Ocean & Coastal Management 116 (2015) 9–19

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

A scenario-based approach to evaluating potential environmental impacts following a tidal barrage installation

Ian M. Kidd [a, *], Andrew Fischer [a], Shuhong Chai [b], Jenny A. Davis [c]

[a] Institute for Marine and Antarctic Studies, University of Tasmania, Launceston, Tasmania 7248, Australia
[b] National Centre for Marine Engineering and Hydrodynamics, Australian Maritime College, University of Tasmania, Launceston, Tasmania 7248, Australia
[c] Institute for Applied Ecology, University of Canberra, Australian Capital Territory 2617, Australia

ARTICLE INFO

Article history:
Received 16 April 2015
Received in revised form
20 June 2015
Accepted 22 June 2015
Available online xxx

Keywords:
Total exclusion barrage
Remnant estuary
Tidal prism
Bathymetry
Migratory species
Morphology

ABSTRACT

Total exclusion barrages have a high impact on estuarine systems as they are permanent barriers to tidal flow. The environmental impacts of five putative barrages in various locations within the Tamar River estuary in northern Tasmania, Australia were assessed by considering likely hydrological, morphological and ecological outcomes. We found that all hypothetical barrages would produce downstream silt accretion, some to the point where a major port would become unusable without ongoing dredging. The closer a barrage was located to the mouth of the estuary, the greater the loss of tidal prism, the lower the effect of flushing by floodwaters, and the greater the loss of estuarine biodiversity. Eradication of invasive rice grass (*Spartina anglica*) in the mid estuary is potentially a positive outcome, whilst constant head-pond surface heights could cause bank erosion and subsidence. Loss of tidal wetlands would contravene the international treaties protecting the migratory waterbirds which use these habitats. Installation of a barrage at the uppermost location appears to represent the best trade-off between adverse impacts and increased recreational and visual amenity. Unfortunately, barrage installation at any site within the estuary fails to address the major anthropogenic stressors of reduced riverine inflows and tidal flushing. A wider sustainability analysis is needed in which the costs of meeting environmental, social and economic objectives are considered.

1. Introduction

Tidal barrages, or structures which prevent marine water from moving upstream in an estuary, have been installed in past decades, in many parts of the world, for tidal power generation, storm surge protection, storage of freshwater and provision of impoundments for recreation (Gray et al., 1992). Morris (2013) classified barrages into three categories, permeable (may be raised and lowered to protect from storm surges); sills (retain high water whilst allowing higher tides to penetrate) and causeways, which exclude tidal influence. The latter, also known as total exclusion barrages, have particularly high impacts because they are a permanent barrier to the movement of tides and salt. Estuarine barrage installation has become less frequent as environmental repercussions have become better understood and the trade-offs with a range of ecosystem services are regarded as less acceptable. There is a paucity of analyses assessing the impacts of barrages in the peer reviewed literature, despite evidence of acute detrimental impacts (Morris, 2013).

The United States leads the world in estuarine and stream rehabilitation, where 306 barrages or dams were removed from 1999 to 2008 (American Rivers, 2008) as part of a billion dollar per annum ecological restoration industry (Bernhardt et al., 2005). Debate over the building of a major barrage on the Severn in the UK concentrated on environmental issues with arguments for (Kirby and Shaw, 2005) and against (Clark, 2006), notwithstanding that the barrage had the potential to generate an average 2 GW or 5% of UK power demands (REUK, 2009). A barrage constructed near Cardiff in Wales had a significant accretion impact on adjacent coastal areas while causing erosion at distances up to 72 km away (Phillips, 2007). Salt water became trapped behind a fixed barrage on the River Lagan in Northern Ireland causing oxygen depletion and damage to the aquatic environment (Walker et al., 1996). The Marina Barrage was recently built in Singapore as a freshwater storage and to prevent low-lying areas flooding during torrential tropical downpours. The Singaporean government claim it

* Corresponding author.
E-mail address: imkidd@utas.edu.au (I.M. Kidd).

