 2001; SE&R, 2006). Given the measurement redundancy, dual agency responsibility, and frequent calibration, the diversions are probably not subject to significant gross or systematic error. There are several proximal rain gages in Mohave Valley, thus estimates of direct rainfall are reasonable. There are no really good estimates of surface runoff into the marsh, however, they are expected to be comparatively small in relation to other inflows. Consider if all the surface runoff was somehow accumulated and poured in at one time, most hydrologist would be surprised to see the marsh rise six inches (except on 50+ year storms). Even so, this would only amount to about 2,100 ac-ft, and there is really no evidence that the marsh receives this amount of runoff.

So, if we are reasonably confident about the inflows, what about the outflows? First, the Refuge released very little water through the South Dike during 2005–2010, so the outflows must result from ET and seepage. The average annual ET estimate of 28,720 ac-ft is based on a surface area of 4,200 acres, but along the western edge of the marsh there are numerous backwaters and shallow moist soil areas that fluctuate with the marsh elevation (which itself typically fluctuates about three feet per year). Therefore, the ET may be greater than estimated. Also, the internal diversions are likely lost to ET (maybe some seepage), which approximately removes from the marsh another 3,736 ac-ft per year.

Finally, it is possible that the marsh net annual seepage (groundwater-in minus groundwater-out) is always a positive quantity. Without an extensive network of water level sensors and computer modeling, it is impossible to know the magnitude of the actual seepage rates, which will vary with location and season. Because it is so difficult to measure, net annual seepage is often inferred in water balances by summing all the other water balance components. Measurement errors can, however, easily distort the interpretation. In the end, it is not entirely clear why the inflows are consistently exceeding the outflows, but explanations proffered are probably reasonable and would need further study to validate.

Chapter 5 . WATER AVAILIBILITY

5.1. Summary

First, let's summarize average annual inflows from 2005–2010 to Topock Marsh. The marsh actually received annually averaged diversions via the Inlet Canal (with transmission losses subtracted) and the Farm Ditch of 33,646 ac-ft, plus an estimated direct rainfall of 1,753 ac-ft, or a total of 35,399 ac-ft. On the other hand, the average outflows from ET (28,720 ac-ft), Farm Ditch seepage (360 ac-ft), South Dike return flows (26 ac-ft), and internal diversion operations (3,736 ac-ft) totaled about 32, 842 ac-ft. For a relatively large water body, the near balance of inflows and outflows here is remarkable given the averaged values, measurement error, unknown surface runoff, seepage, etc.

As the Refuge prepares to develop a Comprehensive Conservation Plan for the next decade, it is interesting to consider some water management options that may emerge as a result of these revised water balance data and infrastructure capability. It is understood that a purely water accounting compliance perspective does not carry the day, and it will be integrated with other priorities such as species management, recreation, etc. As a starting point, however, this section looks at a few plausible, and perhaps some not so plausible, water management options. Lastly, we look at a short-term scenario that illustrates the usefulness of Table 2 regarding annual water resource planning and accounting. The annual totals could be subdivided into monthly increments or, alternatively, rolled up into annual and multi-year forecasts.

5.2. Water Resource Options

5.2.1 Water Quantity

In the West, water conservation often means using every drop you've got for beneficial use. From that perspective, a few suggestions emerge:

(1) By using only the new Fire Break Canal, the Refuge could avoid the seepage losses from the inlet canal (3,826 ac-ft) and the fire break (360 ac-ft). These flows could be used for marsh refresh, flow-through projects (e.g., new moist soil units, fish reserves), or new internal diversions (e.g., Bermuda Field riparian enhancement, Sacramento Wash rehabilitation).

(2) The Refuge needs to use its entire entitlement. The decree accounting diversions for the past five years (Table 2, Line 10) have averaged 37,864 ac-ft, or nearly 3,975 below the diversion entitlement of 41,839 ac-ft. As explained above, consumptive use is of limited concern. Combined with the first item above, the Refuge would have an additional 8,161 ac-ft/year for beneficial uses as proposed above.

(3) An argument could be made that the Refuge should reduce or be prepared to reduce the surface area of the marsh in the hotter periods and/or drier years – almost the reverse strategy of today (see SE&R, 2006). This situation occurred inadvertently in 2011, and is subsequently being analyzed to a limited extent by the USGS for the USFWS. Table 5 shows that when the marsh elevation is lowered from 456.5 to 454.0 ft amsl, the surface area contracts from 4,045 to 3,129 acres, respectively -- a 23 percent reduction (it drops even faster below that elevation). At the same time, marsh volume is greatly reduced from 14,495 to 5,573 ac-ft, which facilitates freshening with less water.

(4) The Fire Break Canal could have nearby fish reserves (shaded ponds) that are fed by gravity flow or siphon to rear endangered fish species. These could be maintained in the winter months using the Phase II auxiliary pumps or Topock Marsh back-flow if needed.

(5) Groundwater that nourishes the floodplain is not counted against Havasu's entitlement unless it is mechanically withdrawn and metered. Across the floodplain, there are numerous depressions that, with a little excavation, would become moist soil or even isolated standing water habitats. If the locations were

carefully chosen, the feature might behave similar to Three-Mile Lake (a former oxbox feature just north of FBC), whose water quality appears to be quite reasonable. Recall, groundwater elevations rise and fall about four feet along the Fire Break Canal, so some of these depressions could be planned as ephemeral wetland areas. The highest ground water elevations are in April-May, and the lowest September-October (Guay, 2001). Thus depressions could have standing water from about March to June and coincide with breeding seasons for some wading birds.

(6) As described above, Phase 2 construction includes four pumps capable of yielding 40 cfs or 79.2 ac-ft/day. Recall ET losses alone during hot summer days are approximately equivalent to 59.8 cfs/day. At the time of this writing, the annual energy cost estimate of operating these pumps quarter time is $65,000. However, there are some potentially important or useful special options for the pumps that include: (1) providing head and flow control (siphon or overflow) along the FBC for special uses like canal maintenance, fish pond flow-through, or moist soil recharge, fire suppression, etc; and (2) providing flows to the marsh when gravity feed is otherwise unavailable (e.g., drought, winter).

