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Environmental issues in seawater reverse osmosis desalination: Intakes and outfalls

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ABSTRACT

Seawater reverse osmosis (SWRO) desalination has some environmental impacts associated with the construction and operation of intake systems and the disposal of concentrate. The primary impact of conventional open-ocean intake systems is the impingement and entrainment of marine organisms. These impacts can be minimized by locating the intake in a geographic position where oceanic productivity is low. Velocity-cap intakes tend to reduce impacts by minimizing the number of fish entrained and some new traveling screens can allow the survival of some marine organisms. Mitigation, such as environmental restoration of habitat or restocking, can provide an acceptable solution to impacts where they are significant. Subsurface intake systems avoid impingement and entrainment impacts, but can cause other, less important impacts (e.g., visual, beach access). Concentrate disposal can locally impact benthic communities, if poorly diluted discharge is allowed to flow across the marine bottom. Impacts to benthic communities from concentrate discharges can be minimized by using properly-designed diffuser systems, designed and located based current and flow modeling.

The experiences of SWRO desalination to date indicate that environmental impacts can be satisfactorily minimized with proper design based on a reasonably complete environmental impact analysis prior to facility siting and design.

1. Introduction

As the need for development of new fresh-water supplies increases, global seawater desalination capacity will continue to expand. Therefore, there is considerable worldwide interest in the assessment of the potential environmental impacts of all aspects of desalination processes including both thermal and reverse osmosis. The least energy-intensive, and as a result often the most economical, seawater desalination process is reverse osmosis (SWRO). This review paper carefully evaluates the environmental impacts associated with the SWRP process, which currently has the greatest rate of increase in installed capacity and will dominant future capacity increases [1]. In 2012, the global installed seawater desalination plant capacity was about 5000 million m^3/year with about 45% of this capacity located in the Middle East [1]. Future planned expansion of desalination use shows that at least 68% of the new facilities will use the SWRO process [1]. Few stand-alone thermal desalination plants will be used with the majority of the thermal facilities being constructed with SWRO systems as hybrids.

Environmental impacts of SWRO can be classified broadly into three categories, including energy consumption [2,3], intakes [4,5,6], and outfalls [4,7,8]. This review covers the environmental issues regarding solely intakes and outfalls. Since recent publications have covered many of the advances in intake and outfall design, including environmental impacts [4,6], this review will emphasize new data and publications on environmental investigations involving SWRO.

SWRO is being projected to become an integral part of future water supplies in many coastal regions that have not needed it in the past, such as California [9] and Texas [10] in the United States, parts of Europe [11], Southeast Asia [12] and China [13]. Higher quality and more up to date scientific information is required to assess the environmental impacts of SWRO desalination, as new projects are being evaluated sometimes based on old or misleading assumptions [14]. Perhaps two of the most important issues that have been raised are impacts of impingement and entrainment caused by open-ocean intakes [15] and concentrate impacts on marine benthic fauna and flora, and fisheries [16].

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2. Review: intakes

2.1. Environmental impacts of intake systems: introduction

Environmental impacts of intake systems for SWRO facilities are of three primary types, depending on the intake design, which are impingement and entrainment of marine organisms, construction (temporary and permanent), and facility operation [3,4]. The largest capacity SWRO facilities tend to use surface-water intake systems (which may be co-shared intakes with electric power generation plants), canal intakes, canal intakes with settling basins, off-shore intakes, deep-water intakes, or passive-screen intakes [15,17–20]. Each of these systems has a different set of potential environmental impacts, specific impacts of concern, or degrees of impacts.

Perhaps the environmental impact of greatest concern with regard to all surface intake systems is impingement and entrainment of marine organisms, which is a function of system design, operation, and local marine biology at the intake head. When designing any intake system, whether a surface-water or a subsurface system, a critical criterion is the proposed location of the SWRO plant and associated intake system, which can affect local seawater quality [15,21,22]. The quality of seawater impacts the design and operation of the downstream pretreatment processes of the SWRO plant and the ability to operate the primary membrane system in a viable and efficient manner [23]. Also, the quality of the raw seawater strongly influences the ultimate quality of the discharge water (concentrate) requiring disposal. In areas of greater biological activity, the pretreatment processes must be intensified, which causes greater chemical usage and associated potential impacts to the environment at the discharge end of the system. A global increase in the spatial and temporal frequency of harmful algal blooms also impacts facility location and pretreatment options [24,25]. A good example of the strategic location of new, large-capacity SWRO plants is in the United Arab Emirates, where the plants are constructed along the coast of the Arabian Sea instead of the Arabian Gulf because of lower average salinity and lower organic carbon concentrations. The water quality benefits offset the additional costs associated with building and operating a long pipeline to deliver the treated water to the larger population centers [26].