http://dx.doi.org/10.1016/j.ocecoaman.2015.06.016
0964-5691/

successful, but this may not be an accurate assessment as Xu et al. (2011) found increased levels of 13 emerging organic contaminants. The barrage truncates the estuary at the coast with no remnant estuary against which comparisons may be made. The Lower Nakdong River in South Korea is barraged to prevent salt water intrusion, but sedimentation problems and constant dredging have necessitated changes to gate operation in a bid to increase sediment flushing (Ji et al., 2011). The Wansbeck barrage in Northumberland is opened for 3 days per month during October to March in an attempt to counteract sandbar formation across the mouth (Worrall and McIntyre, 2007). Behind the impoundment, sedimentation rates over 20 years (1987–2007) are nearly 400 mm yr^{-1}, and algal blooms are a problem. Worral and McIntyre concluded that the barrage was not fulfilling its objectives and the situation was only likely to get worse. A barrage on the Petitcodiac River (Canada) diminished the estuarine bore and the tidal prism to such an extent that the remnant estuary atrophied to 10% of the former width, and extensive salt marshes developed (Morris, 2013). The bathymetry from the head of the original estuary effectively migrated 16 km to the new head of the estuary at the barrage (Kidd et al., 2015). Siltation above the barrage also became a problem, as did erosion of the upstream banks. Flow has now been increased by opening the gates on the barrage and the width is returning to normal. A major barrage constructed at Goolwa near the mouth of the Murray River in South Australia in the 1940s to convert lakes Albert and Alexandrina to fresh water decreased the tidal prism by 85%, resulting in the mouth of the Murray becoming unnavigable within 12 months (Harvey, 1996). Sand carried along the coast by longshore drift and into the estuary by asymmetrical tides and aeolian processes settles in the remaining tidal zone (Webster, 2005). This has resulted in the mouth closing completely, on average, every second year (Jenson et al., 2000; Walker, 2003). Continued significant environmental degradation is expected, caused by reduced flows, increased sedimentation and the accumulation of nutrients (Jenson et al., 2000). Any total exclusion barrage removes the upstream tidal prism which places the remnant system out of equilibrium. As a general rule, a loss of tidal prism will produce sedimentation (Dennis et al., 2000). To regain equilibrium, the remnant estuary must either increase its tidal prism, or reduce its cross-sectional area. The former requires a significant increase in the tidal range as predicted by some models (Prandle, 1980); and the latter requires a positive net sediment supply (Morris, 2013). The ASMITA model (Aggregated Scale Morphological Interaction between Tidal Inlet and Adjacent Coast) (Stive et al., 1998), is able to calculate equilibrium volumes and surface areas following sea level rise, dredging and infilling. Prandle (2003, 2004) and Prandle et al. (2006) produced morphodynamic models for different estuary types without specific reference to installation of a barrage. In an earlier paper Prandle (1980) discussed the similarities of barrage installation with AC circuit theory and modelled the likely effects on tidal ranges without specific reference to morphological effects. van Dongeren and de Vriend (1994) produced a 1D computer model which in part simulated the effects of truncating a 20 km estuary at 15 km. Their interest was in tidal flats but the model also predicted atrophy of the channel, over 100 years. Bottom-up models (EMPHASYS Consortium, 2000) of tidal dynamics, sediment transport, salt intrusion etc. can be determined from tides at the mouth, estuarine bathymetry, river flows and bed roughness. All involve simplifications and assumptions, and are accurate over time scales of a few tidal cycles. The UK Parliamentary Office of Science and Technology (POST, 2013) cautioned that modelling always begins with a simplification of how the estuary works and, in the case of the Severn Barrage, there were a lack of comparative data available for model calibration. The assessment of morphological change due to a barrage is best modelled with a top-down approach such as a regime model (EMPHASYS Consortium, 2000).

Excessive silting in the upper Tamar River estuary in northern Tasmania, Australia (Fig. 1) has prompted calls for the installation of a total exclusion barrage (a permanent barrier to tidal flow), with the aim of addressing one of the perceived stressors (tidal asymmetry resulting in the upstream transport and deposition of flocculated silts and clay) and providing new ecosystem services based on the creation of a large freshwater lake or headpond. Although one recent proposal is for a barrage near the mouth of the estuary (~22 km inland), past proposals have advocated barrages at sites further upstream. In April 2013 the Launceston Flood Authority (LFA) proposed an AU$25 million barrage across the mouth of the North Esk River (Examiner 2013), 70 km from the coast and 11.5 km from the estuary head.

As well as potentially addressing the issue of excessive silt accretion, additional benefits provided by the creation of a large freshwater lake include a reliable source of water for horticultural and agricultural crops, enhanced recreational opportunities for a variety of water-based sports, enhanced visual amenity and the potential to generate hydropower. Little public discussion has occurred of the negative hydrological and morphological impacts on the remnant estuary and near-shore marine region, nor the likely ecological effects on the entire estuary.

We hypothesised that the impacts of a barrage on estuarine hydrology, morphology and ecology in the Tamar River estuary would vary with the distance of the installation from the mouth. We have used a scenario-based approach to evaluate the outcomes of tidal barrage installation at four sites along the estuary and one at the mouth of a major tributary.

2. Methods

2.1. Site description

The Tamar River estuary has provided a convenient shipping route, fresh water, and good soils for agriculture since European settlement in 1804 (Edgar et al., 2000). The estuary, which is classified as a mesotidal drowned river valley (Edgar et al., 2000), although the upper reaches are better categorised as a coastal-plain estuary (Kidd et al., 2014). The estuary comprises three distinct waterways, the Tamar River estuary and two major tributaries, the North and South Esk Rivers. The North Esk River is tidal for 11.7 km and is therefore a continuation of the main estuary. The waterways meet at the city of Launceston (population of 90,000), approximately 70 km upstream of the estuary mouth. An extensive silt belt runs for ~20 km downstream of Launceston (Fig. 1b).

The tidal range increases from 2.34 m at the mouth to 3.25 m at Launceston (Foster and Nittim, 1987) and is therefore hypersynchronous (Dyer, 1997). At the mouth, tidal constituents are M_2 dominated (1.117 m) followed by N_2 (0.252 m), K_1 (0.161 m), S_2 (0.136 m) and O_1 (0.113 m) (Foster and Nittim, 1987). In the lower North Esk the corresponding constituents are: M_2 (1.432 m), N_2 (0.300 m), K_1 (0.042), and S_2 (0.083). The combined M_4 and M_6 constituents amount to ~0.2 m (Kidd et al., 2014); indicative of asymmetrical tidal velocities. Flood tides peak at 40 cm s^{-1} and ebb tides reach 30 cm s^{-1} (Foster et al., 1986). In times of low freshwater inflows, sediment which has flocculated at the salt water boundary is carried upstream and deposited in the upper estuary ((Foster et al., 1986), Fig. 2). In normal flows, salt intrudes almost to the Tamar Island wetlands. However, during the recent decadal long drought, salt intruded further to Home Reach (Fig. 1c) and killed exotic riparian willows (*Salix* sp.).

The North and South Esk Rivers provide many ecosystem services and benefits to the community. Drinking water is drawn from