Desalination xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

The use of simulated whole effluents in toxicity assessments: A review of case studies from reverse osmosis desalination plants

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HIGHLIGHTS

- Wastewater from desalination plants can impact the surrounding biota.
- Interactive effects may be identified by testing simulated whole effluents.
- We review three case studies in which simulated whole effluents were tested.
- Use of simulated effluents enabled various chemical combinations to be assessed.
- Drawbacks were consistent with assessments that use real effluents.

ARTICLE INFO

Article history:
Received 30 October 2014
Received in revised form 7 January 2015
Accepted 8 January 2015
Available online xxxx

Keywords:
Brine
Environmental impact
Ecotoxicology
Marine
Wastewater

ABSTRACT

Seawater desalination is an increasingly common means to meet the demand for freshwater. Resulting wastewater discharges can, however, impact biota of the surrounding environment. Concern exists that interactive effects specific to the outputs of each desalination plant may result in unique impacts difficult to predict by studying existing plants or assessing the effects of individual chemicals found in waste streams. Given this, we highlight an alternative approach to assess potential toxicity of desalination outfalls. Specifically, we review three recent case studies from Australia in which simulated whole effluents were used in toxicity assessments before desalination plants were constructed. This approach enabled potential toxic effects of wastewater to be considered before the plants became operational and, in one case, even facilitated consideration of potential effects of different treatment processes and suppliers. As in many whole effluent toxicity assessments, the time required for testing and restricted range of species considered were limitations. Given the benefits of this method, however, the use of simulated whole effluents is a development that could facilitate an improved capacity to forecast impacts of proposed desalination plants.

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http://dx.doi.org/10.1016/j.desal.2015.01.014
0011-9164/© 2015 Published by Elsevier B.V.

1. Introduction

Global population growth and associated patterns of consumption are placing increasing pressure upon resources, particularly freshwater [1]. Water scarcity is projected to worsen across much of the globe in the coming century, with severe shortages anticipated to affect 2.7 billion people in more than 80 countries [2]. Consequently, there is growing interest in methods to enhance the availability of freshwater. In coastal regions, desalination of seawater is increasingly explored and utilised as a method to complement other sources of water supply [3]. The process of desalination has a relatively long history in the Middle East (particularly the United Arab Emirates, Kuwait and Saudi Arabia), with capabilities rapidly expanding in the United States, Europe, China and Australia [3,4].

Desalination of seawater can, however, have environmental impacts, with particular concern often focussed on the potential effects of the resulting wastewater discharges returned to the marine environment. These discharges can have negative effects because of their highly saline nature, and also because they contain chemicals added during processing activities including chlorination, pH adjustment, coagulation, flocculation, dechlorination, antiscaling and membrane cleaning [3,5]. The resulting saline and chemical-rich waste streams can adversely affect surrounding environments by degrading water and sediment quality, impairing the functioning of marine life and disrupting the intactness of ecosystems (reviewed in [3,6,7]). Importantly, not only can individual contaminants (i.e., salinity or chemical additive) have a specific impact, but their effect may be exacerbated when added to the water column in combination, as occurs in the effluent from a desalination plant [8,9]. Thus, while some general conclusions can be drawn regarding the broad ecological effects of effluents, impacts may be relatively specific to each plant because the waste stream produced is dependent on the local seawater characteristics as well as the chemicals, processes and specific running conditions chosen for use.