2.2. Impingement and entrainment

Impingement and entrainment are collectively defined as the removal (mostly permanently) of marine organisms during operation of an intake system, which could be used for power plant cooling or the operation of a desalination plant. The greatest amount of research on this issue has been performed by the electrical power generation industry for mostly freshwater intake systems and a few seawater systems [27–44]. As discussed in Hogan [15], there are specific definitions for impingable and entrainable organisms. The U.S.E.P.A defines impingable organisms to be "large enough to be retained by a mesh with a maximum opening of 14.2 mm, including 9.5-mm mesh and 6.35 by 12.7 mm mesh. The group includes larger, actively moving juvenile and adult organisms [45]". "Entrainable organisms are small enough to pass through the above specified mesh size. Entrainable organisms include small organisms with limited to no swimming ability. Some of these organisms (or life stages of organisms), such as fish eggs, may be fully passive, lacking the ability to avoid intake flow regardless of velocity [45]".

Impingement and entrainment of marine organisms in terms of probability and magnitude are impacted by intake location (issue of biological productivity), ambient hydraulics (low currents produce higher risk), water quality (water temperature and dissolved oxygen that impact organism mobility), species-specific morphology and physiology (dimensional attributes and geometry), and intake design and operation [15]. Within the United States, the European Union, and Australia, pre-design investigations of the marine environment are generally required before a system can be permitted for construction and operation. The details of the design must be evaluated within the context of the marine pre-permitting investigation. The scope of investigation and duration of these marine studies can be a significant cost in the overall facility budget and can delay project implementation for years. A detailed discussion of the typical scope and duration of these marine studies is given in Hogan [15].

There are considerable differences in the design approaches to reduce impingement and entrainment to acceptable levels. In open-ocean intake systems without passive screens, the intake velocity is minimized at the point of raw water entry into the system and traveling screens are used downstream of the intake to remove marine organisms before they enter the SWRO plant. Some SWRO systems use passive screen intakes in which impingement and entrainment are minimized based on the screen design and selected entrance velocity.

The actual impact of impingement and entrainment on the local and regional marine environment is very difficult to assess and has been controversial. For example, environmental regulatory agencies in the state of California in the United States basically assume that there is a 100% mortality of any marine organism entering the intake (entrainment) which is ultraconservative. Therefore, it is important to view this issue with great care and consider various technical approaches to impact analysis, because it can greatly impact the permitability and economics of an SWRO facility.

There are two different approaches to estimation of mortality caused by entrainment, which are the demographic and conditional mortality approaches [15]. The demographic methods convert the lost organisms to equivalent numbers of adults, which necessitates that the detailed life history of each organism must be known. The number of eggs and larvae that survive to adulthood must be estimated along with fecundity, age-of-maturity, and life span [33]. The estimates made using this approach can be the loss of biomass or the loss of mature females that produce the eggs. The conditional mortality approach, known as the empirical transport model, was developed to assess impacts of power plant cooling water intakes [46]. This model produces a ratio between the number of organisms entrained and the number of organisms at risk of entrainment to estimate the proportional ratio caused by entrainment [47]. This method does not necessitate detailed knowledge of the life-cycle history of a given organism. A comparison of the methods with the advantages and disadvantages is given in Table 1 taken from Hogan [15].

Specific investigations of the impacts of impingement and entrainment have been conducted for SWRO facilities [48,49,50]. Some regulatory jurisdictions (e.g., in the State of California) use the conservative assumptions that the loss of ichthyoplankton (eggs and larvae) caused by impingement and entrainment significantly impacts local and regional fisheries. However, few scientific investigations support this assumption, which has been questioned in a few recently conducted assessments [51].

An intake environmental assessment was conducted to quantify the impact of a 170,722 m^3/d SWRO facility for the West Basin Municipal Water District in southern California [48]. The number of entrained fish larvae, fish eggs, and target invertebrate larvae were 10,164,117, 834,490,494, and 3,936,378 respectively. Despite the seemingly large numbers, the natural high mortality of these ichthyoplankton and the reproductive capacity of the species are significant factors that reduce the real impact. The report concludes that.

> "*The estimates of impacts from the ETM* (*model*) *need to be considered with the levels of entrainment since the natural number of larvae entrained may be very small relative to the reproductive capacity of the particular species. Although this can be done using adult equivalent modeling approaches, this is not necessary when the absolute levels of entrainment are so very low as was the case in this study for all the taxa analyzed with the exception of silversides. For example, the total entrainment estimates for white croaker and California halibut larvae for*