WHITE PAPER

TREATING A MOVING TARGET: HARMFUL ALGAL BLOOMS

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Introduction

Harmful algal blooms (HABs), though challenging to predict, are anticipated to increase in quantity and distribution, challenging effective operation of coastal desalination facilities today and in the future. The purpose of this paper is to provide an overview of HABs, including their basic characteristics, factors that influence their generation, and key risks to desalination facilities. Five areas of plant design, including detection and monitoring systems, intakes, screens, dissolved air flotation, and membrane filtration equipment, will be discussed in terms of their strengths and shortcomings to address HABs.

Abstract

HABs are the result of anthropogenic or environmentally-driven eutrophication events that pose risk to human health, natural resources and coastal facilities. HABs are projected to grow in frequency and distribution in coming years. In parallel with this trend, more thermal and membrane desalination facilities will be constructed globally. As a result, many coastal facilities will be susceptible to HAB risks. Understanding the nature of HABs, their challenges, and ways in which they can be monitored and mitigated are the first steps needed to effectively address HAB risks.

The purpose of this paper is to present an overview of HABs, including their typical characteristics, discuss factors that lead to their development, and identify specific aspects of HABs that pose the greatest risks to thermal and membrane desalination facilities. Five areas of desalination facility and operations design capable of addressing these risks, including detection and monitoring technologies, intakes, screens, dissolved air flotation, and membrane filtration equipment, will be discussed in terms of their strengths and shortcomings to address HABs. While these technologies offer compelling advantages to manage the change in water quality that accompanies HABs, engineers and operators must fully consider technical, economic, and other tradeoffs in order to properly plan and manage events when they occur. As these technologies continue to improve, engineers and operators will have the ability to respond to HAB events and design new desalination facilities more efficiently in the future.

I. INTRODUCTION

HABs are phenomena in which populations of photosynthetic marine organisms suddenly and rapidly increase beyond typical ambient levels, posing risk to human health, natural resources, and coastal facilities. While HABs are widely considered to be unpredictable events, studies show that their frequency and distribution is on the rise. Figure 1 exemplifies the expansion of paralytic shellfish poisoning (PSP), an indicator of HAB activity, between 1970 and 2006.

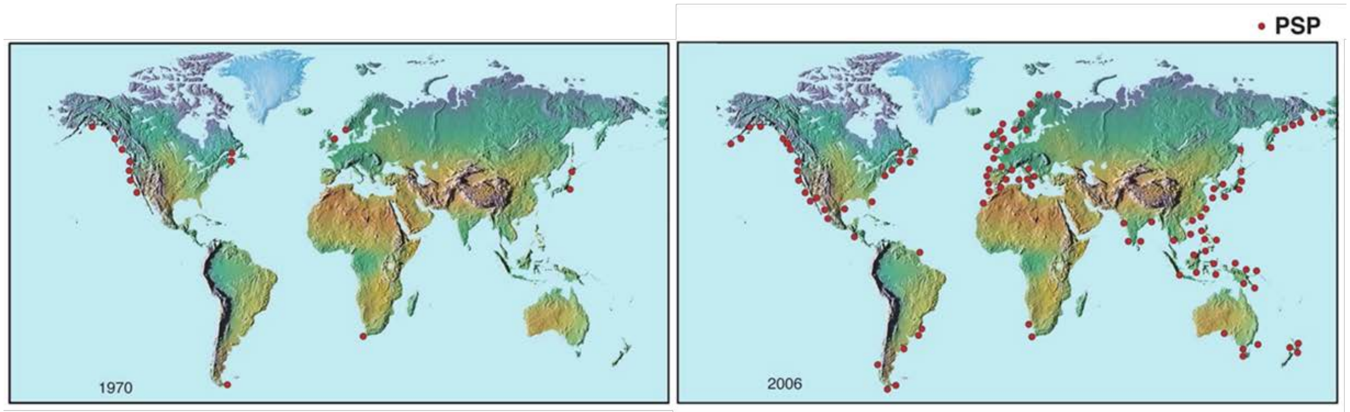

Figure 1. Global HAB Events [1]

