Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Five-Year Evaluation of a Remote Screen System at Beal Lake, Arizona

U.S. Department of the Interior
Bureau of Reclamation

November 2010

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EXECUTIVE SUMMARY

Beal Lake is a historical backwater on the lower Colorado River that is being developed as a protected habitat for native fishes listed under the terms of the Endangered Species Act. As a part of the Bureau of Reclamation's continued commitment to provide protected habitats for native species under the Lower Colorado River Multi-Species Conservation Program, major improvements were made to this isolated backwater to make it suitable for native fishes. Among these improvements, a screen system was the installation in 2004 to allow enough surface water flow to compensate for summertime evaporation losses and to prevent all life-stages of nonnative fishes from entering the lake. This report provides an overview of the hydraulic performance and physical condition of the screen system after five years of installation, and provides recommendations for future operation.

Using data on surface water level elevation, which has been recorded on either side of the screen system since July 2005, we compared summertime water level differentials to evaluate the long-term hydraulic performance of the screen system. A full inspection of the structural components of the screen system was performed in November 2009.

Mean monthly water levels varied considerably during the summer from year to year. Water levels on either side of the screen system only remained near equilibrium throughout the summer in 2005 (the first year following installation). By 2009, the summertime water level differential fluctuated between 0.8 and 1.2 feet. During the structural inspection of the screen system, a thick layer (0.5 to 1 inch) of sediment and organic material covered the screens despite the screens being constructed of an anti-biofouling material (i.e., copper-nickel alloy). In addition, a thick (4 inch) layer of material was also found on the inside of the screens and connecting pipes. This large build-up of material appeared to occur over time due to inadequate cleaning, and likely contributed to the observed reduction in hydraulic performance.

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1.0 INTRODUCTION AND BACKGROUND

Razorback sucker *Xyrauchen texanus* and bonytail chub *Gila elegans* are native fishes of the lower Colorado River and are currently listed as endangered under the terms of the Endangered Species Act (ESA). Initially, declines in razorback and bonytail populations were attributed to dam construction along the lower Colorado River that greatly altered the conditions of their native habitat. However, further research indicated that the introduction of nonnative fishes is also a major factor leading to the decline of these species due to competition and predation (Minckley and Deacon 1968; Minckley 1983).

One effort that attempted to address the declining populations of native fishes was written into the 1997 Biological Opinion (BO) composed by the U.S. Fish and Wildlife Service, under the requirements of the ESA, and issued to the Bureau of Reclamation's (Reclamation) Lower Colorado River Region. Within the 1997 BO, Reasonable and Prudent Alternative 3 (RPA 3) required Reclamation to complete and maintain native fish impoundments. To meet these conditions of compliance, Beal Lake, which is located on the Havasu National Wildlife Refuge and within the 100-year historic floodplain of the lower Colorado River, was dredged in 2001 to create a viable refuge for native fishes. In 2005, when the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) came into effect, the RPA 3 obligations of the 1997 BO continued and were included under the LCR MSCP (LCR MSCP Final Habitat Conservation Plan 2004).

Beal Lake is a naturally occurring 225-acre backwater of the Lower Colorado River located near the town of Needles, CA (Figure 1). While some upwelling of groundwater occurs, the majority of flow into Beal Lake occurs from surface water supplied by an inlet canal located between Topock Marsh and Beal Lake (Figure 2). In an effort to exclude nonnative fishes from Beal Lake, a permeable rock filtration system (i.e., rock structure) was installed in the inlet canal in 2001. However, shortly after its installation the surface water elevation of Beal Lake began to drop, falling to a level nearly 2 feet below Topock Marsh in subsequent months (personal communications Gregg Garnett, Bureau of Reclamation, Boulder City, NV). It was determined that the permeable filter within the rock structure was at least partially clogged with sediment and was not passing an adequate volume of water to balance evaporative losses from Beal Lake.

Without an adequate water supply, there was a concern that the water quality in Beal Lake would be compromised during the summer months (i.e., increased temperatures and decreased dissolved oxygen), and therefore greatly decrease the quality of the fish habitat.

To allow for an adequate volume of water to flow from Topock Marsh to Beal Lake while still excluding nonnative fishes, the rock structure was retrofitted in 2004 with three 18-inch diameter PVC pipes equipped on each end with 0.6 mm slot sized wedge-wire screens (Figure 3). The wedge-wire screens were constructed of a copper-nickel alloy to prevent biofouling. An in-line valve was installed in the middle of each pipe, which can be accessed from the surface of the rock structure, to allow the pipes to be closed when necessary (e.g., to reduce water flow into Beal Lake or to allow for repair or replacement of screens). A fourth pipe was also installed and capped to provide the opportunity to add another set of screens in the future. To measure the water level difference on either side of the rock structure and provide information regarding the hydraulic performance of the screen system, a water level monitoring station was installed in July, 2005 (Normandeau 2006).

Initial testing in 2005 indicated that the screen system was capable of providing adequate water flow to compensate for evaporation losses from Beal Lake (Normandeau 2006). However, to ensure optimum system operation, it was recommended that route cleaning events be conducted at least monthly, especially during the summer when evaporation losses were highest. Because of the site limitations, it was recommended that physically scrubbing the surface of the screens with a brush and flushing the pipes[1] would be the most effective cleaning method (Normandeau 2006). While the recommended cleaning events occurred, over time it became difficult to remove all the material from the surface of the screens. Additionally, it became apparent that some of the structural components of the screen system were in need of replacement. As a result, Reclamation determined that an extensive cleaning and maintenance effort was required.

