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Research article

Dredging for dilution: A simulation based case study in a Tidal River

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A B S T R A C T

A 2-D hydrodynamic finite element model with a Lagrangian particle module is used to investigate the effects of dredging on the hydrodynamics and the horizontal dilution of pollutant particles originating from a wastewater treatment facility (WWTF) in tidal Oyster River in New Hampshire, USA. The model is driven by the semi-diurnal (M_2) tidal component and includes the effect of flooding and drying of riverine mud flats. The particle tracking method consists of tidal advection plus a horizontal random walk model of sub-grid scale turbulent processes. Our approach is to perform continuous pollutant particle releases from the outfall, simulating three different scenarios: a base-case representing the present conditions and two different dredged channel/outfall location configurations. Hydrodynamics are investigated in an Eulerian framework and Lagrangian particle dilution improvement ratios are calculated for all cases. Results show that the simulated hydrodynamics are consistent with observed conditions. Eulerian and Lagrangian residuals predict an outward path suggesting flushing of pollutants on longer ($>M_2$) time scales. Simulated dilution maps show that, in addition to dredging, the relocation of the WWTF outfall into the dredged main channel is required for increased dilution performance. The methodology presented here can be applied to similar managerial problems in all similar systems worldwide with relatively little effort, with the combination of Lagrangian and Eulerian methods working together towards a better solution. The statistical significance brought into methodology, by using a large number of particles (16000 in this case), is to be emphasized, especially with the growing number of networked parallel computer clusters worldwide. This paper improves on the study presented in Bilgili et al., 2006b, by adding an Eulerian analysis.

1. Introduction

In order to compensate for projected coastal population increases and the associated rise in ecological pressure, the environmental regulations in the United States are becoming more and more stringent. This makes it increasingly difficult for smaller towns with limited financial and technological resources to meet these regulations. In the case of Waste Water Treatment Facilities (WWTF's) that discharge into ecologically sensitive urban waterways, such as estuaries and rivers, this implies a need for periodic upgrading or replacement of the treatment technology to make up for increased volume and/or changing pollutant types. Since enhancements to the technological operation are almost always financially unviable and in some cases even impossible, towns usually explore alternative operational methods to solve their WWTF discharge problems. These include measures to enhance flushing; such as dredging operations, outfall consolidation and/or relocations, diffuser reconfigurations or any combination of these. This means that a water quality problem quickly becomes an environmental management problem that requires decision makers to receive input from scientists, engineers, public (usually through non-governmental organizations) and even politicians, before any decision to proceed is made and any permission is issued. Moreover, the input from different groups, which is usually qualitative in the beginning, will often be contradictory. This makes it more important to base any decision on scientifically sound quantitative data from a range of fields (hydrological, biological, geological, geophysical, social, economical, etc.) grouped within a conceptual framework that shows linkages between the considered measures of rehabilitation, as emphasized by Bathrellos et al., 2012 and Gilvear et al., 2013.

The Town of Durham secondary WWTF in Oyster River, New

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Hampshire (Fig. 1) is a well-maintained, long operating facility that encounters times, such as during reduced river flow conditions, when the EPA dilution standards are nearly breached or temporarily not met. Several options are considered to remedy the situation: upgrading the waste treatment method, relocating the outfall to a more dynamic deeper location, and dredging around the outfall pipe (State of New Hampshire General Court, 2010). The last option is the least costly and fastest solution, but it does introduce several additional issues that would need to be addressed to get the appropriate permissions (Monge-Ganuzas et al., 2013; Leuken and Wang, 2010; Erftemeijer and Lewis III, 2006; Thrush and Dayton, 2002). These include, but are not limited to, impacts on local channel morphology, re-suspension of possibly contaminated buried sediments, management of removed material and direct impacts on local flora and fauna due to changes in flow and sedimentation patterns. These concerns create important managerial and operational problems (Van Vuren et al., 2015; Manap and Voulvoulis, 2015) that need to be addressed before any authorization would be given. Dredging, however, also has the additional benefit of keeping the channel useable for recreational purposes throughout the tidal cycle, which emerges as a significant benefit to the local community. Although there are several methods to predict the effect of the aforementioned operational measures on water quality (Petus et al., 2014; Leon-Munoz et al., 2013; Muhammetoglu et al., 2012; Hunt et al., 2010; Ramos et al., 2007), validated numerical models can provide reliable predictions in the cases that demand prompt and cost-effective solutions that engineers and managers can use in operational decision making. As stated by Fan et al., 2009, these models do not necessarily need to be multifaceted to be useful since complexity requires more data to be calibrated and verified. The immediate objective in this paper is to provide the WWTF management team with a working methodology that can be used in the present and future decision making processes with relatively little effort. The broader and more important objective is to present the applicability of similar methods and tools for general use in comparable situations where quantitative and sustainable decision making tools are needed by the managerial community.