HAB threats are particularly acute for coastal desalination facilities, many of which employ membrane-based technologies that are sensitive to biomass and the organic materials that they produce. Thermal desalination facilities, such as multi-effect distillation and multi-stage flash distillation plants, are also susceptible to increased turbidity, total suspended solids (TSS), and total organic content (TOC) loading resulting from HAB events [2]. Nearly 3,380 seawater desalination plants with a combined production capacity of over 40.9 million m^3/day are now in operation. This seawater desalination capacity is anticipated to increase by an additional 13 million m^3/day over by 2020 [3]. Coupled with HAB trends, this increase escalates the risk that HABs pose to desalination facilities. Understanding the nature of HABs, their challenges, and ways that they can be monitored, treated, and mitigated will enable tools and techniques to be implemented at existing and new desalination facilities to address HAB risks.

II. HARMFUL ALGAL BLOOMS

HAB events are linked to populations of microalgae, phytoplankton, and certain varieties of cyanobacteria that form the base of the food chain in marine ecosystems. These photosynthetic, single-celled organisms depend on light and nutrients, such as iron, phosphate and nitrogen, to grow and multiply. Ambient levels of these nutrients are limiting; that is, they sustain microalgae, phytoplankton, and cyanobacteria life while maintaining stable population levels of each organism.

Anthropogenic and natural pressures can cause nutrient concentrations to become unbalanced in seawater ecosystems. For example, anthropogenic pressures, such as municipal wastewater discharge or fertilizer runoff, add elevated concentrations of nitrogen and phosphate to seawater supplies. Natural pressures, such as wind patterns, transport and deposit iron-rich sands into oceans. In shallow layers of ocean water, where light is plentiful, an influx of limiting nutrients creates conditions where microalgae, phytoplankton, and cyanobacteria concentrations can quickly multiply. This phenomenon is known as eutrophication.

In response to a rapid expansion in their food source, populations of various strains of algae and seaweed that feed on microalgae, phytoplankton, and cyanobacteria will tend to grow quickly, or bloom. Blooms come in many forms, as is illustrated in the images in Figure 2.

(A) (B) (C)

Figure 2. HAB Types [1]. ***(A) A "red tide", a bloom of single-celled marine organisms that typically discolors seawater to shades of red. (B) A characteristically green cyanobacterial bloom. (C) A foam-producing*** **Phaeocystis** ***bloom event.***

Regardless of their cellular toxicity or ability to produce biotoxins, blooms can be classified as HABs if they cause harm to human health, natural resources, and coastal facilities. Red tide events, for example, may consist of dinoflagellates that produce the natural biotoxin domoic acid. Domoic acid is toxic to fish and shellfish, and can result in extensive fish kill events. For example, in 2008, a red tide event in the UAE killed 650 tons of fish in Dibba and over 700 tons of fish near Khor Fakkan [4]. Humans may suffer toxic symptoms if they ingest fish with bioaccumulated biotoxins. Conversely, foams produced during *Phaeocystis* blooms are non-toxic, but may damage ecosystem health by depleting oxygen supplies in seawater, which may in turn lead to fish kills. Aesthetics may also limit beach accessibility and the availability of other coastal resources for recreational use.

III. CHALLENGES FOR DESALINATION FACILITIES

HABs pose significant challenges to coastal desalination facilities that treat seawater for municipal and industrial applications. One key challenge stems from the nature of water quality constituents that emerge during the course of HAB events.

3.1 Water Quality Constituents

As populations of algae, seaweed, or other organisms comprising an HAB rapidly increase, levels of turbidity, TSS, TOC, and taste and odor compounds resulting from biomass growth will also quickly rise. Pretreatment technologies, such as screens and media filtration systems, may become overwhelmed by the increase in TSS, particularly if concentrations exceed equipment design limits. If the screening/pretreatment system fails to maintain operation, the downstream desalination system will be impacted. In the case of thermal desalination, the availability and output of the facility may be affected. For reverse osmosis (RO) desalination, the membranes may experience particulate fouling or biofouling, necessitating cleaning. The RO facility may also encounter substantial unplanned maintenance requirements and elevated energy costs due to losses in hydraulic head pressures. In municipal drinking water facilities, failure to remove taste and odor compounds may result in customer dissatisfaction and loss of trust in the safety of their water supply [5]. Production capacity may become limited and, in some cases, the facility may need to be shut down to avoid further damage. This scenario may be particularly problematic in arid regions where water supplies are already limited, or in industrial applications where consistent water supplies are required at high levels of plant availability.

