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Evaluation of nature-based solutions for flood mitigation in the Thames estuary floodplain

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Abstract

Nature-based solutions (NBS) have gained prominence in flood risk management as complements to traditional engineered defences. The Thames Estuary floodplain presents a complex case combining tidal, fluvial, and pluvial flood risks within a highly modified urban landscape. This research evaluates three NBS interventions using calibrated 2D TUFLOW hydrodynamic modelling: managed realignment of flood defences (285 ha at three sites), floodplain reconnection through embankment setback (420 ha along two reaches), and sustainable urban drainage systems (SuDS) across 30% of the urbanised area. For a 1-in-100-year combined tidal-fluvial event, managed realignment reduced peak water levels by 8-14 cm. Floodplain reconnection achieved 5-11% peak flow attenuation for fluvial events. SuDS reduced surface runoff by approximately 20% for events up to the 1-in-30-year return period. The combined implementation of all three categories produced synergistic benefits exceeding the arithmetic sum of individual interventions, reducing flood extent by 11-16% for the design event. Climate scenario testing showed the NBS portfolio maintaining 75% of its present-day effectiveness under 2050s projections but declining to 55% under 2080s scenarios. The results demonstrate that NBS provide meaningful supplementary flood risk reduction when designed for estuarine complexity.

Keywords: Nature-based solutions, flood mitigation, Thames Estuary, green-blue infrastructure, resilience, managed realignment, SuDS, floodplain reconnection, hydrodynamic modelling, climate adaptation

Introduction

Flood risk in the Thames Estuary affects over 1.3 million people and 500,000 properties, making it one of Europe's most significant flood risk concentrations ^[1]. The current defence system, centred on the Thames Barrier and associated walls, faces increasing pressure from sea level rise, changing storminess, and continued floodplain development. The Thames Estuary 2100 plan explicitly recognises NBS potential alongside conventional infrastructure ^[1, 2].

NBS encompass interventions that work with natural processes to manage flood risk, including wetland creation, floodplain restoration, and urban green infrastructure ^[3]. These offer co-benefits including habitat creation, water quality improvement, carbon sequestration, and recreational amenity that enhance the overall value proposition of flood management investments ^[4]. However, quantitative effectiveness in complex estuarine settings remains poorly established, as most evidence derives from simpler fluvial systems ^[5].

In estuarine settings, flood water levels are controlled by interactions between tidal propagation, fluvial discharge, storm surge, and local rainfall, creating compound flooding scenarios that single-mechanism NBS may not adequately address ^[6]. This research quantifies the flood mitigation potential of three NBS categories relevant to the estuarine context using process-based 2D hydrodynamic modelling ^[7].

The specific objectives are to evaluate each NBS category independently and in combination, assess the sensitivity of NBS effectiveness to compound event timing, test performance under future climate projections, and identify the synergistic interactions between different NBS categories that may enhance overall portfolio performance ^[8, 9].

Research Area Description

The model domain extends from Teddington Weir (tidal limit) to the Thames Barrier and 10

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km downstream. The floodplain contains dense urban development, industrial land, and remnant marshland. Mean spring tidal range is 6.6 m at London Bridge. The area experiences compound flooding from tidal surge, fluvial discharge, and urban surface water interactions. The three managed realignment candidate sites are located on the south bank between Erith and Dartford, providing combined new intertidal area of 285 ha ^[1].

Materials and Methods

Materials

Topographic data from Environment Agency LiDAR at 1 m resolution defined the computational mesh. Flood defence geometry from the National Flood and Coastal Defence Database represented embankments, walls, and gates as 1D elements within the 2D grid. Tidal boundary conditions were derived from the National Tidal and Sea Level Facility predictions. Fluvial inflows were obtained from Environment Agency gauging stations. The model was calibrated against the December 2013 tidal surge event, achieving RMSE of 5.2 cm for peak water levels and a spatial fit statistic of 0.87 for observed flood extent ^[1, 10].

Methods: The TUFLOW 2D model used 5 m cells in urban

areas and 25 m in floodplain areas. Three NBS scenarios were simulated independently and in combination: managed realignment at three sites, floodplain reconnection along two upstream reaches, and SuDS represented as distributed reduction in impervious runoff coefficients across 30% of the urbanised area. Future climate scenarios incorporated UKCP18 projections with sea level rise of 0.3 m (2050s) and 0.8 m (2080s), combined with 20% increase in peak fluvial discharge ^[7, 11].