The urgent need to obtain potable water in many parts of the world has meant that, historically (particularly before the 1970s), environmental issues associated with desalination had largely been overlooked or an issue of secondary concern [10,11]. Increasingly, however, the disposal of wastewaters is drawing attention both in terms of environmental approvals and public perception (i.e., obtaining a 'social licence to operate'). This attention is particularly strong in developed nations such as Australia where environmental issues are often high on the public agenda and desalination is becoming more common [12,13]. Within Australia, desalination has the potential to provide an important source of potable water to growing coastal populations (~85% of the population lives within 50 km of the coast) and over the last few years a number of large (~50–200 GL a^{-1}) reverse osmosis plants have been built across the country to augment domestic water supplies of most of the major cities [12,14]. Perhaps less in the public eye, but equally important economically, is the production of water by desalination for industrial applications such as mining — to date industry applications have mainly involved saline groundwater, but increasingly seawater is being considered as a potential intake source and receiver of waste streams [12,15]. Ongoing uncertainty regarding the potential impacts of wastewater from desalination plants means, however, that limits of pollutants in wastewaters set by regulators in Australia are often highly precautionary, adding significantly to the cost of establishing and operating desalination plants. Consequently, a key issue is the development of a better understanding of the salinity and toxin tolerance of marine species in the vicinity of outflows [12], as this capability would likely bring both ecological and economic benefits.

Given concern regarding the potential impacts of waste streams, it is increasingly common for assessment of their toxicity to be conducted before a desalination plant becomes operational, and often before construction even begins. By conducting assessments early in the process, Australian regulators are able to assess the likely risks to the environment and, where deemed acceptable, to set licensing conditions (e.g., permissible waste stream volumes and concentrations) before any impact occurs. Complicating such testing, however, is the potential influence of local seawater characteristics, synergies among the specific chemicals released by each plant, and likely differing responses of the complex biota in the receiving environment [1]. One approach to this kind of assessment is to simply ignore the potential influence of synergistic effects — that is, to identify the potential effect of each contaminant that may be in an effluent and then add predicted responses to forecast the combined toxicity of waste streams. While such an approach takes into account local plant designs and likely running conditions, it cannot account for any interactive effects among the chemicals considered nor facilitate an understanding of the conditions which drive an interactive response [16]. An alternative approach is to conduct whole effluent toxicity (WET) assessments using wastewater collected from similar desalination plants that are already operational elsewhere. While this method addresses concerns regarding potential synergistic effects of multiple chemicals, the local context may be overlooked. That is, identifying similar plants can be difficult, with potential that the closest similar plant has differing seawater characteristics. Further, even where similar plants do exist within a suitable distance and samples can be obtained, information about associated running conditions and procedures may not be something the plant operators are willing to provide if this is outside of their normal licence conditions. Without such information, just how similar the actual (sampled) effluent under real running conditions is to that expected from the theoretical plants is difficult to gauge. In turn, this means that the results from WET testing may be hard to relate to the potential toxicological impacts of planned plant [8].

A need exists, therefore, for a way to consider the potential impacts of the whole (combined) effluents expected to be produced by proposed desalination plants which takes into account the specific characteristics of local environment, plant design and likely running conditions. An emerging way to do this is by WET testing of simulated whole effluent(s) manufactured to represent the outflow which will likely be produced by a specific plant under predicted running conditions. While this method holds promise and is increasingly utilised and advocated in literature resulting from applied studies (such as consultants reports and government documents, e.g., [17–19]), it has received relatively little attention in the academic literature and not, to our knowledge, been used widely outside of Australia. Here, our overall objective was to consider the potential utility of simulated whole effluents in toxicity assessments by reviewing three Australian case studies. Specifically, we consider the Cape Riche, Victoria and Gorgon reverse osmosis desalination plants. We have chosen this subset of Australian desalination plants as they provide a good indication of the various methods and approaches used in testing of simulated whole effluents (described below). In this review we summarise the background to each project, effluents simulated, models and hypotheses of interest, WET testing done, results (largely in terms of management applications), and assess any features of the assessments which constrained the efficacy of this approach.

2. Case studies

Simulated whole effluents are increasingly used in toxicity assessments conducted prior to and during the development of desalination plants. In a growing number of cases, reports summarising these assessments in terms of the specific approach used and results obtained are made freely available, which enables their comparison. Here, we review three such projects and their reports, specifically; the Cape Riche seawater desalination plant summarised in [5], the Victorian Desalination Project constructed in Wonthaggi as detailed in [20], and the Gorgon Development at Barrow Island documented in [8]. These reports form the basis of the following comparison(s), with detail included in this section obtained from them unless otherwise indicated.