(7) Water use in Beal Riparian area exceeds the need of the trees and could potentially be reduced by 50 percent. The USBR might want to consider either a soil amendment (to retain moisture) or construct shallow, narrow "streambeds with local river rock" substrate that meanders through the area to provide standing water that attracts insects. The water savings could be used for other restoration purposes or even passed on to Beal Lake.

5.2.2. Water Quality

In the period from 2005–2010, the marsh released an average of 26 ac-ft to the river through the South Dike. This meager outflow quantity and operational pattern will likely lead to an increase in salts in the marsh which are reflected in specific conductance (SC) values. This occurs primarily because the average ET of 28,720 ac-ft is about twice the full marsh volume at 456.5 ft amsl or 14,495 ac-ft. Each time the marsh evaporates, twice in one year, the mass of salts in the water column are in theory left behind and added to the salt load of the incoming water. The river has a typical SC of 950 to 1,050 μS/cm (microsiemens per centimeter). Gradually overtime and without some flow-through, the marsh will get saltier. The concentration of salts may be a wildlife stressor more than a grave situation.

To check the validity of this claim, we can compare specific conductance values provided by Guay (2001) and some recent values from 2011. In 1995–1997, Guay had three measurement stations in the north, middle, and south of the marsh that collected hourly data. Guay found average specific conductance readings of 1,140, 1,358, and 1,604 μS/cm, respectively, which coincided with the southerly flow. He also provides USBR records for the South Dike where they collected periodic SC readings from 1983–1995. The mean was 1,467 μS/cm $\pm$ 533 (1σ), with a minimum and maximum of 775 and 2,740 μS/cm, respectively. The extreme values seem to be correlated with unusual river flows (Figure 2) for the years of 1984 and 1993.

In 2011, Arizona Fish and Wildlife Conservation Office (AZFWCO) deployed water quality buoys at seven sites in Topock Marsh and found a minimum and maximum of 1,890 and 2,720 μS/cm, respectively. This overstates the issue somewhat as inflows were largely cut off throughout much of the summer. These surface water data and crude calculations (not provided) suggest that not releasing some marsh waters will lead to the gradual accumulation of salts in the system. Note there have been a few soil and groundwater surveys on HNWR that reveal floodplain salinization. With this understanding, here are a few water quality related proposals:

(1) The Refuge should release between 2,000 and 4,500 ac-ft per year to simply remove salts. It is recommended that we measure specific conductance with a handheld device at four locations quarterly to assess trends (see below). The timing of the releases could be driven by other management concerns. For example, releases could occur in the winter/spring months when salt concentrations are usually greatest, nesting has not began, and future expected inflows are sufficient to refill quickly. Or conversely, the Refuge could release water in the summer (increase inflows simultaneously) to drive down water temperatures as they peak in July and August. Releasing 4,500 ac-ft from its summer high of 456.5 ft amsl will lower the marsh surface slightly more than one foot (Table 5).

(2) Determine if using only the FBC provides sufficient circulation in backwater areas, especially in the north. Wind driven currents may be sufficient to cause uniform mixing.

(3) Determine if selenium is bioaccumulating in the marsh – this would likely affect water management.

5.3. Water Balance Example - Fire Break Canal plus Fish Ponds

This is a practical water balance example that might be an actual scenario in a few years as the Refuge continues to provide water to the farmers along the inlet canal, uses the FBC to deliver the majority of marsh inflows to minimize transmission losses, but also uses the Farm Ditch to raise endangered fish. Alternatively, the Refuge could excavate areas near the Fire Break Canal and have flow-through cells year round instead of using the Farm Ditch. In this scenario, the Refuge might still assist in a limited fashion in the operation of the Inlet Canal, but the water accounting would have been transferred to USBR (with charges to the local farmers' water rights) unless water is released past the farmers' impoundment for the Refuge's benefit (not anticipated to be a likely situation).

Table 2 shows 4,713 ac-ft enter the Inlet Canal to cover the farmers' average annual withdrawal of 4,576 ac-ft, with an estimated transmission loss of 137 ac-ft. Next, we assume the Farm Ditch is partitioned in segments for fish rearing – the cells allow flow-through but not fish passage. The maximum Farm Ditch flow rate is 5,992 ac-ft/yr. The Bermuda Fields use a projected 212 ac-ft for irrigation, and the Refuge withdraws 1,000 ac-ft from the Sacramento Wash well for irrigation or other purposes. We then sum the diversions and subtract from 41,839 ac-ft (the entitlement) to determine the amount of inflow the Refuge should pass through the Fire Break Canal, which is 34,635 ac-ft. The

Refuge can, at a later time, schedule the inflows according to other priorities/objectives that will emerge in the Comprehensive Conservation Plan.

The Refuge does not exceed it diversion entitlement of 41,839 ac-ft. And, using the 2005–2010 average unmeasured return flow of 33,298 ac-ft, and a measured return flow of 4,500 ac-ft (to promote improved water quality and circulation), the decree accounting consumptive is only 4,042 ac-ft, well below the entitlement of 37,339 ac-ft. If marsh water levels are above average, additional water can be released through the South Dike or used to enhance internal diversion projects.