[1] This process is consistent with methods used to estimate the hydraulic capacity of the screen system (Normandeau 2006). All values controlling flow through the pipes in the rock structure are closed, as well as all the outer valves controlling flow from Topock Marsh. With the Topock embayment isolated, a stationary irrigation pump is used to lower the Topock embayment and create a water level differential across the rock structure. Once a head differential of about 2 feet is reached, the inline values on top of the rock structure are opened so water can rapidly flow through the screen system and flush deposited sediment from the pipes.

This report provides an overview of the long-term hydraulic performance and physical condition of the screen system after five years of installation, and provides recommendations for future operation of this system.

2.0 METHODS AND MATERIALS

2.1 Long-Term Hydraulic Performance

The water level monitoring station consists of a Global Water™ SIT 60 unit attached to two independent water level sensors located on either side of the rock structure (Normandeau 2006; Figure 4). The SIT 60 is autonomous, and is powered by a solar charged battery. Data are transmitted hourly via satellite uplink to a website for collection and storage.

Water surface elevation on either side of the rock structure has been recorded hourly since July, 2005. Using these data, we compared monthly average water level differentials on either side of the rock structure to evaluate the hydraulic performance of the modified screen system over the past five years. Our analysis focused on the time period between May and September when monthly evaporation and evapotranspiration rates are the highest (BOR 2003). Also included is data collected in 2010, which was recorded after the extensive maintenance effort conducted in 2009.

2.2 Screen System Evaluation and Maintenance

Over a three-day period beginning on November 2, 2009, Reclamation staff conducted an extensive maintenance effort on the screen system at Beal Lake. This involved dewatering both sides of the rock structure, removing each of the six wedge-wire screens, and conducting a thorough cleaning of each component of the screen system. As part of this maintenance effort, Normandeau staff performed an inspection of the system to document the condition of each component. A detailed description of the maintenance process and condition of each component is presented.

3.0 RESULTS AND OBSERVATIONS

3.1 Hydraulic Performance

Average monthly water elevations recorded on the Topock side embayment (outside) were consistently higher than the water elevations recorded on the Beal Lake side embayment (inside) throughout the summer during all years. Therefore, monthly averages were used to evaluate the magnitude of difference in water elevation that the Topock side embayment maintained compared to the Beal Lake side embayment. For instance, a monthly differential of zero would indicate that water levels on either side of the rock structure were at equilibrium, whereas a monthly differential of 0.5 feet would indicate that the Topock side embayment remained on average 0.5 feet higher than the Beal Lake side embayment for the month. Some data were omitted from the analysis. All data collected in 2007 were omitted due to the valves in the screen system being mistakenly closed during most of the year and opened only during cleaning events. In addition, data collected in July and August 2008 were omitted because the sensors were not functioning properly.

Mean monthly water elevations on either side of the rock structure remained near equilibrium only in 2005, when the difference in water elevations remained less than 0.1 feet from equilibrium throughout the summer (Figure 5). During subsequent years, the average monthly water elevation in the Topock embayment was higher than in Beal Lake, with differences ranging from about 0.3 to over 1.0 feet. In 2006, the water level differential peaked in June (0.94 feet), but decreased in the subsequent months; the monthly water level differential decreased from 0.68 feet in July to 0.23 feet in September, 2006. Mean monthly water level differences were comparatively low in 2008 during the months of May (0.25 feet) and June (0.31 feet), and reached equilibrium by September. The highest monthly water level differences occurred in 2009, when differentials of over 0.8 feet were consistently reported throughout the summer. In 2010, following the extensive maintenance effort, average monthly water level differentials increased throughout the summer from a low of 0.06 feet in May to a high of 0.66 feet in August (Figure 5).

3.2 Screen System Evaluation and Maintenance

3.2.1 Overview

In preparation of the maintenance effort, Reclamation staff constructed a temporary dam across the inlet canal between the rock structure and Beal Lake. This prevented water from backfilling the embayment from Beal Lake. Similarly, the outer valves connecting the inlet canal to Topock Marsh were closed to isolate the upstream embayment and allow for dewatering. Once each embayment was isolated, two submersible hydraulic pumps were used to remove water from both sides of the rock structure so that the screens could be easily accessed. These hydraulic pumps were operated continuously while the maintenance effort was occurring to compensate for groundwater recharge.

3.2.2 Wedge-Wire Screens

Structural Components

Once exposed, the bolts connecting the screens to the pipes and the air burst system were disconnected and the screens were removed from the pipes. The bolts, washers, and nuts connecting the screens to the pipes were extremely corroded (Figure 6). All of these original components were manufactured from galvanized steel and, in some cases, nearly 50% of the steel had been lost due to galvanic corrosion. The screens themselves were structurally sound and functional. No visible corrosion was noted on either the outside or the inside of the screens once they were removed. The gap width of the wedge-wire material was within the original 0.6 mm specification. However, a thin patina of carbonates had formed on the outer surface of the screens (Figure 7).

Once removed from the pipes, the screens were transported to the maintenance yard of the Havasu National Wildlife Refuge for cleaning. Spraying the screens with a high-pressure washer proved to be ineffective at removing the patina and, due to the relatively soft alloy used to construct the screens, Reclamation staff was reluctant to use mechanical or abrasive means to clean the screens. Therefore, the screens were hand sprayed with a commercially available solution of muriatic acid and allowed to soak from approximately 45 minutes. After soaking, the muriatic acid solution and mineral deposits were removed from the screens using a high-pressure washer.

