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Managing wastewater effluent to enhance aquatic receiving ecosystem productivity: A coastal lagoon in Western Australia

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ABSTRACT

Large amounts of waste are generated in urban centers that if properly managed could promote ecological services. In order to promote nutrient cycling and productivity without endangering aquatic ecosystems, management of wastewater treatment and effluent discharges to receiving waters must be assessed on a case-by-case basis. We applied this premise to examine a municipal wastewater treated effluent discharge in a shallow oligotrophic coastal lagoon in Western Australia. Three-dimensional hydrodynamic-ecological modeling (ELCOM–CAEDYM) was used to assess the reaction of ecosystem for effluent quality. Two scenarios were evaluated for the summer 2000–2001 period, the actual or "current" (conventional secondary treatment) and an "alternative" (involving substitution of biological nutrient removal by advanced treatment). The residence time of the simulated numerical domain averaged 8.4 ± 1.3 days. For the current scenario the model successfully estimated phytoplankton biomass, as chlorophyll-a concentration (Chl-a), that is within field-measured ranges and previously recorded levels. The model was able to reproduce nitrogen as the main limiting nutrient for primary production in the coastal ecosystem. Simulated surface Chl-a means were 0.26 (range 0.19–0.38) μg Chl-a/L for the current scenario and 0.37 (range 0.19–0.67) μg Chl-a/L for the alternative one. Comparison of the alternative scenario with field-measured Chl-a levels suggests moderate primary production increase (16–42%), within local historical variability. These results, suggest that such a scenario could be used, as part of a comprehensive wastewater management optimization strategy, to foster receiving ecosystem's productivity and related ecological services maintaining its oligotrophic state.

1. Introduction

As agriculture practices have improved over the last century, populations have increased and moved to urban areas generating large amounts of solid, liquid and gaseous byproducts (Foley et al., 2005; Langergraber and Muellegger, 2005). In modern urban management plans, until very recently, these byproducts were viewed as wastes that need to be rendered harmless and then disposed of (Langergraber and Muellegger, 2005; Miller, 2006). By contrast, along natural food webs "wastes" are rarely concentrated but usually dispersed and/or biodegraded and cycled (Pomeroy and Wiebe, 1988). In this work we assessed using such nature strategy and advocate the management of wastewater as a valuable resource instead of as a waste. Global net primary production (NPP) has been estimated at 104.9 × 10^9 t C per year, marine ecosystems account with 46.2% of this production (Field et al., 1998). Annual global marine NPP is estimated to be: 52% consumed by herbivores, 36% net decomposed (respired), 10.8% recycled (via the microbial loop) and 1.2% partially stored in sediments (Duarte and Cebrian, 1996). An average energy transfer of 10% from primary consumers to each subsequent superior consumers' level has been used as a general approximation for marine systems (Pauly and Christensen, 1995). Water serves as medium for carrying and dispersing excretions and remains of organisms. Modern industrialized society approach to deal with excretions has been using water (often of potable quality) to transport to centralized facilities (usually energy-intensive) as wastewater treatment plants (WWTPs) (Andreen, 2006; Langergraber and Muellegger, 2005; Metcalf and Eddy, 2003), where the natural food chain is by-passed and so called wastes are made palatable to bacteria.

Two main drivers have motivated modern wastewater regulations and management: public health and environmental concerns (Andreen, 2006). Since the introduction of the Clean Water Act in 1972 in the United States, regulations have evolved toward more strict controls on effluent discharges, e.g. total suspended solids

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(TSS), total dissolved solids (TDS), biological oxygen demand (BOD), total organic carbon (TOC), nutrients and pathogens (Andreen, 2006; Metcalf and Eddy, 2003). In recent decades a trend to adapt water resources' policies towards sustainable management has progressed as evidenced in elements of the European Union Water Framework Directive, the Australian National Water Initiative and decentralization policies in USA, but all these policies have encountered technical and social implementation difficulties (Andreen, 2006; Hussey and Dovers, 2006). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality are based on the definition of "environmental values" or "beneficial uses" (Hussey and Dovers, 2006), where waste absorption is, generally, not included. On the other hand, several disinfection, tertiary and advanced treatment technologies have been developed in recent decades, and despite their usually high cost and depending on influent quality and effluent destination, they can be applied to achieve target quality levels (Burkhard et al., 2000; Lazarova et al., 1999; Metcalf and Eddy, 2003; Suty et al., 2004).