Chapter 6 . RECOMMENDATIONS

The following summarizes some previously suggested water management related recommendations and/or proposes several potential options:

Strategic

1. Consider partitioning the marsh at "choke points" and using water operations more intensively to promote specific habitats in certain areas that address a priority list of managed species (see SE&R, 2006; Ducks Unlimited, 2003). This might require, for example, extensive drawdown in one sector (e.g., for wading birds) while maintaining higher water levels in another (e.g., for recreational fishing). Operating the marsh as a single unit reduces the number of management options and leads to relatively static conditions (with little dynamic disturbances that naturally would have occurred).
2. Develop a detailed topographic map for the entire river reach (e.g., through LiDAR acquisition) to support informed decision making.
3. Request a controlled flooding project from USBR for hydrologic disturbance and desalinization of the floodplain.
4. Connect the FBC and the Farm Ditch. The two inlets come within 0.8 tenths of a mile in a couple locations, but their river diversion points are about 1.5 miles apart (provides head). The eastern soils would be suitable for maintaining standing water as they are less permeable.
5. Replicate a "Pintail Slough" area every 10 years for a few decades.
6. Increase the diminutive percentage of riparian trees (cottonwood/willows) on the Refuge. Set a goal of 200 trees per year.
7. Increase the re-use of Topock Marsh water (e.g., irrigation)

Research

1. Fish barrier research. Investigate other fish barrier methods (sound, scent, etc) with national fish experts. Fish barriers will be used in fish reserves.
2. Analyze 2011 aerial photography of Topock Marsh to evaluate the bio-response to low marsh water levels. Several backwater areas of the marsh never received surface inflows.
3. Develop a method to construct an artificial shallow riparian stream that attracts insects for targeted bird species.

Inlet Canal

1. Maintain the USGS water measurement station at the river to help determine seepage losses in first mile if needed.
2. Draft a formal water operation/accounting agreement(s) with USBR regarding the modified Inlet Canal.
3. Install a flowmeter on the Red Pump.
4. Replace the TIC's dilapidated screw-gates

Farm Ditch

1. Minimize use for normal operations to prevent seepage losses.
2. Remove culvert one-mile downstream of river if unneeded to reduce head loss (and gage water diversions from the point of diversion).
3. Adjust or relocate flap gates if warranted.
4. Repair or add an additional culvert at marsh end to increase discharge.
5. Remove vegetation every 5 to 10 years.
6. Consider segmenting into fish reserves.

South Dike

1. New calibration data for 2011 inflows needs review by USFWS hydrologist. Solicit formal input from USBR regarding its use for inflows.
2. The flows and water levels between the new and old SD in the slough areas need to be monitored for a year to understand the hydrodynamics of these areas. The slough could be used for recharge and discharge if understood.

Bermuda Field

1. Develop a restoration plan for the 20 acres of native trees that enhances the existing resources. Irrigation infrastructure may already be adequate. This may be a project that can be majority executed by Refuge staff. Use wind/solar pump to maintain artificial stream beds.

Beal Lake and Slough

1. Determine seepage and hydraulic relationships for slough and Beal Lake. South Dike instrumentation that records Topock Marsh elevation and slough elevation can provide a preliminary indication of the magnitude of seepage near Beal Lake.
2. Establish internal water measurement scheme to allow assessment of this unit's water uses (e.g., measure inflows and seepage across dike using instrumentation).
3. Design enhanced seepage conveyances.

Water Quality

1. On a quarterly basis, take specific conductance and temperature measurement at four locations. The river and the three boat launches will be adequate for detecting trends in water quality. Adjust SD releases to move water quality trends up or down. Measurements will show if inflows from the FBC are circulating to other areas.
2. The Sacramento Wash well should be resampled a couple more times during operation to assess influence of the Colorado River water on the well.
3. Resume selenium monitoring. Data from the 1990's indicated that the threshold for adverse impacts had been reached (at Havasu NWR and elsewhere on the lower Colorado River), although no impacts have yet been observed or recorded (e.g., biological mutations).

Sacramento Wash

1. Investigate cooperative agreements involving Sacramento Wash well water that can support ecologic restoration and ground water cleanup on Havasu NWR lands.
2. Use well water to establish a riparian corridor along Topock Bay.