After a thorough rinsing, the screens were reinstalled in their original location using stainless steel bolts, nuts, and washers. The washers used to reattach the screens to the pipes were equipped with a neoprene backing to reduce corrosion. To increase flow through the screen system, Reclamation installed an additional set of new screens on the fourth pipe of the screen system that had been previously capped.

Bio-Fouling

When initially exposed for cleaning, the screens were covered with a layer of sediment, organic matter, and algae approximately 0.5 inch thick (Figure 8). The sediment appeared to provide a medium that allowed algae and other biological organisms to grow (Figure 9). This combination of sediment and organic material was not strongly affixed to the screens and was easily removed with a high pressure washer before screen removal. Based on samples taken, much of the organic material on the screens was comprised of decomposed matter which could not be identified; however some organisms were identified and included Annelida (*Olgiochaeta)*, Cnidaria (*Cordylophora caspia*), Ecotprocta (*Plumatella sp.*), Porifera (*Dorsilla radiospiculata*), and insects classified as Diptera (*Chironomidae*) (Table 1). Several forms of algae were also identified from samples collected from the outside of the screens including *Spirogyra sp.,* and *Cladophora sp.,* and cyanobacteria classified as *Lyngbya* and *Scytonema*.

3.2.3 PVC Pipe

Structural Components

A close inspection of the PVC pipes revealed that they were structurally intact and had no signs of damage. The flanges connecting the screens to the PVC pipes were also undamaged and structurally sound. The original gaskets that were installed between the PVC pipes and the screens were brittle and partly deteriorated (Figure 10). The original gaskets were replaced with new gaskets when the screens were reinstalled.

Bio-Fouling

Examination of the pipes revealed that a considerable amount of organic and inorganic material had settled on the inside of each pipe, and formed a layer approximately 4 inches thick (Figure 11). This material was a gelatinous mixture of living mollusks, their empty shells, decomposed organic material, and fine sediment. Two genera of mollusks were identified; which included *Corbicula* and *Dreissena*. Also found on the inside of the pipes were dense colonies of the freshwater sponge Porifera (*Dorsilla radiospiculata*), as well as the sessile Cnidaria (*Cordylophora caspia*), and both colonies and statoblasts of Entoprocta (Table 1). Many of the organisms found inside the pipes were also found on the inside of the screens. The inside of the pipes were cleaned using a portable "hydro-jet" hydraulic sprayer.

4.0 DISCUSSION

This report was intended to provide an overview of the hydraulic performance and condition of the screen system at Beal Lake following five-years of installation. This structure was installed as a prototype system to determine if using cylindrical wedge-wire screens would be effective in delivering enough surface flow to compensate for evaporative losses in Beal Lake during the summer while preventing entrainment of nonnative fishes.

Our review of the hydraulic performance of the screen system indicated that summertime water level differences on either side of the rock structure varied considerably from year to year. While this variation in part reflects the annual performance of the screen system, caution should be used when interpreting these results as they may also reflect management activities and other extraneous environmental factors that influenced water flow into Beal Lake. Also, our analysis only included data collected during the months between May and September when evaporation rates have been shown to be the highest (BOR 2003). During months outside of this period, the water levels on either side of the rock structure were at or near equilibrium.

Water levels on either side of the rock structure remained near equilibrium throughout the summer only in 2005. The reason for this is likely attributed to the onsite testing that occurred in 2005 to estimate the flow capacity of the screen system (Normandeau 2006). As part of this effort, the screens were thoroughly cleaned and the pipes were flushed multiple times before and during testing. The frequency of these events likely prevented the buildup of sediment and biomass on the screens and inside the pipe, which allowed the screen system to function efficiently throughout the year.

In 2006, the water elevation in the Topock embayment remained consistently higher than in the Beal Lake embayment, especially in May (0.73 ft) and June (0.94 ft). While the screen system did not receive the same level of cleaning as it did in 2005, this large differential was probably further exaggerated by a renovation effort that was conducted at Beal Lake in April, 2006 (USFWS 2008). During this renovation effort, the surface water elevation in Beal Lake was lowered by about 6.5 feet. The process of refilling Beal Lake began in early May, and coincided with the beginning of the peak evapotranspiration season. Consequently, Beal Lake did not completely refill and remained lower than Topock Marsh throughout the summer. Water levels on either side of the rock structure did not reach equilibrium until the fall when air temperatures and evaporation rates decreased.

Hydraulic data were also confounded by extraneous factors in 2008. During this year, water level differentials were comparatively low, and remained less than 0.4 feet in May and June and had reached equilibrium by September. However during this year, the culvert in the inlet canal between the rock structure and Beal Lake began to fail, which substantially reduced the amount of flow that could enter Beal Lake. Sometime in late summer this structure failed completely, which eliminated surface flow into Beal Lake. Therefore, the water level data recorded during this year mostly reflects the conditions occurring only in the embayment and inlet canal immediately downstream of the rock structure and not in the main body of Beal Lake. Since the surface area of the embayment is much smaller than Beal Lake, it requires less inflow to maintain the water levels near equilibrium. The culvert in the inlet canal was repaired in early May 2009[2].