Ecosystems have limited ability to recover from disturbance (Thrush and Dayton, 2010), and to perform ecological services (Haberl et al., 2004). There are several examples of coastal areas where effluent discharges have created environmental problems, including eutrophication, diminishing their ability to perform ecological services (Cloern, 2001; Smith et al., 2006). On the other hand, there is increasing recognition of the value of wastewater byproducts (i.e. effluent, nutrients and energy) and it has been suggested that reusing these byproducts can help to ameliorate the pressure on natural resources (Haberl et al., 2004; Langergraber and Muellegger, 2005; Miller, 2006). We propose that through case-by-case optimization of the use of: available treatment technologies, real-time control-management systems, and receiving waters' mixing-dispersion ability, it may be possible to match nutrient discharge to the receiving ecosystem's assimilative capacity. This could provide enhanced ecological services without compromising long-term functionality (Andreen, 2006). Under these premises we studied the discharge of Beenyup, a conventional municipal WWTP, to a semi-enclosed shallow oligotrophic coastal lagoon, where NPP is nutrient limited by nitrogen (Lord and Hillman, 1995). Using hydrodynamic–ecological models we compared the response of the receiving ecosystem under two effluent quality scenarios: the current management practice and an alternative that, by omitting biological nutrient removal in conventional WWTP, presumably promotes biomass production and associated ecosystem services in the receiving environment. Simulation results are discussed from the perspective that using the case-by-case approach shown, in combination with comprehensive analysis of other local management options, could be helpful in optimizing wastewater management strategies.

2. Methods

2.1. Study site

Beenyup, a conventional municipal WWTP, located on the coast of Western Australia (WA) just north of the capital Perth (Fig. 1), serves approximately 600,000 residents (mean flow-rate 1.4 m^3/s), and is operated by the local water authority, Water Corporation of Western Australian (WCWA, 2009). Wastewater effluent is discharged offshore, within the legally protected Marmion Marine Park, from two adjacent outlets, 1620 m and 1820 m from the coastline, each equipped with a 200 m-long diffuser on the sea floor at 10 m depth (Lord and Hillman, 1995; WCWA, 2009). The receiving shallow coast (maximum 14 m depth) is characterized by a series of submerged limestone reefs running parallel to the shoreline between 2 and 10 km offshore. These reefs generate a semi-enclosed lagoon where the wind field has the strongest current control and is mainly balanced by the bottom friction (Hillmer and Imberger, 2007; Zaker et al., 2007). Southerly wind predominates year round, with more variability during winter and stronger steady breeze in summer (Zaker et al., 2007). In general, WA's coastal waters are oligotrophic, characterized by low nutrient concentrations and low productivities, associated with suppression

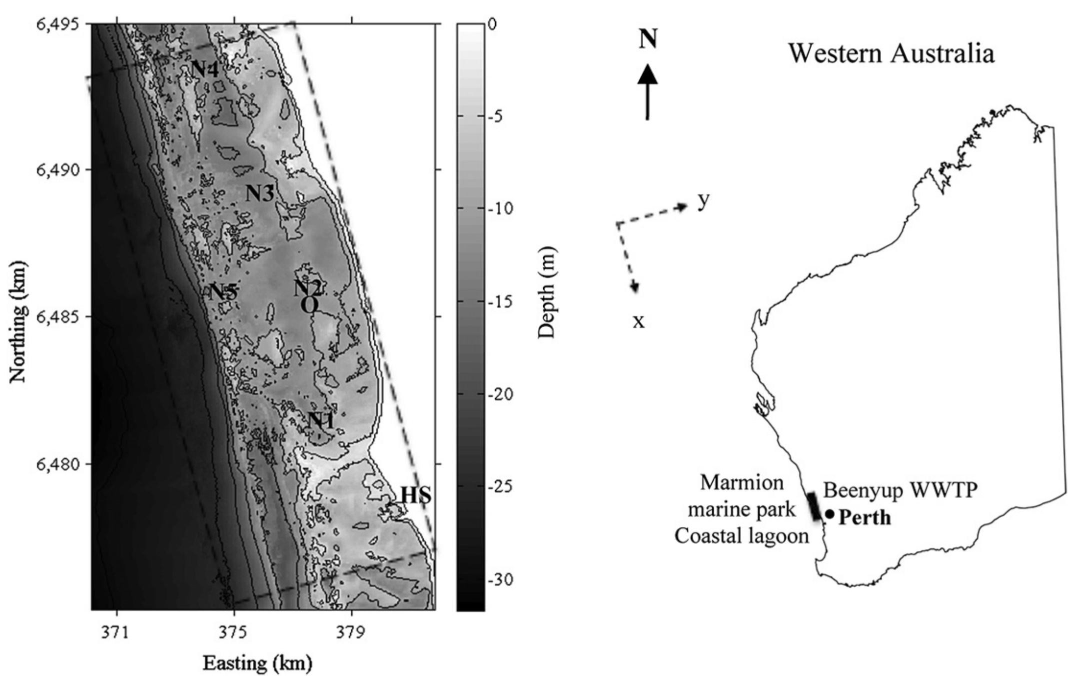

Fig. 1. Beenyup wastewater treatment plant (WWTP) and coastal receiving waters bathymetry. Approximate location of outfall diffuser (O), water quality stations (N1–N5), Hillarys boat harbor meteorological station (HS), numerical domain boundaries (dashed area) and coordinates system (indicative *x*/*y* axis).