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FIGURES and TABLES

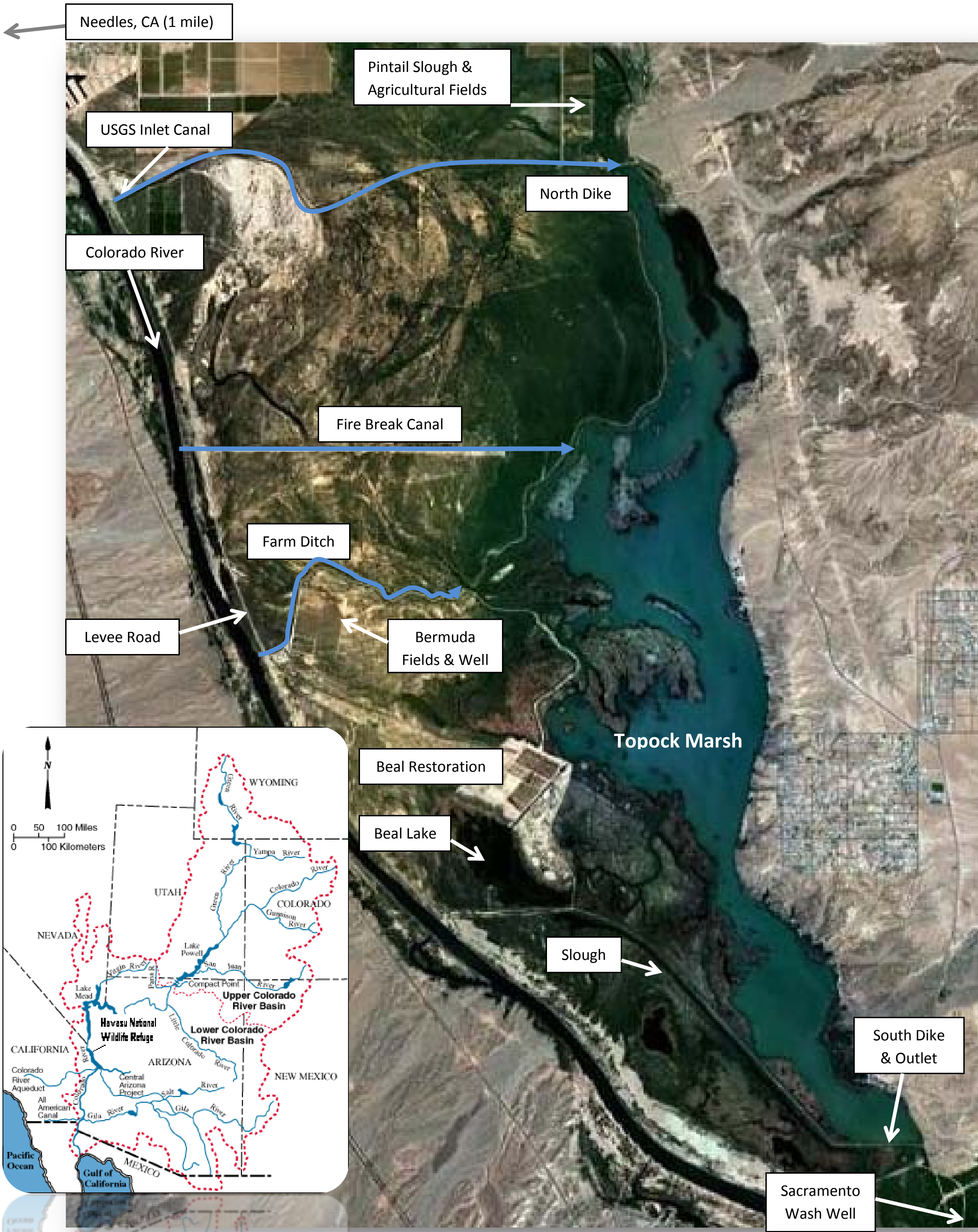

Figure 1. Lower Colorado River Basin and Topock Marsh and related water infrastructure (scale approx 1 inch ≈ 1 mile).

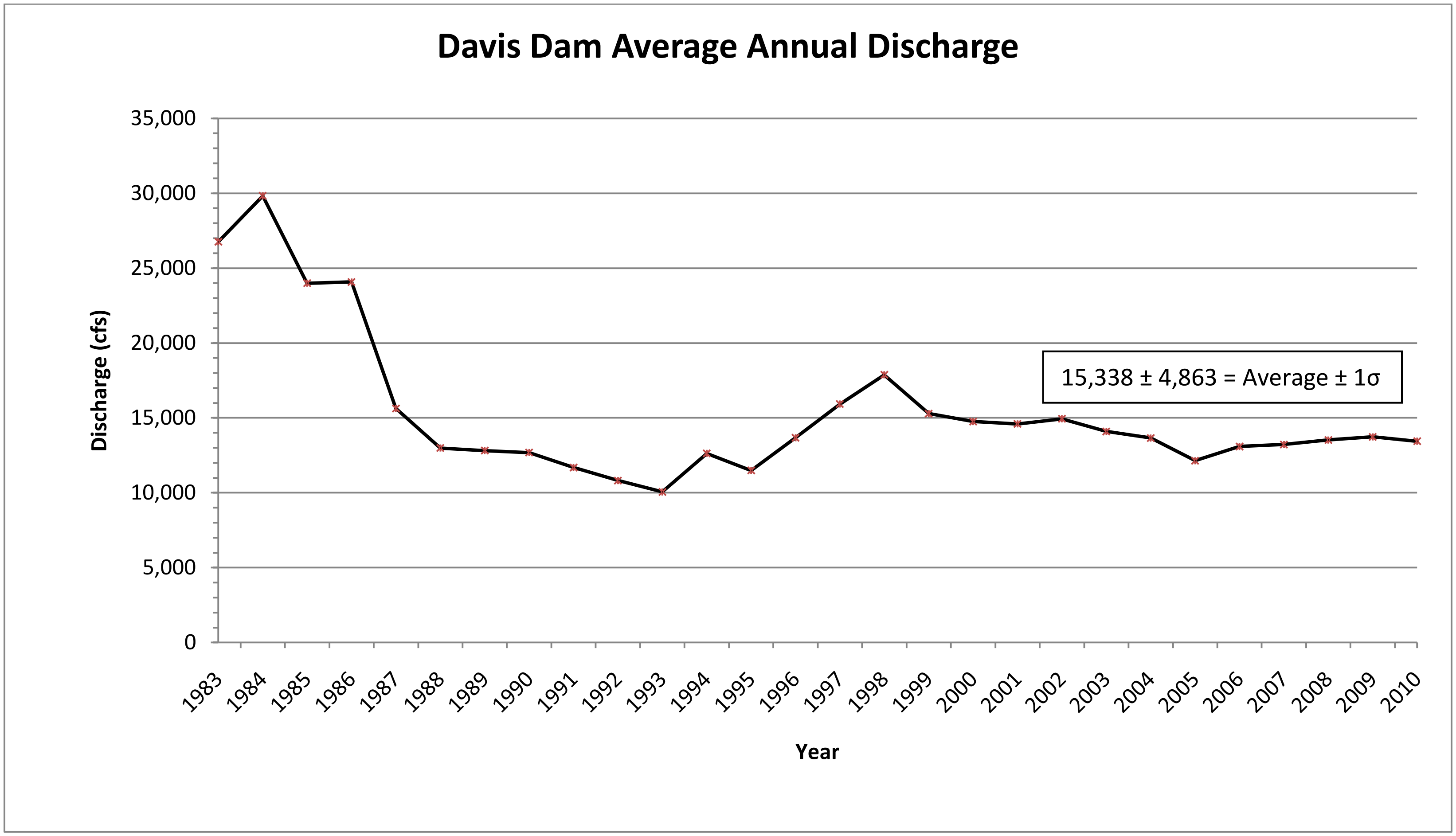

Figure 2. Davis Dam discharge 1983–2010.