Data recorded in 2009 is probably the best example of the screen system's extended performance since its installation in 2004. During this year, summer water level differentials remained

[2] When the culvert was cleared and water flow was returned to Beal Lake, the water elevation in the downstream embayment dropped by 1.5 feet within an hour.

relatively high, ranging from about 0.8 to 1.2 feet. This large difference was most likely attributed to the thick layer of material that had formed on the outside of the screens and inside the pipes. Extensive biofouling has been shown to significantly reduce the surface porosity, and thus flow capacity, of wedge-wire screen material (Hanson 1979). Based on the estimated flow capacity, the screen system is capable of delivering approximately 4 times more flow than is needed to compensate for the highest estimated evaporation rate from Beal Lake (Normandeau 2006). However, this estimate was derived shortly after installation and when the screen surfaces and pipes were not obstructed by debris fouling.

Although the screen system was periodically cleaned by physically scrubbing the surface of the screens with a brush and flushing the pipes, this effort was clearly not sufficient enough to maintain adequate flow through the system. Although the screens were constructed of an anti-biofouling material (i.e., nickel-copper alloy), which was found to effectively inhibit biological growth (Normandeau 2007), sediment can accumulate on the surface of the screens without proper cleaning. If this accumulation is not removed, it can form a layer on the screens which filamentous algae and other aquatic organisms can adhere to (Boulton et al. 1999). Over time, this material can fill the interstitial spaces of the screens, and reduce the screen porosity and flow capacity. Without adequate flow, sediment and organic material can more readily deposit on the inside the pipes. An example of the importance of adequate cleaning was apparent in the 2010 water level data, which was recorded after the extensive maintenance effort. Water levels on either side of the rock structure initially remained near equilibration in 2010. However beginning in June, the water level differential began to steadily increase (an average monthly differential over 0.6 feet was recorded in August, 2010). This differential in water elevation between the Beal and Topock sides of the rock structure was surprising considering the renovation of the existing system and the installation of a fourth set of screens prior to the 2010 season.

The current configuration of the rock structure makes the screen system difficult to clean and maintain. A permanent air burst system is not feasible due to the lack of electrical power at the site, and a portable system was shown to be inadequate (Normandeau 2006). In addition, only the screens located in the Topock embayment can be exposed for manual cleaning. One possible solution that would allow better access to the screens would be to construct an additional flow control structure on the inlet canal downstream of the rock structure. This would allow the Beal Lake embayment to be dewatered and provide easier access and more efficient cleaning of all screens during the summer months. Still, physically scrubbing the screens only removes sediment and other particulates on the surface of the screens and does not remove materials that have accumulated on the inside the pipes. While manipulating the water levels on either side of the rock structure and artificially flushing the pipe has been shown to remove fine particulates from inside the pipes (Normandeau 2006), during this process larger debris can become impinged on the inside of the screens and can fill the interstitial spaces of the wedge-wire screens. To reduce this potential, it is recommended that a system be designed that would allow larger debris (e.g., mollusk shells) that accumulates on the inside the pipes to be easily removed. This would be a more effective cleaning procedure than flushing the pipes, and would reduce the need for removing the screens to eliminate large debris that had accumulated inside the system.

Future structural modifications should also include a wing wall or other similar support structure to elevate the system off of the substrate and prevent sediment from the rock structure from depositing around the screens. The screens are currently located at the base of the rock structure and in all cases, were partially buried with sediment. Supporting the screens in the water column would allow flow to more efficiently pass through the entire screen and would also provide better access for cleaning.

Future installations of screens on the lower Colorado River should use stainless steel components (i.e., bolts, nuts, washers) to attach the screens. The galvanized fasteners used in the original construction were heavily corroded. This may in part have been due to galvanic corrosion, which occurs when two dissimilar metals (in this case galvanized steel and nickel-copper alloy) form a natural battery when placed in contact with each other. The neoprene lined washers used to reinstall the screens in 2009 should insolate and reduce this interaction. However future applications may also consider installing zinc anodes on each of the screens, especially in applications where the water has high salinity.

The hard deposits found on the surface of the screens were likely a combination of calcium and magnesium carbonates, which are common and naturally occurring minerals in the hard water of the Colorado River, and copper carbonate from the screens. Under normal applications, the build-up of a patina is controlled by the natural flow of water over the screen surface. However, the low flow conditions at Beal Lake combined with the layer sediment and other material on the screens, likely contributed to the build-up of these carbonates on the surface of the screens. The diluted solution of muriatic acid was effective in removing the patina, however it is not recommended that this be a common maintenance solution; rather routine cleaning of the screen to remove sediment and increase flow should reduce or eliminate this problem.

The presence of mollusks inside the screen system was not surprising. Many species of mollusk have microscopic free-swimming larvae or "veligers", which drift in the water column for up to three or four weeks before settling onto suitable substrate. Given the small size of these veligers, it is conceivable that they simply passed through the screens as larvae and settled on the inside the pipe, where they matured. Two nonnative genera of mollusks were identified in the samples collected inside the pipe. Most of the mollusks found in the samples were from the genus *Corbicula* (which include *Corbicula fluminea* or commonly known as Asian Clams). However, a few individuals from the genus *Dreissena* were also identified. While our analysis did not identify these individuals to species, members of this genus include the invasive quagga mussel (*D. rostriformis bugensis)*, which were first discovered in Lake Mead in 2007 (Lake Mead National Recreation Area News Release, Dated January 16, 2007), and since have been documented throughout the lower Colorado River (Western Invasive Mussel Management Workshop, San Diego, CA, 2010). To date, quagga mussels have not been identified in either Topock Marsh or Beal Lake, however, the possible presence of this species is of concern. Quagga mussels are an aggressive species that can block water conveyance structures. Presence of these organisms should be confirmed and closely monitored. If quagga mussels become firmly established, they will likely create the need for extensive future maintenance efforts.