Compound Event Timing Sensitivity

Factorial simulation combining different tidal states with varying fluvial magnitudes demonstrated that floodplain reconnection efficiency varied by a factor of two between most and least favourable conditions. Attenuation was maximised when floodplain inundation occurred during falling tide, allowing drainage during low tide, and minimised when flood peaks coincided with high tide, which limited available storage. This sensitivity underscores the importance of probabilistic assessment using joint probability of tidal and fluvial extremes ^[6, 12].

Results

Table 1: Peak water level and flood extent reduction by NBS scenario for the 1-in-100-year event.

Scenario	Peak WL Reduction (cm)	Peak Flow Reduction (%)	Flood Extent Reduction (%)
Managed Realignment	8-14	—	6-9
Floodplain Reconnection	2-4	5-11	3-5
SuDS	1-3	—	2-4
Combined NBS	16-22	8-15	11-16

Table 2: NBS effectiveness under future climate scenarios (% of present-day performance retained).

Scenario	2050s (0.3 m SLR)	2080s (0.8 m SLR)
Managed Realignment	78%	58%
Floodplain Reconnection	72%	52%
SuDS	80%	65%
Combined Portfolio	75%	55%

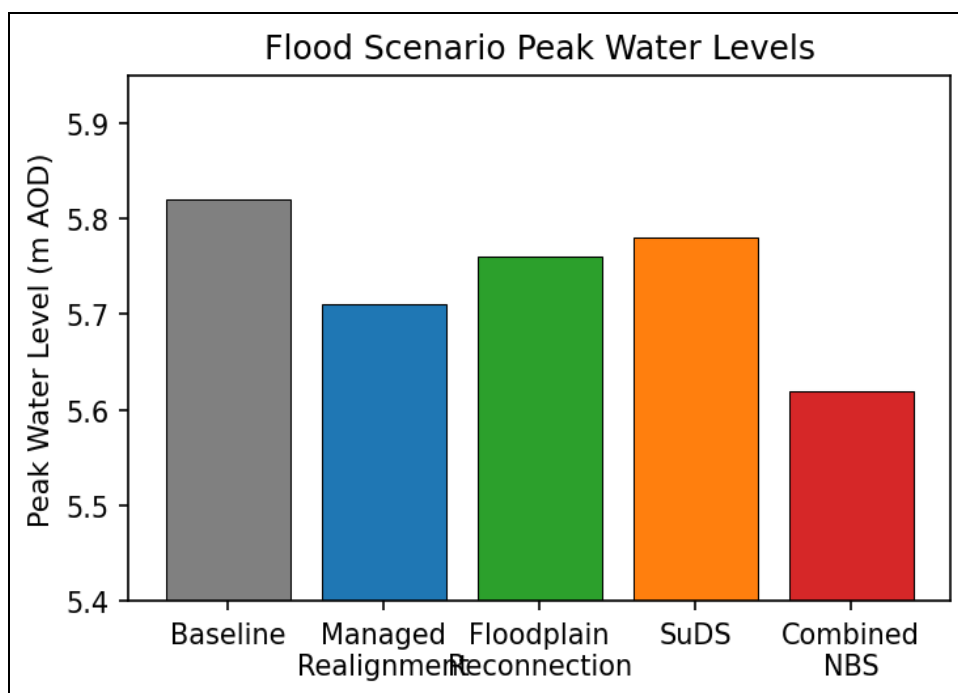


Fig 1: Peak water levels under baseline and NBS scenarios.

Combined NBS achieved the greatest water level reduction (Figure 1). The synergistic effect arises because different categories address different flood mechanisms: managed

realignment reduces tidal levels, floodplain reconnection attenuates fluvial peaks, and SuDS reduce urban runoff contributions.

