POSEIDON WATER

Appendix J
Fish-Friendly Pumping

Renewal of NPDES CA0109223
Carlsbad Desalination Project

White Paper
Fish-Friendly Axial Flow Pumps

Prepared for

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1. Introduction

The Carlsbad Desalination Project (CDP) is currently permitted to produce up to 56,000 acre feet per year (AFY) of desalinated water while operating in conjunction with the Encina Power Station (EPS) by using the power plant's cooling water discharge as its source water. The planned retirement of the EPS at the end of 2017 will result in the need to retrofit the CDP for a transition to stand-alone operation. At such time, the CDP will be considered an "expanded facility" and will become subject to the provisions of Chapter III.M of the Water Quality Control Plan, Ocean Waters of California (Desalination Amendment).

When the CDP transitions to stand-alone operation, Poseidon proposes to dilute the brine from the seawater reverse osmosis (SWRO) process with additional seawater withdrawn specifically for this purpose (i.e., flow augmentation). Flow augmentation at the CDP would be accomplished through the use of low-impact fish-friendly pumps to minimize potential stresses to entrained marine life.

Fish-friendly pumps were originally designed for transferring fish in the aquaculture industry. Such pumps have demonstrated the capacity to transfer fish with little or no injury. Since their inception, fish-friendly pumps have been used in fish passage and protection facilities to convey fish to a safe release location. There are several types of fish-friendly pumps available, each designed with the common goal of safely transferring live fish. To date, most of the data on fish pump performance has been limited to juvenile and adult life stages of freshwater species. Each fish-friendly pump type employs certain fundamental principles that reduce the potential injury and mortality to fish. To varying degrees, fish-friendly pump designs limit fish exposure to stressors, such as pressure, shear, and strike. More specifically, fish-friendly pumps limit fish exposure to:

- dramatic pressure differentials and high rates of pressure change;
- shear forces caused by rapid flow acceleration or deceleration;
- potential for blade strike by limiting the number of blades on the impeller and/or increasing blade thickness; and
- other sources of mechanical injury (e.g., pinching in gaps between the impeller and housing)

A. Report Objective

This review of fish-friendly pumps is provided to describe the design and operational features of the various pump types and more specifically to describe the features of the axial flow pump that make it appropriate for safely pumping dilution flow at the CDP. The Desalination Amendment states that "*an owner or operator proposing to use flow augmentation as an alternative brine discharge technology must use low turbulence intakes (e.g., screw centrifugal pumps or axial flow pumps) and conveyance pipes"* to minimize injury to marine organisms entrained in the flow. Poseidon is proposing to use axial flow pumps at the CDP.

2. Archimedes Pumps

A. Design

An Archimedes screw pump is comprised of a long worm wheel (or screw) in a diagonal pipe (Figure 1) or open trough (Figure 2). The screw rotates at a constant speed within an inclined trough which conveys liquid up the spiral and discharges it in a surge-free stream at a rate equal to the feed (ASCE 1982). Archimedes screw pumps have been in use since at least the 3rd Century B.C. primarily as water lifting devices. Since then, their application has spread to the handling of sewage, sludge, storm, irrigation, and wastewater. Archimedes screw pumps have been used in both upstream and downstream fish passage schemes. Relative to their use in fish passage, older designs resulted in some damage to fish from blade strike (at the base of the screw) and fish becoming stuck between the screw and the housing. However, modern Archimedes screw pumps have been engineered with tapered blade widths and reduced (or eliminated) gaps between the screw and the housing. Archimedes pumps have advantages over other pump designs including: high reliability, long life, low service requirements, and the capacity to handle multiphase flow (i.e., liquids with solids).

Archimedes screws have recently seen more application as turbines (i.e., a pump in reverse) in hydropower applications for use in generating electricity with water. As a turbine, the Archimedes screw has been shown to be quite fish-friendly for fish moving downstream with the flow of water through the unit. Historically, however, Archimedes screws have been used to pump fluid to higher elevations. As a pump, the Archimedes screw has also been shown to be quite fish-friendly for fish collected and transferred with the water flow. The large footprint required to fit Archimedes Pumps renders them impractical for many retrofit applications or where space is at a premium.

Figure 1. Screw pumps mounted in diagonal pipes (Source: Fish Flow Innovations).

Figure 2. Screw pump mounted in open trough in a hydropower application (https://parlonsenergie.wordpress.com/tag/fribourg/).