Based on our review of the hydraulic data and observations made during the extensive maintenance effort, it is clear that routine cleaning and maintenance is vital to the performance of this structure. The continued use of cylindrical wedge-wire screens at Beal Lake will require that a more regimented cleaning schedule be adopted. This should reduce the frequency of extensive cleaning efforts similar to the one performed in 2009.

5.0 RECOMMENDATIONS

A summary of the recommendations made regarding the continued maintenance and operation of the screen system at Beal Lake include:

- The screens at the rock structure should be cleaned routinely on an established schedule. Cleaning events during the peak evaporation season (May – September) should occur at a minimum bi-weekly and screens should be cleaned on at least a monthly basis during the remainder of the year. Cleaning events should consist of scrubbing and pressure washing the surface of the screens as well as flushing each pipes (by manipulating water levels in the Topock embayment using the irrigation pump; see Normandeau 2006) a minimum of three times.

- An additional flow control structure downstream of the rock structure should be constructed. This would allow easier access to all screens on either side of the rock structure and allow for a more thorough cleaning process.

- A system to remove material from inside the pipes using suction should be investigated; this would allow removal of large debris (i.e, mollusk shells) from inside the pipes without requiring removal of the screens.

- The screen system should be retrofitted so that the wedge-wire screens are supported and are suspended off the substrate. A wing dam or other similar structure should be constructed to prevent sediment from the rock structure from settling around the screens. This would improve flow efficiency as well as the ability to clean and maintain the bottom of the screens.

- Future installation should not use galvanized fasteners to attach the screens to the pipes, and an inspection of the structural components screen system should be conducted annually. Future maintenance efforts and extensive cleaning should be scheduled on an as-needed basis.

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TABLES

Table 1. Summary of the organisms collected during maintenance of the Beal Lake screen system, 2009

		Outside Screen	Inside Screen	Inside Pipe
Algae				
	Cyanobacteria Lyngbya	X		
	Cyanobacteria Scytonema	X		
	Cladophora sp.	X		
	Spirogyra sp.	X		
Porifera (Freshwater sponge)				
	Dorsilla radiospiculata		X	X
Cnidaria				
	Cordylophora caspia	X	X	X
Ectoprocta (Bryzoa)				
	Plumatella sp. (statoblast)		X	X
	Plumatella sp. (colony)			X
	Umatella gracillis		X	X
Mollusca				
	Physella sp. (Gastropod)		X	X
	Corbicula sp.		X	X
	Dreissena sp.			X
Platyhelminthes				
	Turbellaria		X	
Annelida				
	Oligochaeta	X		
Diptera				
	Chironomidae	X		