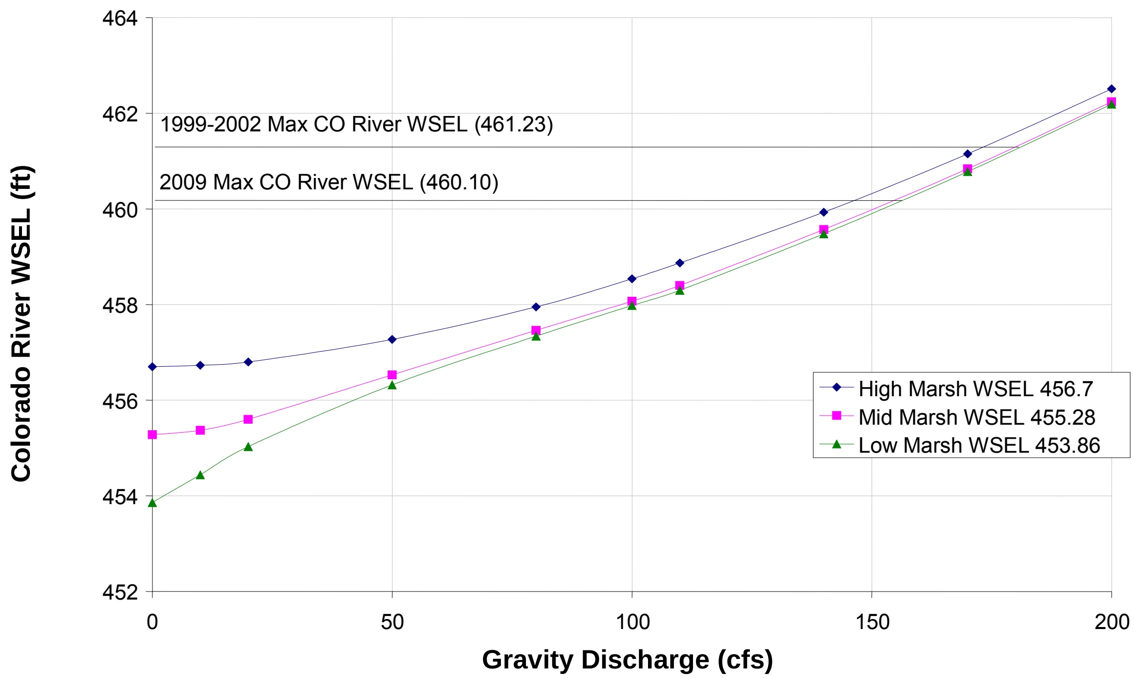

Figure 3. Estimated Discharge from Fire Break Canal

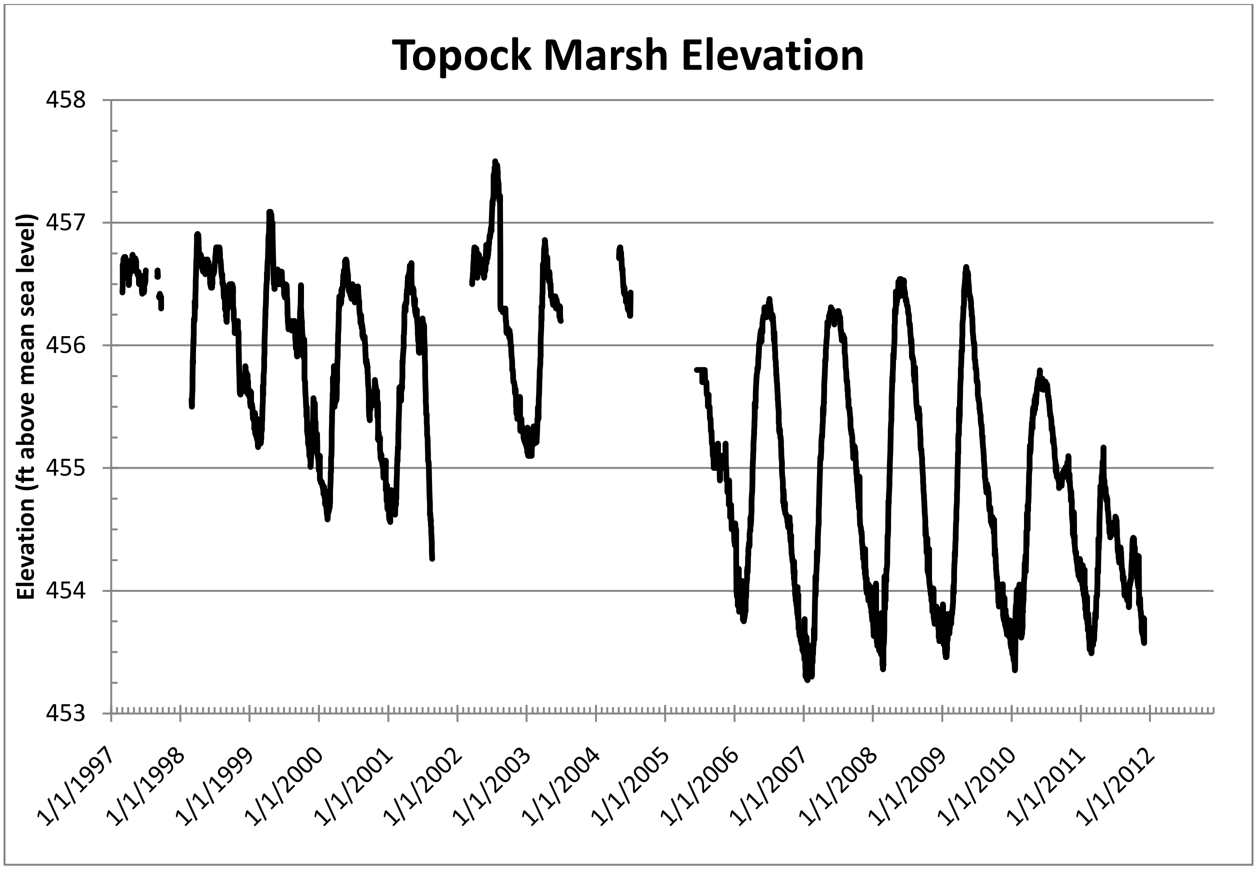

Figure 4. Topock Marsh water elevations 1997—2011 (partial record).