3.2 Emerging Contamination

Some varieties of photosynthetic organisms which bloom during HAB events produce chemical compounds toxic to marine and human life. Saxitoxins, for example, are known toxic substances that can cause marine mammal mortalities and human gastrointestinal symptoms, paralysis, and death [2]. While many biotoxins and the species from which they originate are becoming well understood, many other emerging contaminants lack similar proof. Furthermore, as non-native HAB species are introduced into new regions through mechanisms such as ship ballast water transfer, biotoxin and species characterization become even more complex [6].

A variety of methods can be used to detect and identify HAB organisms and biotoxins, ranging from light-based to genetic and immunological techniques. However, many of these techniques are intricate, expensive, and time-consuming. The ability of toxins to pass through pretreatment, RO, and thermal desalination systems is also not well understood. While the molecular weight and charge of many biotoxins suggest that RO membranes would theoretically reject them effectively [5], and a pilot study at the West Basin Municipal Water District confirmed that “domoic acid showed 100 percent removal by the RO membranes” [7], the removal of domoic acid or other biotoxins on full-scale desalination applications has not yet been proven. Similarly, while thermal desalination facilities are expected to be less affected by biotoxins [2] due to their ability to potentially degrade problematic compounds, further documentation is needed in order to determine the technique’s biotoxin rejection capabilities [8].

IV. HAB PREVENTION, TREATMENT AND MITIGATION

Several technologies and strategies offer engineers and operators the ability to address HAB risks as a desalination facility is designed and operated. These solutions are described in the following sections.

4.1 Detection and Monitoring Technologies

Detection and monitoring technologies, such as seawater analyzers and remote sensing technology, can be used to identify HAB organisms and indicators of HAB activity. For example, nitrogen analyzers can be used to monitor concentrations of the limiting nutrients in a water supply, and enable engineers and operators to determine whether changes in detected nutrient levels may impact HAB development. Chlorophyll-A analyzers, which detect light-capturing pigments present in photosynthetic organisms, can be used to monitor HAB concentrations. Analyzers such as these can be used to provide operators with advance warning of HAB events, and enable them to correct desalination pretreatment schemes effectively in response. Engineers can also use data from seawater analyzers to characterize seawater near a new project site and design pretreatment systems appropriately.

Remote sensing technologies such as NASA's MODIS satellite imaging system can also be used to identify and monitor indicators of HAB activity, such as chlorophyll-A (see Figure 3). Unlike seawater analyzers, however, satellite imaging technologies "offer the advantage of providing worldwide coverage over an extended temporal baseline" due to the frequency in which data is collected and the geographic range that satellite images are able to capture [6]. The availability of this information not only enables engineers to investigate temporal HAB trends, such as whether blooms tend to occur seasonally, but it also allows them to understand potential HAB activity in regions where ground-level monitoring is weak or does not exist. Spatial trends can also be inferred using satellite imaging technology; when chlorophyll-A detection is combined with oceanic and meteorological data, for example, engineers and operators can deduce whether blooms are likely to spread. Satellite imaging data can thus be used to aid plant design, facility site selection, and help operators plan for potential HAB events.