FIGURES

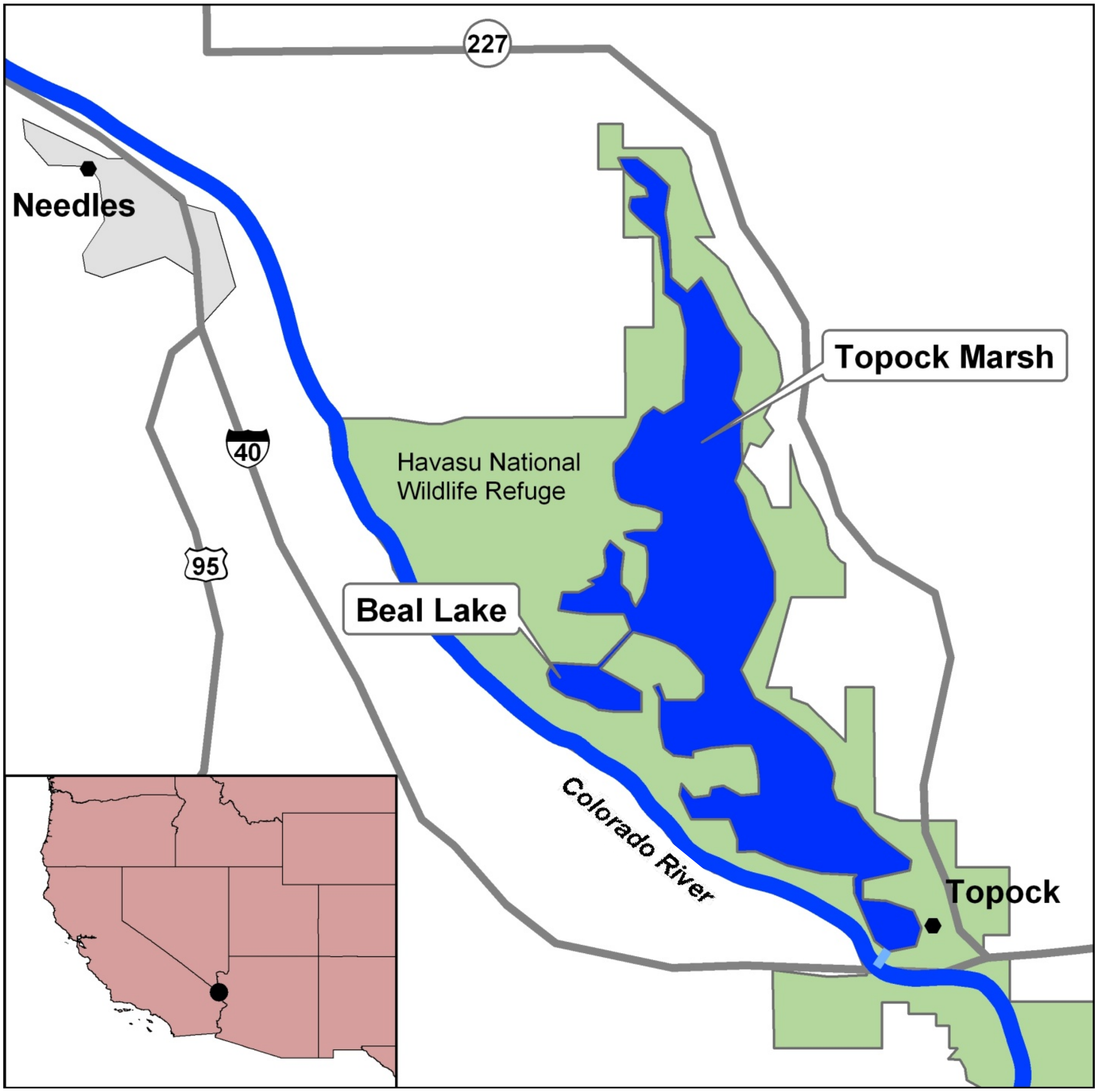

Figure 1.

Study area map of Beal Lake and Topock Marsh, Lower Colorado River, Arizona.

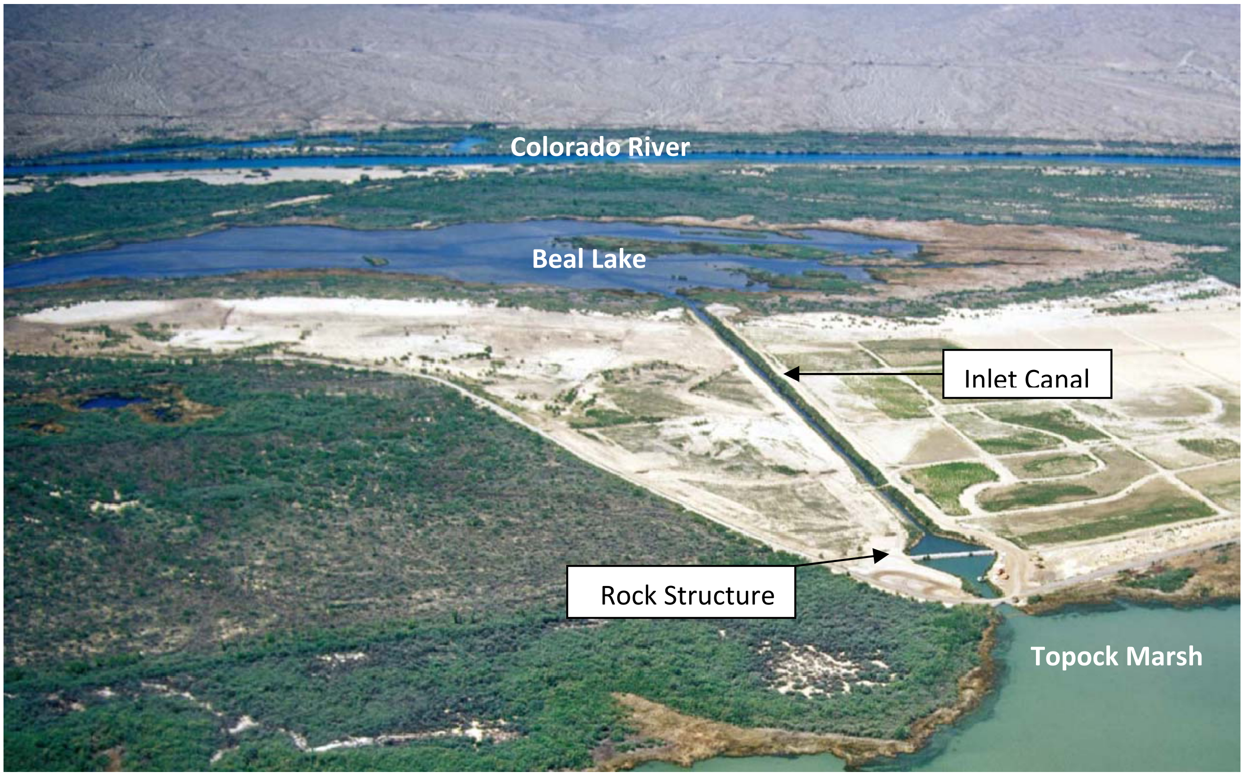

Figure 2.

Aerial photo of rock structure and inlet canal between Topock Marsh and Beal Lake, Arizona.