Figure 5. Sacramento Wash borehole and well details
Havasu Nationa Wildlife Refuge
Summarized: Brad Guay, 11/24/2010

Water Quality

Depth (Ft below grade)

From	To	Temp °C	pH	TDS
0	10			
10	20			
20	30			
30	40	26.7°	8.0	495
40	50	30.2°	7.5	430
50	60	31.8°	7.5	429
60	70	32.0°	7.0	403
70	80	33.0°	7.0	398
80	90	32.5°	7.0	338
90	100	34.7°	6.5	356
100	110	33.5°	7.0	349
110	120	34.1°	7.0	392
120	130	33.5°	7.0	420
130	140	34.1°	7.0	435
140	150	30.8°	7.0	445
150	160	30.0°	7.0	435

Well Diagram

Stratigraphy

Depths	
0 - 34'	**Silty Clay**, Lt. Br with some sand and gravel, saturated after 6'
35 - 74'	**Sand and Gravel,** mostly med-coarse sand, w/ some pea to cobble sized gravel; fluvial?, good water yield
75 - 82'	**Sand**, some clay and gravel; possibly interbedded layers; maybe fluvial/alluvial contact?, more sub-angular and sub-rounded material; @ 82' water bearing again, with foamy "milky coffee" appeareance; TDS drop
83 - 156.5'	**Sand, w/ gravel,** f-c sand with variable gravel; esp. coarse, hard gravel 85-92' that was water bearing; fairly uniform after 92', moderate water yield.

Davis Dam Discharge by Month (cfs)												
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
1990	6,622	10,330	15,010	16,530	15,920	17,260	17,920	15,650	11,810	9,716	7,711	7,555
1991	6,167	9,264	11,120	14,950	15,070	16,370	17,390	15,170	11,320	10,180	8,140	4,996
1992	6,585	7,758	9,944	13,350	13,530	15,900	16,590	12,100	9,941	9,585	8,190	6,282
1993	2,563	1,758	5,595	15,110	14,080	14,590	15,140	13,460	10,890	9,358	7,685	10,000
1994	9,525	10,080	15,670	17,400	15,460	15,610	15,120	14,200	11,450	10,770	9,989	6,194
1995	5,425	8,675	12,600	15,490	13,990	14,570	13,850	14,530	11,730	10,800	7,540	8,494
1996	9,390	12,260	16,940	20,240	19,110	18,660	16,520	14,220	11,660	9,371	6,918	8,861
1997	12,500	18,880	18,170	19,610	19,780	17,820	17,640	19,000	14,740	11,500	11,540	10,160
1998	20,000	22,260	19,340	17,510	18,060	17,440	18,630	14,790	15,880	12,950	16,620	21,280
1999	11,890	12,520	16,550	18,560	19,120	18,270	15,750	14,510	15,640	16,330	14,360	9,907
2000	10,600	13,150	16,560	20,190	19,320	16,990	16,780	14,400	12,920	12,910	11,280	12,000
2001	10,570	14,910	15,150	19,610	18,690	18,800	17,780	13,940	13,280	11,310	10,700	10,570
2002	11,430	15,060	18,040	19,740	18,690	18,220	17,250	15,720	13,880	10,840	10,780	9,785
2003	10,830	11,410	17,450	20,460	17,070	16,600	15,900	13,150	12,380	12,760	10,850	10,160
2004	10,930	13,690	17,280	19,010	18,580	18,360	16,290	13,310	12,040	8,051	8,387	8,055
2005	4,741	4,907	7,686	17,460	16,760	16,470	17,100	12,940	14,210	12,600	12,430	8,075
2006	9,687	11,310	12,970	16,330	17,010	18,230	15,850	13,300	12,960	11,640	8,521	9,165
2007	9,150	12,170	15,320	17,780	17,150	17,220	15,790	13,430	13,780	10,940	9,179	6,771
2008	9,096	12,860	16,520	19,560	17,140	16,610	15,580	13,980	12,280	11,180	11,250	6,445
2009	11,460	11,990	17,650	19,240	16,010	14,430	15,040	13,740	13,460	11,100	11,010	9,640
2010	8,149	8,373	14,960	15,990	16,540	16,660	15,800	14,580	14,980	13,410	11,710	9,767
2011	8,378	10,580	16,050	17,810	15,310	16,040	15,640	13,540	12,340	N/A	N/A	N/A
Mean of monthly Discharge	9,349	11,554	14,844	17,815	16,927	16,869	16,334	14,257	12,890	11,300	10,228	9,246

Table 1. Davis Dam discharge by month (cfs) 1990-2011

Source: USGS, U.S. Geological Service, 2011, website: http://waterdata.usgs.gov/nwis/nwisman/?site_no=09423000&agency_cd=USGS