Within the aforementioned framework, our approach is to simulate a base-case representing the present conditions, and two potential dredge/outfall location scenarios to study how these configurations would affect the tidal velocities, distribution of pollutants and the resulting lateral dilution improvement ratios. Emphasis is put on maximum current magnitudes in the vicinity of the outfall since these are directly used within USEPA approved steady-state mixing-zone models, such as CORMIX (Jirka et al., 2006) to model near-field worst-case scenarios. Lagrangian particle methods, which are naturally suited for modeling the motion of waterborne particles, are used to simulate pollutant distributions throughout the river in tidal time. Simulated Eulerian residuals are incorporated into the analysis to confirm the results from the Lagrangian method. Although Lagrangian particle methods that use a large number of particles have been used rather widely in coastal ocean research over the past few years (Harms et al., 2000; Bilgili et al., 2005; Meyers and Luther, 2008; Hendrawan and Asai, 2014; Shan et al., 2014), their use in practical management problems of smaller scale has not been widespread, only appearing in a few cases (Swanson et al., 2014). Dutta et al., 2013, state that many of the management models still use spreadsheets that do not incorporate sophisticated physical models or forecasting tools. We are trying to fill this gap and share this with the management community to present another tool to enable better decisions. Every step of the methodology is detailed to highlight techniques and the difficulties associated with them that may be encountered when tackling such problems.

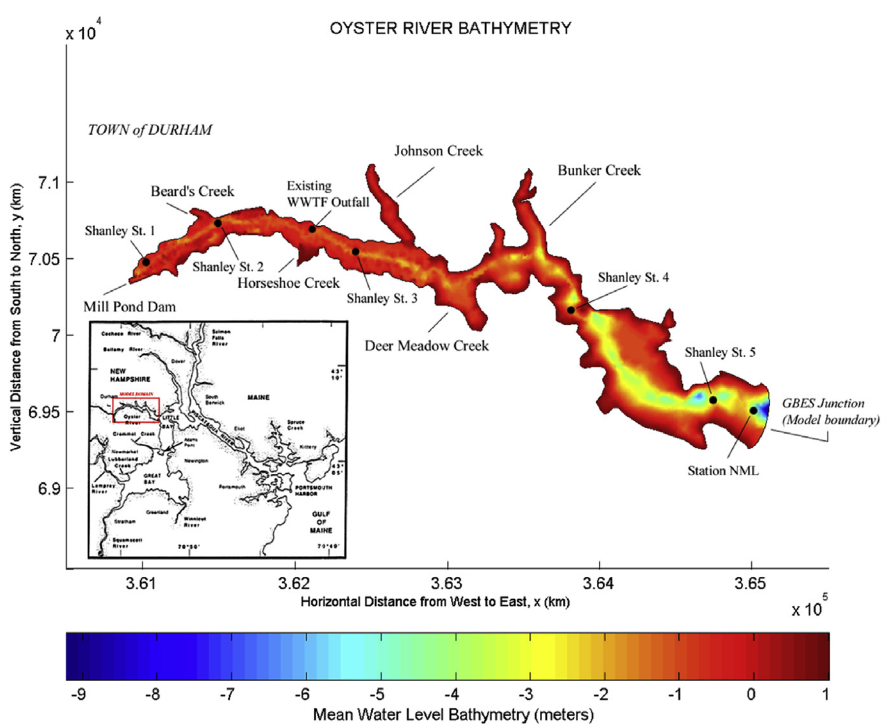

Fig. 1. The Oyster River domain geometry and its mean water level bathymetry. Important geographic features and tidal current stations used in this study are also shown. Inset establishes the model domain (red rectangle) in relation to the Great Bay Estuarine System (GBES). Oyster River lies in a box bounded by NAD83 geographic coordinates (−70.86°, 43.14°) on the upper right and (−70.92°, 43.12°) on the lower left. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)