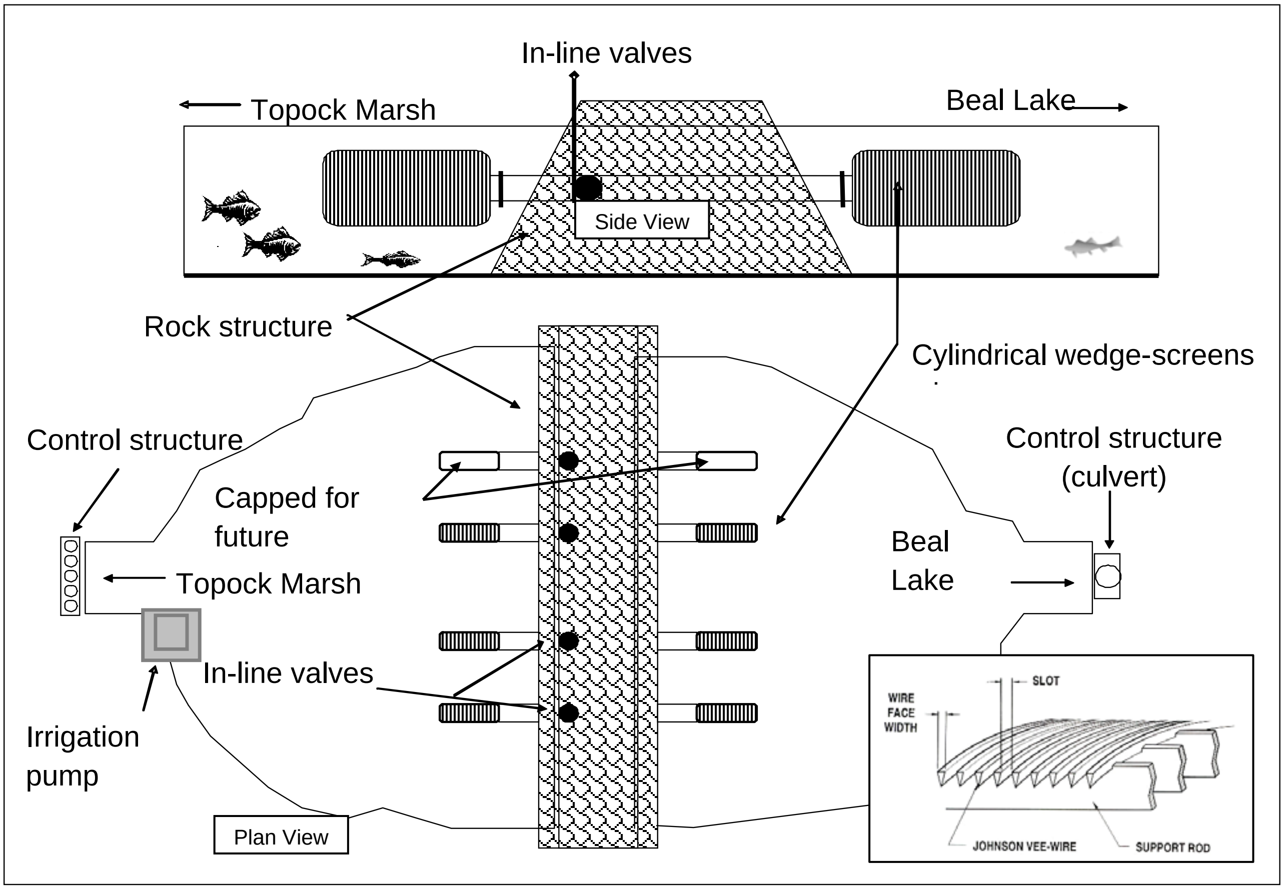

Figure 3.

Plan view and side view schematics of the rock structure with installed prototype cylindrical wedge-wire screen system. Insert depicts wedge wire screen technology.

Figure 4. Remote water level monitoring system (SIT60) and attached solar panel installed on the western side of the rock structure.

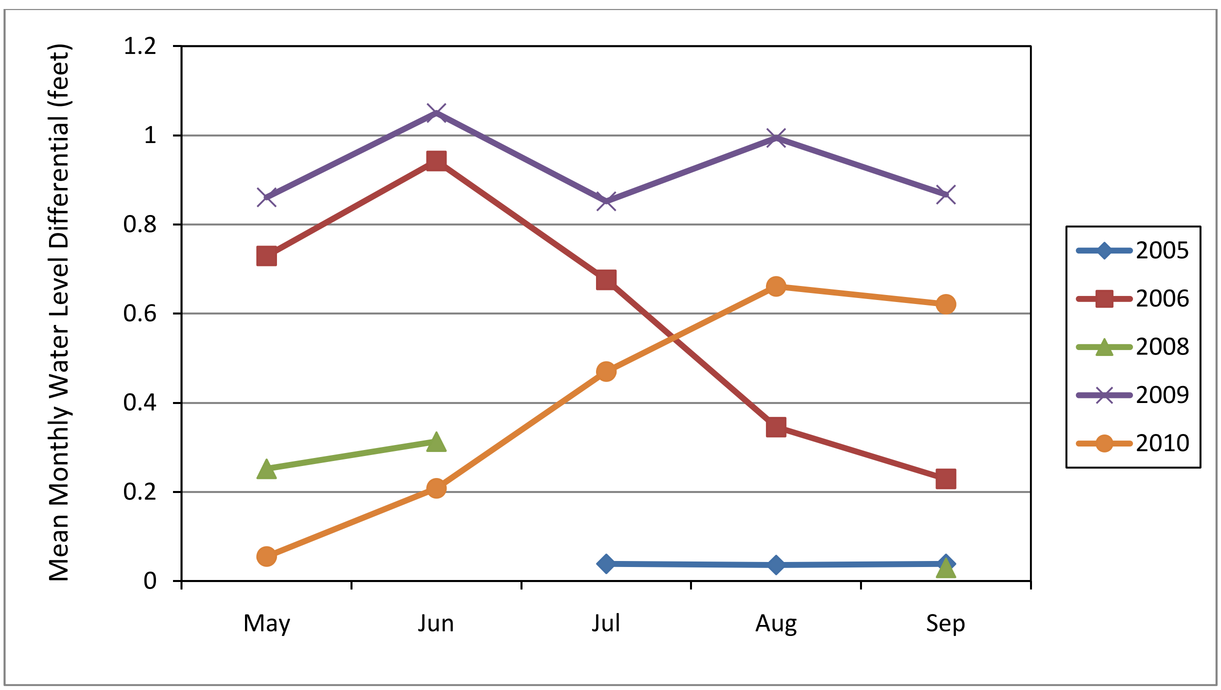

Figure 5. Mean monthly differences in surface water elevation between the Topock side embayment and the Beal Lake embayment from 2005 to 2010. Data are presented as magnitude (in feet) of difference between each embayment. Data collected in 2007, and July and August 2008 was omitted from the analysis.