3. Centrifugal Pumps (Hidrostal)

A. Design

Screw-impeller or centrifugal pumps consist of two sections: the screw section which provides a positive displacement action and the centrifugal section which converts part of the impeller energy to pressure in the spiral casing (Figure 3 [ASCE 1982]). Hidrostal is the leading manufacturer of screw-impeller centrifugal pumps, which have been used and evaluated for fish pumping for over 30 years. Hidrostal pump impellers consist of a single spiral vane, which extends axially into the suction of the pump (Figure 3). The vane's long radius curves and low angles give a gradual pressure generation and slow change from axial to radial direction (Hidrostal 2011). The screw-impeller centrifugal pump has been shown to offer a potentially effective means of transporting fishes with low mortality.

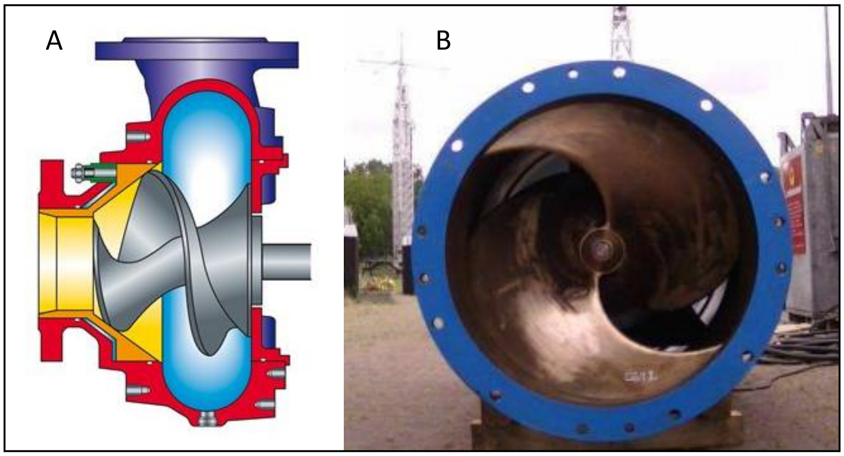

Figure 3. (A) Cut away diagram of a screw centrifugal impeller (Source: Hidrostal) and (B) impeller of Bedford pumps SAF.90.05.12 (Source: Spierts and Vis 2012).

4. Axial Flow Pumps

A. Design

An axial flow pump consists of a propeller within a pipe driven by a sealed motor. The motor is either installed within the pipe or mounted to the pipe from the outside typically penetrating at an elbow (Figure 4). These pumps are smaller in dimension than many conventional pumps and are designed for low heads and high flow. The fish-friendly pumps have impellers and guide vanes designed to create optimal water flow which allows fish to pass through the pump safely. The edges are rounded and the space between the impeller blades is much wider, which reduces the potential for impact with minor effects on the pump efficiency (Fairbanks Nijhuis 2013).

Fish-friendly axial flow pumps are available from Fairbanks Nijhuis (also known as Fish Flow Innovations) and Bedford Pumps, Ltd. Each manufacturer's design is shown in Figure 4. Bedford Pumps can manufacture their range of pumps in solid brass for seawater applications.

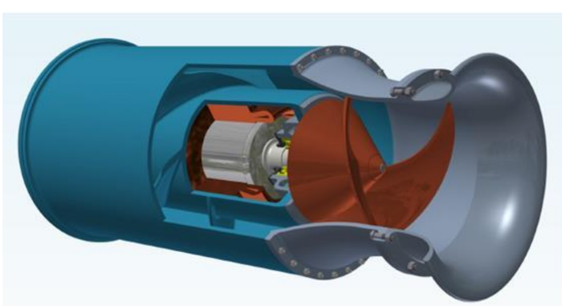
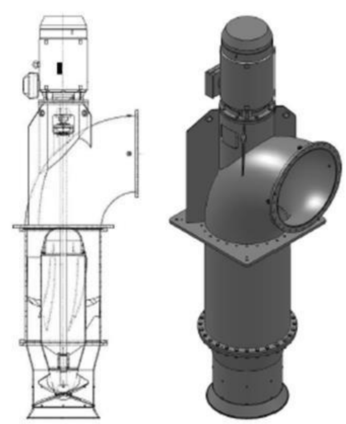

Figure 4. Bedford Pump's submersible fish-friendly axial flow pump (left) and Nijhuis' fish-friendly axial flow pump (right).

B. Case Study

i. Field Trial - Netherland's Dry Dock (Vis and Kemper 2012)

VisAdvies BV, and ecological consulting firm, conducted a full-scale evaluation of pump passage survival with a Bedford fish-friendly axial flow pump (model SAF.90.05.12) in 2012. The survival trials were conducted at a dry dock in the Netherlands.

The test species included eel (*Anguilla anguilla*), bream (*Abramis brama*), roach (*Rutilus rutilus*), perch (*Perca fluviatilis*), and ruff (*Gymnocephalus cernua*). Eels were tested in two size classes (less than or equal to 45 cm and greater than 45 cm). Bream, roach, perch, and ruff were tested in two size classes (less than or equal to 15 cm and greater than 15 cm). Each trial was designed to include 50 individuals.