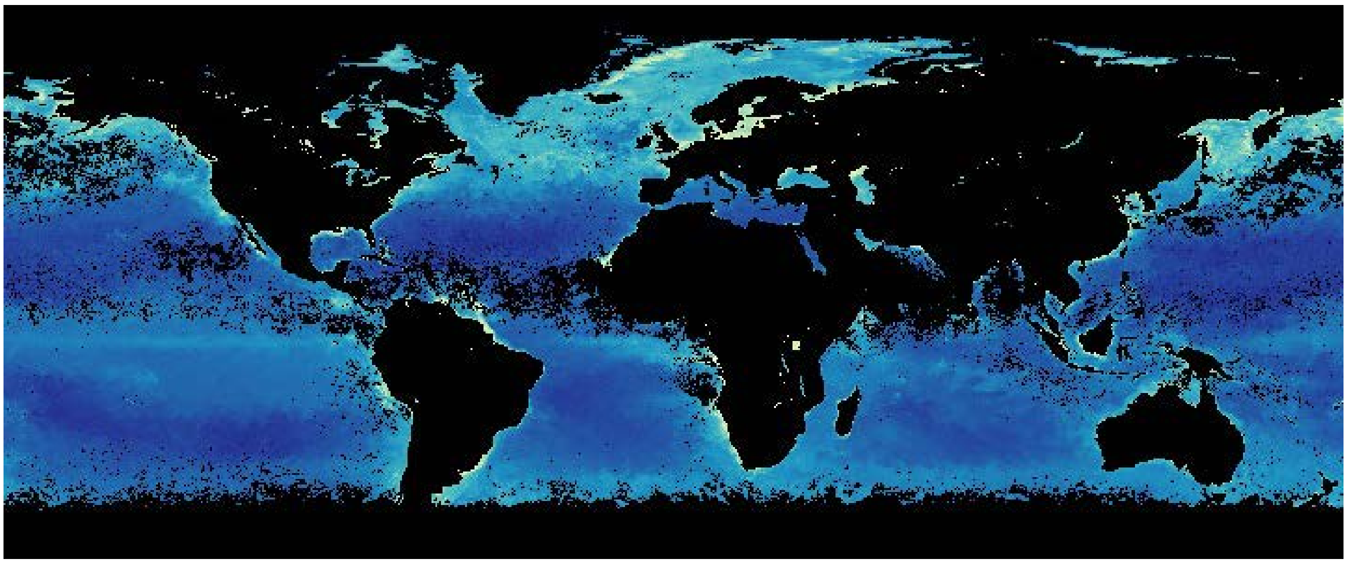

Figure 3. Chlorophyll-A Remote Sensing [9]

Despite the benefits of seawater analyzers and remote sensing technologies, there are several shortcomings that may impact their effective use. First, certain types of seawater analyzers can difficult to utilize and maintain, particularly during HAB events when turbidity, TSS, and TOC levels are very high. Nutrient analyses are often time consuming to conduct, which can hinder response time during HAB events. Satellite imaging technologies can only provide data on parameters that are measurable remotely, and should be cross-referenced with ground data for accuracy when possible. Data gaps may also be present due to meteorological interferences such as low clouds [6].

4.2 Intakes

Intake system designs, including the type of structure chosen and its placement in or near the ocean, can be a highly effective means to prevent HABs from adversely impacting desalination facilities. Three examples of intake structures that offer promising protection to desalination facilities include open intakes with an offshore intake terminal, submerged intakes, and beach wells. Open intakes, which extend farther and deeper into the ocean, may avoid regions in which biomass may accumulate, as well as the seawater's photic zone, where HAB organisms tend to grow. Submerged intakes, which extend into the ocean along the ocean floor, can also be used to draw seawater from zones where biomass is far less concentrated. Beach wells, which are applied to membrane desalination facilities more frequently than to thermal desalination facilities as a function of well flow capacity and desalination recovery rates, are land-based intake systems that can leverage natural filtration through surrounding sands to prevent HAB organisms from entering a seawater desalination facility.

While open intake, submerged intake, and beach well intake structures may prevent gross biological material from entering a desalination facility, they do not avert dissolved constituents such as TOC and toxins effectively. Measures such as placing intakes in regions where seawater circulation patterns are likely to sweep contamination away from the structures may provide some additional protection to the RO facility. However, the addition of proper pretreatment and cleaning mechanisms at the desalination facility is necessary to ensure that equipment integrity is maintained and that effective seawater treatment may take place.