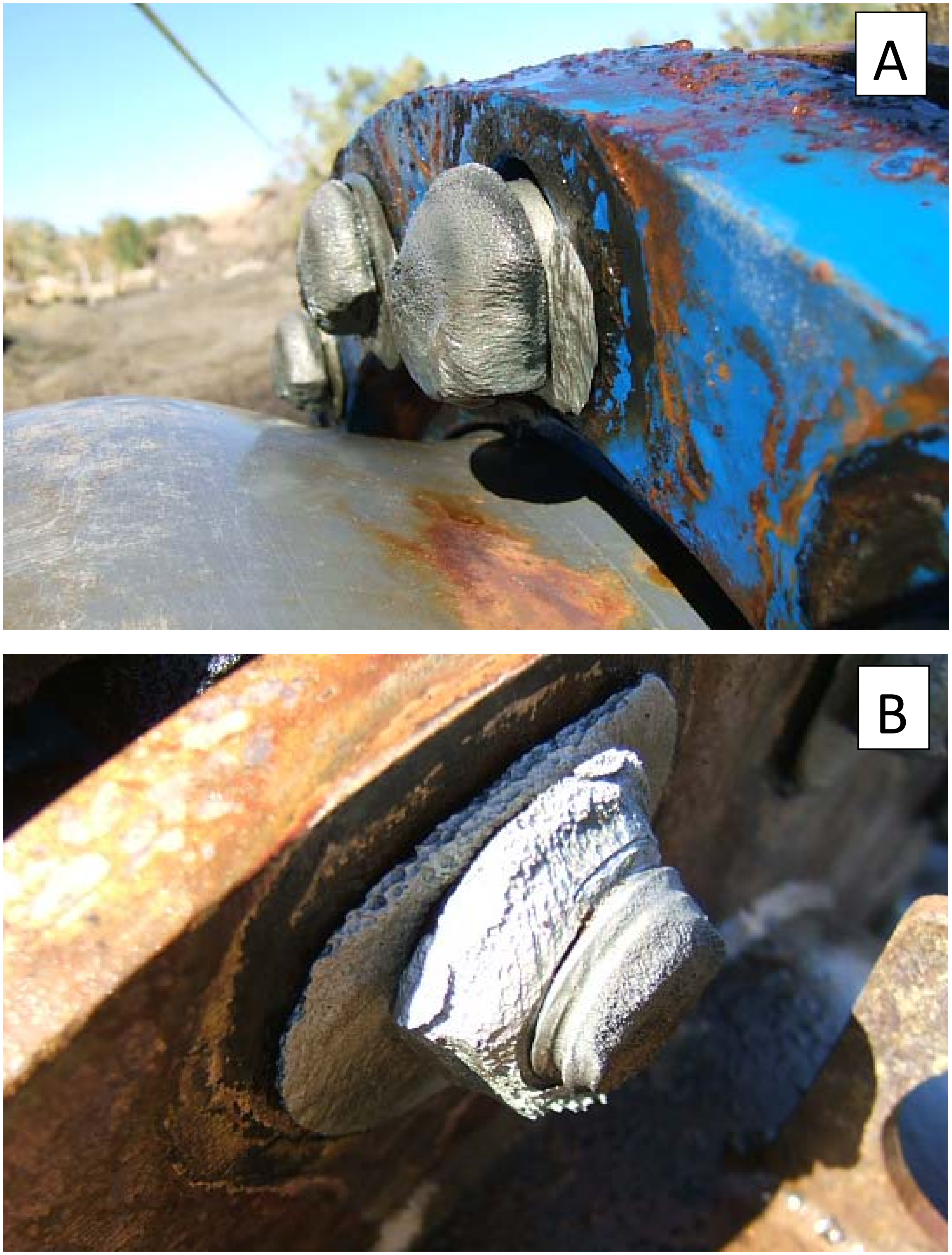

Figure 6. Original fastening components used to attach the wedge-wire screens to the PVC pipes consisted of galvanized bolts (A), nuts and washers (B), which were highly corroded following five years of installation.

Figure 7. A thin patina of carbonates (most likely calcium and magnesium, which are common and naturally occurring minerals in the hard water of the Colorado River, and copper from the screens themselves) had formed on the outer surface of the wedge-wire screens.

Figure 8.   Wedge-wires screens covered with fine sediment and algae.

Figure 9. A partically cleaned screen showing attached algae which pentrated the intersitial spaces of the screen.

Figure 10. Gaskets which were originally installed between the PVC pipes and the wedge-wire screens were brittle and partly deteriorated.

Figure 11. Organic and inorganic material that had settled and formed a layer approximately 4 inches thick on the inside of each PVC pipe.