Table 2. Water Balance of Topock Marsh

Line #	Inflows (Diversions, Withdrawals, Rainfall)	Units in Acre-Feet (ac-ft) 2003	2004	2005	2006	2007	2008	2009	2010	Average 2005-10	Water Balance Example
1.	Inlet Canal[1]	44,526	49,956	36,128	35,476	37,793	36,490	36,055	35,476	36,236	4,713
2.	Inlet Canal minus Farmer Withdrawals[2]	*38,738*	*43,462*	27,892	30,429	33,257	33,108	32,841	32,433	31,660	4,576
3.	Inlet Canal @ North Dike[3]	*34,089*	*38,246*	*24,545*	27,569	31,442	27,961	30,148	25,339	27,834	0
4.	Farm Ditch[4]	*6,679*	*7,493*	5,990	6,995	7,129	5,596	5,105	5,136	5,992	5,992
5.	Fire Break Canal[5]								0	0	34,635
6.	Bermuda Well[6]	190	211	213	212	212	212	212	212	212	212
7.	Sacramento Wash Well[7]								0	0	1,000
8.	Direct Rainfall[8]	1,824	2,324	3,192	686	595	2,202	1,302	2,541	1,753	1,753
9.	Col. Riv. Diversions Entering Marsh[9]	40,568	45,515	30,355	34,355	38,358	33,389	35,100	30,321	33,646	40,447
10.	Decree Accounting Diversions[10]	45,607	51,166	34,095	37,636	40,598	38,916	38,158	37,781	37,864	41,839
	Outflows (Return Flows, ET)										
11.	South Dike Measured Return[11]	5,868	2,469	86	57	12	0	0	0	26	4,500
12.	Havasu NWR Unmeasured Return[12]	32,841	41,490	29,928	33,070	35,716	34,247	33,577	33,247	33,298	33,298
13.	Evapotranspiration (Ac-Ft)[13]	26,075	27,318	25,799	28,280	30,461	30,307	29,337	28,137	28,720	28,720
	Consumptive Use/Losses & Gains										
14.	Decree Accounting Consumptive Use[14]	4,478	5,657	4,081	4,509	4,870	4,669	4,581	4,534	4,541	4,042
15.	Traditional Consumptive Use[15]	39,739	48,697	34,009	37,579	40,586	38,916	38,158	37,781	37,838	37,339
16.	Water Balance: Inflows-Outflows[16]	10,448	18,052	7,663	6,704	8,480	5,284	7,065	4,725	6,653	8,980

Footnotes:

[1.] Data source is USGS (2011) online data converted from annual average discharge (cfs); USGS operates gage; Bidirectional acoustical flowmeters installed mid-2000's; the 2003 and 2004 data seem inflated and have been discussed by SE&R (2006) and in this report.
[2.] Data source is USBR (2011) Decree Accounting Reports (DAR); red values in table are estimates based on subsequent data relationships in measured data, usually 2005/06–2010 data; DAR published values for 2003/'04 are 42,997/49,405 ac-ft, respectively; these values are computed by USBR using USGS Inlet inflows minus three farm pumps withdrawals(Pelican Farms/Chesney, Vanderslice, Fort Mohave); USBR operates flowmeters on farm pumps which were first equipped with real-time telemetry in mid-2000's; average withdrawal by farmers for 2005–2010 = 4,576 ac-ft or 13% of flows through Inlet.
[3.] Data source is USBR (Blythe Hydrographic Office) internal data (current year available online) -- also operates gage; acoustical flowmeter upgrade in ~ 2005; 2003–'05 are estimated from 2006–'10 data trends; note average transmission loss across four miles is estimated at 12 % of inflows (~3%/mile).
[4.] Data source is USBR (2011) DAR; Farm Ditch values first appear in 2005 DAR; 2003/04 values estimated from 2005–2010 data trends; gage operated by USBR (Blythe Hydrographic Office) and current year available online; gage located one mile east of river diversion point so values do not reflect transmission loss before and after gage; assume 3% loss/mile; Farm Ditch inflows represent 15% of total diverted river water through inlets.
[5.] Fire Break Canal was under construction 2010-2011 and gravity-fed diversions began in September 2011 as river staged dropped; USGS will operate a gage and report data.
[6.] Data source is normally totalizer on wellhead reported annually by USFWS (apparently estimated for several years); well is located 940 yards NE of maintenance shop and used to supply a pivot irrigation system for 53 acres.
[7.] Data source is totalizer on well reported by USFWS; well is located 660 yds NE of Topock Marina and was operated in 2011 to spray irrigate 22 acres of fire restoration lands. Daily use records kept by USFWS through Sept 2011.
[8.] Data source is the Arizona Meteorological Network, AZMET (2011), Mohave Station; precipitation is direct rainfall computed as 4,200 acres times annual rainfall.
[9.] Colorado River Diversions (not groundwater wells) minus estimated transmission loss in Farm Ditch = (Line 3 + 0.97 x Line 4)
[10.] Lines 2 + 4 + 5 + 6 + 7 ; Havasu NWR has not exceeded its entitlement of 41,839 ac-ft since 2005.
[11.] Data source is USBR (2011) DAR; South Dike (SD) had a Langemann Bifold Gate and new gaging system installed in mid-2000's to better maintain marsh levels; in 2011, the marsh elevation was sufficiently low to allow river inflows through the SD; USBR calibrated the structure for inflows that summer.
[12.] Data source is USBR (2011) DAR; USBR's approach for reporting unmeasured return flows changed in 2003 (see SE&R, 2006), and subsequently HNWR is credited with relatively large return flows (see this report).
[13.] Data source is the Arizona Meteorological Network, AZMET (2011), Mohave Station; values are Evapotranspiration (ETоa) or the original reference ET (see http://ag.arizona.edu/pubs/water/az1324.pdf); open water evaporation is = ETоa x correction factor of 1.0 x 4,200 acres.
[14.] Data source is USBR (2011) DAR; the large unmeasured returns effectively eliminates the possibility of exceeding the consumptive use entitlement of 37,339 ac-ft. Note: Line 14 = Line 10 minus Lines (11 + 12); this will not be true for my adjusted numbers from 2003/04, so I simply reported actual USBR values.
[15.] Line 10 – Line 11; consumptive use using diversions minus return flows; this does reflect transmission losses in the inlet canals.
[16.] Lines 8 + 9 – 11 – 13; actually inflows minus outflows; ignores storm runoff, seepage, groundwater pumping.