4.3 Screens

Screens typically provide a first tier of pretreatment for both thermal and membrane desalination facilities by removing debris and large diameter TSS from seawater. As seawater is drawn through screens, two processes may impact sea life: impingement and entrainment. While impingement refers to “biota, typically fish, becoming physically trapped on the intake screens”, entrainment entails “biota getting drawn into the intake with the seawater inflow” [7]. Due to their cellular size, ambient levels of microalgae, phytoplankton, and cyanobacteria may be easily entrained into desalination facilities. Additional pretreatment is required to prevent damage to desalination equipment, particularly RO membranes, which are susceptible to biofouling. During HAB events, however, microalgae, phytoplankton, cyanobacteria, and other organisms, which feed on them may pose an impingement risk to desalination facilities by blocking or fouling the screen itself. This will not only limit seawater flow into the facility, but may increase the risk of particulate fouling or biofouling to downstream membrane technology and limit total throughput. The latter is particularly problematic for thermal desalination facilities, which typically operate at lower recoveries than RO plants.

While screens are a necessary component of a seawater desalination facility’s pretreatment design, measures must be made to ensure that HAB events do not adversely impact their treatment efficiency. Proper screen selection and sizing, particularly in regions prone to HABs, will ensure that there is adequate flow capacity during a bloom event. Equipment such as bubble diffusers may reduce the risk of jellyfish impingement, should a jellyfish bloom occur. Proper design of downstream pretreatment designs, such as dissolved air flotation (DAF) systems and membrane filtration, will ensure that elevated TSS concentrations that pass through the screens are mitigated prior to impacting critical desalination equipment.

4.4 Dissolved Air Flotation (DAF)

In desalination applications, DAF pretreatment is known for its ability to efficiently separate algae and other low-density solids from seawater. Pilot and full-scale DAF technologies have demonstrated their ability to provide robust seawater treatment during HAB events over the past five years. For example, in late 2008, a severe, persistent red tide event occurred along the coast of the UAE. Over the course of the HAB, numerous desalination facilities were forced to shut down, including the Federal Electricity and Water Authority’s (FEWA) Al Ghalilah SWRO plant, the Fujairah Fresh Water Company plant in Fujairah port, Sharjah Electricity and Water Authority’s (SEWA) Khor Fakkan SWRO plant, and Abu

Dhabi Water and Electricity Authority's (ADWEA) Fujairah 1 facility. During the HAB, a pilot facility outfitted with an advanced DAF technology continued to function effectively at the Fujairah 2 facility (see Figure 4), which was under construction nearby [4].

(A) (B)

Figure 4. Fujairah 2 DAF Pilot [11]. ***(A) Normal operating conditions; (B) Red tide conditions***

Following the commissioning of the Fujairah 2 plant in 2011, the advanced DAF system maintained production again during another severe red tide which, similar to the 2008 HAB event, caused many neighboring facilities to shut down. The ability for DAF systems to maintain production, particularly in water scarce regions or where maintaining high levels of plant availability is important, renders it an attractive option for municipal and industrial desalination facilities.

Despite the promising aspects of DAF technologies, there are several setbacks that must be considered when potentially incorporating it into a desalination facility design. First, DAF systems, particularly advanced designs such as those implemented at the Fujairah 2 facility, are more complex than traditional DAF systems and expensive to construct and operate. While some desalination experts suggest incorporating DAF technologies into facility designs as a preventative maintenance measure [12], these costs must be weighed against the risk of HAB events occurring, plant availability requirements, and other factors to ensure that the potential investment is cost-effective.

4.5 Membrane Filtration

Membrane filtration systems, including microfiltration (MF) and ultrafiltration (UF), are pretreatment technologies that have the ability to efficiently remove TSS from seawater. Membrane filtration as pretreatment to RO is used throughout the world, and is able to protect RO membranes reliably with minimal energy consumption [13]. UF and MF systems in particular have proven effective during HAB events. For example, during a pilot study in Hong Kong where red tides occurred several times over two years, membrane filtration pretreatment technologies maintained their recovery levels without signs of irreversible fouling [4]. According to desalination experts, conservatively designed membrane filtration systems which operate at low fluxes may be sufficient for "all but the most severe blooms", and are considered superior to single or two-stage granular media filter alternatives [12].