The experimental set up included the installation of a full-scale pump in the dry dock (Figure 5). Fish were introduced directly to the pump suction and forced to pass through the pump. The pump was operated at 330 rpm and discharged 1.3 m^3/sec (20,605 gpm). Fish were collected on the pump discharge side in a floating net pen fitted with a fyke net. Fish were checked for immediate condition (injury and survival) and live fish were placed in a holding system to monitor for latent mortality over a 48-hr period.

Figure 5. Photos of the pump passage test facility in the Netherlands. Clockwise from top left: pump test facility, discharge of pump into net pen during testing, and latent mortality holding tanks.

A total of 373 fish were tested and all survived passage through the pumps (100% survival). A small proportion of the larger fish (bream) fish were injured with the predominant injury being scale loss. Results are given below in Figure 6.

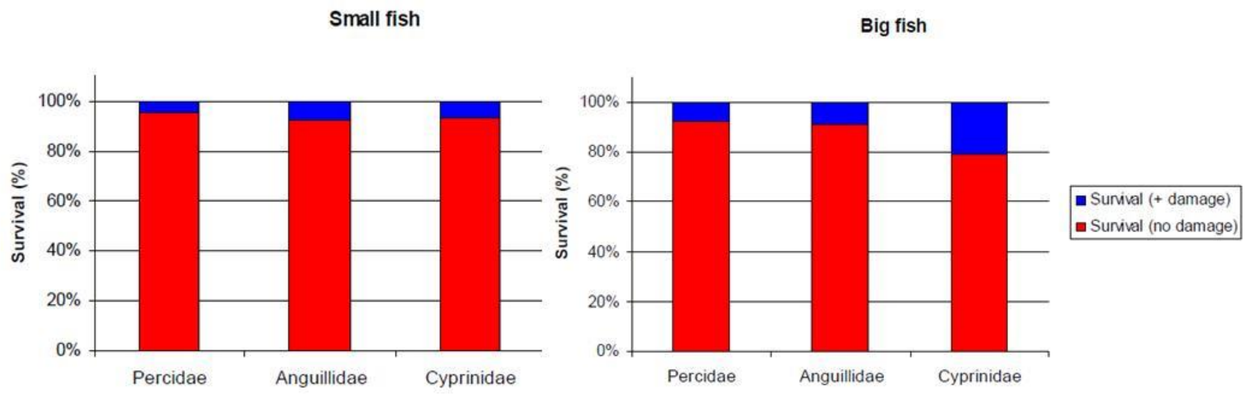

Figure 6. Overview survival rates for the three fish groups tested: Percidae (perch and ruff), Anguillidae (eels), and Cyprinidae (bream and roach).

The authors concluded that the Bedford fish-friendly axial flow pump was very effective in safely pumping live fish during these trials.

5. Discussion

Fish-friendly pumps have been shown to be effective for pumping live fish in water with little or no mortality and injury. Survival rates are typically well above 90% and often approach 100%. In some studies there were no significant differences detected between treatment and control fish (Patrick and Sim 1987; McNabb et al. 2003) or differences detected were only seen in unique circumstances (e.g., periods of high water temperature [Helfrich et al. 2001]). Some studies suggest that larger fish have slightly lower survival than smaller fish (Spierts and Vis 2012), while others have detected no differences (McNabb et al. 2003). Similarly, there is conflicting evidence for the impact of pump rotation speed on survival. Spierts & Vis (2012) and Christie (1990) observed reductions in survival at higher pump speeds while Helfrich et al. (2001) did not. Fish density and debris loading did not appear to impact survival (Helfrich et al. 2001).

Similar trends were observed with injury, scale loss, and stress levels. Christie (1990) observed greater injury rates at higher pump rotation speeds. Helfrich et al. 2001 observed no differences in scale loss between treatment and control fish. Helfrich et al. (2001) also observed no differences in injury except with splittail in one month which was attributed to nitrogen super-saturation in holding facilities.

Fish-friendly axial flow pumps, in particular, have been demonstrated to safely pass juvenile and adult fishes in full-scale testing (Vis and Kemper 2012). In addition, this pump design has advantages over other designs since it requires only small footprint for installation, making it the most feasible for retrofit applications where insufficient space is available. In addition, since the motor and rotating shaft are accessible from the deck level, maintenance efforts are minimized.

Fish-friendly axial flow pumps are commercially available and could be used to meet the requirements of the Desalination Amendment which states that "*an owner or operator proposing to use flow augmentation as an alternative brine discharge technology must use low turbulence intakes (e.g., screw centrifugal pumps or axial flow pumps) and conveyance pipes*".

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