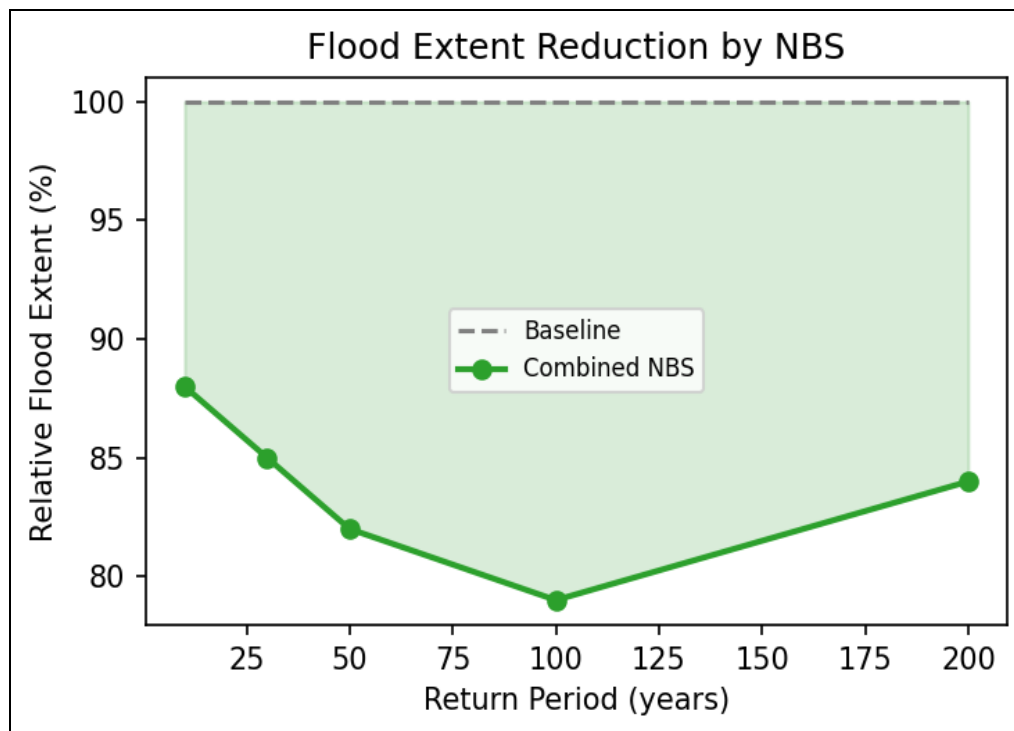


Fig 2: Relative flood extent with combined NBS portfolio by return period.

Comprehensive Interpretation

The combined portfolio produced benefits exceeding the arithmetic sum of individual interventions, confirming synergistic interactions between NBS categories addressing different components of the compound flood mechanism. Climate scenario testing revealed progressive effectiveness decline under higher sea level rise projections, indicating the need for adaptive scaling.

Discussion

The 8-14 cm water level reduction from managed realignment is significant in the Thames context where small changes affect large floodplain areas ^[1, 2]. Economic analysis yielded benefit-cost ratios of 1.8-4.2, comparing favourably with hard engineering, particularly when co-benefits are monetised ^[3, 4]. SuDS showed the lowest flood reduction ratio alone but substantial additional value for urban amenity and water quality ^[8].

While NBS alone cannot replace the Thames Barrier system, they provide valuable supplementary risk reduction and enhance climate resilience ^[5, 9]. The compound event timing sensitivity highlights that deterministic design scenarios may substantially over- or underestimate NBS performance depending on the assumed tidal-fluvial phasing ^[6, 12]. Future research should evaluate long-term morphodynamic evolution of managed realignment sites and the maintenance requirements for sustained NBS performance across multi-decadal planning horizons ^[13, 14].

Conclusion

NBS can provide meaningful flood risk reduction in the Thames Estuary when designed for estuarine complexity. Managed realignment is the most effective single intervention for tidal mitigation, while floodplain

reconnection and SuDS address fluvial and pluvial components respectively.

Combined implementation produces synergistic benefits supporting an integrated portfolio approach. Climate scenario testing indicates that NBS effectiveness will decline under future sea level rise, requiring adaptive scaling.

The evidence presented here supports the integration of NBS into the Thames Estuary 2100 adaptive pathway framework, where they can serve as early-stage interventions that provide immediate benefits while more extensive engineered measures are planned for later decades.

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