While membrane filtrations systems are compelling pretreatment systems for desalination facilities that may experience HAB impacts, they must be carefully designed to ensure that treatment is maintained efficiently. Tradeoffs such as increasing the capacity of MF and UF systems in order to maintain throughput at reduced flux rates during HAB events must be evaluated, for example, to assure that the design is cost-effective. The prevalence of emerging contaminants such as transparent exopolymer particles (TEP), a sticky polysaccharide that some strains of algae produce, must also be considered in light of negative impacts they may incur to membrane systems. Increased levels of TEP in source waters have been shown to result in "elevated rates of backwashable and non-backwashable fouling" [14], for example.

V. SUMMARY AND CONCLUSIONS

With the frequency and distribution of HAB events on the rise, the potential for new and existing desalination facilities to be adversely impacted is projected to increase in the future. These impacts will largely stem from the larger quantities of toxic and non-toxic constituents that HAB species produce. If they remain untreated, these constituents may not only impact desalination treatment processes, but human health and natural resources as well. As the nature of HABs becomes better understood and techniques to prevent, treat, and mitigate them developed and refined, engineers and operators will have the ability to respond to HAB events and design new desalination facilities more efficiently in years to come.

VI. AUTHORS INFORMATION

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Holly Churman is the Technology Manager at Water Standard, managing efforts relating to research, demonstration and integration of water treatment technologies for water-based improved and enhanced oil recovery and other applications in the oil and gas industry. Prior to joining Water Standard, Ms. Churman served as Senior Applications/Process Engineer for Veolia Water Solutions & Technologies, where she designed advanced water treatment and desalination solutions for seawater and industrial water and wastewater projects globally. Ms. Churman has authored a number of technical papers related to technology design, development, and sustainability, and has presented on these subjects at national and international forums. She is a member of the International Desalination Association Young Leaders Program Committee and the Produced Water Society Technical Committee. A registered professional engineer in Texas and West Virginia, USA, Ms. Churman earned her Bachelor of Science and Master of Science degrees in Environmental Engineering from the Massachusetts Institute of Technology and Stanford University.

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VII. REFERENCES

1. Woods Hole Oceanographic Institute. "Harmful Algae." http://www.whoi.edu/redtide/home. 2013.

2. Caron, David et al. "Harmful algae and their potential impacts on desalination operations off southern California." *Water Research*. 2009.

3. DesalData. "Projects and Plants." http://www.desaldata.com/projects. 2016.

4. Pankratz, Tom. "Red tides close desal plants." *Water Desalination Report.* Dec. 2008. www.desaldata.com/news/24629.

5. Anderson, D.M. and S. McCarthy. "Red Tides and Harmful Algal Blooms: Impacts on Desalination Operations." Middle East Desalination Research Center, Muscat, Oman. 2012.

6. Bishop, Jonathan Philip and Patrick Joseph Phelan. "Using Remote Sensing to Assess Risk to Reverse Osmosis Infrastructure from Algae." Proceedings of the IDA World Congress, Perth, Australia. 2011.

7. Mackey, Erin et al. "Assessing Seawater Intake Systems for Desalination Plants." WateReuse Research Foundation. 2011.

8. Pankratz, Tom. "Buoys will gather red tide data." *Water Desalination Report.* Mar. 2009. www.desaldata.com/news/25220.

9. Cotruvo, Joseph et al. Desalination Technology – Health and Environmental Impacts. Boca Raton: Taylor & Francis Group. 2010.

10. NASA Earth Observations. http://neo.sci.gsfc.nasa.gov/view.php?datasetId=MY1DMM_CHLORA. 2013.

11. Gaid, Kader. “Desalination Drinking Water Plant: Fujairah 2. From Pilot to Full Scale Plant: A Success Story.” Proceedings of the ALADYR International Desalination Seminar, Chile, 2012.

12. Pankratz, Tom. “HAB Treatment Strategies.” *Water Desalination Report.* Feb. 2012. www.desaldata.com/news/31186.

13. Capannelli, Gustavo et al. “Ultrafiltration for Improvement of Desalination Efficiency.” Proceedings of the IDA Desalination Conference, Santa Margherita, Italy. 2011.

14. Villacorte, Loreen O. et al. “Membrane Fouling by Marine Algal Bloom: the Role of Transparent Exopolymer Particles (TEP)”. Proceedings of the IDA World Congress, Perth, Australia. 2011.