Location	Mean		Maximum		Minimum	
	2009	1999-2002	2009	1999-2002	2009	1999-2002
Needles Bridge (USGS Stream Gage)	458.76	461.16	462.31	463.44	455.39	461.94
Inlet Canal(1)	457.06	459.46(2)	460.61	461.74(2)	453.69	460.24(2)
Fire Break Canal(1)	456.55	458.95	460.10	461.23	453.18	459.73
Farm Ditch Canal(1)	456.33	458.73	459.88	461.01	452.96	459.51

(1) Elevations estimated by adjusting the USGS Needles Bridge information using the information presented in Table 3-1.
(2) 1999-2002 Inlet Canal data is from Water Management Plan by Shoreline Restoration and Engineering (2006) and was lowered by 0.1 feet to account for difference between the assumed adjustment to the inlet canal location, 1.6 feet, versus the actual survey difference of 1.7 feet.
Source: URS, 2010

Table 3. Colorado River elevations for a typical wet month (June)

Marsh Elevation (NGVD 29)	Lined Canal – Gravity Discharge	
	50 cfs	100 cfs
High, 456.70	47%	24%
Mid, 455.28	60%	33%
Low, 453.86	63%	34%

(1) Using the Fire Break Canal adjusted USBR stream gage data for the 4 wet months of June, July, August, and September for the period from June 2006 to September 2009. USBR stream
Source: URS, 2010

Table 4. Percentages of time Fire Break Canal can gravity discharge (1)

Table 5. Elevation, surface area, and volume relationships of Topock Marsh (Source: Guay, 2001)

Marsh Elevation (ft amsl)	Marsh Surface Area (acres)	Marsh Volume (ac-ft)
456.5	14495	4045
456.0	12552	3777
455.5	10707	3617
455.0	8933	3485
454.5	7219	3372
454.0	5573	3129
453.5	4181	2463
453.0	3104	1850
452.5	2285	1467
452.0	1628	1136
451.5	1158	767
451.0	825	578
450.5	577	429
450.0	386	334
449.5	243	240
449.0	146	151
448.5	83.4	102
448.0	49.3	36.5
447.5	33.2	28.6
447.0	20.7	21.4
446.5	11.7	14.7
446.0	5.8	9.3
445.5	2.4	4.9
445.0	0.6	2.3
444.5	0.06	0.11
444.0	0.02	0.04
443.5	0.01	0.02
443.0	0	0.01
442.5	0	0

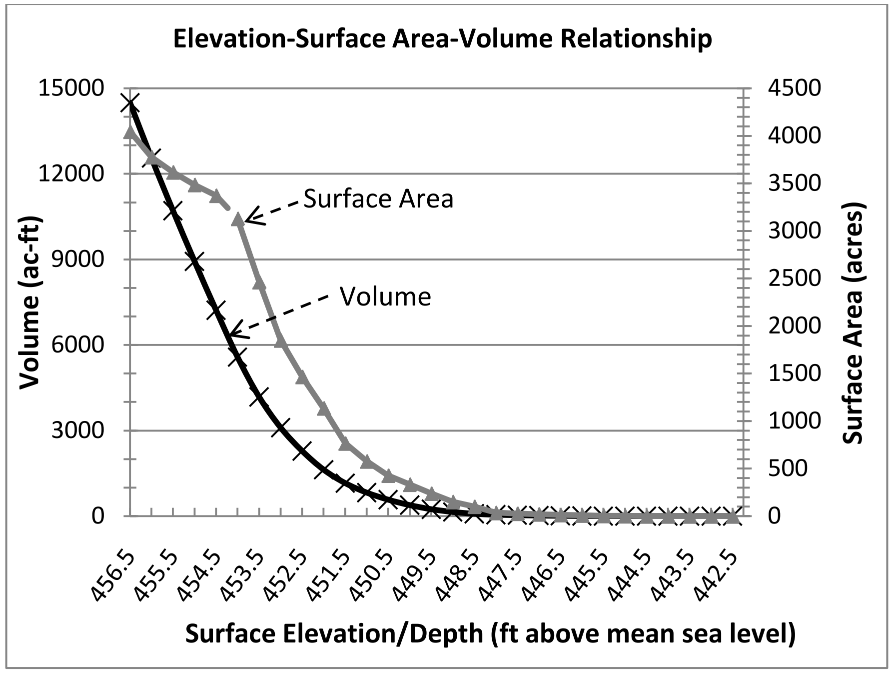

Table 6. Sacramento Wash well water anaylytical results

Sample Date 11/10/10

Field Parameters	Units	Result
Dissolved Oxygen	mg/L	5.33
Oxidation-Reduction Potential	mV	159
pH	pH units	7.84
Salinity	Percent	0.42
Specific Conductance	mS/cm	870
Temperature	Deg C	35.9
Turbidity	NTU	5.1

General Chemistry Parameters	Units	Result
Total Alkalinity	mg/L $CaCO_3$	100
Boron	mg/L	0.38
Calcium	mg/L	23
Iron	mg/L	<0.02
Fluoride	mg/L	3.8
Potassium	mg/L	5.1
Magnesium	mg/L	4
Manganese	mg/L	<0.01
Sodium	mg/L	130
Ammonia-N	mg/L	<0.1
Nitrate-N	mg/L	2.5
Sulfate	mg/L	47
Dissolved Silica	mg/L	28.6
Total Dissolved Solids	mg/L	490 J
Total Kjeldahl Nitrogen	mg/L	<0.4
Total Organic Carbon	mg/L	<1

Stable Isotopes	Units	Result
$\delta^{18}O$	Per mil	-10.3
$\delta^{2}H$	Per mil	-75.3

Trace Metals	Units	Result
Aluminum	µg/L	<50
Antimony	µg/L	<10
Arsenic	µg/L	15
Barium	µg/L	130
Beryllium	µg/L	<1
Cadmium	µg/L	<3
Chromium (Method 6010B)	µg/L	18
Chromium (Method 6020A))	µg/L	19.2
Cobalt	µg/L	<3
Copper	µg/L	<5
Hexavalent Chromium	µg/L	17.5
Lead	µg/L	<10
Mercury	µg/L	<0.2
Molybdenum	µg/L	11
Nickel	µg/L	<5
Selenium	µg/L	0.73
Silver	µg/L	<3
Thallium	µg/L	<0.5
Vanadium	µg/L	20
Zinc	µg/L	<10